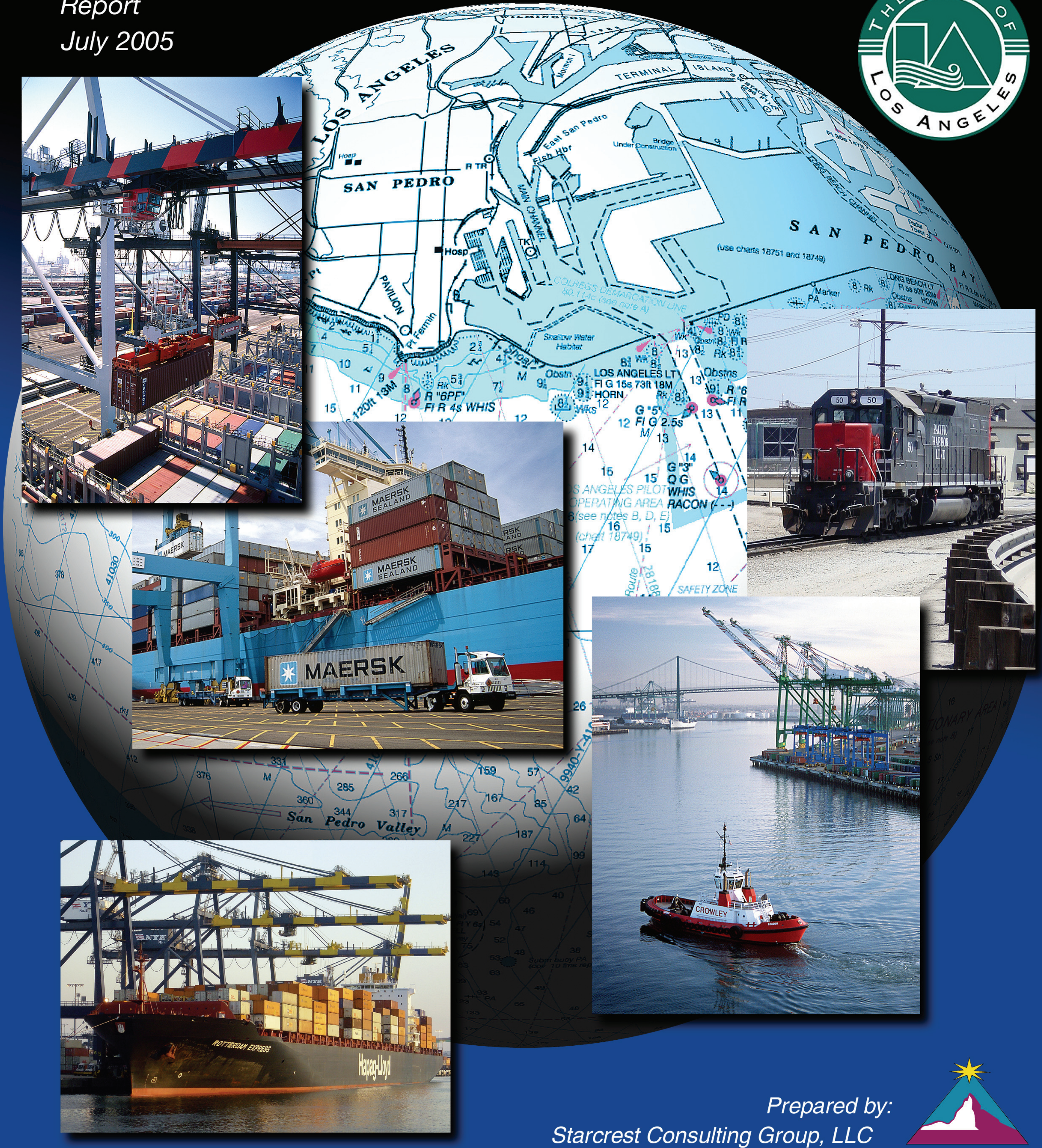
PORT OF LOS ANGELES BASELINE AIR EMISSIONS INVENTORY - 2001

Report
July 2005



Prepared by:
Starcrest Consulting Group, LLC

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Authors:	Guiselle Aldrete, Consultant for Starcrest Bruce Anderson, Principal, Starcrest Joseph Ray, Principal, Starcrest Sam Wells, Consultant for Starcrest
Contributors:	Clyde Durham, Consultant for Starcrest Joyce Kristiansson, Consultant for Starcrest
Editors:	Christopher Patton, Port of Los Angeles T.L. Garrett, Port of Los Angeles
Photography:	Melissa Anderson, ©MSPD
Document Preparation:	Denise Anderson, Consultant for Starcrest Melissa Anderson, Principal, Starcrest

ACRONYMS AND ABBREVIATIONS

ARB	(California) Air Resources Board
APL	American President's Line
AQMP	Air Quality Management Plan
ASTM	American Society for Testing and Materials
BAH	Booz Allen Hamilton, Inc.
BNSF	Burlington Northern Santa Fe Railroad
BSFC	brake specific fuel consumption
CHE	cargo handling equipment
CO	carbon monoxide
DAS	Distribution and Auto Service
DB	dynamic breaking
DF	deterioration factor
DMV	Department of Motor Vehicles
DPM	diesel particulate matter
DWT	deadweight tons
EEAI	Energy and Environmental Analysis, Inc.
EF	emission factor
EI	emissions inventory
EMD	(GE) Electromotive Division
EPA	U.S. Environmental Protection Agency
FCF	fuel correction factor
FTP	Federal Testing Protocol
g/day	grams per day
g/hr	grams per hour
g/mi	grams per mile
GTM	Gross ton-mile
GVWR	gross vehicle weight rating
HC	hydrocarbons
HDV	heavy-duty vehicle
HFO	heavy fuel oil
hp	horsepower
hrs	hours
HVAC	heating/ventilation/air conditioning
ICTF	Intermodal Container Transfer Facility
IFO	intermediate fuel oil
IMO	International Maritime Organization
ISO	International Organization for Standardization
ITB	integrated tug/barge
kts	knots
kW	kilowatts
LAXT	Los Angeles Export Terminal
lbs/day	pounds per day
LDA	light duty auto
LDT	light duty truck

LDT-DSL	light duty truck-diesel
LF	load factor
LPG	liquefied petroleum gas
LSDO	low sulfur diesel oil
MarEx	Marine Exchange of Southern California
MATES II	Multiple Air Toxins Exposure Study
MCR	maximum continuous rating
MDO	marine diesel oil
MGO	marine gas oil
MMA	Meyer, Mohaddes Associates, Inc.
MMGT	millions of gross tons
MMGTM	millions of gross tons-miles
M&N	Moffatt & Nichols Engineers
mph	miles per hour
MW	megawatts
NMHC	non-methane hydrocarbons
NO_X	oxides of nitrogen
OGV	ocean-going vessel
PCAC	Port Community Advisory Committee
PCEEI	Pleasure Craft Exhaust Emissions Inventory
PCST	Pacific Cruise Ship Terminals
P.E.	Professional Engineer
PHL	Pacific Harbor Line
PM	particulate matter
PM_{10}	particulate matter less than 10 microns in diameter
$PM_{2.5}$	particulate matter less than 2.5 microns in diameter
POLB	Port of Long Beach
ppm	parts per million
RIA	Regulatory Impact Analysis
RO	residual oil
Ro-Ro	roll-on/roll-off
rpm	revolutions per minute
RSD	Regulatory Support Document
RTG	rubber tired gantry crane
RTL	rich text language
S	sulfur
SCAQMD	South Coast Air Quality Management District
SO_2	sulfur dioxide
SoCAB	South Coast Air basin
SSA	Stevedoring Services of America
SUV	sport-utility vehicle
TEU	twenty-foot equivalent unit
THC	total hydrocarbon
TICTF	Terminal Island Container Transfer Facility
TOG	total organic gases
tpd	tons per day

tpy	tons per year
U.S.	United States
UP	Union Pacific Railroad
USACE	U.S. Army Corps of Engineers
USCG	United States Coast Guard
VLCS	very large cargo ship
VMT	vehicle miles of travel
VSR	Vessel Speed Reduction
VTS	Vessel Traffic Service

SECTION 1 INTRODUCTION

The Port of Los Angeles (Port) has prepared a 2001 Baseline Emissions Inventory (EI) in response to concerns from the public about the potential health impacts to surrounding communities from Port operations and to provide the Port with a planning document for development, prioritization and implementation of emission control strategies to reduce these impacts.

The specific health concern of the public was exposure to diesel particulate matter. This concern was primarily based on the following:

- In 1998, the California Air Resources Board (ARB) identified diesel particulate matter (PM) as a toxic air contaminant and initiated a statewide risk management process with the publication of the Diesel Risk Reduction Plan in 2000.

- The Multiple Air Toxics Exposure Study (MATES II), released by the South Coast Air Quality Management District (SCAQMD) in 2000, estimated that the cancer risk in the South Coast Air Basin (SoCAB) was 1,400 per million, with 70% of all risk attributable to diesel PM. The California Environmental Protection Agency has recommended 300 per million as a reasonable cancer risk level. Modeling conducted for MATES II showed the Port area to be significantly impacted by emissions of diesel PM.

To address community concerns about air quality and other impacts, the Board of Harbor Commissioners on 10 October 2001, acting on the request of Mayor James Hahn, adopted a "goal that there will be no net increase in air emissions or traffic impacts from future Port operations." The date 10 October 2001 was established as the baseline date for the "no net increase" policy. To initiate action on meeting the goal, the Board directed staff to plan, schedule and carry out several environmental baseline studies on the impact of Port operations on the surrounding communities. The Board approved the Concept Plan for the Port-wide Environmental Studies in December 2001 that combined several of the original air quality initiatives into a single Air Studies Program, including:

- Preparation of a baseline air emission inventory;

- Preparation of a health risk assessment of Port emissions on local communities, including prerequisite monitoring for ambient levels of particulate matter, specifically diesel particulate matter; and

- Development of diesel emission control mitigations necessary to achieve the Board's goal of "no net increase" in Port emissions.

This study provides emission estimates for all significant sources operating in the Port. It also provides the requisite data for preparation of a Port-wide health risk assessment, development of air quality emission control strategies necessary to achieve the Board's goal of "no net increase" in Port emissions, production of future updates to the EI and preparation of project environmental analyses, and it is intended to be used for these purposes. Development of this EI has been coordinated with the U.S. Environmental Protection Agency - Region 9 (EPA), ARB, and SCAQMD.

1.1 Purpose and Scope

The purpose of this study is to develop a comprehensive activity-based EI that estimates emissions, focusing on emissions of diesel particulate matter, associated with Port operations. The scope includes five source categories: ocean-going vessels (OGVs), harbor craft (e.g., tugboats, ferries, commercial fishing vessels, dredges, etc.), off-road cargo handling equipment (CHE), railroad locomotives and on-road heavy-duty vehicles (HDV). The baseline year for the EI is calendar year 2001. To the extent practicable, the emission estimates are based on activities that occurred during this period. The inventory does not include stationary sources, as these are included in stationary source permitting programs administered by the SCAQMD.

The activity-based or "bottom-up" EI was based on interviews and conversations with tenants who own, operate, maintain, and/or lease equipment and charter vessels. The activity and operational data collected was then used to estimate emissions for each of the various source categories in a manner consistent with the latest estimating methods. The information that was gathered, analyzed and presented in this report improves the understanding of the nature and magnitude of Port-wide emission sources and is unprecedented in that it represents the first EI specifically covering Port sources of emissions disaggregated from all other sources contained in regional EIs.

Annual baseline emission estimates for 2001 were developed for:

- Oxides of nitrogen (NO_X)
- Total organic gases (TOG)
- Carbon monoxide (CO)
- Particulate matter less than 10 microns in diameter (PM_{10})
- Particulate matter less than 2.5 microns in diameter ($PM_{2.5}$)
- Diesel particulate matter (DPM)
- Sulfur dioxide (SO_2)

The following facilities were included in the baseline EI study:

- 22nd St. Sportfishing
- Al Larson Marina
- APL
- Auto Warehousing
- Cal-Cartage
- California Sulfur
- California Ship Services
- California Yacht Marina
- Catalina Channel Express
- Cerritos Yacht Anchorage
- Conolly-Pacific
- Crescent Wharf & Warehouse
- Crowley Marine Services
- Distribution & Auto Services
- Eagle Marine Services
- Evergreen Marine
- Foss Maritime
- Harbor Ice & Cold Storage
- Holiday Harbor
- Hugo Neu-Proler
- Ice Distributors
- Island Yacht Anchorage
- Jankovich & Sons
- Kinder Morgan
- L.A. Cruise Ship Terminal
- Los Angeles Fire Department
- L.A. Grain
- L.A. Harbor Sportfishing
- Los Angeles Harbor Department Construction and Maintenance
- Los Angeles Harbor Department Pilot Station
- LAXT
- Leeward Bay Marina
- Lighthouse Yacht
- L.A. Harbor Cruise
- Manson Construction
- Marine Terminals (MTC)
- Mike's Main Channel
- Millenium Maritime
- Exxon-Mobil
- Pacific Yacht Landing
- Pasha Stevedoring & Terminals
- Peninsula Tugboat Service
- Perel Marinas
- Phillips Petroleum
- San Pedro Boatworks
- San Pedro Forklift
- Sause Brothers
- Seaway Company
- Shell Oil
- So. Calif. Marine Institute
- So. Calif. Ship Services
- Southwest Marine
- Spirit Cruises
- SSAT
- Trapac
- Tri-Union
- Union Pacific Intermodal Container Transfer Facility
- U.S. Borax
- U.S. Water Taxi
- Ultramar
- Vopak
- Westway Terminal
- Yacht Haven Marina
- Yang Ming Marine Transport
- Yusen Terminal

The APM Terminal opened in August 2002, but was not included in this emissions inventory since it was not part of Port operations in 2001. Other terminal reconfigurations have taken place since 2001 and will need to be considered when comparing this baseline EI to future year updates.

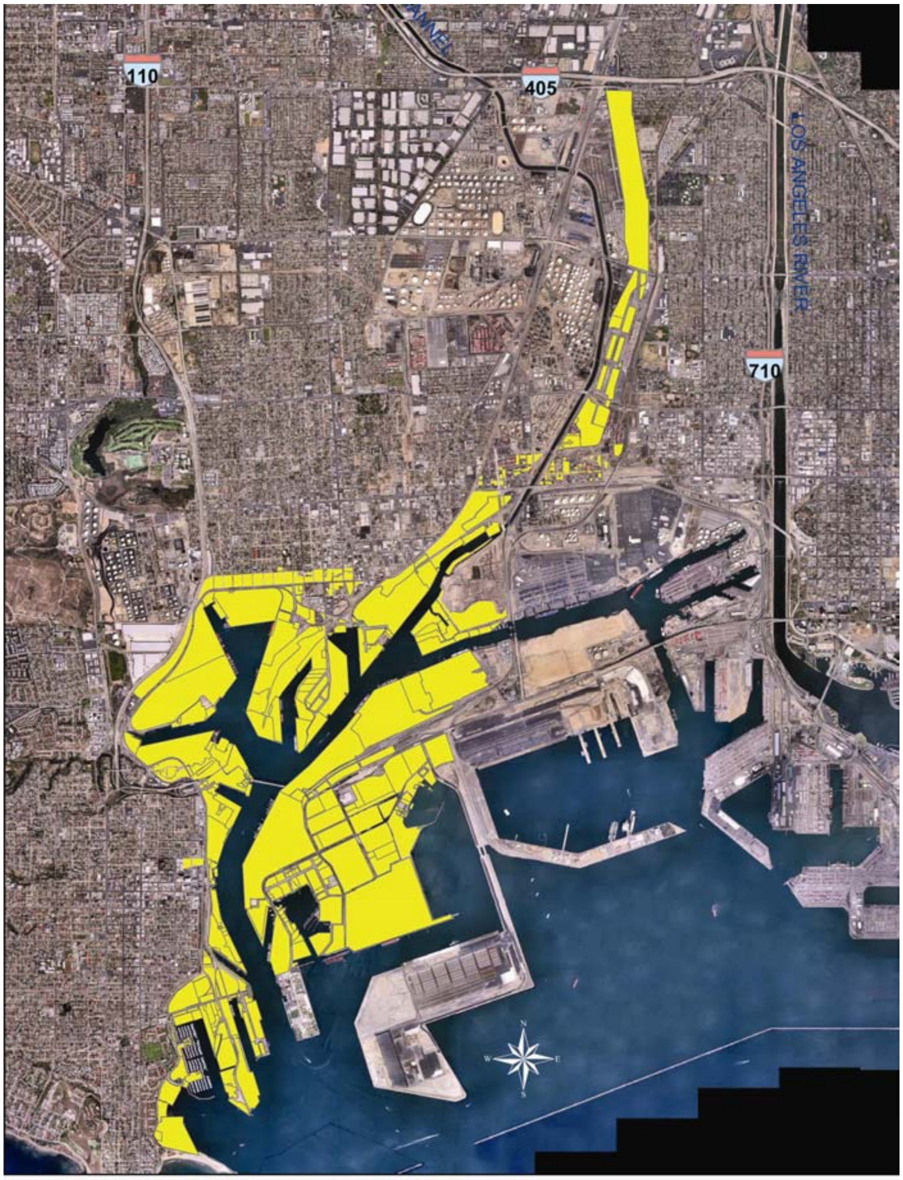
Not all emission-producing operations within the Port were included in the EI. There are certain industrial operations and other emission-producing activities that are located on Port property or on private property within the Port boundaries. Many of these operations and activities are within the Port for historical reasons, such as use or ownership of a site included in the expansion of Port boundaries. Other operations take place on property leased from the Port, but are not in any way related to the activities or operations of the Port, such as a sewage treatment facility. The Port has no authority or influence over these operations other than as a landlord or leaseholder. These sources and facilities were not included in the emissions inventory, as they would not be expected to take part in Port-related emission reduction initiatives and are covered by other air quality programs and regulations. The following is a list of the facilities that were not included in the baseline EI study:

- Los Angeles Department of Recreation and Parks
- LAAC Boy Scouts of America
- Meristar H&R Operating
- Los Angeles Yacht Club
- Cabrillo Beach Yacht Club
- Maritime Museum
- College of Oceaneering
- University of Southern California

Geographical Extent of Study

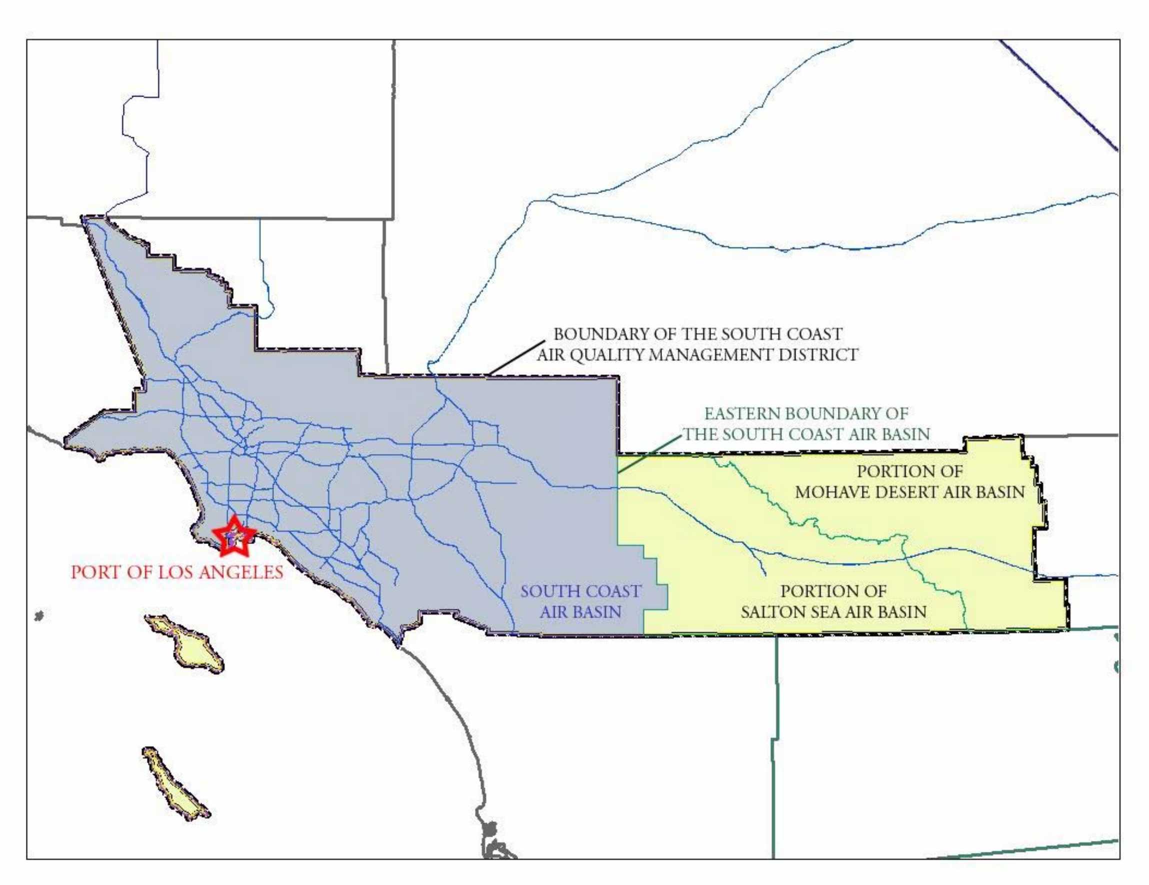
The Port of Los Angeles is a major marine port located in Southern California. The EI includes tenant emissions that occur on Port-owned land within the Port boundary/district. The Port is located in Los Angeles County approximately 20 miles south of downtown Los Angeles and adjacent to Long Beach. Los Angeles and Long Beach harbors are independent commercial ports within San Pedro Bay. Figure 1.1 shows the active terminals that were included in the 2001 baseline and illustrates the geographical boundary of the land-based on-Port component of the EI.

Figure 1.1: Baseline Inventory In-Port Study Area



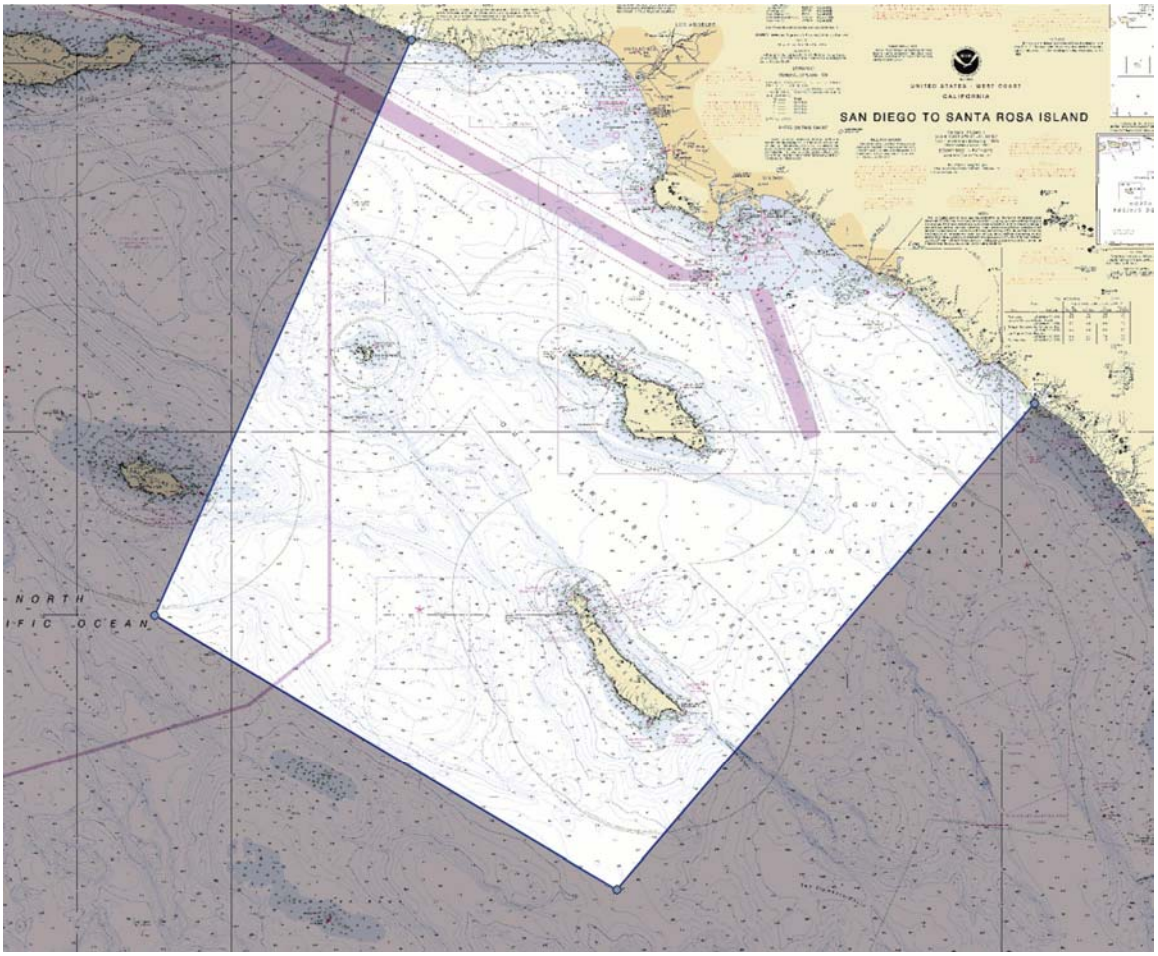
In addition to on-Port emissions, emissions from locomotives and on-road trucks transporting Port cargo have been estimated for activity that occurs outside the Port but within the SoCAB boundaries. Figure 1.2 shows the SoCAB boundary. Since both the Port and the Port of Long Beach (POLB) are interconnected with intermodal transportation linkages, every effort was made to only account for freight movements originating from or having a destination at the Port.

Figure 1.2: South Coast Air Basin Boundary



The geographical extent of the emissions inventory for marine vessels is the same boundary that was used in previous marine vessel inventories for the SCAQMD. Figure 1.3 shows the geographical extent of the out-of-port study area for marine vessels.

Figure 1.3: OGV and Harbor Vessel Out-of-Port Geographical Extent



1.2 Background

This section provides background information on the operations of the Port and Port emission sources, including how cargo is moved through a port, the types of equipment used for these cargo movements and characteristics of the fuels and engines used.

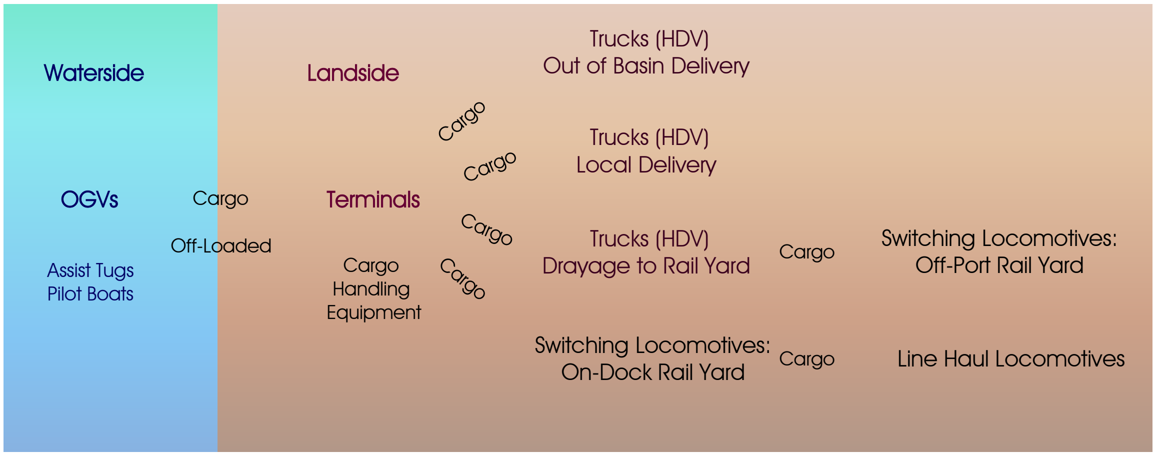
Marine Container Terminal Operations and Cargo Movements

The Port of Los Angeles is a significant part of the international cargo transportation system, serving as the interface between marine and land transportation modes. The predominant marine terminal activity at the Port is the movement of containerized cargo from and to OGVs.

A modern marine container terminal is a complex facility that integrates a variety of different physical components and operational processes. The physical components consist of OGVs, berths/wharves (docks), cranes, backland storage areas (grounded, wheeled or a combination), truck entrance and exit gates, and maintenance and administration buildings. The operational processes include stevedoring (loading/unloading ships), on-terminal container handling and storage, trucking and drayage, and rail operations. The Port typically owns the major terminal infrastructure (wharves, container storage yard, and buildings). The tenant or operator typically owns the wharf cranes and cargo handling equipment.

Containerized cargo can be divided into import and export movements, where imports are the goods received from vessels and exports are the goods loaded onto vessels for shipment. Figure 1.4 presents the general movement of imported containerized cargo and illustrates the types of emission-producing equipment associated with each handling or transportation step.

Figure 1.4: Movement of Imported Containerized Cargo



In the import cargo transportation system, OGVs are met outside the breakwater by the pilot boat that transfers a Port pilot aboard who guides the ship through the harbor and to the berth. Generally, one or two assist tugs meet the OGV just inside the breakwater and escort the vessel to its berth, helping with turning, maneuvering or standing by to assist if needed.

Large electric wharf cranes are used to unload containers from the ship to waiting terminal tractors, each with a removable chassis to receive the container. Containers are commonly measured as twenty-foot equivalent units (TEUs) that refer to the length of the containers. For example, a forty-foot long container would be counted as two TEUs. Wharf cranes are built for efficient movement of containers and can typically transfer 25 to 40 containers per hour. The number of cranes operating simultaneously to load/unload one vessel can vary, depending on the size of the vessel, the number of vessels at berth, crane gauge (distance between crane legs), and availability of cranes.

Terminal tractors (also called yard hostlers) move cargo from the dock into the terminal. Container terminals operate in one of two distinct modes, or a combination of the two. These modes are known as wheeled operations and grounded operations.

In a wheeled operation, the terminal tractor with a chassis receives a container from the wharf crane and then moves the container and chassis to a pre-assigned location within the terminal. The container and chassis are left there, to be picked up by an on-road HDV for transport out of the terminal, while the terminal tractor returns to have another chassis attached and to receive another container.

In a grounded operation, the terminal tractor with a chassis receives a container from the wharf crane and then moves the container and chassis to where a rubber tired gantry (RTG) crane (or straddle carrier crane) or top loader (similar to a large forklift) is operating. These units remove the container from the chassis and place the container in a stack. The terminal tractor returns with its chassis to receive another container. The stacked container is later loaded by an RTG or top loader onto a chassis pulled by an on-road HDV for transport out of the terminal.

The primary advantages of a wheeled operation compared with a grounded operation are that the wheeled operation can handle a higher number of containers per hour and uses less cargo handling equipment to move containers because there are fewer handling steps involved. Because of this, wheeled operations generally have lower emissions per container than grounded operations. Their disadvantage is that they require significantly more terminal acreage than grounded operations, which support higher TEU-per-acre densities.

From the terminal, cargo is transported by truck or rail to its initial delivery location. Trucks can transport the cargo to areas outside the SoCAB, to local delivery locations, to trans-loading warehouses, or to off-Port rail yards where the cargo is loaded onto railcars. Cargo can also be loaded directly onto railcars within the terminal (a feature known as on-dock rail). Switch engines are used locally to arrange rail cars and to move them to the larger rail yards, where the cars are assembled into unit trains that are moved by line haul locomotives. It is generally not considered cost effective to transport cargo by rail less than 700 to 800 miles, so rail cargo is typically transported out of California.

Export cargo handling has the same components as the imports, except the flow is reversed, as presented in Figure 1.5.

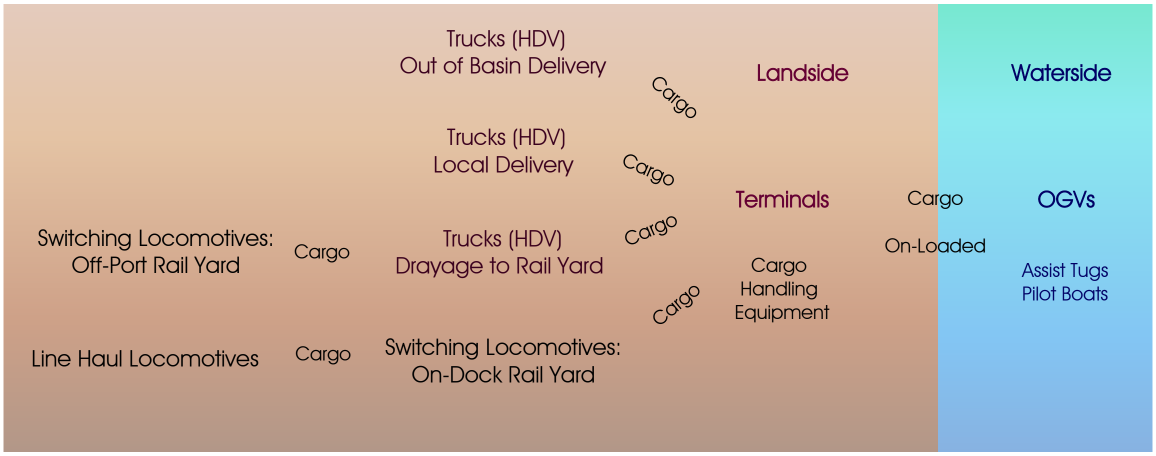


Figure 1.5: Movement of Exported Containerized Cargo

The combined import and export cargo shipped through the Port of Los Angeles in 2001 was approximately 120.1 million metric tons. On the landside of the transportation system, 67.7% of the cargo tonnage was transported by trucks and 32.3% by rail.

Fuel Types and Standards

Most of the equipment that moves and otherwise handles cargo is powered by one of the many forms of diesel fuel. There are three basic categories of diesel fuel used by these sources: on-road, off-road, and marine. On-road diesel fuel is used by the HDVs that are licensed to operate on public roadways, and is the most heavily regulated fuel category. Off-road or nonroad diesel fuel can be used only by equipment that is not licensed to operate on public roadways, including locomotives, and is also used in most harbor vessels. Off-road diesel is commonly dyed red to visually distinguish it from on-road diesel. The marine category of fuels consists of fuel oils, distillates, and gas oils as well as marine diesel fuel; the use of these fuels is predominantly in OGVs and some large towboats. These fuels have to meet certain specifications associated with their properties (such as viscosity and sulfur content) but are not regulated with respect to emissions potential by regulatory agencies. In addition to diesel fuel, a relatively small number of pieces of cargo handling equipment are powered by propane, and even fewer pieces of equipment are gasoline powered.

On-road diesel within the state of California is regulated with respect to its emission-producing characteristics by the ARB, and is nationally regulated by the EPA. In August 2003, ARB passed new fuel standards that will require diesel fuel sulfur content to be 15 parts per million (ppm) or less by 2006. The current sulfur limit for this fuel is 500 ppm, though it is typically produced with lower sulfur content ranging from 150-350 ppm. The new state rule will apply to fuel sold for both on-road and off-road vehicles. EPA's national diesel fuel regulation calls for a similar 15 ppm sulfur cap in 2007, but applies to fuel used in on-road vehicles only.

Off-road diesel meeting current ARB specifications has a similar 500 ppm limit on the sulfur content. However, federal off-road diesel may also be used locally (for example, in a locomotive that was fueled outside California), and this fuel has a higher sulfur limit of up to 5,000 ppm. Based on a literature search, in-use sulfur levels are usually slightly lower than these limits, typically about 350 ppm and 3,500 ppm, for CARB diesel and federal diesel, respectively (*see* EPA 1999, 'In-Use Marine Diesel Fuel,' EPA420-R-99-027). Harbor vessels were reported to be mostly operating on 500 ppm diesel fuel.

OGV fuel purchases (known as bunkers) are made at the lowest price along a ship's voyage and the vessels are not necessarily bunkered in California. Bunker specifications are set by the International Organization for Standardization (ISO) and the International Maritime Organization (IMO). OGV propulsion engines are most commonly operated on intermediate fuel oil (IFO) 380[1] although some run on higher or lower viscosity blends. All IFO blends are considered to be residual marine fuel oils, having an American Society for Testing and Materials (ASTM) and ISO sulfur limit of 4.5% (45,000 ppm). As with the regulated diesel fuel blends, refiners usually blend well below these limits, with 2.8% to 3.5% being common for IFO brands. Auxiliary engines on OGVs supply the electrical demands of the ship and are fueled with either IFO 380 or a lighter fuel such as marine diesel oil (MDO), which is also known as #4 diesel. Occasionally, auxiliary engines are fueled by lighter distillate fuels such as marine gas oil. Ship boilers are fueled by any of the above mentioned fuels with the most common being MDO. The information on all in-use fuel used in source category emission estimates was acquired, to the extent possible, through interviews.

Engine Types and Standards

The engines powering the vessels and equipment covered by this emissions inventory cover a wide array of characteristics and emission standards, although they are virtually all compression ignition engines (typically known as diesel engines, although some marine engines burn other types of fuel oil). The most basic division of diesel engines for regulatory purposes is into offroad and onroad categories. Offroad diesel engines are further divided into marine engines, mobile equipment engines, and locomotive engines. Onroad engines were the first mobile source category to be regulated, with emission limits affecting diesel engines beginning back in the late 1980s, and recently offroad engine standards have started to become effective. Onroad diesel engines are commonly used to power HDVs such as trucks and large vans. These onroad engines burn onroad diesel fuels.

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[1] The numerical value represents the kinematic viscosity of the fuel in centistokes at 50°C.

Marine Engines

For regulatory purposes, the EPA has differentiated marine engines into three categories identified by individual cylinder displacement. Category 1 engines are similar to common land-based offroad diesels (such as those powering cargo handling equipment) with cylinder displacements less than 5 liters (L) and power output greater than 37 kilowatts (kW). They are typically used in small commercial and recreational vessels. Category 1 engines are typically in the class termed "high-speed" diesel engines because their maximum engine speed generally exceeds 2,000 revolutions per minute (rpm). These engines are designed to burn offroad diesel, although some operators have configured the engines to burn onroad diesel.

Most Category 2 engines are similar to those used in locomotives, and have a cylinder displacement ranging from 5 to 30 L. They are typically used as OGV auxiliary engines and as propulsion engines in medium sized commercial vessels and OGVs. Category 2 engines are typically in the class termed "medium-speed" diesel engines with a maximum engine speed ranging generally from 1,000 rpm – 2,000 rpm. These engines are designed to burn offroad diesel and marine diesel oil.

Category 3 engines are unique engines that are specifically designed for OGV propulsion and have cylinder displacements of greater than 30 L (per cylinder). These massive engines (engine mechanics can commonly climb inside these engines while performing certain types of maintenance) are classified as slow-speed engines with a peak engine speed less than 200 rpm. Category 3 engines are designed to burn intermediate or heavy fuel oils such as IFO 380.

An overview of the various engines identified during the emissions inventory process, and their regulatory standards, is presented below by source category class.

OGVs inventoried in the baseline EI generally consist of compression ignition propulsion and auxiliary engines. Some specialty ships such as bulk liquid carriers can have additional independent diesel engines (typically Category 1 or 2) that power pumps or specialty equipment. Propulsion engines are typically Category 2 or 3 diesel engines that perform the function of propelling the OGV; some also have a secondary, indirect function of supplying power for the ship's electrical needs by the use of shaft generators or exhaust economizers. A shaft generator uses the rotation of the vessel's drive shaft to power an electrical generator, while an exhaust economizer uses the heat from the propulsion engine's exhaust to generate steam for electrical generation. Aside from these means of generating electrical power, the vessel's electrical needs, such as for navigational computers, communications equipment, air conditioning, pumps, lights, winches, cranes, etc., are supplied by the auxiliary engines, which are Category 1 or 2 engines. Steamships are an exception, in that the vessels' main boilers supply both propulsion and electrical power by producing steam which turns the propeller shafts and electrical generators.

Due to the international nature of OGVs, the engines on board internationally flagged ships and Category 3 engines on U.S. flagged ship have not been included in domestic engine regulations; rather, they have been left to regulation by the IMO. On 27 September 1997 the IMO adopted the International Convention on the Prevention of Pollution from Ships, also known as MARPOL 73/78. Annex VI of that Convention establishes a NO_X limit (Tier 0 standard); however, it does not set a limits for hydrocarbons, CO, or PM. Annex VI, effective 19 May 2005, establishes a retroactive standard for all new marine diesel engines (>37 kW) produced on and after 1 January 2000. The Annex VI NO_X standards are:

- 17 g/kW-hrs for engine speeds <130 rpm
- $45n^{-0.2}$ g/kW-hr (where n is engine speed, rpm) for engine speeds $\geq$130 rpm and <2,000 rpm
- 9.8 g/kW-hr for engine speeds $\geq$2,000 rpm

Domestically, the EPA initially did not set standards for Category 3 engines; however, a legal settlement resulting from court action was published on 29 May 2002 calling for the establishment of three standards for Category 3 engines: first tier standards, second tier standards, and voluntary low-emission engine standards. The first tier standards are similar to those in the MARPOL Annex VI and would be enforceable under U.S. law for new engines built in 2004 and later. The EPA standards would apply to vessels flagged in the U.S. and its not currently clear whether the U.S. government has the authority to impose these standards on foreign flagged vessels. The second tier standards would be achieved by the use of engine-based controls (such as exhaust gas after-treatment) and would apply for engines built in 2006 or later. The voluntary low emission engine standard would not be a mandatory standard.

Category 1 and 2 engine standards are addressed in the Harbor Vessel discussion below.

Harbor vessels typically use Category 1 and Category 2 marine engines and the vessels are generally US flagged. These vessels are regulated under the EPA marine engine Category 1 and 2 emission standards that were adopted in the final 1999 rule. These standards are based on the land-based standard for offroad and locomotive engines which include NO_X + total hydrocarbon (THC,) PM, and CO.

The EPA 1999 marine engine standards for U.S. flagged vessels are as follows:

- Category 1 Marine Engine Standards

Power ∃37 kW & cylinder displacement (D) < 0.9 dm^3; starting 2005	5.0 g/kW-hr CO 7.5 g/kW-hr NO_X + THC 0.40 g/kW-hr PM
0.9 dm^3 ≤ D <1.2 dm^3 starting 2004	5.0 g/kW-hr CO 7.2 g/kW-hr NO_X + THC 0.30 g/kW-hr PM
1.2 dm^3 ≤ D <2.5 dm^3 starting 2004	5.0 g/kW-hr CO 7.2 g/kW-hr NO_X + THC 0.20 g/kW-hr PM
2.5 dm^3 ≤ D <5.0 dm^3 starting 2004	5.0 g/kW-hr CO 7.2 g/kW-hr NO_X + THC 0.20 g/kW-hr PM

- Category 2 Marine Engine Standards

5.0 dm^3 ≤ D <15.0 dm^3 starting 2007	5.0 g/kW-hr CO 7.8 g/kW-hr NO_X + THC 0.27 g/kW-hr PM
Power <3,300 kW 15 dm^3 ≤ D <20 dm^3 starting 2007	5.0 g/kW-hr CO 8.7 g/kW-hr NO_X + THC 0.50 g/kW-hr PM
Power ∃3,300 kW 15 dm^3 ≤ D <20 dm^3 starting 2007	5.0 g/kW-hr CO 9.8 g/kW-hr NO_X + THC 0.50 g/kW-hr PM
20 dm^3 ≤ D <25 dm^3 starting 2007	5.0 g/kW-hr CO 9.8 g/kW-hr NO_X + THC 0.50 g/kW-hr PM
25 dm^3 ≤ D <30 dm^3 starting 2007	5.0 g/kW-hr CO 11.0 g/kW-hr NO_X + THC 0.50 g/kW-hr PM

Recreational marine diesel engines over 37 kW (or 50 hp) were regulated by EPA in the 2002 nonroad engine rule (separate from the 1999 rule making). Recreational vessels include power boats, cruisers, yachts, large sail boats, and other types of pleasure craft. The recreational standards are again based on cylinder displacement and the standards are similar to the Category 1 limits presented above.

- Recreational Marine Engine Standards

0.5 dm^3 ≤ D <0.9 dm^3 starting 2007	5.0 g/kW-hr CO 7.5 g/kW-hr NO_X + THC 0.40 g/kW-hr PM
0.9 dm^3 ≤ D <1.2 dm^3 starting 2004	5.0 g/kW-hr CO 7.2 g/kW-hr NO_X + THC 0.30 g/kW-hr PM
1.2 dm^3 ≤ D <2.5 dm^3 starting 2004	5.0 g/kW-hr CO 7.2 g/kW-hr NO_X + THC 0.20 g/kW-hr PM
D ∃2.5 dm^3 starting 2004	5.0 g/kW-hr CO 7.2 g/kW-hr NO_X + THC 0.20 g/kW-hr PM

Off-Road Engines

Off-road engines, in the context of the Port's baseline EI, are engines that power equipment that is not designed for use on public roads. Examples include yard trucks that are used to move containers within terminals, and cranes used to lift containers onto and off of railcars. The first federal standards (Tier 1) for new offroad diesel engines were adopted by EPA in 1994 and applied to engines over 37 kW. These standards were phased in from 1996 to 2000. In 1996, a Statement of Principles (SOP) pertaining to nonroad diesel engines was signed among EPA, the ARB, and the major diesel engine manufacturers. On August 27, 1998, the EPA signed the final rule reflecting the provisions of the SOP. This 1998 regulation introduced Tier 1 standards for equipment under 37 kW and increasingly more stringent Tier 2 and Tier 3 standards for all equipment with phase-in schedules from 2000 to 2008. The Tier 1-3 standards are met through advanced engine design, with limited or no use of exhaust gas after-treatment (e.g., oxidation catalysts). Tier 3 standards for NO_X+THC are similar in stringency to the 2004 standards for highway engines; however, Tier 3 standards for PM were never adopted.

The schedule for implementing the Tier 1 through 3 offroad emission standards runs through 2008, depending on the Tier level and horsepower category. All Tier 1 standards were in place by 2000, with PM emission standards ranging from 0.75 down to 0.4 g/bhp-hr depending on horsepower group, with larger engines having lower limits). Tier 1 standards for NO_X are 6.9 g/bhp-hr for most engines, and 7.1 or 7.8 g/bhp-hr (combined NO_X+non-methane hydrocarbons (NMHC) for the smallest engine groups. Tier 1 CO limits range from 8.5 to 4.1 g/bhp-hr, and the larger categories of engines have a limit of 1.0 g/bhp-hr for HC.

The Tier 2 standards are being implemented between 2001 and 2006. When fully implemented, PM for the larger categories will be decreased to 0.15 g/bhp-hr, NO_X+NMHC will be reduced to between 4.8 and 5.6 g/bhp-hr, and CO for most size categories will be reduced to 2.6 or 3.7 g-bhp-hr. The Tier 3 standards will further reduce NO_X+NMHC to between 3.0 and 3.5 g/bhp-hr between 2006 and 2008.

In 2004, the EPA adopted Tier 4 emission standards, which are to be phased in between 2008 and 2015. The Tier 4 standards require that emissions of PM and NO_X be further reduced by about 90%. Such emission reductions can be achieved through the use of control technologies similar to those required to meet the 2007-2010 standards for highway engines (such as advanced exhaust gas after-treatment). The Tier 4 standards for offroad engines will lower PM emissions from most size categories to 0.015 to 0.03 g/bhp-hr, and NO_X to 0.30 or 0.50 for most size groups.

The after-treatment devices that will be used to meet the Tier 4 standards will require the use of low-sulfur fuel. To accommodate this, the ARB has mandated reductions in the sulfur content of nonroad diesel fuels to a maximum of 15 ppm, effective in 2006.

- Tier 4 Offroad Emission Standards

Power < 19 kW (25 hp) Starting in 2008	0.30 g/bhp-hr PM 5.6* g/bhp-hr NO_X
$19 \leq P < 56$ kW (75 hp) Starting in 2013	0.022 g/bhp-hr PM 3.5* g/bhp-hr NO_X
$56 \leq P < 130$ kW (175 hp) 2012 – 2014	0.015 g/bhp-hr PM 0.30 g/bhp-hr NO_X
$130 \leq P < 560$ kW (750 hp) 2011-2014	0.015 g/bhp-hr PM 0.30 g/bhp-hr NO_X
$P \geq 560$ kW (750 hp)	
2011-2015 generators	0.022 g/bhp-hr PM 0.50 g/bhp-hr NO_X
2011-2015 all others	0.03 g/bhp-hr PM 2.6 g/bhp-hr NO_X

* NO_X + NMHC

Locomotive Engines

Locomotives typically operate in one of two different duty cycles, line haul and switching. Line haul refers to the overland transportation of trains, typically over long distances, whereas switching refers to the local movement of railcars for pickup and delivery, to set them up for line haul transportation, or to prepare them for local delivery. Locomotives used for line haul operations are typically equipped with large, powerful engines of 3,000 hp or more, while switching locomotives use smaller engines, typically having 1,200 to 3,000 hp. Older line haul locomotives have often been converted to switch duty as newer line haul locomotives with more horsepower have become available.

In 1997, EPA adopted locomotive emission standards for NO_X, HC, CO, PM, and smoke, applicable to newly manufactured and remanufactured railroad locomotives and locomotive engines. The rule took effect in the year 2000 and applies to locomotives originally manufactured during or after 1973, any time they are manufactured or remanufactured. Electric locomotives, historic steam-powered locomotives, and locomotives originally manufactured before 1973 are not regulated.

Three sets of emission standards were adopted, with applicability of the standards depending on the date a locomotive is first manufactured. The first set of standards, Tier 0, apply to locomotives and locomotive engines originally manufactured from 1973 through 2001, any time they are manufactured or remanufactured. The second set of standards, Tier 1, apply to locomotives and locomotive engines originally manufactured from 2002 through 2004. These locomotives and locomotive engines will be required to meet the Tier 1 standards at the time of original manufacture and at the time of each remanufacture. The final set of standards, Tier 2, will apply to locomotives and locomotive engines originally manufactured in 2005 and later. Tier 2 locomotives and locomotive engines will be required to meet the applicable standards at the time of original manufacture and each subsequent remanufacture.

The emission standards apply separately to two different duty cycles, line haul and switching. Line haul refers to the overland transportation of trains, typically over long distances whereas switching refers to the local movement of railcars to set them up for line haul transportation or to prepare them for local delivery. Each locomotive must comply with both sets of standards regardless of whether they are intended for duty in one or the other service.

The Tier 0, Tier 1, and Tier 2 locomotive emission standards, and the years they become effective, are listed below.

- Tier 0 Locomotive Standards (1973 - 2001)

Line-haul:	1 g/bhp-hr HC*	Switching:	2.1 g/bhp-hr HC*
Line-haul:	5 g/bhp-hr CO	Switching:	8 g/bhp-hr CO
Line-haul:	9.5 g/bhp-hr NO_X	Switching:	14 g/bhp-hr NO_X
Line-haul:	0.6 g/bhp-hr PM	Switching:	0.72 g/bhp-hr PM

- Tier 1 Locomotive Standards (2002 - 2004)

Line-haul:	0.55 g/bhp-hr HC*	Switching:	1.2 g/bhp-hr HC*
Line-haul:	2.2 g/bhp-hr CO	Switching:	2.5 g/bhp-hr CO
Line-haul:	7.4 g/bhp-hr NO_X	Switching:	11 g/bhp-hr NO_X
Line-haul:	0.45 g/bhp-hr PM	Switching:	0.54 g/bhp-hr PM

- Tier 2 Locomotive Standards (2005 and later)

Line-haul:	0.3g/bhp-hr HC*	Switching:	0.6 g/bhp-hr HC*
Line-haul:	1.5g/bhp-hr CO	Switching:	2.4 g/bhp-hr CO
Line-haul:	5.5g/bhp-hr NO_X	Switching:	8.1 g/bhp-hr NO_X
Line-haul:	0.2g/bhp-hr PM	Switching:	0.24 g/bhp-hr PM

* - HC standard is in the form of THC for diesel engines

In addition to these emission standards, smoke standards limit 30-second and 3-second peak smoke opacity to 40% and 50%, respectively (for Tier 0, 1, and 2) and limit the opacity of steady-state emissions to 30% (Tier 0), 25% (Tier 1), and 20% (Tier 2).

On-Road Engines

The on-road vehicles that are the focus of this study fall into the category of HDVs by virtue of their gross vehicle weight rating (GVWR), which is a measure of the maximum allowable weight of vehicle plus cargo. These vehicle are almost exclusively powered by compression-ignition engines burning diesel fuel, due to the relative fuel efficiency of this type of engine.

Emission standards for on-road vehicles have generally preceded standards for offroad, marine, and locomotive engines. Standards for diesel HDVs have become increasingly stringent, starting in 1987 with the following limits:

- 1987 Diesel HDV Standards
  - 1.3 g/bhp-hr THC
  - 15.5g/bhp-hr CO
  - 6.0 g/bhp-hr NO_X
  - 0.60 g/bhp-hr PM

In 1991, the NO_X standard was lowered to 5.0 g/bhp-hr and the PM standard was reduced to 0.25 g/bhp-hr, and a new NMHC standard of 1.2 g/bhp-hr was introduced (in addition to the existing THC standard). The PM limit was further reduced in 1994 to 0.10 g/bhp-hr.

Standards adopted in 1997 established tighter NO_X/NMHC limits slated for implementation in 2004. This standard gives manufacturers an option of complying with one of two limits: 2.4 g/bhp-hr for a combination of NO_X and NMHC, or 2.5 g/bhp-hr for NO_X and 0.5 g/bhp-hr for NMHC. Although originally intended to be effective with the 2004 model year vehicles, a court settlement reached in 1998 between the EPA, the U.S. Department of Justice, the ARB, and major engine manufacturers resulted in a agreement by the manufacturers to meet the 2004 standards early, by October 2002. (The dispute was over high NO_X emissions during certain driving modes, caused by engine management software that was optimized for fuel efficiency but caused higher NO_X emissions in the process.)

The most recently enacted HDV emission standards will become effective in 2007, and will set the following limits:

- 2007 Diesel HDV Standards
    - 0.14g/bhp-hr NMHC
    - 0.20g/bhp-hr NO_X
    - 0.01g/bhp-hr PM

The PM standard will be effective for all engines beginning with the 2007 model year. The NO_X and NMHC standards will be phased in between 2007 and 2010. These standards are far below the existing standards and will require manufacturers to design after-treatment devices that will, in turn, require a very low concentration of sulfur in the fuel in order to work properly. As previously mentioned, in 2006 the allowable diesel fuel sulfur content will decrease to 15 ppm.

1.3 General Methodology

The Port's baseline emissions inventory methodology was closely coordinated from its inception with a similar baseline emissions inventory concurrently developed for the POLB, and with EPA, ARB, and SCAQMD. The ARB, part of the California Environmental Protection Agency, is responsible for improving and/or maintaining air quality within the State of California.[2] The SCAQMD is the air pollution control agency for major portions of Los Angeles, San Bernardino, and Riverside counties and for Orange county in Southern California, and has been delegated responsibility for improving and/or maintaining air quality within the region. Both ports and these agencies held regular meetings throughout the EI process to discuss and agree on methodology, to receive updates on project progress, to review and comment on the findings, and review and comment on the draft report. In addition, the report has been reviewed by Ed Avol, University of Southern California School of Medicine and consultant to the Port Community Advisory Committee (PCAC), David Howekamp, consultant to the PCAC, and James Corbett, P.E., Ph.D., University of Delaware.

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[2] See *http://www.arb.ca.gov/html/mission.htm.*

An activity-based approach was employed to develop this comprehensive EI. This approach utilizes interviews and conversations with terminal owners, equipment operators, Port staff, and others with firsthand knowledge of either equipment details or operational parameters (e.g., Port Pilots and Marine Exchange of Southern California(MarEx). Prior to initiation of the inventory effort, a detailed proposed approach was developed by both the Port of Los Angeles and the port of Long Beach and submitted to the EPA, ARB, and SCAQMD for review. Modifications to the draft approach were made in response to agency questions, comments, and suggestions. Findings from the data collection efforts also resulted in modifications to the draft approach. This report documents the final agreed upon approach to the EI.

For each of the source categories, data was collected through an interview process and emissions were estimated using the agreed upon methods that were consistent (as feasible) with the POLB EI. Where differences exist, they will be noted in this report. The primary differences between this EI and the POLB EI are:

- This EI includes marine vessels, whereas the POLB EI does not.
- This EI estimates emissions based on 2001 activity, whereas the POLB study is based on 2002 activity.

In the technical field of estimating air emissions, there are significant distinctions between off-road and on-road vehicles or equipment. Off-road equipment includes vehicles or equipment that are not designed or licensed to operate on public roads; for the EI this includes cargo handling equipment, locomotives, and marine vessels. The on-road category consists of vehicles that are typically licensed to operate on public roads, such as HDVs. The important distinctions between these two source categories are, first, the methods by which emissions are estimated and, second, that the on-road vehicles have been significantly regulated in the past (with respect to emissions) as compared with off-road equipment. Each of the source categories has different emission estimating methodologies that are summarized below (additional details on the methods used are presented in the appropriate source category section of this report).

Ocean-Going Vessels

OGVs consist of various types of vessels commonly distinguished by the cargo they carry. The most common classes include: auto carriers, bulk carriers, containerships, cruise ships, general cargo ships, ocean-going tugboats, refrigerated vessels, roll-on roll-off (RoRo) ships, and bulk liquid tankers. OGVs require the use of the Port's Harbor Pilots when arriving and departing the Port of Los Angeles. The OGV emissions inventory combines marine industry and emissions estimating expertise, locally derived activity-based data, and the latest emissions estimating methods.

The basic methodology for estimating emissions from these vessels was built on previous marine emissions studies developed in California, elsewhere in the nation, and international studies. In addition to using available data on every OGV visit to the Port in 2001, the Port implemented an unprecedented Vessel Boarding Program that focused on gathering specific vessel characteristics and operational data and gaining an understanding of how the different types of OGVs arrive, depart, and transit the Port, as well as how they operate while at dock or during "hoteling."

With the cooperation of nearly every shipping line, over 60 vessels were boarded, some more than once for a total of more than 100 boardings. The result of this ambitious program was a notable improvement in the understanding of the operating modes of these large vessels during their harbor transit at slow speeds. The approach and arrival/departure into the Port is a small component of an OGV's overall operation. This portion of a voyage, however, is important because it is the portion that takes place while the ship is in the closest proximity to populated areas and while the propulsion engines are not operating at the speeds at which they were designed to operate most efficiently. The type of information presented in the OGV section (Section 2) is the first of its kind in a marine vessel emissions inventory, including how large propulsion engines operate at low loads and how this affects emissions.

The study looks at several zones of operation that take place within the geographical extent of the study. These zones include the "fairway" that extends from the boundary of the study area to the precautionary zone, the precautionary zone itself just outside the breakwater, the harbor, and dock-side hoteling. Activity data focused on the precautionary zone, the harbor, and dock-side hoteling because these are the operational zones in which the OGVs are closest to populated areas.

Activity data and vessel characteristics were used with the latest emission factors, developed from the latest emission testing data sets. Emissions were estimated for the various operational modes within the zones listed above.

Section 2 provides further detail on the emission estimating methods used for the OGV source category.

Harbor Craft

Harbor craft are commercial marine vessels that spend the majority of their time within or near the Port and harbor. Harbor craft are a separate source category from ocean going vessels due to the different emission estimate methodology used. Harbor craft include:

- Assist tugboats
- Towboats/push-boats/ tugboats
- Ferries and excursion vessels
- Crew boats
- Work boats
- Government vessels
- Dredges and dredging support vessels
- Commercial fishing vessels
- Recreational vessels

The Port harbor vessel operators and marina managers were interviewed to develop a harbor craft list. Valuable data was provided for assist tugs in the form of histograms on engine operations and loads. This is the first time that data of this caliber has been used in a marine emissions inventory. In addition to the local interviews, several data sources were used to enhance the harbor craft data gathered:

- ARB's 2002 Statewide Commercial Harbor Craft Survey
- Carl Moyer grant program applications
- United States Army Corps of Engineer's (USACE) Waterborne Commerce Statistic Center

The emission factors found in the 1999 EPA Final *Regulatory Impact Analysis* (RIA) were used for estimating the harbor craft emissions for Category 1 engines. For Category 2 engines, emission factors published by ENTEC (discussed in Sections 2 and 3) for medium speed vessels were used. For recreational vessels, the emission factors were obtained from ARB's Pleasure Craft Exhaust Emissions Inventory[3] (PCEEI).

Section 3 provides further detail on the emission estimate methods for the harbor craft source category.

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[3] ARB, 1998 "Proposed Pleasure Craft Exhaust Emissions Inventory", MSC 98-14, Tables 3a and 3b.

Cargo Handling Equipment

CHE consists of various types of equipment and vehicles that fall within the off-road designation and are used to move cargo within terminals and other off-road areas. The emission estimates for this group were prepared by the ARB using their OFFROAD[4] model, which has been developed to estimate emissions from off-road equipment fleets. Equipment operators and owners were interviewed and equipment lists were developed that formed the inputs for the OFFROAD model. The comprehensive equipment lists included all reported CHE that operated at the Port in 2001, with the following specifications for each piece of equipment:

- Equipment type, make and model
- Engine make and model
- Model year
- Horsepower
- Load data
- Annual operating hours
- Fuel used

The OFFROAD model typically uses ARB's latest available equipment information input values, when developing emission estimates for the whole state or for a subdivision such as a county or air quality control region. These default input values are generally representative of the off-road fleets for those relatively large areas. A major goal of the Port's EI, however, was to provide specific information on the fleet that actually operates within Port boundaries. Therefore, the OFFROAD model defaults for equipment population, model year, horsepower, and hours of operation were not used. Instead, terminal-specific information collected during the interview process was used to estimate the emissions, thus providing a higher level of accuracy for the EI than would have been achieved through the use of ARB's more general default data.

Section 4 provides further detail on the emission estimating methods for the CHE source category.

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[4] ARB, 2003. See *http://www.arb.ca.gov/msei/off-road/off-road.htm*.

Rail/Locomotive Activity

Railroad operations are typically described in terms of two different types of operation, line haul and switching. Line haul refers to the movement of cargo over long distances (e.g., cross-country) and occurs within the Port at the initiation or termination of a line haul trip, as cargo is either picked up for transport to destinations across the country or is dropped off for shipment overseas. Switching refers to the assembling and disassembling of groups of railcars at various locations in and around the Port, the sorting of the cars of inbound cargo trains into contiguous "fragments" for subsequent delivery to terminals, and the short distance hauling of rail cargo within the Port.

To estimate emissions from railroad activities within the Port, detailed information was obtained from railroad operators and others with knowledge of rail activities, and also by accompanying switch engines during their normal operations to gain firsthand knowledge of Port rail activities. As part of the data collection program, interviewers rode along with switch engine crews to observe operational characteristics associated with the different functions that the switch engines perform in their daily work. This is the first Port related inventory to extensively utilize direct observations and detailed data to estimate emissions for this source category.

Because of different types of information provided by the railroad companies, emissions were estimated using two basic methods. For most of the switching activities, emissions were estimated on the basis of percentage of time spent in the different throttle notch settings. (Diesel locomotive power levels are adjusted by the engineer in a series of eight steps called notches, plus an idle setting.) This information was obtained from on-board dataloggers. For line haul activities (and a limited amount of switching activity), fuel usage was used as a surrogate measure of the level of activity of the locomotives. The EPA has published emissions information for switch and line haul locomotive operations in both throttle notch and fuel consumption modes, so the emission estimates have not been compromised by the use of different methods for switching versus line haul operations. As feasible, cross-checks between methods have been developed to demonstrate the degree of agreement between methods.

Section 5 provides a more complete description of the locomotive emission estimating methods and steps.

HDVs

There are two components to the estimation of HDV emissions presented in this report: on-road travel and on-terminal operations. Most HDV activity within the Port, in terms of operating hours and miles traveled, takes place on the public roads within the Port as the trucks travel to and from the terminals to drop off or pick up their cargo, and as they sometimes wait for entry outside terminal gates. The trucks also operate within each terminal, typically entering through a controlled access gate, traveling through the terminal to drop off and/or pick up cargo, and then exiting the terminal.

ARB's on-road emission estimating model, EMFAC2002[5], was used to develop emission factors for HDV operations, at various speeds and at idle. An important model input parameter is the model year distribution of the HDVs because on-road vehicle emissions vary greatly depending on their model year, and the emission factors developed by the model are based on the age distribution of the fleet being modeled. A goal of the HDV portion of the EI was to identify the actual model year distribution of the truck fleet servicing the Port facilities rather than use the EMFAC2002 model's default age distribution. The Port-specific HDV model year distribution was developed by the ARB and the SCAQMD querying over 7,000 license plate numbers, obtained from local terminals, using the California Department of Motor Vehicles (DMV) registration database. This is the first time such a database has been assembled for Port trucks.

For estimating on-road (off-terminal) HDV emissions, on-road activity information was developed by a traffic consultant, Meyer, Mohaddes Associates, Inc. (MMA), using trip generation and travel demand models that were used in previous Port traffic studies.[6] This previous traffic study has been used by the Port for transportation planning projects; therefore, the same methods and models were used to estimate traffic volumes on Port roadways for this EI to be consistent with past and current traffic studies and planning projects.

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[5] ARB, 2002. See *http://www.arb.ca.gov/msei/msei.htm*. EMFAC2002 is the emission factor model approved by EPA for use in estimating emissions for on-road vehicles in California; it is not approved for off-highway CHE or for emissions outside California.

[6] MMA, June 2001, Ports of Long Beach/Los Angeles Transportation Study, and MMA, Inc., April 2004, Port of Los Angeles Baseline Transportation Study.

The models use container throughputs for each terminal to calculate the number of heavy-duty truck trips that would be associated with moving that respective volume of cargo (minus rail movements) into and out of the Port. Based on these trip volumes and known existing traffic volumes on roadways, the models then "route" the trucks from the various terminals to the major entry and exit points to and from the Port. The models also incorporate the distance and average speed for each roadway, thus providing volume, distance, and speed for each roadway segment used. On-road emissions were then estimated by multiplying the number of trucks and the distance by the appropriate EMFAC2002 emission factor based on the speed traveled in each roadway segment.

For estimating on-terminal HDV emissions, terminal operators were interviewed with regards to on-terminal traffic patterns, including time spent waiting at the entry gate, time and distance on terminal while dropping off and/or picking up cargo, and time spent waiting at exit gates. As with off-terminal emissions, on-terminal emissions were estimated by multiplying the appropriate EMFAC-derived emission factor by the time and distance parameters established for the terminals.

Section 6 provides further detail on the emission estimating methods for the HDV source category.

1.4 EI Limitations

There are always limitations to every emissions inventory due to the very nature of such an estimation effort:

- ➢ The inventory provides only a "snapshot" of emissions by source category.
    - ❑ Tenants and operators change
    - ❑ Equipment types, engines and fuels change
    - ❑ Operational modes of marine container terminals change with availability of land (i.e., wheeled vs. grounded modes)

- ➢ Emissions are estimated from hundreds of pieces of off-road and on-road equipment and marine vessels that operate using a vast variety of engine types, under a range of duty cycles, and consume different fuel types. The equipment is also operated within variable spatial and temporal parameters.

For each source category, the limitations regarding data collected, activity and emissions estimates, and other limiting elements are identified and discussed at the end of each respective section.

1.5 Results

Baseline (2001) emission estimates of NO_X, TOG, CO, PM_{10}, $PM_{2.5}$, DPM, and SO_2 are presented in tons per year (tpy) and tons per day (tpd) in Tables 1.1 and 1.2, respectively. Tons per day estimates were developed by dividing the tons per year estimates by 365 days per year.

Emission factors and model output for particulate emissions are expressed as PM or as PM_{10}. In the cases where the emission factor or model output is expressed as PM, it has been assumed to be 100% PM_{10}. Based on the EPA NONROAD FTNT model, $PM_{2.5}$ is assumed to be 92% of PM_{10}. Another measure of particulate emissions, diesel particulate matter (DPM), only includes particulate emissions from diesel engines. For categories in which diesel fuel is the only fuel burned, such as locomotives and HDV, then PM_{10} and DPM are equivalent. For categories such as CHE in which other fuels, such as propane, are used, DPM has been estimated by subtracting the non-diesel PM_{10} emissions from the total PM_{10} emission estimate.

Emissions of organic compounds can be reported in various ways depending on the end use of emission estimates. The ARB defined "total organic gases", TOG[7], as a means of reporting estimates of total hydrocarbon (HC) plus oxygenated components such as alcohols and aldehydes that take part in ozone formation reactions. When applicable, EPA's conversion factors for hydrocarbon emission components were used to convert HC values to TOG[8], where HC multiplied by 1.07 yields TOG.

Table 1.1: 2001 Emissions by Source Category, tpy

	NO_X	TOG	CO	PM_{10}	$PM_{2.5}$	SO_2
Ocean-Going Vessels	6,922.7	233.6	553.9	561.0	449.9	4,117.5
Harbor Craft	3,530.7	376.0	1,622.8	178.0	163.7	506.4
Cargo Handling Equipment	1,862.6	204.5	725.5	111.6	102.6	44.1
Railroad Locomotives	2,465.8	99.7	249.4	60.1	55.2	89.8
Heavy-Duty Vehicles	4,463.5	185.5	815.3	87.9	77.9	33.6
Total Port	**19,245.3**	**1,099.3**	**3,966.9**	**998.6**	**849.3**	**4,791.4**

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[7] ARB, 1996. "California Non-Methane Organic Gas Test Procedure".

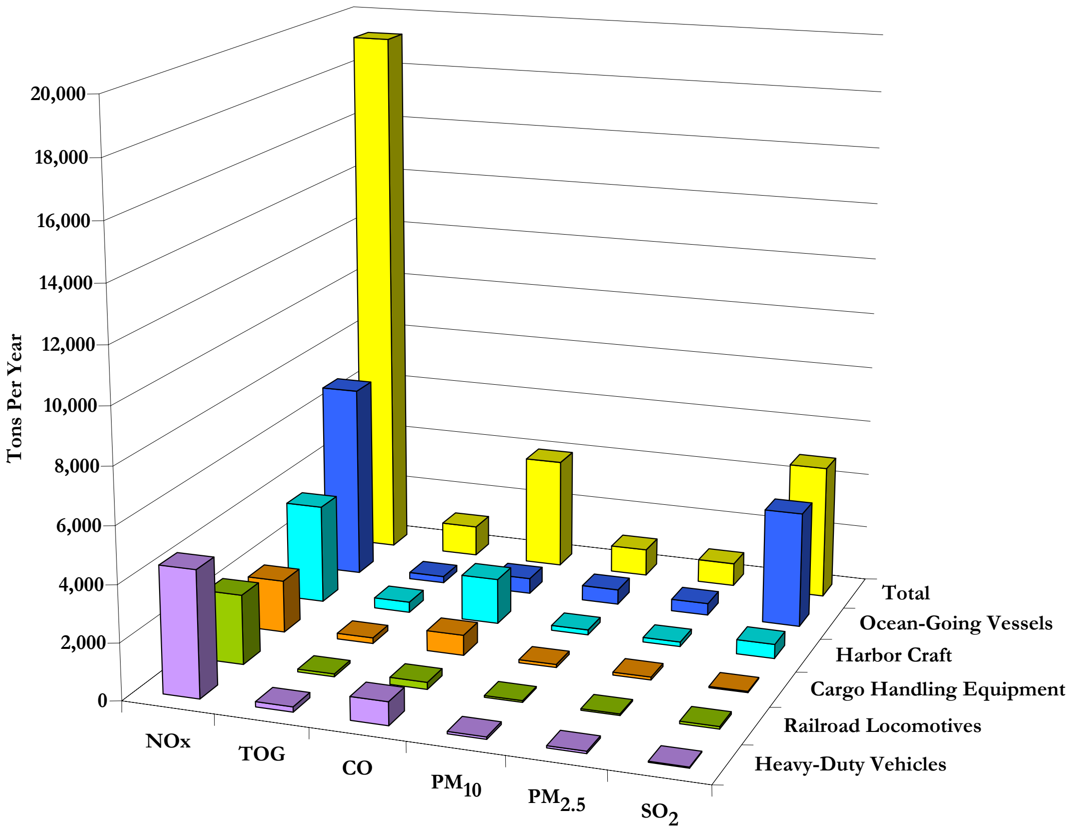
[8] EPA, May 2003. "*Conversion Factors for Hydrocarbon Emission Components*", EPA 420-P-03-002.

Table 1.2: 2001 Emissions by Source Category, tpd

	NO_X	TOG	CO	PM_{10}	$PM_{2.5}$	SO_2
Ocean-Going Vessels	18.97	0.64	1.52	1.54	1.24	11.28
Harbor Craft	9.67	1.03	4.45	0.49	0.45	1.39
Cargo Handling Equipment	5.10	0.56	1.99	0.31	0.28	0.12
Railroad Locomotives	6.76	0.27	0.68	0.16	0.15	0.25
Heavy-Duty Vehicles	12.23	0.50	2.24	0.24	0.21	0.09
Total Port	**52.73**	**3.00**	**10.88**	**2.74**	**2.33**	**13.13**

Emission totals by category are illustrated in Figure 1.6.

Figure 1.6: POLA Emissions by Source Category, tpy



1.6 Report Organization

This report is organized as follows:

- Section 1 Introduction.
- Section 2 Ocean-Going Vessels.
- Section 3 Harbor Craft.
- Section 4 Cargo Handling Equipment.
- Section 5 Railroad Locomotives.
- Section 6 Heavy-Duty Diesel-Fueled Vehicles.

SECTION 2 OCEAN-GOING VESSELS

This section presents in detail the estimates of emissions from ocean-going vessels (OGVs) calling at the Port of Los Angeles (Port) in 2001, whether inbound from the open ocean or transiting from the neighboring Port of Long Beach (POLB). OGVs calling only at the POLB or bypassing both ports without physically stopping at a Port of Los Angeles dock have not been included in this study. Harbor vessels, including tugboats, fishing boats, and dredges, are discussed in Section 3. This section presents the geographical delineation of the emissions inventory area, the vessel types and characteristics that called on the Port, data and information sources used to estimate both activity and emissions, emission estimate methodology, and emission estimates.

2.1 Approach

Several previous marine vessel emissions inventories[9] have been prepared for the Los Angeles area. The most recent, the 1999 Arcadis studies cited in the footnote below, were prepared using an activity-based methodology that provided a greater resolution of emission sources than previous studies and included commercial marine vessel activity in both the Port of Los Angeles and the POLB. Since that time, there has been a steady increase in the understanding of the operational and physical characteristics of OGVs associated with port activities (near the coast) culminating in published studies in the U.S. and Europe.[10]

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[9] Previous studies include:
1) ARB *1991-3. Inventory of Air Pollutant Emissions from Marine Vessels.* Booz-Allen Hamilton, Inc. Final Report 1991, updates 1992 & 1993.
2) SCAQMD, Pera C. 1996. *Marine Vessel Emissions Inventory and Control Strategies.* Acurex Environmental Corporation. Final Report FR-119-96. 12 December 1996.
3) SCAQMD, Pera C. 1999a. *Analysis of Marine Emissions in the South Coast Air Basin.* Arcadis Geraghty & Miller. Final Report FR 99-100. 6 May 1999.
4) SCAQMD, Pera C. and Popek D. 1999b. *Marine Vessel Emissions Inventory. Update to 1996 Report: Marine Vessel Emissions Inventory and Control Strategies.* Arcadis Geraghty & Miller. Final Report. 23 September 1999.

[10] Studies include:
1) Port of Houston Authority and Texas Natural Resource Conservation Commission, 2000. *Houston-Galveston Area Vessel Emissions Inventory.* Starcrest Consulting Group, LLC (Starcrest). Final Report. November 2000.
2) Corbett J.J. 2002. "2002 Emissions from Ships in the Northwestern United States." *Environmental Science & Technology*, Vol. 36, No. 6, 2002.
3) European Commission, 2002. *Quantification of Emissions from Ships Associated with Ship Movements between Ports in the European Community.* ENTEC. Final Report July 2002.
4) The Port of New York & New Jersey and United States Army Corps of Engineers, 2003. *New York, New Jersey, Long Island Nonattainment Area Commercial Marine Vessel Emissions Inventory.* Starcrest. Final Report. April 2003/Errata version January 2004.

One of the primary goals of the Port of Los Angeles for the baseline marine vessel emissions inventory was to better define the activites at the Port and to better define assumptions used in estimating emissions such that the inventory will become more representative of actual conditions. To that end, this study conducted an intensive activity-based approach building on of previous inventories, and thus advancing the understanding of OGV operations within the Port region.

Throughout the development of this baseline inventory, five major areas were the focus for improvements in methodology over the 1999 Arcadis study. These areas are listed below and are further detailed throughout Section 2:

- Improved estimates of propulsion engine load factors.
- Incorporation of the most current emission factors.
- Improved understanding of auxiliary engine characteristics, activity, and load factors.
- Inclusion of emission factor adjustments for propulsion engine low load/speed operational conditions.
- Implementation of an extensive vessel boarding program.

The overarching approach implemented in developing the baseline OGV emissions inventory is the extensive use of locally specific data and operational characteristics, which are employed to develop and define activity parameters. This results in a more accurate estimation of power requirements for propulsion engines, auxiliary engines, and boilers by vessel type, engine speed type, and propulsion engine technology.

2.2 Geographical Delineation

The geographical extent of the emissions inventory for marine vessels is the same boundary that was used in previous marine vessel inventories for the South Coast Air Basin (SoCAB). The portion of study area outside the Port's breakwater is four-sided, geographically defined by the following:

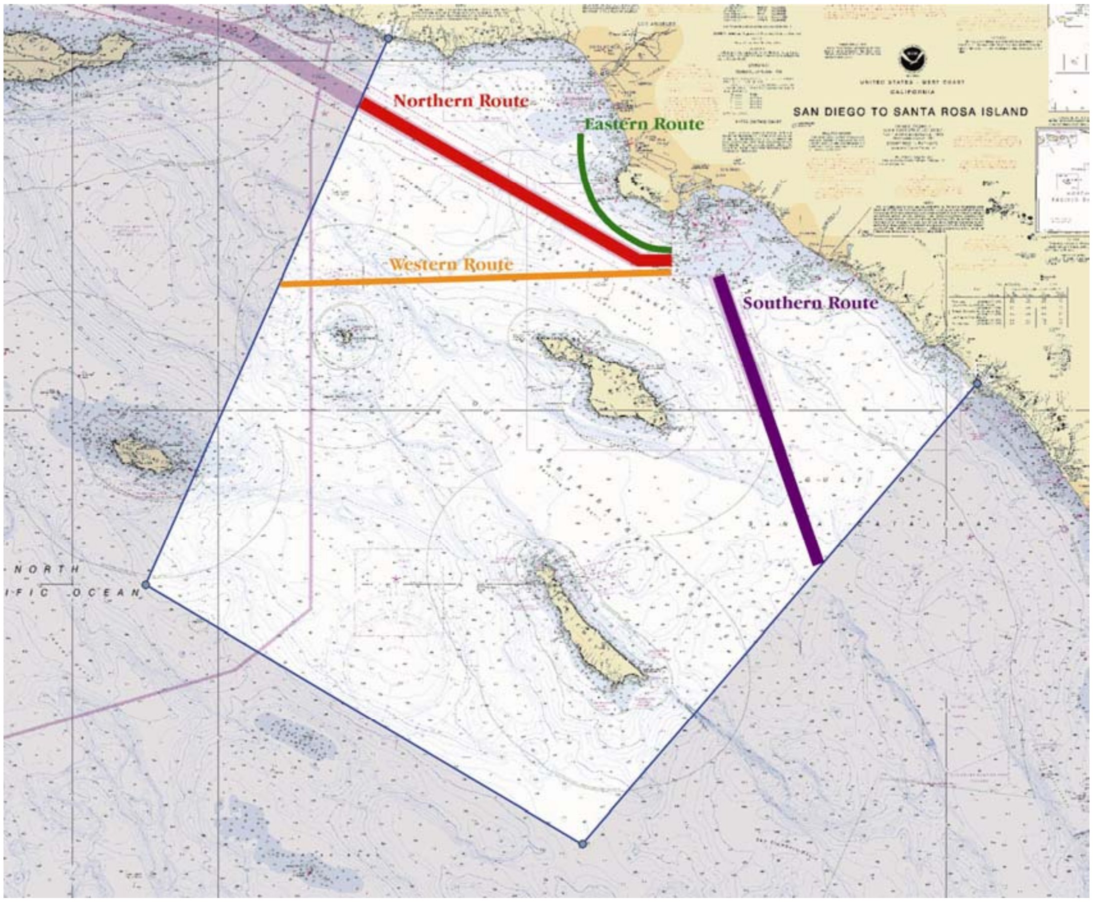
- The northwest corner is located where the Ventura County and Los Angeles County lines intersect the Pacific Ocean (34°02'42.4" N latitude by 118°56'41.2" W longitude).
- The southwest corner is located over the water, just south of the Territorial Sea boundary, south of San Nicolas Island (33°00'00.0" N latitude by 119°30'00.0" W longitude).
- The southeast corner is located over the water, south of the Territorial Sea, south of San Clemente Island (32°30'00.0" N latitude by 118°30'00.0" W longitude).

- The northeast corner is located where the Orange County and San Diego County lines intersect the Pacific Ocean (33°23'12.7" N latitude by 117°35'46.4" W longitude).

Figure 2.1 shows this portion of the study area as well as the major north and south shipping routes. The Marine Exchange of Southern California (MarEx) ship routes were used along with their estimates of travel distances offshore from Point Fermin. These trip segments were organized into four routes (comprising both inbound and outbound traffic) reflecting north, east (El Segundo), west, and south routes, as designated by MarEx:

- North: The predominant trade route for OGVs in terms of ship calls, involving coastwise trade to the U.S. continental ports as far as Seattle (San Juan Straights) but also to Alaska and the Far East (Great Circle Route).
- South: The second most traveled direction for ship calls was from the South, serving not only Mexico and other ports but also traffic through the Panama Canal (a few ships have ports-of-call in Houston, Texas).
- West: Mainly involved with travel to Hawaii, but may include some towboat trips to the Channel Islands.
- East: This is a short trip between the Port and El Segundo, the location of a petrochemical complex to the north which has an extensive anchorage area; it never has an "at-sea" trip leg. Note that the "east" trip is a slight misnomer because it is really towards the north, but was so designated for purposes of distinguishing it from the other routes.

Figure 2.1: Geographical Extent and Major OGV Routes



In addition to the MarEx system, electronic nautical charts from Maptech[11] were used.

This portion of the study area outside the Port's breakwater is divided into several zones that represent different operational modes that impact vessel characteristics and thus emission estimates. Working from the outside edge of the study area is the largest geographical zone called the "fairway" which extends from the boundary of the study area to the precautionary zone. The fairway (see Figure 2.2) represents the area where ships are generally operating at or near open water speeds also referred to sea speed, service speed, or cruising speed.

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[11] Maptech, *2002 Chart Navigator.*

The precautionary zone is a designated area where ships are preparing to enter or exit a port. Therefore OGV speeds are reduced to 12 knots or less. The precautionary zone for the Port extends in a line south from Point Fermin approximately seven nautical miles, then due east approximately seven nautical miles, then cuts northeast for approximately three nautical miles, and then cuts back northwest to marker FI R 2.5s (which is located at the eastern side of the Long Beach entrance/cut of the breakwater). The precautionary zone is illustrated in Figure 2.2 as the dark gray area closest to the Port and is enlarged in Figure 2.3. OGV activity in the precautionary zone includes the transition between fairway speeds and pilot pick-up on inbound trips, and the transition between pilot drop-off and sea speed on outbound trips. Inbound arriving OGVs transition from one of the four routes (see Figure 2.1) and align their course on the Los Angeles Channel's entrance buoys G1, G3, and G5 (see Figure 2.4). The pilot boats rendezvous with inbound OGV and the pilots are transferred aboard by the use of a Jacob's ladder or rope ladder (see Figure 2.5). Assist tugboats (discussed in Section 3 Harbor Craft) generally meet inbound OGVs and leave outbound OGVs just inside the breakwater entrance, called Angels Gate. Outbound traffic departure is similar to inbound arrivals though aligning off of the R6 and R2 buoys, where the pilot transfers from the OGV to the pilot's boat. Once the pilot has been safely transferred off the ship the OGV generally will align with one of the four routes to continue on its voyage. Finally, in the precautionary zone there are seven anchorages where OGVs can anchor and wait for berths to open.

The final zone of the study area is the harbor, located within the breakwater. The harbor is characterized as the area with the slowest OGV speeds where docking, undocking, and dock-side maneuvering take place and where vessel hoteling occurs at dock. The harbor is where cargo is unloaded from and/or loaded onto the ships at the shore-side terminals (see Section 4 Cargo Handling Equipment). For this study, the harbor was segmented into three main areas: San Pedro, West Basin, and East Basin. Figure 2.6 identifies these areas. There are anchorages located within the breakwater but most of them are located within the POLB boundary and, therefore, are not accounted for in this inventory.

Figure 2.2: Fairway

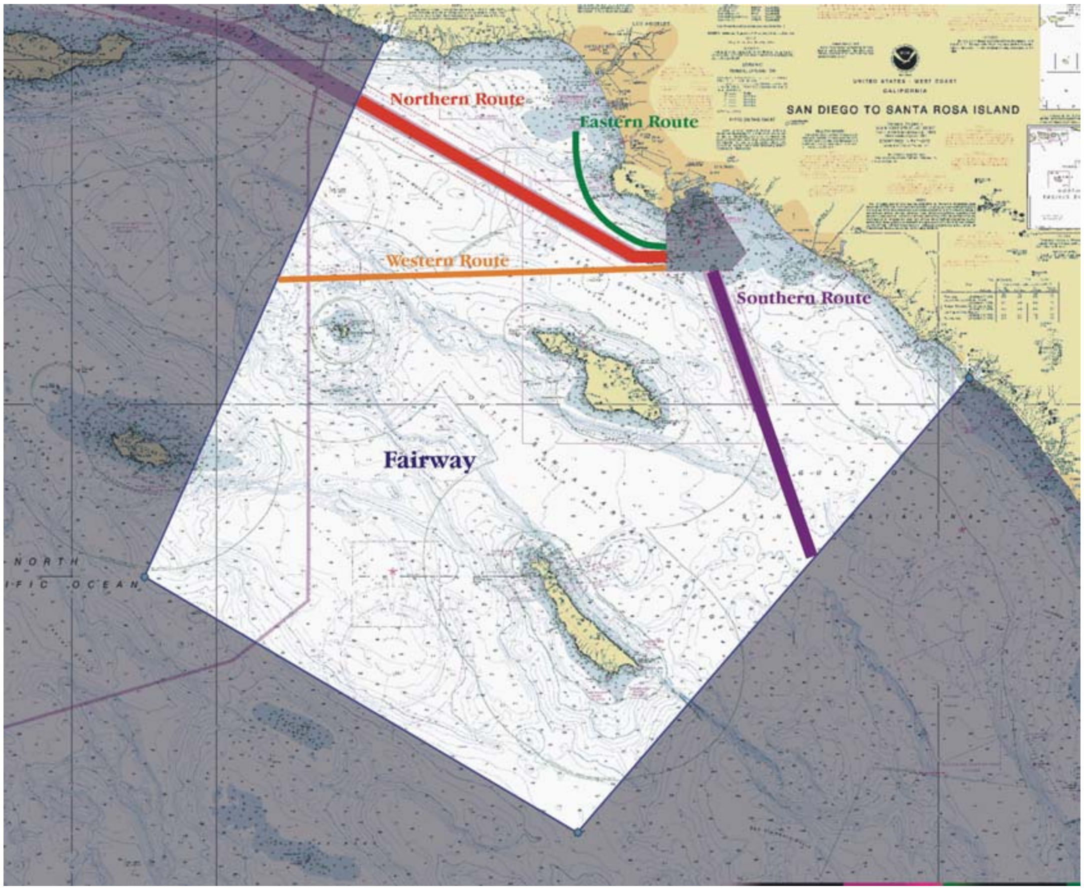


Figure 2.3: Precautionary Zone

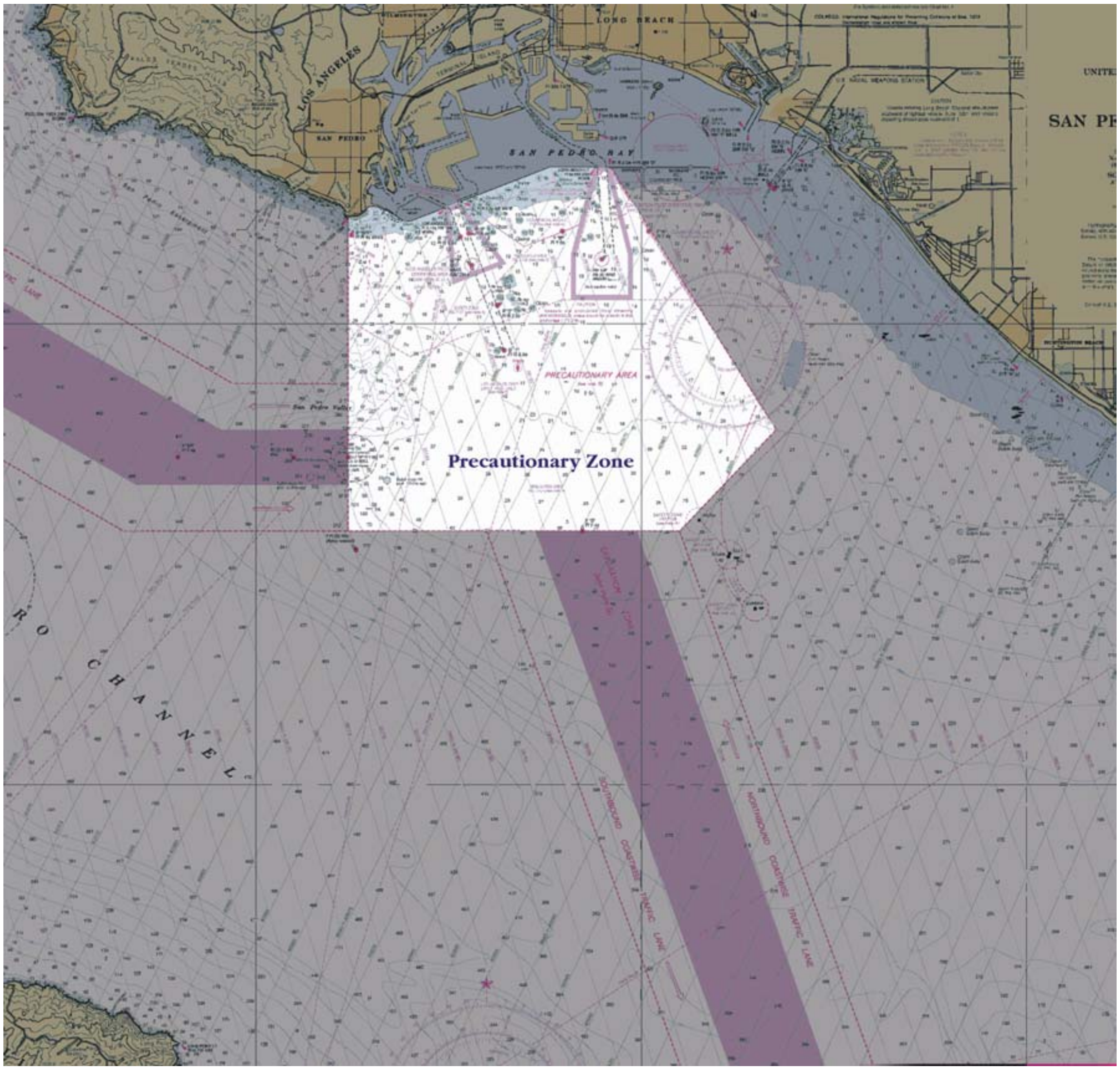


Figure 2.4: Entrance/Exit Buoys

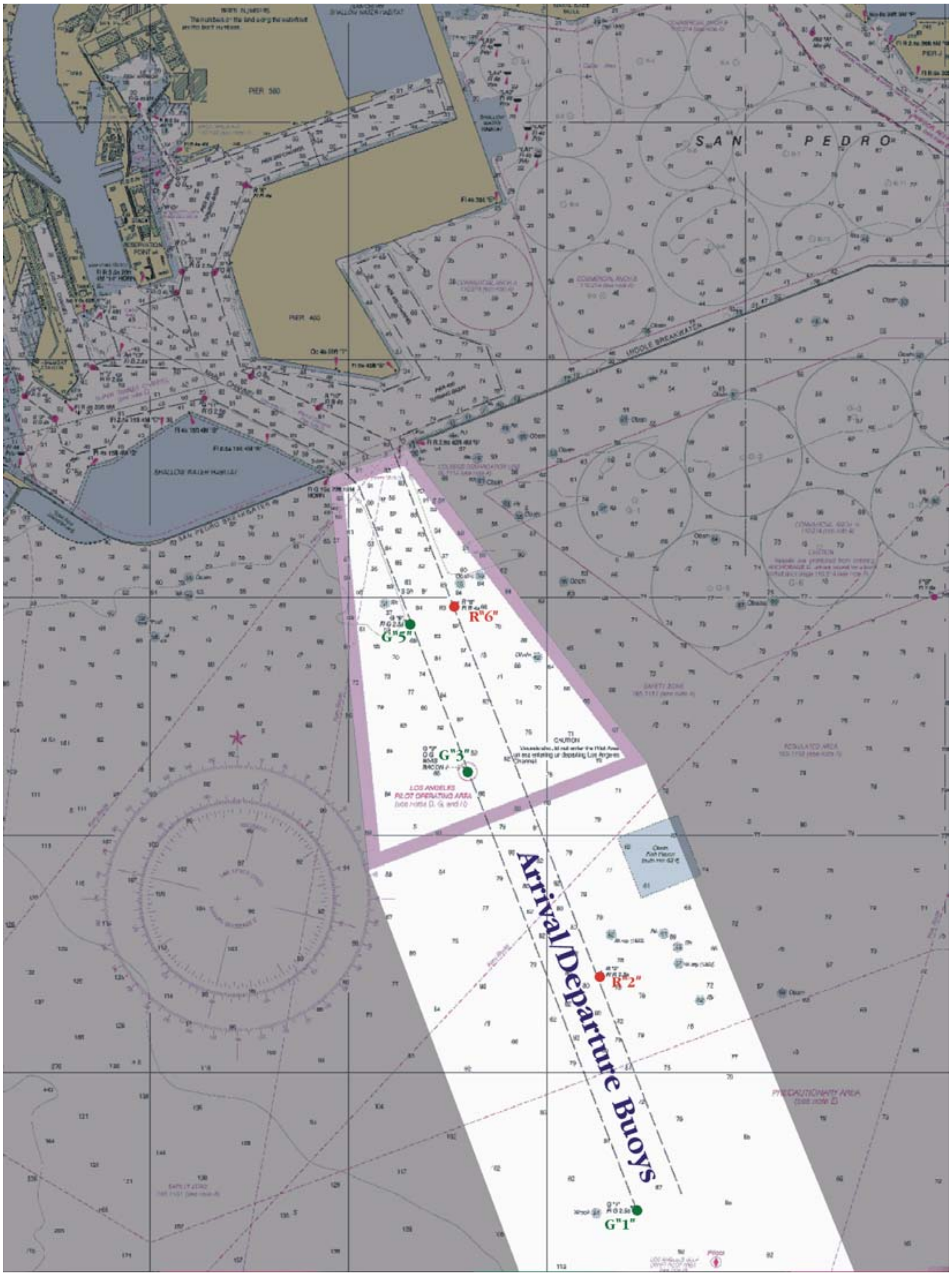
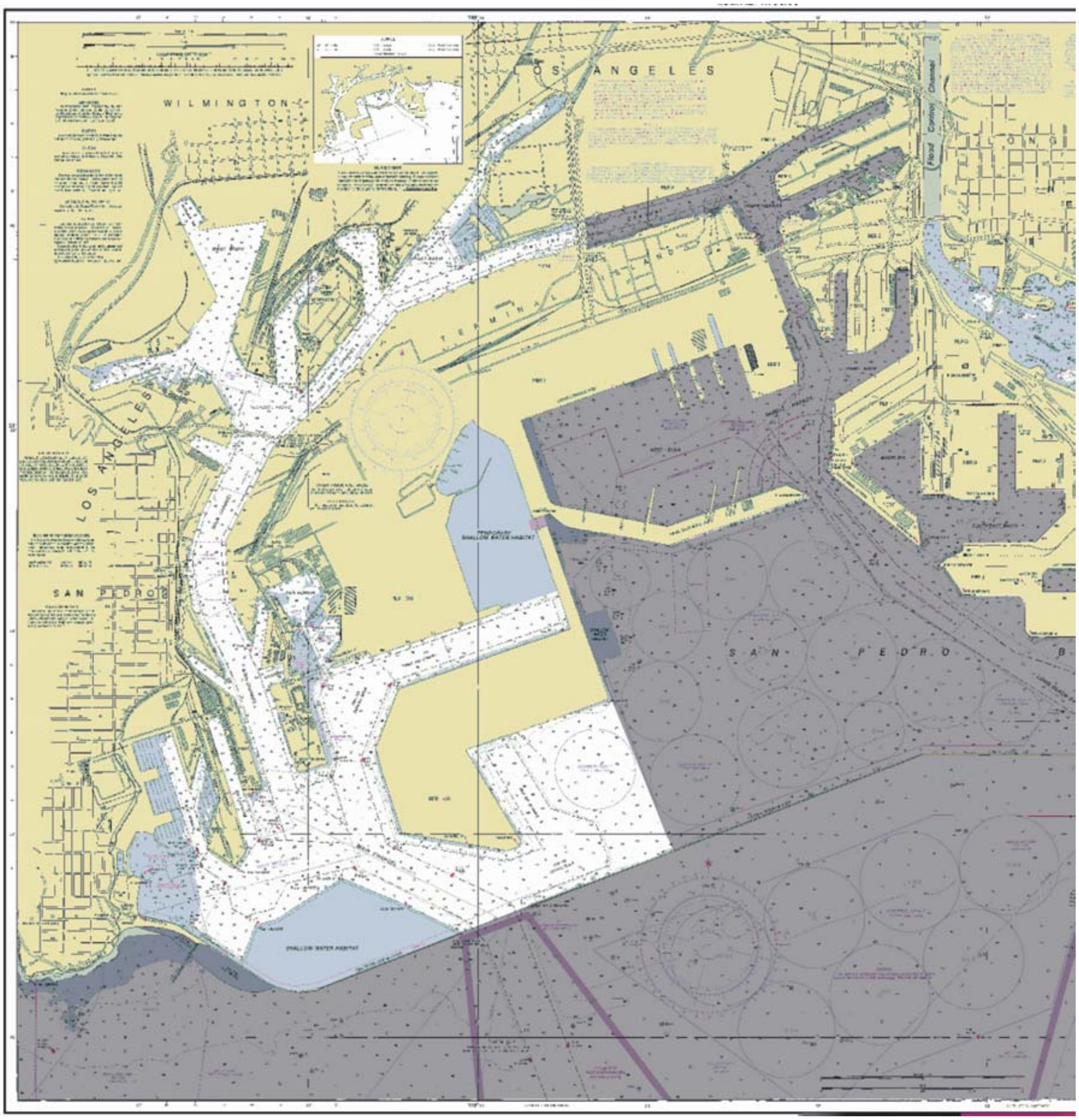


Figure 2.5: Pilot Transfer

Figure 2.6: Port of Los Angeles Harbor



2.3 Vessel Descriptions

OGVs are typically over 5,000 deadweight tons (DWT) and several hundred feet long. Air emissions are produced from the main power plant used for propulsion or from auxiliary engines, which are mainly used for the ship's electrical power system and, on some OGVs such as tankers, for pumps that move liquid cargos to land-based facilities via piping. Most of a ship's emissions are produced by compression ignition (internal combustion) engines, although there are a few steamships (external combustion). In addition, almost all OGVs have an auxiliary boiler (external combustion). The compression-ignition power plants are also known more simply as diesel engines, although they also use fuels of a different grade than diesel, such as intermediate fuel oil. Emissions are typically vented through a stack approximately one meter wide and over 30 meters above the waterline, with the smaller auxiliary engines and boilers having smaller stack diameters at approximately the same release height.

Oxides of nitrogen are the largest pollutant from a mass emissions perspective, mainly because diesel engines operate at a high temperature, which causes NO_X to form more readily than in lower temperature combustion conditions. Particulate matter has generally the lowest mass emissions of all pollutants, but is a local public health concern, since diesel smoke is considered by the State of California to be toxic. Sulfur dioxide formed from sulfur contained in the fuel, is associated with regional haze, secondary PM formation, and sulfuric acid formation. Carbon monoxide and hydrocarbons are other criteria pollutants produced and are contained in the estimate of emissions.

Most OGVs are foreign flagged ships, whereas harbor vessels are almost exclusively domestic. Over 90% of the OGVs that visited in 2001 were registered outside the U.S. A total of 769 individual vessels called at the Port in 2001. Figures 2.7 and 2.8 show the breakdown of the ships' registered country or flag by discrete vessel and by the number of calls, respectively.

Although only 5% of the individual OGVs are registered in the U.S., they comprise 11% of all calls. This is most likely because the U.S. flagged OGVs making shorter, more frequent stops along the West Coast.

Figure 2.7: Flag of Ship by Discrete Vessel

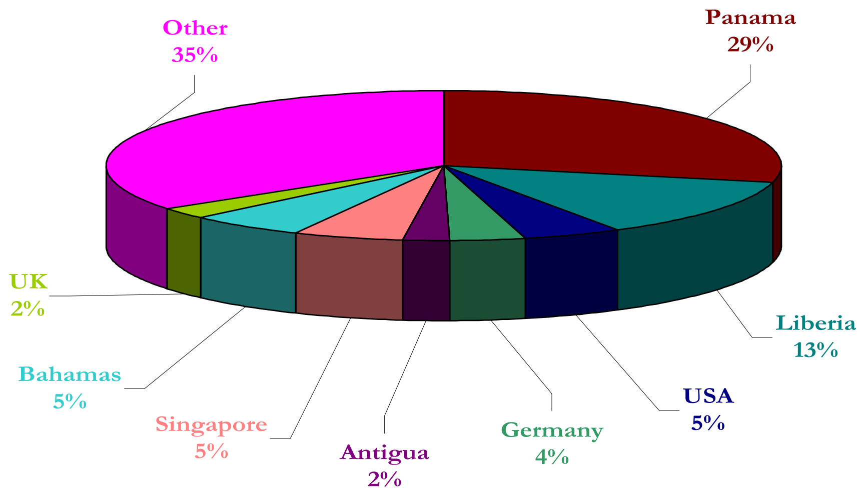
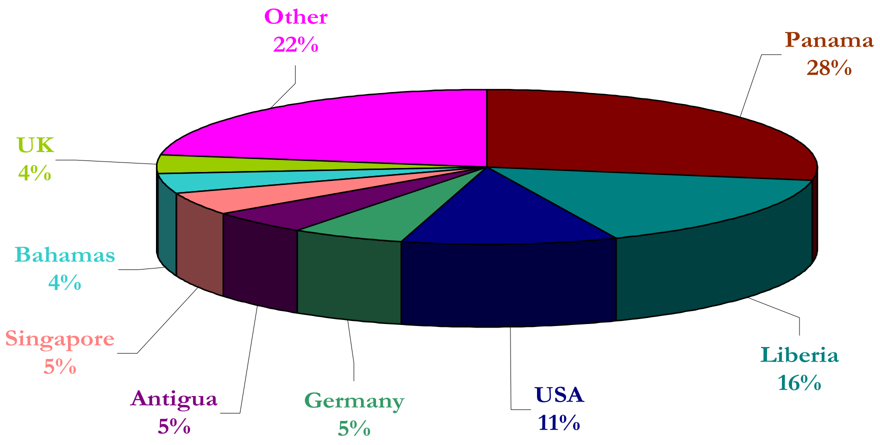


Figure 2.8: Flag of Ship by Vessel Call



This study categorized OGVs based on their primary cargo types. This categorization process is needed because it is not practicable to model each vessel as a unique source. Some vessels have dual purposes, such as being a general cargo ship that is also designed to carry containers, but they are classified as best as possible using local and international sources of information. The vessel types as used in this report are:

- Auto Carrier
- Bulk Carrier
- Containership
- Cruise Ship
- General Cargo
- Miscellaneous
- Ocean-going Tugboat (Other Tug)
- Roll-on roll-off (RoRo)
- Refrigerated vessel (Reefer)
- Tanker

In the baseline year of 2001, some 769 vessels made a total of 2,717 OGV inbound calls to the Port. The distribution of OGV types by frequency of call is presented in Table 2.1. The number of vessels by engine type, vessel type and deadweight tonnage class is presented in Appendix A.

Table 2.1: Inbound Calls by OGV Type, %

OGV Type	Number of Calls	% of Calls
Auto Carrier	146	5%
Bulk Carrier	203	7%
Containership	1,584	58%
Cruise Ship	320	12%
General Cargo	64	2%
Miscellaneous	7	<1%
Other Tug	17	1%
RoRo	27	1%
Reefer	73	3%
Tanker	276	10%
Total	**2,717**	100%

2.3.1 Vessel Type Descriptions

Auto Carrier

Transportation of imported vehicles is the primary use of the auto carrier, although a few domestic vehicles are exported overseas. They are very similar in design to a RoRo (see later discussion in this section) because they have drivable ramps. Both can have substantial ventilation systems so as to prevent vehicle fuel vapors from pooling in the lower decks, which could present a major risk for explosion or fire. Auto carriers are typically configured with direct drive propulsion engines and separate auxiliary engines to supply electrical needs. The auto carrier vessels that called on the Port in 2001 had a weighted average Lloyd's Register speed of 18.7 knots and had a weighted average age of 13.5 years old. Figure 2.9 presents a typical car carrier.

Figure 2.9: Auto Carrier

Bulk Carrier

Bulk carriers have open holds with giant hatches so as to carry dry goods that can be loaded from a conveyor belt and chute, such as coal, coke, salt, sugar, cement, gypsum, lime mix, agricultural products, alumina, and other similar fine-grained commodities that can be poured, scooped or augured. Bulk carriers span the range between small "tramp" ships and the Panamax (approximately 50,000+ DWT) and Capesize (approximately 140,000+ DWT) bulk carriers that can also haul containers as well as general cargo. Bulk carriers are typically configured with direct drive propulsion engines and separate auxiliary engines to supply electrical needs. The bulk vessels that called on the Port in 2001 had a weighted average Lloyd's Register speed of 14.5 knots and had a weighted average age of 10.5 years old. Figure 2.10 presents a typical bulk carrier.

Figure 2.10: Bulk Carrier

Containership
Ships that carry 20- and 40-foot containers on their decks are known as containerships, being the fastest, largest, and most frequent category of OGVs that call at the Port. These vessels are primarily used by shipping lines to transport retail goods across the Pacific Rim, most originating in Asia. These ships are some of the largest ships that call at the Port, ranging from approximately 9,800 DWT to 77,900 DWT. Because of their efficiency as a mode of ocean transportation, containership calls will continue to grow at the Port. Cargo types include almost everything that can be made to fit in the 20- or 40-foot containers. The container business operates on tight margins and high volume so OGVs need to be fast and efficient to compete in the market place, thus the trend to newer, larger containerships. During the inventory process, several new containerships were visited and observed. The containerships that called on the Port in 2001 had a weighted average Lloyd's Register speed of 22.6 knots and had a weighted average age of 8.0 years old. Typical containerships that call at the Port are shown in Figure 2.11 through 2.13.

Figure 2.11: Containership

Figure 2.12: Containership

Figure 2.13: Containership

Cruise Ship

There is a significant passenger cruise service operating from the Port. These boats are known not only for their speed but also their heavy auxiliary engine demands, since they often provide heating and electricity for over a thousand people at times. Cruise ships are somewhat difficult to model because their overall size, onboard auxiliary power, configurations, and frequency of calls vary greatly between the various cruise lines. Typically, newer cruise ships work on a diesel-electric configuration with some using turbines to generate electricity, while older cruise ships use direct drive and auxiliary engines. The cruise ships that called on the Port in 2001 had a weighted average Lloyd's Register speed of 19.2 knots and had a weighted average age of 10.0 years old. A typical passenger cruise ship is presented in Figure 2.14.

Figure 2.14: Cruise Ship

General Cargo

Like the bulk carriers, general cargo ships tend to be slower. They can carry diverse cargoes such as steel, palletized goods, turbines, a few containers (usually on the top deck), large excavating machinery, and other heavy loads. Most general cargo ships have electric boom cranes for loading or unloading. General cargo ships are typically configured with direct drive propulsion engines and separate auxiliary engines to supply electrical needs. The general cargo vessels that called on the Port in 2001 had a weighted average Lloyd's Register speed of 15.6 knots and had a weighted average age of 13.4 years old. A typical general cargo ship is shown in Figure 2.15.

Figure 2.15: General Cargo Ship

Miscellaneous
This category includes three kinds of OGVs, of which very few operate within the Port area:

- Cable ship (OCL)
- Semi-submersible heavy-lift vessel (OHL)
- Oceanographic research vessel (ROR)

Cable ships are used for submarine cable installation and maintenance. Semi-submersible heavy-lift vessels lift, transport and unload large floating objects, such as Navy vessels and offshore construction barges. An oceanographic research vessel is capable of operating a variety of biological and oceanographic sampling equipment to provide a working platform for oceanographic study. The miscellaneous classed ships that called on the Port in 2001 had a weighted average Lloyd's Register speed of 15.0 knots and had a weighted average age of 23.0 years old.

Ocean-going Tugboats
Some towboats were recorded by the Port's vessel activity data and the MarEx, and were included in the inventory. These tended to be ocean-going tugboats that towed barges and traveled the coast of California or in a few cases made runs to Hawaii or Mexico. Integrated tug and barge (ITB) vessels were also included in this class. Ocean-going tugboats are typically configured with direct drive propulsion engines and separate auxiliary engines to supply electrical needs. Since these vessels generally do not transport time sensitive cargo they generally are considered in the same category as slow ships. Ocean-going towboats and tugboats not included in

this section are considered harbor vessels and are discussed in Section 3. An ocean-going tugboat is shown in Figure 2.16.

Figure 2.16: Ocean-going Tugboat

Figure 2.17 shows an integrated tug boat and barge.

Figure 2.17: Integrated Tug Boat and Barge

Refrigerated vessels

Refrigerated vessels, often called "reefers," are dominated by fruit carriers, which require cooling to prevent cargo spoilage. These are similar to bulk or general cargo carriers, but their holds are refrigerated to keep produce cold. These ships typically carry fruits, vegetables, meats, and other perishable cargos. Most of the below deck cargo is stored on pallets in a refrigerated cargo hold within the vessel. The cargo is also transported inside refrigerated containers that are placed on top of the closed cargo hold. Reefers are typically configured with direct drive propulsion engines and separate auxiliary engines to supply electrical needs (including the refrigeration units). The refrigerated vessels that called on the Port in 2001 had a weighted average Lloyd's Register speed of 20.1 knots and had an weighted average age of 10.3 years old. A typical refrigerated vessel is presented in Figure 2.18.

Figure 2.18: Refrigerated Vessel

Roll-on Roll-off

These OGVs are similar to the automobile carrier but can accommodate larger wheeled equipment – they are a favorite for use by the military when transporting large, heavy military equipment. Several RoRo ships are multi-cargo ships that carry equipment/vehicles under the deck and containers above deck. RoRo ships are typically configured with direct drive propulsion engines and separate auxiliary engines to supply electrical needs. The RoRo vessels that called on the Port in 2001 had a weighted average Lloyd's Register speed of 14.8 knots and had an weighted average age of 23.0 years old. A typical RoRo vessel is presented in Figure 2.19.

Figure 2.19: Roll-On Roll-Off Vessel

Tanker

The tanker activity in the Port for 2001 was comprised mainly of crude oil tankers, as well as a few chemical tankers. Tankers range from approximately 10,000 DWTs to over 100,000 DWTs (very large cargo ship, or VLCS). A limited number of petroleum bulk and refinery terminals are located in the Port. In addition, there is some significant tanker trade with the Port of El Segundo where another petrochemical complex is located. Tankers are typically configured with direct drive propulsion engines and separate auxiliary engines to supply electrical needs. The tanker vessels that called on the Port in 2001 had a weighted average Lloyd's Register speed of 14.7 knots and had a weighted average age of 12.5 years old. Figure 2.20 presents a typical chemical tanker and Figure 2.21 presents a typical crude tanker.

Figure 2.20: Tanker

Figure 2.21: Tanker

2.4 Data and Information Acquisition

Activity based emission inventories typically rely on several sources of data and operational information. The baseline OGV inventory utilized five different sources of data and operational knowledge about the Port of Los Angeles marine activities to compile the information necessary to prepare emission estimates. These sources included:

- The Marine Exchange of Southern California
- The Port's Vessel Activity Data
- Lloyd's Register of Ships
- The Vessel Boarding Program and Findings
- Data from nautical charts and maps

Each data source is detailed in the following subsections.

2.4.1 Marine Exchange (MarEx)

The Marine Exchange of Southern California[12] operates the Vessel Traffic Service (VTS) in cooperation with the U.S. Coast Guard, the Ports of Los Angeles and Long Beach, and the State of California. The VTS was established in 1994 to provide traffic monitoring and security functions for the two ports, and is the first private/public VTS partnership in the country that is funded by industry. MarEx requires ships to report their activities to the VTS upon arrival and departure and tracks the ship route taken.

The MarEx data that was evaluated in developing the emission estimates includes vessel names, arrival and departure dates and times, transit speeds and directions, berth of destination, and other information. This data source was primarily used to establish the ship types discussed in the preceding subsection and to establish the distribution of arrival and departure travel directions by route (as described above).

MarEx monitors OGV speeds over the four routes into and out of the Port as part of a Vessel Speed Reduction (VSR) program that was started in May 2001. The effects of this program on vessel speeds was not taken into account in determining fairway speeds for the baseline emission estimates because it represents a pilot control measure and does not represent the normal baseline condition.

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[12] See *http://www.mxsocal.org/mxabout.htm*.

2.4.2 The Port's Vessel Activity Data

The Port of Los Angeles collects and maintains data on vessel arrivals and departures for determining the Port's dockage and wharfage fees. This information was also used in developing the OGV emission estimates. Port vessel activity data was used for several purposes, including establishing: the number of ship calls, names of ships, vessel travel times within the harbor, origination and destination (within the Port of Los Angeles), and dockside hoteling times.

Trip times and operational information about vessel transits through the harbor were provided through multiple interviews and ride-alongs (discussed in Subsection 2.4.4) with most of the Port Pilots. As mentioned earlier, the Pilots navigate the arriving and departing vessels into and out of the Angels Gate.

2.4.3 Lloyd's Register of Ships

Lloyd's Register of Ships[13] (Lloyd's) is considered to be the leader for obtaining ship characteristics such as tonnage, speed, engine power plant configuration, age, and other parameters. The company insures many of the OGVs on an international basis; for these vessels the data are quite complete, however, for other ships using a different insurance certification authority, the data are less robust. Lloyd's was used for obtaining information such as main and auxiliary engine power and vessel speed ratings because it is the best available source of such information.

As discussed below, there is some conjecture about whether Lloyd's data on ship characteristics, such as for propulsion horsepower and vessel speed, have an inherent bias. For example, the Arcadis study (referred to in Section 2.1) concluded that Lloyd's tended to under-predict propulsion horsepower by approximately 8%, a figure that has been used locally for the last several years in developing marine vessel emission estimates. In its time, this was the best conclusion based on information available to Arcadis. However, the new survey results from the Vessel Boarding Program (presented in detail below: Section 2.4.4) suggest that the current Lloyd's data are fairly accurate for propulsion horsepower and vessel speed.

In addition to providing power and speed data, Lloyd's was used to evaluate how auxiliary engines on ships were fueled (by residual oil or distillate fuel), which is important because each has different emission factors. The assumption was that if a ship is dual-fueled, the auxiliary engines probably use diesel fuel oil instead of residual oil. Two data fields in the Lloyd's data include information about the contents of the vessels' fuel tanks. These fields are named "Bunker 1" and Bunker 2." The precise meaning of these data fields is not clear, since they either specify a fuel type or simply indicate "Yes" or "No." In cases where the second fuel field, "Bunker 2," is listed as "No," the ship is assumed to be mono-fueled, using only the

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[13] Lloyd's – Fairplay, Ltd., 2003 *Lloyd's Register of Ships*, Version 2.10 January 2003. See *http://www.lr.org/code/home.htm.*

fuel specified in "Bunker 1." When both fuel fields indicate a fuel type, the assumption is of a dual-fueled vessel. The VBP validates the logic for using Lloyd's data as discussed in the Fuel subsection of Section 2.4.4. Table 2.2 illustrates the assumption logic regarding the Lloyd's fuel fields.

Table 2.2: Logic Regarding Mono-Fuel or Dual-Fuel

Bunker 1 Field	Bunker 2 Field	Outcome
Oil Fuel	No	Residual
Yes	No	Residual
High Velocity Oil	No	Residual
Diesel Oil	No	Diesel
Oil Fuel	Diesel Oil	Dual
Diesel Oil	High Velocity Oil	Dual

Note that high velocity oil is not a standard term but is assumed to be similar to "high viscosity oils" such as IFO 380, which is designated as a residual fuel for the purposes of this report. The method to derive the percentage of dual-fuel use by ship type was to query the inbound trip database as to ship type and ship technology (slow speed motorships, medium speed motorships, and steamships). After evaluation, it was found that the steamship category was not as robust as the others, so steamships were eliminated from the count of ship calls. This was justified to a large extent because of the low number of steamship calls (147 of 2,420 valid Lloyd's entries) and secondly because of a general lack of information about auxiliary engines on steamships, which were not encountered during the Vessel Boarding Program (discussed in the next subsection), and because emission factors for steam propulsion are much lower than for diesel engines. The results shown in Table 2.3 indicate whether the auxiliaries were fueled by residual oil (RO) or in the case of dual-fuel ships, diesel fuel.

Table 2.3: Summary of Mono-Fuel or Dual-Fuel by Vessel Type

OGV Type	RO	Dual	Total	RO%	Dual%
Auto Carrier	53	71	124	43%	57%
Bulk	121	62	183	66%	34%
Containership	528	882	1,410	37%	63%
Cruise	6	140	146	4%	96%
General Cargo	43	13	56	77%	23%
Miscellaneous	1	0	1	100%	0%
Other Tug	0	1	1	0%	100%
RoRo	27	0	27	100%	0%
Reefer	33	33	66	50%	50%
Tanker	142	117	259	55%	45%
Total	**954**	**1,319**	**2,273**		

2.4.4 Vessel Boarding Program and Findings

The best source of local activity data and ship parameters is from the individuals who own and/or operate the vessels. Building on studies undertaken at other ports, the Port of Los Angeles engaged in the most extensive boarding program to be undertaken with respect to an activity-based marine vessel emissions inventory.

Taking advantage of the short trip distances of and times in the Port's ship channel, the Port's environmental staff and consultants accompanied the Port pilots in boarding 65 vessels operated by 19 shipping lines during the summer of 2003. The captains and chief engineers of these vessels were interviewed and provided information about ship movements, engine specifications, and other pertinent operational data. A total of 113 boardings were conducted, including 31 on vessel arrivals, 45 while at berth, and 37 on departure. An additional shipping line submitted vessel specifications, with no boardings of that line's vessels.

The purpose of the VBP was to gain firsthand information/data on the ship's activities and characteristics, and observe various operational parameters while these ships were arriving and departing the Port, and during hoteling. In addition to the interviews, when possible, printed information such as pilot cards and computerized engine readings were obtained. Transit characteristics such as vessel speed, engine speed, main and auxiliary engine loads, and various other parameters (depending on vessel configuration) were recorded as well.

The vessel data that was collected regarding propulsion engines and cruise speeds were compared to the Lloyd's database to evaluate the accuracy of Lloyd's data. The parameters that were compared - deadweight tonnage, maximum engine power, and maximum vessel speed - are crucial to developing accurate estimates of vessel emissions, so it was seen as important to validate the information being obtained from the Lloyds database. For example, maximum speed is a critical component of the load factor calculation, and maximum power is multiplied by the load factor, a time component, and an emission factor to estimate emissions. (These calculations are explained in detail in Section 2.5, Methodology.)

The surveys were mainly oriented towards containerships (being the most frequent OGV type calling at the Port), but other vessel types were also boarded. The amount and type of data collected for each vessel was determined by numerous factors, many of which were beyond the control of the EI project team, such as the technology on board the ship, language barriers, the willingness of the captain and/or crew to provide information, and the individual interests of the captains and chief engineers. It is also important to recognize that the top priority of the pilot, the ship's captain, and the crew is to safely arrive and depart the Port, so they provided information on a time-available basis. Table 2.4 presents a selection of the physical characteristic data recorded for each vessel surveyed. In several cases, complete data was not available for various parameters for the reasons discussed above.

Table 2.4: Vessel Data Obtained from VBP

Service	Vessel ID	Deadweight Tonnage	Speed (knots)		Fuel Type	Fuel %S	Propulsion Engine Power (kW)
			Service	Max			
Container Container	OGV1	58,912	23.2	26.04	IFO380 MGO	-	34,925
Container Container	OGV2	55,604	25	27.72	IFO380 MDO	3.0	49,343
Container Container	OGV3	75,898	24.5	24.5	IFO380	-	48,600
Container Container	OGV4	75,898	24.5	26.84	IFO380	-	48,600
Container Container	OGV5	49,238	22	23.7	IFO380	3.5	32,896
Container Container	OGV6	50,059	22	23.8	IFO380 MDO	2.7	37,075
Container Container	OGV7	66,696	24.7	25.7	HFO MDO	-	49,541
Container Container	OGV8	78,230	25	28.7	IFO380 LSDO	3.5 0.2	62,587
Container Container	OGV9	45,570	22	-	HFO	-	42,000
Reefer Reefer Reefer	OGV10	6,112	16.5	-	IFO MGO MGO	2.0	4,104
Container Container	OGV11	67,480	24.6	24.9	IFO380	2.5	49,343
Container Container	OGV12	66,520	24.5	24.5	IFO380 MDO	2.0	49,541
Container Container	OGV13	53,648	24	-	IFO380 MDO	2.0	42,537
Container Container	OGV14	45,995	24	26	IFO380	-	31,418
Container Container	OGV15	20,976	-	-	IFO380 MDO	-	16,239
Container Container	OGV16	49,541	24.5	25.7	IFO380 MDO	-	49,541
Container Container	OGV17	-	22	24	IFO380 MDO	-	27,799
Container Container	OGV18	34,026	-	-	IFO380	-	23,235
Reefer Reefer Reefer	OGV19	6696	-	-	IFO380 MGO MGO	1.5	4,054
Container Container	OGV20	67,970	-	-	IFO380 MDO	1.6	49,343
Container Container	OGV21	32,800	23	-	IFO380 diesel	-	32,313
Container Container	OGV22	53,648	24	-	IFO380 MDO	-	42,537

Table 2.4: Vessel Data Obtained from VBP (cont'd)

Service	Vessel ID	Deadweight Tonnage	Speed (knots)		Fuel Type	Fuel %S	Propulsion Engine Power (kW)
			Service	Max			
Bulk Bulk	OGV23	22,240	13.9	13.9	IFO380 MDO	1.9 0.5	5,373
Container Container	OGV24	48,550	-	23.7	IFO380	-	
Container Container	OGV25	33,950	-	19.5	IFO380 MDO	2.3 0.5	16,239
Container Container	OGV26	48,550	-	23.7	IFO380 IFO380	-	32,896
Container Container	OGV27	67,473	23	24.6	HFO500 HFO500	3.8	49,343
Container Container	OGV28	36,303	19	20.7	IFO380 MDO	-	20,149
Container Container	OGV29	109,000	-	-	IFO380 IFO380	2.9	63,922
Container Container	OGV30	81,171	25	26	IFO380 MDO	-	62,247
Container Container	OGV31	67,902	25	-	HFO MDO	3.0	54,942
Container Container	OGV32	59,984	25		IFO380		37,004
Container Container	OGV33	66,520	22.5	24.6	IFO380 IFO380	3.0	49,552
Container Container	OGV34	-	-	-	IFO380	1.9	21,269
Container Container	OGV35	104,750	24.5	25	IFO380 IFO380	-	55,701
Container Container	OGV36	23,678	-	-	IFO380 low sulfur	2.5 0.0	22,170
Container Container	OGV37	61,441	24.5		IFO380 MDO	-	49,410
Tanker Tanker	OGV38	17,243	13.4	14.7	IFO380 MDO	-	6,000
Container Container	OGV39	78,300	24.5	28.2	IFO380 MDO	2.9	63,552
Container Container	OGV40	58,912	23	25.6	IFO380	-	34,925
Container Container	OGV41	63,160	25.4	-	IFO380	2.0	42,000
Car Carrier Car Carrier	OGV42	19,455	19.5	20.0	IFO380 MDO	2.2	14,851
Container Container Container	OGV43	66,971	-	-	IFO380 MDO MDO	-	40,040

Table 2.4: Vessel Data Obtained from VBP (cont'd)

Service	Vessel ID	Deadweight Tonnage	Speed (knots)		Fuel Type	Fuel %S	Propulsion Engine Power (kW)
			Service	Max			
Container	OGV44	67,680	23	-	IFO380	-	26,978
Container					MDO		
Container					MDO		
Container	OGV45	67,630	24	-	IFO380	-	41,130
Container					MDO		
Container					MDO		
Container	OGV46	58,912	23	25.6	IFO380	-	34,925
Container					MGO	1.0	
Container	OGV47	80,270	25		IFO380		64,200
Container					LSDO in LA and MDO		
Container	OGV48	63,700	24.5	-	IFO380	-	49,410
Container					MGO		
Container	OGV49	59,840	24	26.5	IFO380	2.7	37,014
Container					IFO380		
Container	OGV50	70,000	24.6	-	IFO380	-	49,343
Container							
Container	OGV51	41,444	24.5	-	IFO380	-	43,731
Container							
Container	OGV52	44,014	20	24	IFO380	3.4	24,866
Container							
Gen Cargo & Container	OGV53	39,760	16	-	IFO380	-	11,200
Gen Cargo Carrier	OGV54	43,131	15	16.7	IFO380	3.5	7,418
Container	OGV55	53,964	20.3	-	IFO380	-	22,500
Container							
Container	OGV56	81,171	25	-	IFO380	-	61,350
Container					MDO		
Container	OGV57	104,750	24.5	25	HDO	2.4	55,701
Container					MDO		
Cruise	OGV58	74,000	19	21	IFO320	2.2	21,840
Cruise					MDO		
Container	OGV59	104,750	24.5	25	IFO380	2.9	55,701
Container					MDO		
Container	OGV60	70,305	24.6	24.9	IFO380	3.4	49,343
Container					MDO		
Container	OGV61	23,298	-	-	IFO380	-	16,239
Container							
Container	OGV62	110,000	24.6	-	IFO380	-	70,976
Container					IFO380		
Car Carrier	OGV63	21,000	20	21.8	IFO380	-	14,328
Car Carrier					IFO380		
Container	OGV64	59,840	24	-	IFO380	-	37,014
Container							
Container	OGV65	25,331	18	21	IFO380	3.4	16,993
Container					IFO380		
Container					IFO380		

The following abbreviations are used in Table 2.4:

IFO	intermediate fuel oil
MGO	marine gas oil
MDO	marine diesel oil
LSDO	low sulfur diesel oil
HFO	heavy fuel oil
S	sulfur

The VBP made important contributions and refinements to the methodology used for OGV emission inventory:

- Characterization of in-port activities and engine operations to develop operating profiles, including transit times, speeds, and in-port maneuvering time-in-mode.
- Comparison of actual on-board engine and vessel parameters, such as maximum speeds with Lloyd's data.
- Establishment of relationship between maximum and actual at-sea ship service speeds.
- Evaluation and incorporation of time-in-setting mode data, real time load readings, and vessel histograms for transit and in-port maneuvering modes.
- Development of significant improvements (over Lloyd's data) to the characterization of auxiliary engines and boilers.
- Development of additional information on the types and amounts of fuel used in main and auxiliary engines and boilers.
- Collection of information on main and auxiliary engine stack parameters.

Comparison of Survey Data with Lloyd's Data

The data in Table 2.4 regarding deadweight tonnage, main engine power, and maximum speed (in knots, kts) were compared with Lloyd's data for the vessels shown. In general, Lloyd's data for DWT, power, and maximum speed compare favorably with the survey data. Dividing the average Lloyd's value by the average survey value showed approximately 97% agreement for each parameter. Table 2.5 presents the comparisons of the two sets of data for main engine power and vessel maximum speed. The main engine power comparison is illustrated in Figure 2.22, and the comparison for vessel maximum speed is illustrated in Figure 2.23. Results for the DWT comparison are similar. The reference lines on Figures 2.22 and 2.23 are representations of straight 1:1 correspondence between data sets and are not illustrative of trends or regression analysis.

Table 2.5: Comparison of Power and Speed Data

Vessel Sequence #	Survey Main Power, kW	Lloyd's Main Power, kW	Ratio Lloyds/Survey
1	4,101	4,043	0.986
2	4,101	4,043	0.986
3	4,101	4,042	0.986
4	5,369	5,296	0.986
5	5,996	5,914	0.986
6	7,412	6,674	0.900
7	11,192	11,200	1.001
8	14,318	12,003	0.838
9	14,840	14,636	0.986
10	16,227	16,000	0.986
11	16,227	16,000	0.986
12	16,227	16,000	0.986
13	16,980	17,200	1.013
14	20,134	22,177	1.101
15	21,253	20,963	0.986
16	21,823	21,600	0.990
17	22,154	22,177	1.001
18	22,483	22,177	0.986
19	23,218	17,506	0.754
20	24,847	20,853	0.839
21	26,957	31,000	1.150
22	27,778	30,967	1.115
23	31,394	27,870	0.888
24	32,289	31,776	0.984
25	32,871	32,423	0.986
26	32,871	32,421	0.986
27	34,899	30,982	0.888
28	34,899	30,982	0.888
29	34,899	34,424	0.986
30	36,976	36,470	0.986
31	36,987	36,476	0.986
32	36,987	32,820	0.887
33	37,047	36,778	0.993
34	40,010	40,040	1.001
35	41,099	41,130	1.001
36	41,969	49,452	1.178
37	42,506	41,897	0.986
38	42,506	41,897	0.986
39	43,699	43,070	0.986
40	49,306	48,635	0.986
41	49,306	43,773	0.888
42	49,306	43,773	0.888
43	49,306	43,773	0.888
44	49,306	43,773	0.888
45	49,373	36,712	0.744
46	49,374	36,712	0.744
47	49,504	48,840	0.987
48	49,504	48,840	0.987
49	49,504	48,840	0.987
50	49,515	48,840	0.986
51	54,901	54,900	1.000
52	55,660	54,840	0.985
53	55,660	54,840	0.985
54	55,660	54,840	0.985
55	61,304	62,640	1.022
56	62,201	62,640	1.007
57	62,540	62,593	1.001
58	63,505	63,500	1.000
59	63,875	63,036	0.987
60	65,092	62,640	0.962
Average Difference			**0.968**

Vessel Sequence #	Survey Max Speed, kts	Lloyd's Speed, kts	Ratio Lloyds/Survey
1	26.00	25.00	0.962
2	25.70	24.50	0.953
3	24.00	24.60	1.025
4	14.70	14.00	0.952
5	26.50	24.00	0.906
6	24.50	24.50	1.000
7	13.90	13.60	0.978
8	19.50	21.00	1.077
9	24.50	24.50	1.000
10	27.70	25.00	0.903
11	25.60	23.20	0.906
12	25.60	23.20	0.906
13	26.04	23.20	0.891
14	24.50	24.50	1.000
15	26.84	24.50	0.913
16	16.50	16.00	0.970
17	16.50	16.00	0.970
18	16.50	16.00	0.970
19	24.60	24.60	1.000
20	28.20	25.00	0.887
21	22.00	24.00	1.091
22	26.00	24.00	0.923
23	21.00	20.00	0.952
24	24.60	24.90	1.012
25	25.70	24.50	0.953
26	21.80	20.00	0.917
27	24.00	24.40	1.017
28	24.00	22.00	0.917
29	20.70	20.70	1.000
30	24.60	24.90	1.012
31	25.00	25.00	1.000
32	16.70	15.50	0.928
33	24.60	24.50	0.996
34	23.80	24.00	1.008
35	23.70	23.70	1.000
Average Difference			**0.968**

Figure 2.22: Comparison of Lloyd’s and Survey Power Values

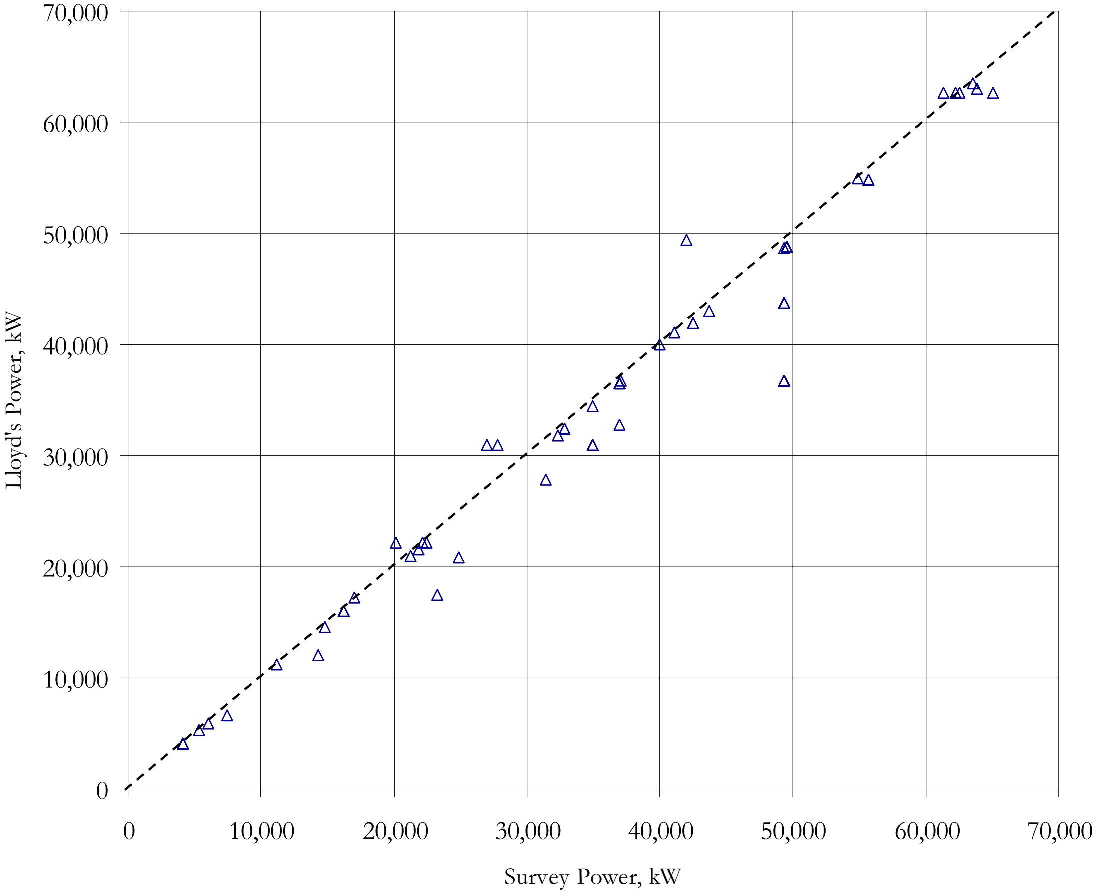
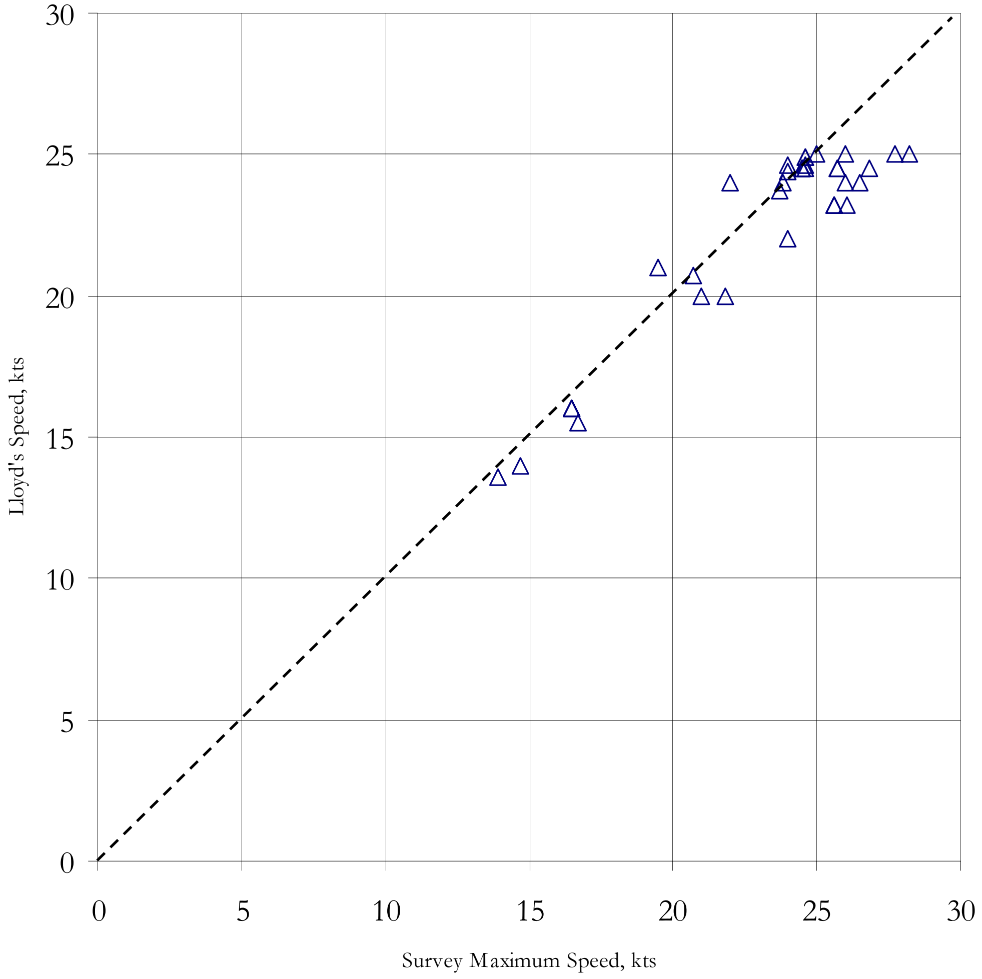


Figure 2.23: Comparison of Lloyd's and Survey Speed Values

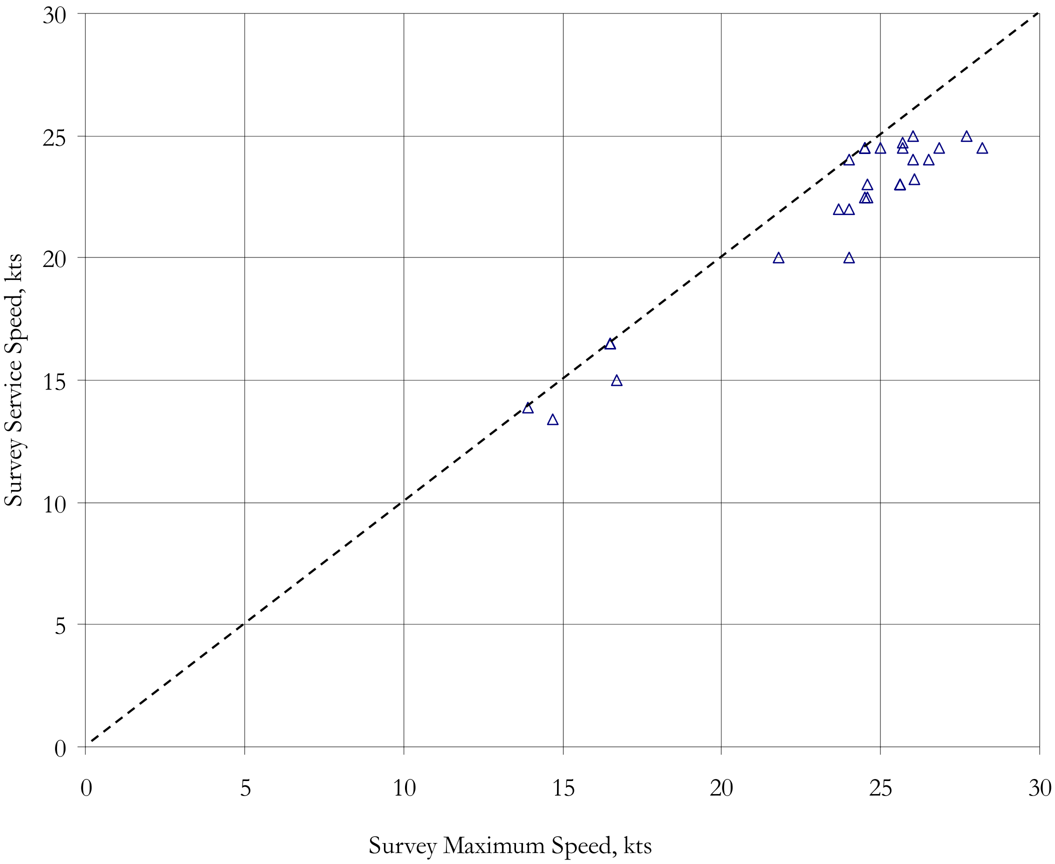


An additional comparison was made between the maximum speeds reported during the survey and the same vessels' reported normal cruising or service speeds. This comparison, presented in Table 2.6, shows that, on average, a vessel's service speed is 94% of its maximum speed. The relationship between maximum speed and service speed is illustrated in Figure 2.24.

Table 2.6: Comparison of Survey Values for Maximum and Service Speeds

Vessel Sequence #	Survey Max Speed, kts	Survey Srvc Speed, kts	Ratio Srvc/Max	Difference Max - Srvc, kts
1	13.9	13.9	1.000	0.0
2	14.7	13.4	0.912	1.3
3	16.5	16.5	1.000	0.0
4	16.5	16.5	1.000	0.0
5	16.5	16.5	1.000	0.0
6	16.7	15.0	0.898	1.7
7	21.8	20.0	0.917	1.8
8	23.7	22.0	0.928	1.7
9	24.0	22.0	0.917	2.0
10	24.0	24.0	1.000	0.0
11	24.0	20.0	0.833	4.0
12	24.5	24.5	1.000	0.0
13	24.5	22.5	0.918	2.0
14	24.5	24.5	1.000	0.0
15	24.6	23.0	0.935	1.6
16	24.6	22.5	0.915	2.1
17	25.0	24.5	0.980	0.5
18	25.6	23.0	0.898	2.6
19	25.6	23.0	0.898	2.6
20	25.7	24.5	0.953	1.2
21	25.7	24.7	0.961	1.0
22	26.0	25.0	0.962	1.0
23	26.0	24.0	0.923	2.0
24	26.0	23.2	0.891	2.8
25	26.5	24.0	0.906	2.5
26	26.8	24.5	0.913	2.3
27	27.7	25.0	0.903	2.7
28	28.2	24.5	0.869	3.7
Average Difference			**0.937**	**1.5**

Figure 2.24: Comparison of Survey Values for Maximum and Service Speeds



Three important conclusions have been drawn from these comparisons and from further evaluation of data obtained during the Vessel Boarding Program:

1. *Close agreement between the survey findings and Lloyd's values for power and maximum speed indicates that there is no need to use an adjustment factor as has been used in past studies.*

   The previous study that established the 92% adjustment factor to Lloyd's reported power value (i.e., dividing Lloyd's value by 0.92) did so for that study based on a limited data set collected over 10 years ago. While that may have been valid based on 1993 sample data, this more recent analysis indicates a much closer agreement.

Differences in values less than 5% could be considered so small as to not be meaningful given the complex systems being modeled. As an example, the 97% agreement, as determined by the survey work, represents a much better alignment of Lloyd's and survey data than the 92% that has been used since the previous study, is within the range of uncertainty and inherent variability in data of this type, and may be within the confidence intervals of the data. Both statistics indicate that Lloyd's slightly under-predicts maximum power, however, applying an adjustment factor does not have a uniform effect. Specifically, since the adjustment method requires that one divide the Lloyd's number by the adjustment factor to obtain the "true" value, the impact of the method using 92% is an actual increase of almost 9% in estimated maximum power, as shown in Table 2.7. Were a 97% adjustment factor to be used instead, the increase in estimated power would be slightly over 3%.

Table 2.7: Example Containership Maximum Power at Nominal 33,000 kW

Method	Lloyd's Power	Offset Percentage	Calculated Maximum Power	Increase
Arcadis	33,000	92%	35,870	8.7
Starcrest	33,000	97%	34,021	3.1

There is inherent variability between the rated maximum power reported by the engine manufacturers and in-use maximum power reported by vessel chief engineers. While the manufacturers know the power that their engines are designed to produce, the engineers may report vessel-specific numbers derived from actual operational experience, making small variations between what Lloyd's and the vessel operators report more likely.

Applying an adjustment factor to Lloyd's reported power and maximum speed disproportionately understates power at low speeds. An evaluation of this adjustment (dividing the Lloyd's value by 0.97) shows that the effect would be a 3.1% increase in the estimate of power and emissions at service speed with an offsetting decrease in the estimated power and emissions at reduced or maneuvering speeds, when the vessels are closer to the harbor and populated areas.

For example, a vessel with Lloyd's speed of 21 knots and Lloyd's power of 100,000 kW would have an estimated service speed of 19.7 knots (21 x 0.94 = 19.7, based on the conclusion in item 2, below, that service speed is, on average, 94% of Lloyd's speed) at a load factor of 83% ($(19.7/21)^3 = 0.83$) using the Propeller Law (actual speed/maximum speed^3), and an estimated power output at service speed of 83,000 kW (100,000 x 0.83 = 83,000).

If both speed and power were adjusted by dividing by 0.97, the vessel would have an estimated maximum speed of 21.6 knots (21/0.97 = 21.6) and maximum power of 103,093 kW (100,000/0.97 = 103,093). Its estimated service speed would be 20.3 knots (21.6 x 0.94 = 20.3), again at a load factor of 83% ($(20.3/21.6)^3 = 0.83$) using the Propeller Law, and an estimated power output at service speed of 85,567 kW (103,093 x 0.83 = 85,567), which is 3.1% higher than estimated using the unadjusted Lloyd's numbers ((85,567 – 83,000)/83,000 = 0.031).

By contrast, at a speed of 12 knots, the unadjusted values would result in a load factor of 19% ($(12/21)^3 = 0.19$) and a power output estimate of 19,000 kW (100,000 x 0.19 = 19,000), while making the adjustments would result in a load factor of 17% ($(12/21.6)^3 = 0.17$) using the Propeller Law, and an estimated power output of 17,526 kW (103,093 x 0.17 = 17,526), which is 7.8% lower than the estimate using the unadjusted Lloyd's numbers ((19,000 - 17,526)/19,000 = 0.078).

1. *The relationship between maximum speed and service speed indicates that service speed can be estimated as 94% of maximum speed.*

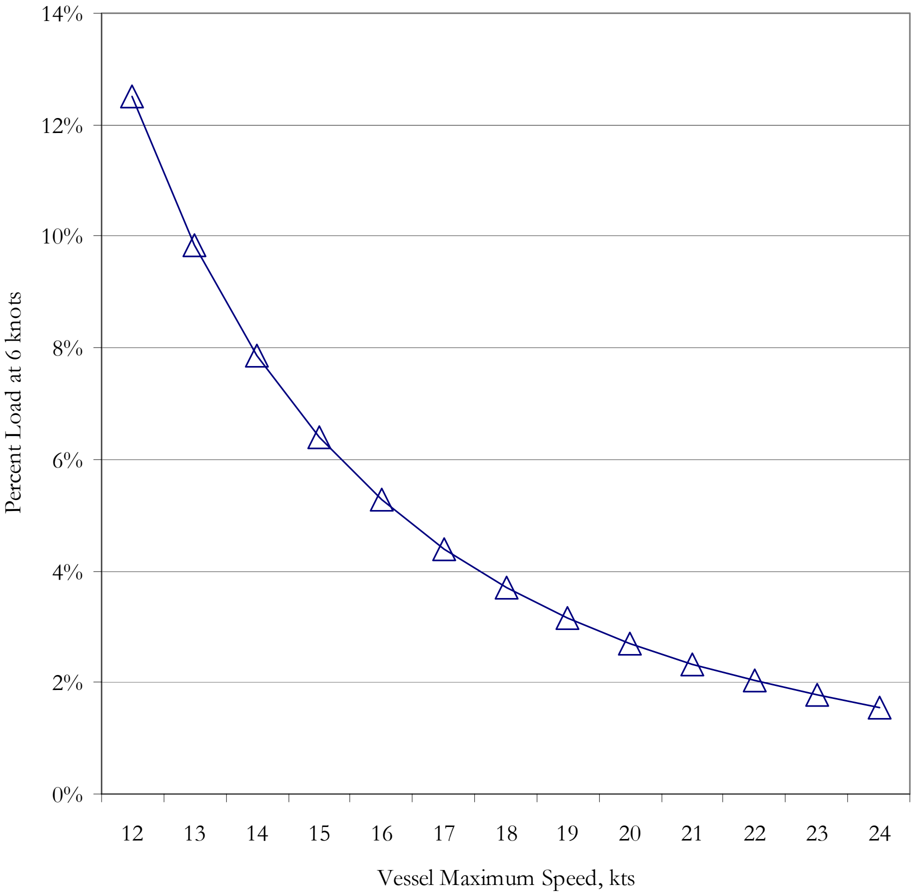
See Table 2.6 and Figure 2.24, which indicate that the average vessel service speed is 94% of its maximum speed. At this percentage, a vessel traveling at its service speed will be estimated to be operating with a load factor of 83%. The load factor equation is based on the Propeller Law, so if actual speed/maximum speed is 94% (0.94), then the load factor will be $0.94^3 = 0.83$, or 83%. This is consistent with assumptions made for previous studies that vessels at cruising speeds maintain a load of approximately 80%.

2. *The lowest practical load factor for maneuvering vessels is 2%.*

   This conclusion is based on the operating modes of direct-drive OGVs, which make up the large majority of OGVs calling on the Port. When maneuvering, these vessels are operated in a number of discrete engine settings, normally referred to as "dead slow," "slow," "half," and "full maneuvering" speeds. These can be either in "ahead" (forward) or "astern" (reverse) modes. For each vessel, these engine settings correspond to a specific engine speed in revolutions per minute (rpm) and a nominal vessel speed (depending on wind, tides, draft of the ship, and various other factors). Typically, the dead slow speed setting (the slowest of the maneuvering settings) results in a vessel speed of around 6 knots with the average of the surveyed vessels at 5.8 knots. To reduce the speed to below dead slow, the vessel has to cycle on and off, with much of the arrival (from the time the pilots board the ship to the time it is berthed at its arrival dock) being conducted with the engine off. Therefore, it is reasonable to assume that the lowest load factor a vessel will maintain is the load factor associated with the dead slow engine speed.

   The average surveyed maximum speed of containerships calling on the Port is 22.6 knots (which can be rounded to 23 knots). The minimum load factor at a dead slow speed of 6 knots would be $(6/23)^3 = 0.018$, which can be rounded to 2% (these values are rounded because they are a means to develop an estimate and do not represent precise values). Vessels with a lower maximum speed would have a higher minimum load factor at the same minimum speed, but 2% has been used for all vessel classes during docking maneuvers. Docking maneuvers are when a OGV either arrives or departs a berth and is characterized by very low speeds and propulsion engines being cycled off and on. The 2% minimum load factor seems reasonable because over the docking time, OGVs will be on average well below 2% (as the engines over that time are cycled on and off). Figure 2.25 illustrates the theoretical load factor at 6 knots for vessels with maximum speed ranging from 12 to 24 knots.

Figure 2.25: Variation in 6-knot Load Factor with Increasing Maximum Speed, knots



Vessel Speeds and Distances

Vessel speeds were observed from the bridge when possible, along with location reference points such that speeds through the various reaches of the harbor could be profiled. These observed average speeds and discussions with the Port pilots and with vessel chief engineers and captains provided a valuable source of survey data which was combined with time-in-mode and real time load data to develop improved vessel operational profiles and activity parameters that would result in more accurate emission estimates. Some general observations can be made regarding this speed data. For example, about three miles from the breakwater, the Port pilot boards the arriving vessel at a speed range of six to ten knots, with nine knots being the observed average. Once the vessel passes the breakwater and is inside the harbor, it slows down to six knots and its speed continues to lower as it approaches the berth. Table 2.8 lists the modes, speeds, and distances by vessel type, for the various reaches within the harbor. Containerships, auto carriers, and cruise vessels are grouped together because they generally maneuver at similar speeds through the harbor while the slower vessels, such as general cargo, reefers, and tankers generally travel at slightly slower speeds. Once inside the breakwater OGVs can transit to the East Channel (primarily break-bulk, general cargos, and lay-berths), north in the Main Channel (Los Angeles Channel) (bulk-liquids, containers, and cruise ships), to the East and West Basins (containers, bulk-liquids, and autos), or east into the Pier 300 Channel (containers and dry-bulk).

Table 2.8: Speed and Distance Table

Zone	Vessel Class	Units	Route North Route, Inbound	North Route, Outbound	South Route, Inbound	South Route, Outbound	East Route, Inbound	East Route, Outbound	West Route, Inbound	West Route Outbound
Fairway		nm	40.0	39.0	34.0	38.0	23.5	21.5	43.5	43.5
	Auto Carriers	knots	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8
	Bulk	knots	17.58	17.58	17.58	17.58	17.58	17.58	17.58	17.58
	Containership	knots	21.26	21.26	21.26	21.26	21.26	21.26	21.26	21.26
	Cruise	knots	18.06	18.06	18.06	18.06	18.06	18.06	18.06	18.06
	General Cargo	knots	14.69	14.69	14.69	14.69	14.69	14.69	14.69	14.69
	Miscellaneous	knots	14.1	14.1	14.1	14.1	14.1	14.1	14.1	14.1
	Ocean-going tug	knots	9.4	9.4	9.4	9.4	9.4	9.4	9.4	9.4
	Ro-Ro	knots	13.91	13.91	13.91	13.91	13.91	13.91	13.91	13.91
	Reefer	knots	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9
	Tanker	knots	13.6	13.6	13.6	13.6	13.6	13.6	13.6	13.6
Precautionary Zone		nm	6.0	4.0	6.5	6.0	6.0	4.0	6.0	4.0
	Auto Carriers	knots	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0
	Bulk	knots	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
	Containership	knots	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0
	Cruise	knots	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0
	General Cargo	knots	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
	Miscellaneous	knots	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
	Ocean-going tug	knots	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
	Ro-Ro	knots	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
	Reefer	knots	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
	Tanker	knots	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0

Table 2.8: Speed and Distance Table (cont'd)

Zone	Vessel Class	Units	North Route, Inbound	North Route, Outbound	South Route, Inbound	South Route, Outbound	East Route, Inbound	East Route, Outbound	West Route, Inbound	West Route Outbound
Harbor - Inbound		nm			<Note: *Distances veried by dock*>					
	Auto Carriers	knots	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
	Bulk	knots	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
	Containership	knots	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
	Cruise	knots	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
	General Cargo	knots	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
	Miscellaneous	knots	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
	Ocean-going tug	knots	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
	Ro-Ro	knots	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
	Reefer	knots	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
	Tanker	knots	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Harbor - Outbound		nm			<Note: *Distances veried by dock*>					
	Auto Carriers	knots	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
	Bulk	knots	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
	Containership	knots	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
	Cruise	knots	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
	General Cargo	knots	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
	Miscellaneous	knots	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
	Ocean-going tug	knots	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
	Ro-Ro	knots	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
	Reefer	knots	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
	Tanker	knots	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0

In Port Maneuvering Time-in-Mode

During the vessel boardings for arrival and departure, observations were noted on time spent at each engine setting in maneuvering mode (dead slow, slow, half, full and stop) for 53 vessels. The amount of time spent in each engine setting during maneuvering depends on the on location of and approach to the destination terminal and turning requirements for the vessel. Information on time in setting was not available for a few vessels; during some boardings the time on board was spent with the ship's engineer if it was not possible to meet while at berth, so settings in the control room could not be monitored; for some boardings before dawn, it was impossible to observe the instrumentation because no lights are used in the bridge at those times and some vessels have dimly lit instruments; and the cruise ships did not have a setting indicator that one could read on the bridge.

Table 2.9 lists the percentage of time spent in each engine setting during maneuvering for 44 containerships by destination container terminal during arrival and departure. (Terminal names have been blinded in column headings, replaced by terminal ID codes.) The data for the other types of vessels is presented in separate tables.

Table 2.9: Percentage of Time Spent in Setting Modes for Containerships by Terminal

	Arrivals						**Departures**					
	LAC -010	**LAC -070**	**LAC -090**	**LAC -030**	**LAC -060**	**LAC -020**	**LAC -010**	**LAC -070**	**LAC -090**	**LAC -030**	**LAC -060**	**LAC -020**
Dead Slow	38%	34%	46%	47%	75%	58%	18%	50%	38%	67%	25%	52%
Slow	25%	17%	14%	6%	13%	15%	17%	8%	41%	11%	36%	22%
Half	5%	11%	8%	14%	10%	2%	8%	0%	6%	0%	9%	3%
Full	0%	12%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%
Stop	31%	26%	32%	32%	2%	26%	58%	42%	14%	22%	30%	24%

Generally, the time at which the propulsion engines are at dead slow is significant. This mainly occurs during the turning of the vessel in one of the turning basins or during the time leading up to the actual docking of the ship (when most of the delicate maneuvering is handled by assist tugboats). Table 2.10 presents the range of time in minutes spent at each setting for the containership boardings. The ahead and astern settings are listed separately to point out how the astern settings are used to move a vessel backward or to slow down the vessel.

Table 2.10: Range of Time in Setting Modes for Containerships by Terminal, minutes

	LAC010		LAC070		LAC090		LAC030		LAC060		LAC020		Overall	Overall
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Minimum	Maximum
Dead Slow	2	23	10	26	5	29	20	54	1	39	19	63	1	63
Slow	3	19	3	20	1	20	2	10	7	36	3	24	1	36
Half	2	16	3	13	1	10	3	34	5	19	3	6	1	34
Full	0	0	12	17	0	0	2	2	0	0	0	0	0	17
Stop	8	45	7	40	15	23	5	40	1	30	5	30	1	45
DS astern	1	10	3	11	1	3	1	5	4	4	1	17	1	17
Slow astern	1	6	2	3	4	4	1	1	0	0	5	5	1	6
Half astern	1	1	0	0	0	0	1	1	0	0	0	0	1	1
Full astern	0	0	0	0	0	0	0	0	0	0	0	0	0	0

In Table 2.11, averages of the time at each setting for arrivals and departures are listed for the container terminals with average total minutes listed at the bottom of the table. The varying total times for arrivals and departures at a terminal could be due to vessels being boarded at varying distances outside the breakwater for arrivals and departures and the fact that some vessels are turned on arrival and others on departure.

Table 2.11: Average Time in Setting Modes for Containerships by Terminal, minutes

	Arrivals							Departures							
	LAC -010	LAC -070	LAC -090	LAC -030	LAC -060	LAC -020	Arr Avg	LAC -010	LAC -070	LAC -090	LAC -030	LAC -060	LAC -020	Dep Avg	Overall Avg
Dead Slow	18	20	29	40	39	36	30	5	16	13	40	14	27	19	25
Slow	13	9	8	5	7	12	9	10	9	14	10	22	19	14	11
Half	5	7	6	19	5	6	8	7	0	6	0	17	4	6	7
Full	0	15	0	2	0	0	3	0	0	0	0	0	0	0	1
Stop	18	16	22	29	1	17	17	25	22	15	13	22	20	20	18
DS astern	6	3	2	3	0	4	3	5	11	0	1	4	14	6	4
Slow astern	4	3	4	1	0	5	3	2	0	0	0	0	0	0	2
Half astern	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Full astern	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Totals	**65**	**72**	**69**	**98**	**52**	**79**	**72**	**54**	**58**	**49**	**64**	**79**	**83**	**64**	**68**

Time in setting mode was also recorded for other types of vessels during boarding including four general cargo vessels, three reefers, one car carrier, and one liquid bulk vessel. The percentages of time in setting modes are summarized below for arrival, departure, an intra-port transfer and a transfer between POLB and Port of Los Angeles berths. Table 2.12 below summarizes the percentage of time spent in each setting mode for these vessels (the sample size is very small for the OGV types in the table).

Table 2.12: Percentage of Time Spent in Setting Modes for Other OGV Vessels by Terminal

	Arrival			Departure		Transfer	
	Gen Cargo LAC040	**Reefer LAO180**	**Liquid Bulk LAO230**	**Gen Cargo LAC040**	**Car Carrier LAO060**	**Gen Cargo LAO010**	**Gen Cargo LA-LB shift**
Slow	28%	23%	7%	40%	8%	22%	15%
Dead Slow	51%	67%	17%	4%	76%	44%	60%
Half	14%	9%	10%	27%	16%	0%	2%
Full	0%	0%	0%	0%	0%	0%	0%
Stop	7%	1%	66%	29%	0%	34%	23%

Table 2.13 presents the average time-in-mode for these vessels during their observed maneuvering. The boarding for the general cargo vessel on arrival took place at an anchorage outside the breakwater. The vessel had arrived during the night and anchored until the next morning. The transfer or shift of the general cargo vessel between POLB berth 94 and Port of Los Angeles berth 154 took the vessel through the Beach Channel to the Long Beach and Los Angeles outer harbors (inside the breakwater) and then up the Main Channel to arrive at its destination.

Table 2.13: Average Minutes in Setting Modes for Other OGV Vessels by Terminal

	LAC040	**LAO180**	**LAO230**	**LAC040**	**LAO060**	**LAO010**	**LA-LB shift**
	Arrival			Departure		Transfer	
	Gen Cargo LAC040	**Reefer LAO180**	**Liquid Bulk LAO230**	**Gen Cargo LAC040**	**Car Carrier LAO060**	**Gen Cargo LAO010**	**Gen Cargo LA-LB shift**
Slow	19	13	5	21	4	7	14
Dead Slow	35	22	11	2	38	20	50
Half	10	10	7	14	8	0	0
Full	0	0	0	0	0	0	0
Stop	5	1	47	15	0	20	24
DS astern	0	28	1	0	0	6	14
Slow astern	0	0	0	0	0	6	2
Half astern	0	0	0	0	0	0	2
Full astern	0	0	0	0	0	0	0
Totals	**69**	**74**	**71**	**52**	**50**	**59**	**106**

All ships that enter the Port require a 180° turn so that they can be sailed out of the harbor, the exception being cruise ships that are berthed at 93A and 93B, which are turned 90° on arrival and departure. For the San Pedro berths there are three turning areas: the turning basin located just north of the Vincent Thomas Bridge, the turning basin in the Main Channel just south of Reservation Point, and the Pier 300 turning basin (see Figure 2.6). The Pier 300 turning basin is somewhat limited in the size of the vessel that can be turned within the basin; the larger containerships are often backed out into the main channel turning basin. The size of the vessel that can be turned within the basin is limited the larger containerships are often backed out into the Main Channel turning basin. The West and East basin vessels are generally turned at the turning basin just north of the Vincent Thomas Bridge; however, depending on weather conditions and the size of the vessel, OGVs can be turned in both basins. As a precaution, the liquid bulk tankers generally turn on arrival to face in the direction of the outer harbor. For containerships, it was observed that some berths require full turns (i.e., Evergreen), while other berths (i.e., TraPac) require that the vessel turn to the side due to its location.

Real Time Load Readings and Vessel Histograms for Transit and In-Port Maneuvering Modes
One of the major outstanding issues that had not been fully addressed in any of the previous studies is what happens to the propulsion engine at low load. It had been assumed that there was a minimum load requirement (ranging from 7-10%) on the propulsion engine to keep the engine running during the maneuvering phase.[14] This issue was made a top priority for the VBP in terms of further research with the chief engineers. Through the interview process, from real time engine load readings that were available on some of the newer vessels, and from the recorded data, a clearer understanding was obtained. It is recommended that the Port incorporate the confirmation of these initial findings into future VBPs.

As described by several chief engineers, when the large propulsion engines reduce engine speed or revolutions per minute, the engine reaches a point when it no longer has enough momentum and energy to power all the air blowers, pumps, compressors and other dependent components associated with the engine. Prior to this point being reached, the chief engineer will bring additional auxiliary engines online to power this support equipment and to keep the engine from stalling. This additional power need is one of the reasons why, during an OGV's approach to the Port, additional auxiliary engines are turned on. This additional load (associated with the blowers, pumps, and compressors) varied from 300 to 1,300 kW (depending on the configuration of each ship). Thus, the propulsion engine can operate at very low loads because it is kept from stalling by these auxiliary powered support systems.

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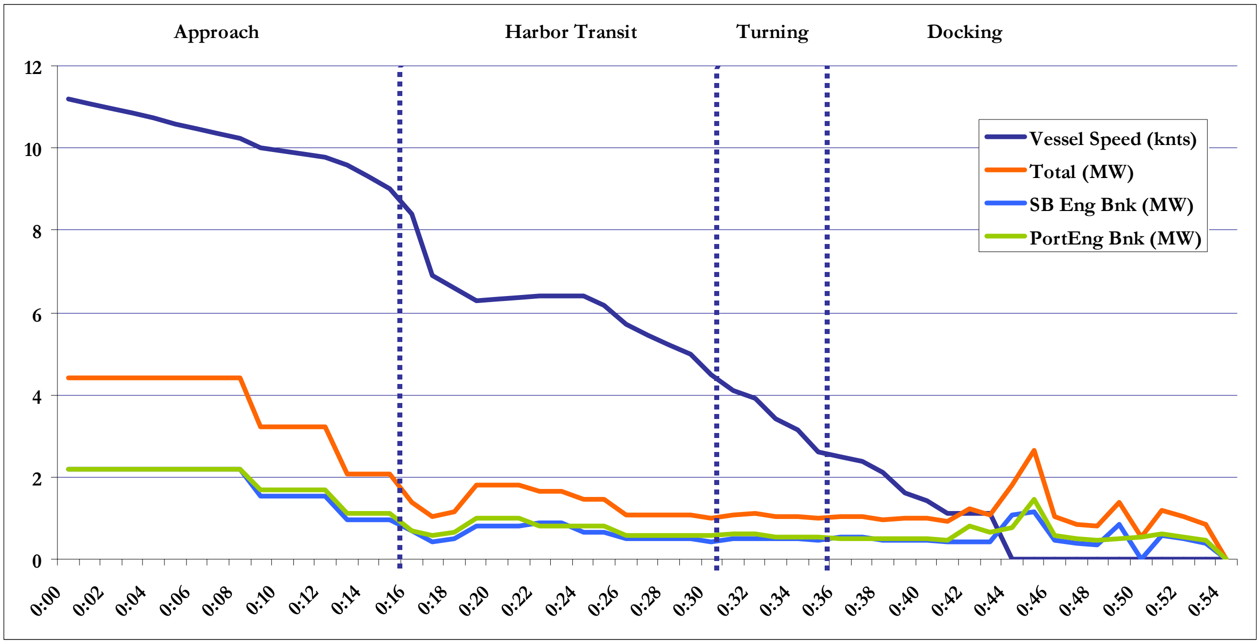
[14] The Starcrest 2002 *New York, New Jersey, Long Island Nonattainment Commercial Marine Vessel Inventory* assumed a 10% increase to the propeller curve to account for this minimum engine load (see Section 5.2.2.1). See explanation of propeller law and propeller curve in Subsection 2.5.1 of this report.

Direct observations confirmed that the propulsion engines operate at very low loads during arrivals and departures; this was observed for both geared drive and direct drive propulsion systems. The following two examples are presented to demonstrate that the propulsion engines do in fact follow the propeller curve during both arrival and departure maneuvering activities.

First, a geared drive cruise ship was observed during a boarding both on arrival and then on departure on the same day. The geared drive allows for any of the propulsion engines to be engaged or disengaged from the gears that link the engine to the propeller shaft (each engine bank turns a propeller shaft and the engines turn faster than the propeller). The ship was configured with four propulsion engines arranged in two banks (starboard and port) with each bank having a rated power of 44.38 megawatts (MW) or a ship total propulsion power of 88.76 MW. Figure 2.26 and Table 2.14 present the inbound time in mode, vessel speed (in knots, kts), engine bank output, and the table also presents the overall percent load of the propulsion system. Figures 2.27 and Table 2.15 present the outbound parameters. The approach is when the vessel is outside the breakwater and not in the harbor. Negative speeds indicate the vessel is operating in reverse.

Figure 2.26: Observed Geared Drive Inbound Mode, Vessel Speed, and Engine Power Demand vs. Time, minutes



Note: SB EngBnk – Starboard Engine Bank
PortEngBnk – Port Engine Bank

Table 2.14: Observed Geared Drive Inbound Mode, Vessel Speed, Engine Power Demand, and Overall Propulsion Load Factor vs. Time

Eng Bank Rated Power (MW-hr)			44.38	44.38	88.76	
Recorded			Engine Power Demand			
Time (min)	Mode	Speed (knts)	SB Bank (MW)	PortBank (MW)	Total (MW)	LF
0:00	Approach to Gate	11.2	2.20	2.20	4.40	5.0%
0:01		11.1	2.20	2.20	4.40	5.0%
0:02		11.0	2.20	2.20	4.40	5.0%
0:03		10.8	2.20	2.20	4.40	5.0%
0:04		10.7	2.20	2.20	4.40	5.0%
0:05		10.6	2.20	2.20	4.40	5.0%
0:06		10.5	2.20	2.20	4.40	5.0%
0:07		10.4	2.20	2.20	4.40	5.0%
0:08		10.2	2.20	2.20	4.40	5.0%
0:09		10.0	1.54	1.69	3.23	3.6%
0:10		9.9	1.54	1.69	3.23	3.6%
0:11		9.8	1.54	1.69	3.23	3.6%
0:12		9.8	1.54	1.69	3.23	3.6%
0:13		9.6	0.97	1.10	2.07	2.3%
0:14		9.3	0.97	1.10	2.07	2.3%
0:15		9.0	0.97	1.10	2.07	2.3%
0:16		8.4	0.67	0.70	1.37	1.5%
0:17		6.9	0.44	0.59	1.03	1.2%
0:18		6.6	0.50	0.65	1.15	1.3%
0:19	Harbor Transit (Maneuvering)	6.3	0.80	1.00	1.80	2.0%
0:20		6.3	0.80	1.00	1.80	2.0%
0:21		6.4	0.80	1.00	1.80	2.0%
0:22		6.4	0.87	0.79	1.66	1.9%
0:23		6.4	0.87	0.79	1.66	1.9%
0:24		6.4	0.67	0.79	1.46	1.6%
0:25		6.2	0.67	0.79	1.46	1.6%
0:26		5.7	0.49	0.58	1.06	1.2%
0:27		5.5	0.49	0.58	1.06	1.2%
0:28		5.2	0.49	0.58	1.06	1.2%
0:29		5.0	0.49	0.58	1.06	1.2%
0:30		4.5	0.41	0.57	0.98	1.1%
0:31		4.1	0.49	0.60	1.09	1.2%
0:32		3.9	0.50	0.62	1.12	1.3%
0:33		3.4	0.49	0.55	1.05	1.2%
0:34		3.1	0.49	0.55	1.05	1.2%
0:35	90 Deg Turn	2.6	0.47	0.54	1.01	1.1%
0:36		2.5	0.54	0.51	1.05	1.2%
0:37		2.4	0.54	0.51	1.05	1.2%
0:38		2.1	0.45	0.50	0.95	1.1%
0:39		1.6	0.47	0.51	0.99	1.1%
0:40		1.4	0.47	0.51	0.99	1.1%
0:41		1.1	0.43	0.48	0.91	1.0%
0:42	Positioning (Docking)	1.1	0.42	0.81	1.23	1.4%
0:43		1.1	0.41	0.65	1.06	1.2%
0:44		0	1.07	0.75	1.82	2.0%
0:45		0	1.16	1.47	2.63	3.0%
0:46		0	0.45	0.59	1.04	1.2%
0:47		0	0.37	0.48	0.85	1.0%
0:48		0	0.34	0.46	0.81	0.9%
0:49		0	0.86	0.51	1.37	1.5%
0:50		0	0.01	0.52	0.53	0.6%
0:51		0	0.56	0.62	1.18	1.3%
0:52		0	0.48	0.55	1.03	1.2%
0:53		0	0.37	0.47	0.84	0.9%
0:54		0	0.00	0.00	0.00	0.0%

Figure 2.27: Observed Geared Drive Outbound Mode, Vessel Speed, and Engine Power Demand vs. Time, minutes

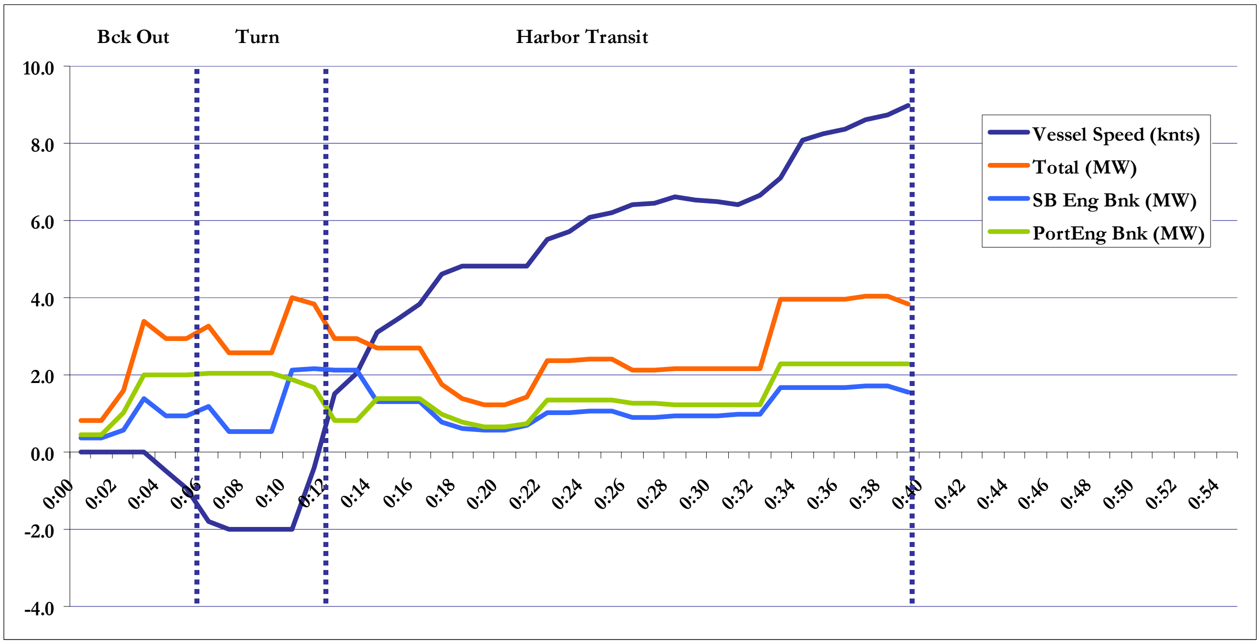


Table 2.15: Observed Geared Drive Outbound Mode, Vessel Speed, Engine Power Demand, and Overall Propulsion Load Factor vs. Time

Eng Bank Rated Power (MW)			44.38	44.38	88.76	MW
Recorded Time (min)	Mode	Speed (knts)	Engine Power Demand			LF
			SB Bank (MW)	PortBank (MW)	Total (MW)	
0:00	Positioning (Backing Out)	0.0	0.36	0.45	0.81	0.9%
0:01		0.0	0.36	0.45	0.81	0.9%
0:02		0.0	0.56	1.02	1.59	1.8%
0:03		0.0	1.40	1.98	3.39	3.8%
0:04		-0.5	0.94	2.02	2.96	3.3%
0:05		-0.9	0.94	2.02	2.96	3.3%
0:06		-1.8	1.20	2.05	3.25	3.7%
0:07	90 Deg Turn	-2.0	0.54	2.03	2.57	2.9%
0:08		-2.0	0.54	2.03	2.57	2.9%
0:09		-2.0	0.54	2.03	2.57	2.9%
0:10		-2.0	2.14	1.88	4.02	4.5%
0:11		-0.4	2.17	1.68	3.85	4.3%
0:12		1.5	2.13	0.81	2.94	3.3%
0:13	Harbor Transit (Maneuvering)	2.0	2.13	0.81	2.94	3.3%
0:14		3.1	1.29	1.40	2.69	3.0%
0:15		3.5	1.29	1.40	2.69	3.0%
0:16		3.9	1.29	1.40	2.69	3.0%
0:17		4.6	0.78	0.97	1.74	2.0%
0:18		4.8	0.60	0.77	1.37	1.5%
0:19		4.8	0.59	0.65	1.24	1.4%
0:20		4.8	0.59	0.65	1.24	1.4%
0:21		4.8	0.71	0.73	1.44	1.6%
0:22		5.5	1.03	1.33	2.37	2.7%
0:23		5.7	1.03	1.33	2.37	2.7%
0:24		6.1	1.06	1.36	2.42	2.7%
0:25		6.2	1.06	1.36	2.42	2.7%
0:26		6.4	0.88	1.25	2.13	2.4%
0:27		6.5	0.88	1.25	2.13	2.4%
0:28		6.6	0.93	1.22	2.15	2.4%
0:29		6.6	0.93	1.22	2.15	2.4%
0:30		6.5	0.93	1.22	2.15	2.4%
0:31		6.4	0.96	1.21	2.17	2.4%
0:32		6.6	0.96	1.21	2.17	2.4%
0:33		7.1	1.68	2.30	3.97	4.5%
0:34		8.1	1.66	2.30	3.96	4.5%
0:35		8.2	1.66	2.30	3.96	4.5%
0:36		8.4	1.66	2.30	3.96	4.5%
0:37		8.6	1.72	2.30	4.02	4.5%
0:38		8.7	1.72	2.30	4.02	4.5%
0:39		9.0	1.53	2.31	3.84	4.3%

As presented in the figures and tables above, the cruise ship's inbound trip within the harbor (maneuvering) is, on average, less than the 2% load factor minimum that was previously discussed. For the outbound trip, the load is relatively higher as the ship is trying to increase speed and momentum, therefore more work is required from the engines.

The second example shows a containership that was observed both during arrival and departure during the same visit with low propulsion loads similar to what the propeller curve would predict. The containership was direct drive (the engine is connected directly to the propeller shaft and the engine and propeller turn at the same rpm) and had a propulsion engine rated at 42 MW. Figure 2.28 and Table 2.16 present the inbound mode, vessel speed, shaft speed, engine demand, and load factor. Figure 2.29 and Table 2.17 present the same data for the outbound trip.

Figure 2.28: Observed Direct Drive Inbound Mode, Vessel Speed and Engine Output vs. Time, minutes

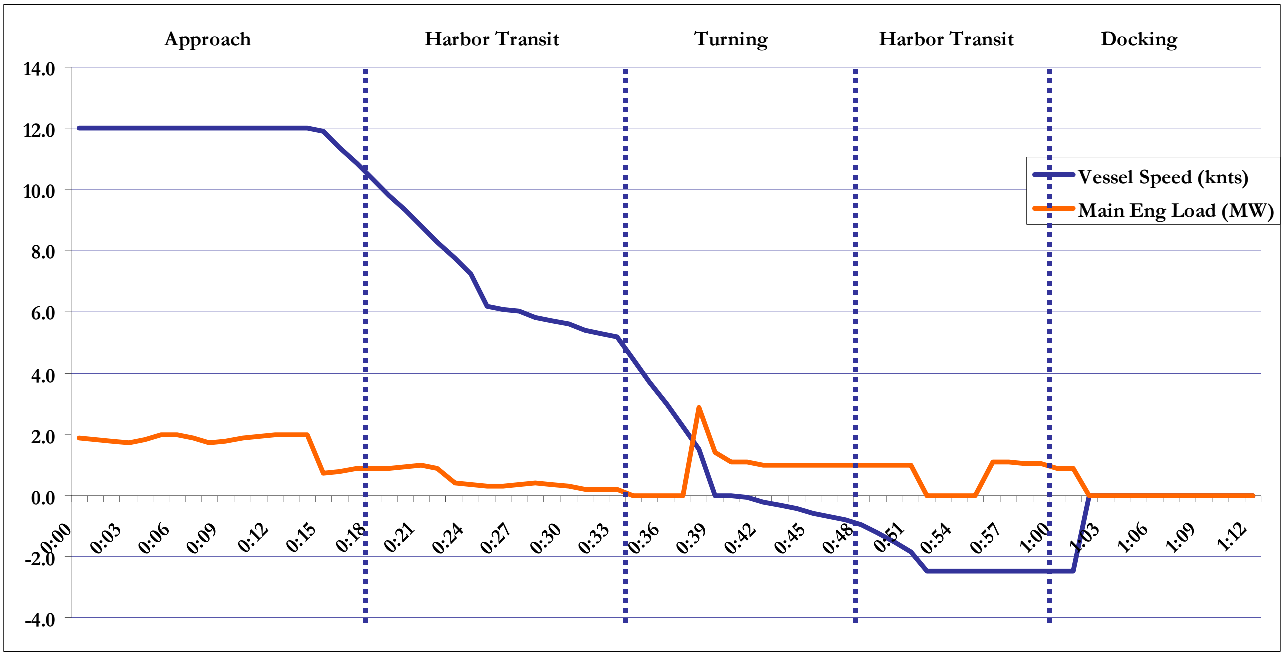


Table 2.16: Observed Direct Drive Inbound Mode, Vessel Speed, Engine Power Demand, and Overall Propulsion Load Factor vs. Time

			MCR (MW):	42.0	
Recorded Time (min)	Mode	Speed (knts)	Shaft Speed (rpm)	Engine Power Demand (MW)	LF
0:00	Approach to Gate	12.0	35.0	1.90	4.5%
0:01		12.0	34.9	1.80	4.3%
0:02		12.0	34.9	1.77	4.2%
0:03		12.0	34.9	1.70	4.0%
0:04		12.0	34.7	1.80	4.3%
0:05		12.0	34.2	2.00	4.8%
0:06		12.0	35.5	2.00	4.8%
0:07		12.0	35.4	1.90	4.5%
0:08		12.0	35.1	1.70	4.0%
0:09		12.0	35.0	1.77	4.2%
0:10		12.0	34.9	1.90	4.5%
0:11		12.0	35.0	1.93	4.6%
0:12		12.0	35.2	2.00	4.8%
0:13		12.0	35.2	2.00	4.8%
0:14		12.0	35.2	2.00	4.8%
0:15		11.9	28.4	0.70	1.7%
0:16		11.4	28.2	0.77	1.8%
0:17		10.9	27.8	0.90	2.1%
0:18		10.3	27.9	0.90	2.1%
0:19	Harbor Transit (Maneuvering)	9.8	28.2	0.90	2.1%
0:20		9.3	28.1	0.93	2.2%
0:21		8.8	27.8	1.00	2.4%
0:22		8.3	28.6	0.90	2.1%
0:23		7.8	24.0	0.40	1.0%
0:24		7.2	23.7	0.37	0.9%
0:25		6.2	23.1	0.30	0.7%
0:26		6.1	23.1	0.33	0.8%
0:27		6.0	23.1	0.35	0.8%
0:28		5.8	23.1	0.40	1.0%
0:29		5.7	23.1	0.35	0.8%
0:30		5.6	23.1	0.30	0.7%
0:31		5.4	23.1	0.20	0.5%
0:32		5.3	23.1	0.20	0.5%
0:33		5.2	23.1	0.20	0.5%
0:34		4.5	0.0	0.00	0.0%

Table 2.16: Observed Direct Drive Inbound Mode, Vessel Speed, Engine Power Demand, and Overall Propulsion Load Factor vs. Time (cont'd)

			MCR (MW):	42.0	
Recorded Time (min)	Mode	Speed (knts)	Shaft Speed (rpm)	Engine Power Demand (MW)	LF
0:35	180 Deg Turn	3.7	0.0	0.00	0.0%
0:36		3.0	0.0	0.00	0.0%
0:37		2.2	0.0	0.00	0.0%
0:38		1.5	-24.4	2.90	6.9%
0:39		0.0	-24.4	1.40	3.3%
0:40		0.0	-22.7	1.10	2.6%
0:41		-0.1	-22.7	1.07	2.5%
0:42		-0.2	-22.6	1.00	2.4%
0:43		-0.3	-22.7	1.00	2.4%
0:44		-0.5	-22.8	1.00	2.4%
0:45		-0.6	-22.8	1.00	2.4%
0:46		-0.7	-22.9	1.00	2.4%
0:47		-0.8	-23.0	1.00	2.4%
0:48		-1.0	-23.1	1.00	2.4%
0:49		-1.2	-23.2	1.00	2.4%
0:50	Harbor Transit (Maneuvering)	-1.5	-23.2	1.00	2.4%
0:51		-1.9	-23.2	1.00	2.4%
0:52		-2.5	0.0	0.00	0.0%
0:53		-2.5	0.0	0.00	0.0%
0:54		-2.5	0.0	0.00	0.0%
0:55		-2.5	0.0	0.00	0.0%
0:56		-2.5	-25.0	1.10	2.6%
0:57		-2.5	-24.7	1.08	2.6%
0:58		-2.5	-24.4	1.05	2.5%
0:59		-2.5	-24.1	1.03	2.4%
1:00		-2.5	-22.5	0.90	2.1%
1:01		-2.5	-22.5	0.90	2.1%

Table 2.16: Observed Direct Drive Inbound Mode, Vessel Speed, Engine Power Demand, and Overall Propulsion Load Factor vs. Time (cont'd)

			MCR (MW):	42.0	
Recorded Time (min)	Mode	Speed (knts)	Shaft Speed (rpm)	Engine Power Demand (MW)	LF
1:02	Positioning (Docking)	0.0	0.0	0.00	0.0%
1:03		0.0	0.0	0.00	0.0%
1:04		0.0	0.0	0.00	0.0%
1:05		0.0	0.0	0.00	0.0%
1:06		0.0	0.0	0.00	0.0%
1:07		0.0	0.0	0.00	0.0%
1:08		0.0	0.0	0.00	0.0%
1:09		0.0	0.0	0.00	0.0%
1:10		0.0	0.0	0.00	0.0%
1:11		0.0	0.0	0.00	0.0%
1:12		0.0	0.0	0.00	0.0%

Figure 2.29: Observed Direct Drive Outbound Mode, Vessel Speed, and Engine Power Demand vs. Time, minutes

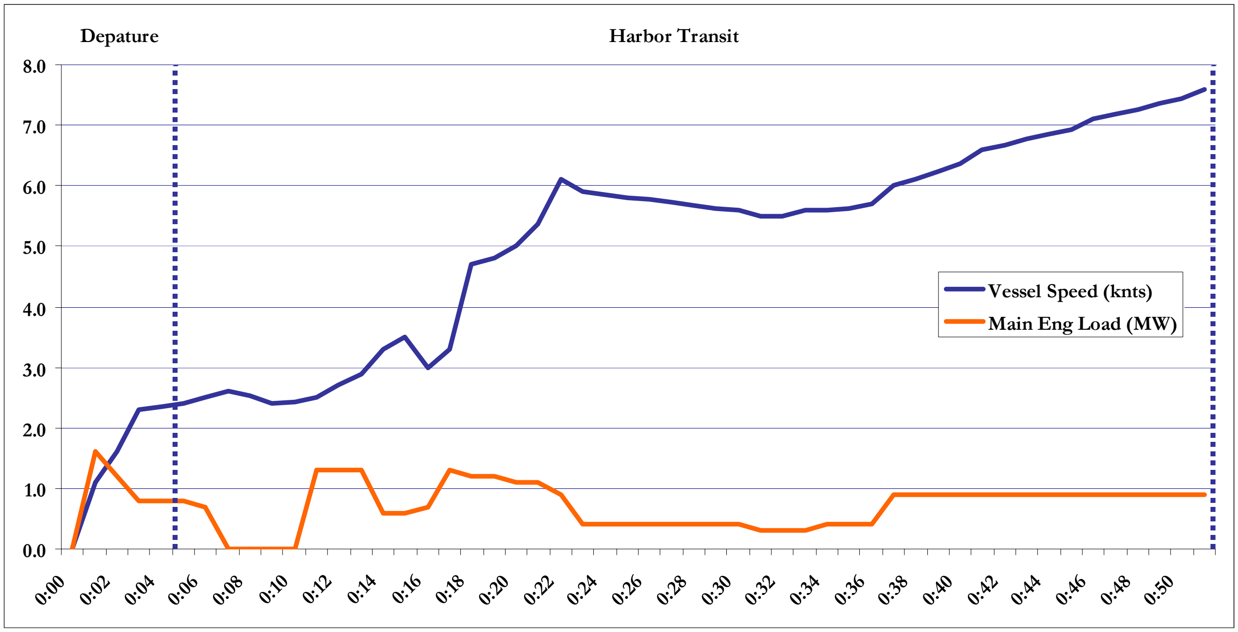


Table 2.17: Observed Direct Drive Outbound Mode, Vessel Speed, Engine Power Demand, and Overall Propulsion Load Factor vs. Time

Recorded Time (min)	Mode	Speed (knts)	Shaft Speed (rpm)	Engine Power Demand (MW)	LF
0:00	Positioning (Dock Departure)	0.0	0.0	0.00	0.0%
0:01		1.1	28.2	1.60	3.8%
0:02		1.6	24.6	1.20	2.9%
0:03		2.3	22.7	0.80	1.9%
0:04		2.4	22.7	0.80	1.9%
0:05		2.4	22.7	0.80	1.9%
0:06	Transit Harbor (Maneuvering)	2.5	23.0	0.70	1.7%
0:07		2.6	0.0	0.00	0.0%
0:08		2.5	0.0	0.00	0.0%
0:09		2.4	0.0	0.00	0.0%
0:10		2.4	0.0	0.00	0.0%
0:11		2.5	23.8	1.30	3.1%
0:12		2.7	23.8	1.30	3.1%
0:13		2.9	23.8	1.30	3.1%
0:14		3.3	22.9	0.60	1.4%
0:15		3.5	23.2	0.60	1.4%
0:16		3.0	23.0	0.70	1.7%
0:17		3.3	27.4	1.30	3.1%
0:18		4.7	28.2	1.20	2.9%
0:19		4.8	28.2	1.20	2.9%
0:20		5.0	28.1	1.10	2.6%
0:21		5.4	28.1	1.10	2.6%
0:22		6.1	27.9	0.90	2.1%
0:23		5.9	23.1	0.40	1.0%
0:24		5.9	23.1	0.40	1.0%
0:25		5.8	23.1	0.40	1.0%
0:26		5.8	23.1	0.40	1.0%
0:27		5.7	23.1	0.40	1.0%
0:28		5.7	23.1	0.40	1.0%
0:29		5.6	23.1	0.40	1.0%
0:30		5.6	23.1	0.40	1.0%
0:31		5.5	21.9	0.30	0.7%
0:32		5.5	21.9	0.30	0.7%
0:33		5.6	21.9	0.30	0.7%
0:34		5.6	23.3	0.40	1.0%
0:35		5.6	23.3	0.40	1.0%
0:36		5.7	23.3	0.40	1.0%
0:37		6.0	27.2	0.90	2.1%
0:38		6.1	27.2	0.90	2.1%
0:39		6.2	27.2	0.90	2.1%
0:40		6.4	27.2	0.90	2.1%
0:41		6.6	28.2	0.90	2.1%
0:42		6.7	28.2	0.90	2.1%
0:43		6.8	28.2	0.90	2.1%
0:44		6.9	28.2	0.90	2.1%
0:45		6.9	28.2	0.90	2.1%
0:46		7.1	27.9	0.90	2.1%
0:47		7.2	27.9	0.90	2.1%
0:48		7.3	27.9	0.90	2.1%
0:49		7.4	27.9	0.90	2.1%
0:50		7.4	27.9	0.90	2.1%
0:51		7.6	27.9	0.90	2.1%

Since the times for arrivals and departures were relatively short and the chief engineers and captains had their full attention on the maneuvering, there was seldom time for in-depth discussion between the Port representative and the captain or chief engineer. Therefore, meetings at berth were scheduled to discuss the vessel specifics, such as horsepower and load, in more detail. Toward the later phases of the VBP, several lines operating ships with newer, more sophisticated electronics provided histograms that provided detailed records on main engine loads, auxiliary loads, and main engine speed during arrival, departure, and hoteling. The vessels with the software were not all set up to print or download the data in a user friendly manner, therefore only a few were able to print the graphs viewed on the monitor screen or send an electronic copy. Nonetheless, these printouts provided a graphical representation of the engine parameters at low speeds observed during ride-alongs.

Figures 2.30 through 2.32 are histograms for the auxiliary and main engines of a 6,600 TEU capacity containership departing the Port, with one main engine at 74,600 brake-horsepower (bhp) and five auxiliary engines at 3,000 kW each.[15] Figure 2.30 shows four hours of the auxiliary engine power in megawatts. While at berth and prior to departure, the auxiliary engine power averaged 1.9 MW (1,900 kW) out of a total of 15 MW available. The spikes on the histogram are for the auxiliary engine power during maneuvering (associated with the use of the bow thrusters for relatively short periods of time) and show that power did not exceed 7,000 kW. There is a slight rise in auxiliary engine load prior to departure and after the ship has cleared maneuvering which is associated (in part) with the engine support equipment (blowers, compressors, pumps, etc.), as discussed above. The increase occurs prior to departure in part because compressed air is needed to start the propulsion engine upon departure. Two hours later, the power goes back down to 1.9 MW. Figures 2.31 and 2.32 depict the main engine revolutions per minute and load, respectively, during departure, both the speed is increased.

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[15] The information from this larger, newer, 6,600 TEU ship is presented only to illustrate several issues and points that have surrounded power demands and engine dynamics during the maneuvering phase of a voyage. Because in 2001 no such large containerships called at the Port, specific information from the vessels depicted on Figures 2.30 – 2.36 was not used in the inventory. However, insight provided by these histograms did provide valuable information to develop better operational profiles and activity parameters for engines.

Figure 2.30: Auxiliary Engine Power during Departure, MW

Figure 2.31: Main Engine Speed during Departure, rpm

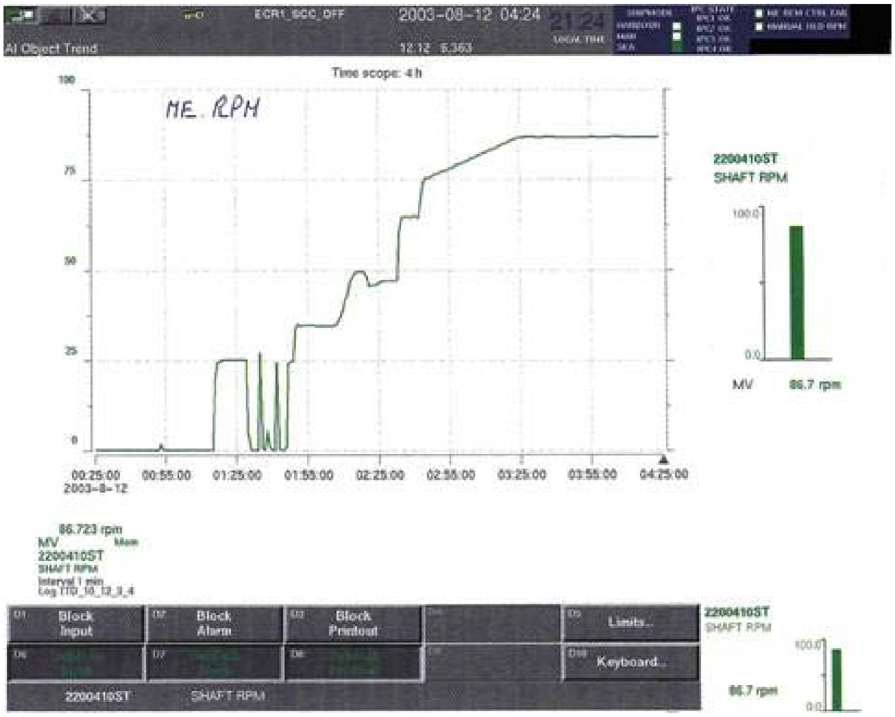
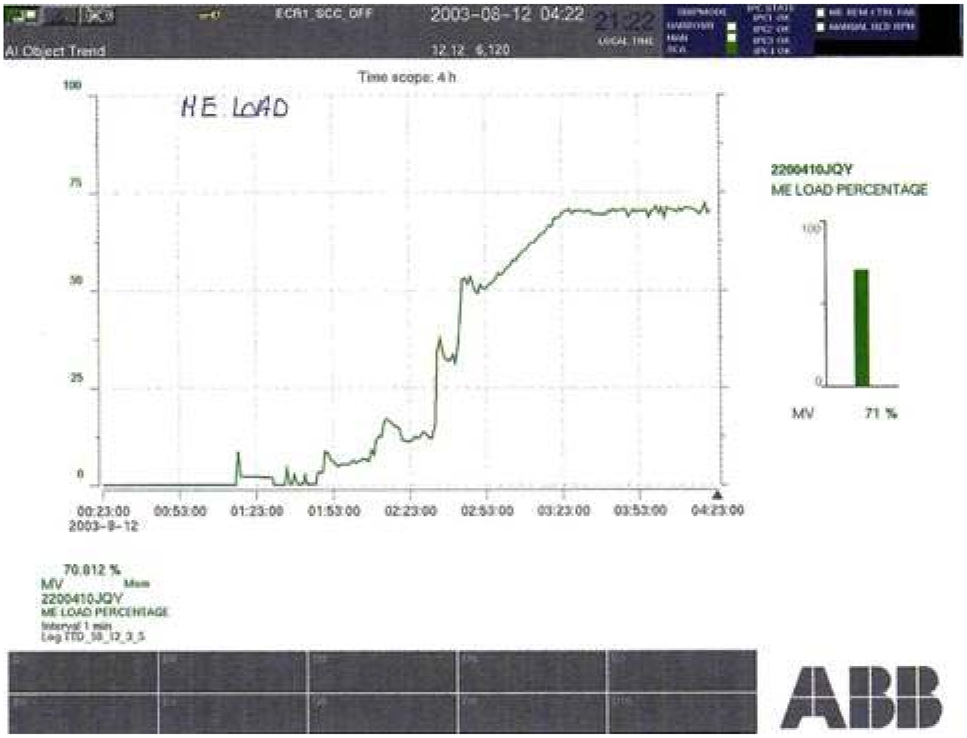


Figure 2.32: Main Engine Load during Departure, %



Figures 2.33 and 2.34 illustrate the same data for an arriving 6,600 TEU containership, with a main engine power of 74,640 bhp and five 3,000 kW auxiliary engines (a sister ship to the departing vessel whose histograms are above). These were printed as the vessel was maneuvering into its berth, therefore the final shut down of the main and auxiliary engines is not shown. The two figures were printed 18 minutes apart for the prior four hours and the handwritten notes were taken as the chief engineer discussed the figures with the interviewer. Figure 2.33 shows one auxiliary engine at approximately 1,800 kW (1.8 MW) at sea. The power jumps up slightly to 1,900 kW when the auxiliary blowers start about the time the vessel starts reducing speed. It also shows approximately when the second and third auxiliary engines started prior to maneuvering. It does not show the actual maneuvering when the auxiliary engine power might have fluctuated and increased if bow thrusters were engaged.

Figure 2.33: Auxiliary Engine Power during Arrival, kW

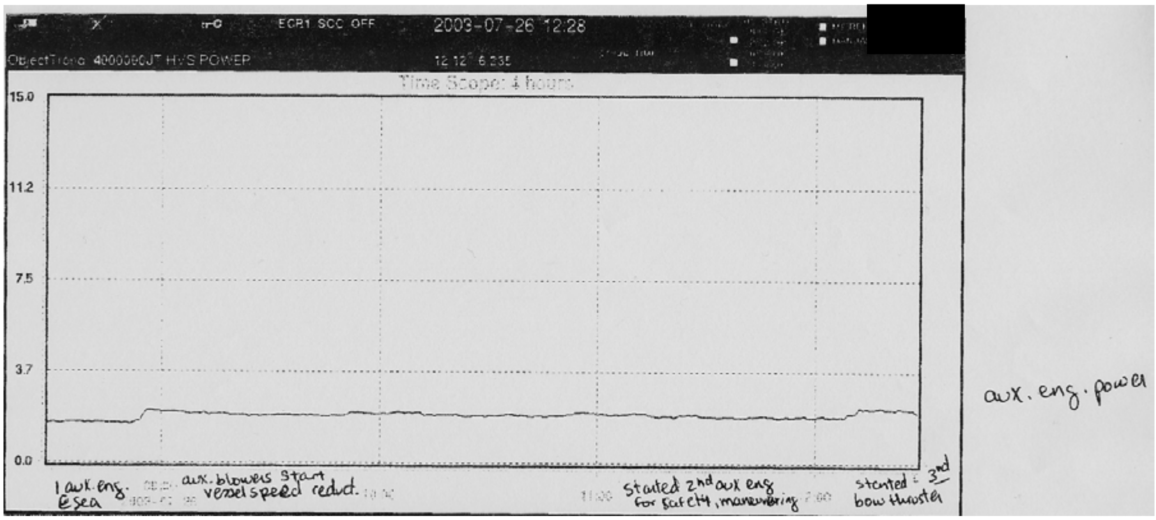


Figure 2.34: Main Engine Load during Arrival, %

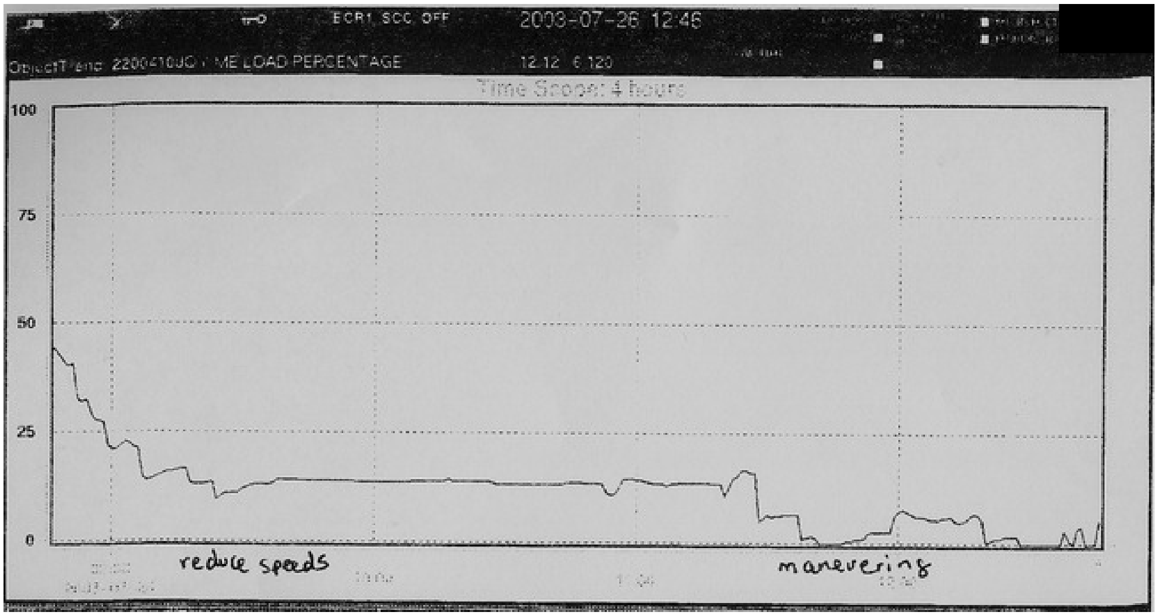
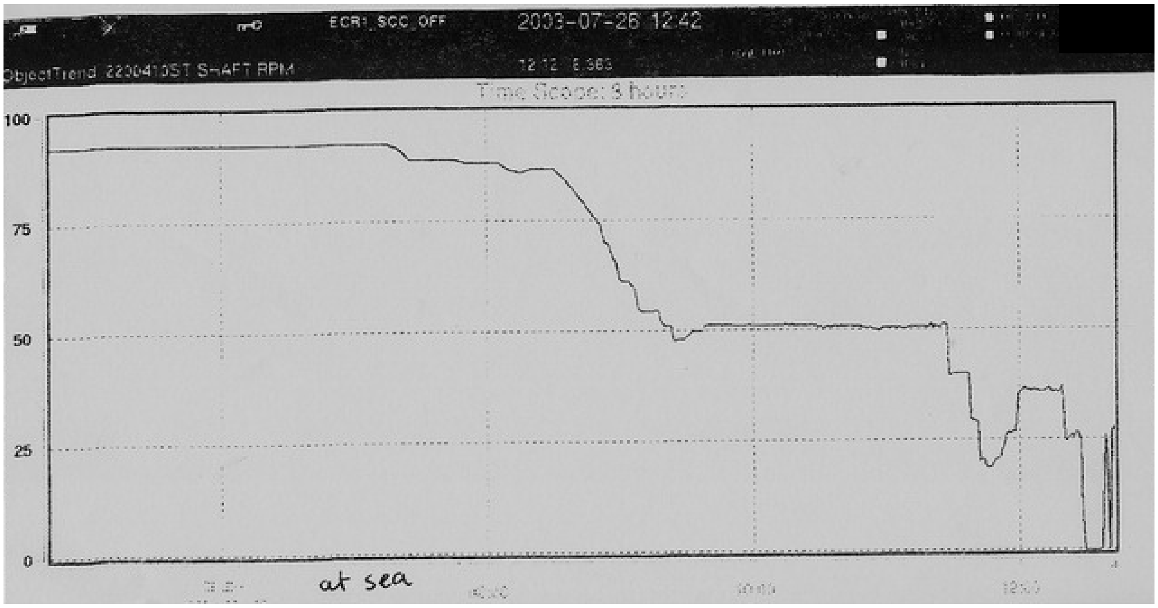


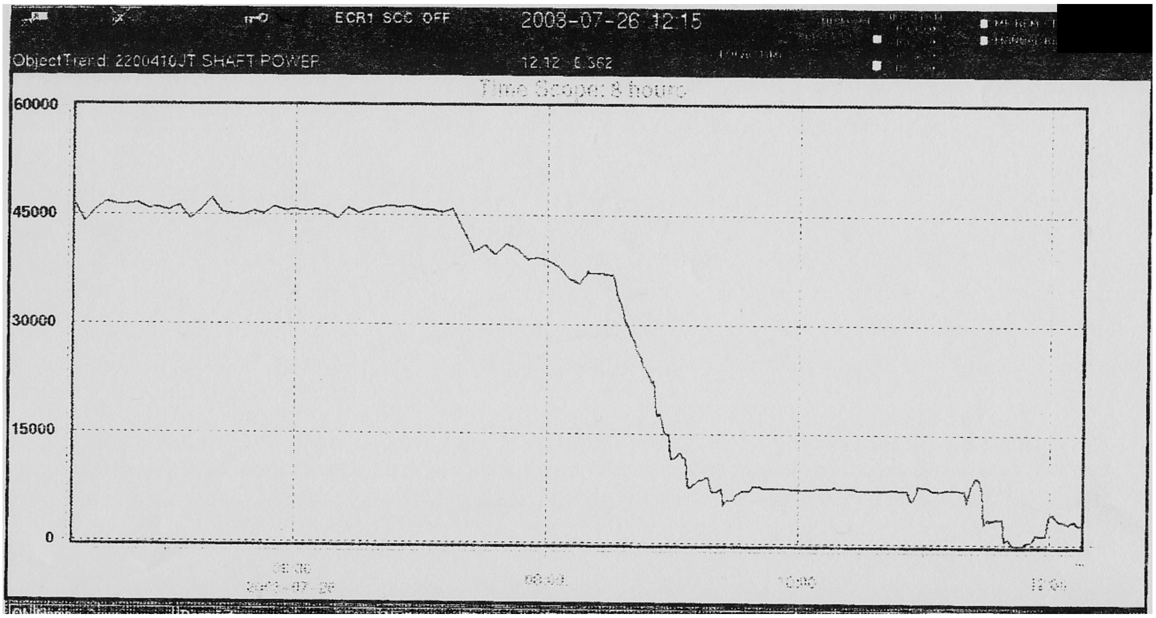
Figure 2.35 (the rpm histogram) was printed 27 minutes after Figure 2.36 (the main engine power histogram); their time range is over an 8-hour period. Both figures show the main engine rpm and kilowatts reducing when the speed is reduced, then holding constant until the pilot is picked up outside the breakwater. At sea, the main engine power was at 45,000 kW.

Figure 2.35: Main Engine Speed during Arrival, rpm



[redacted]

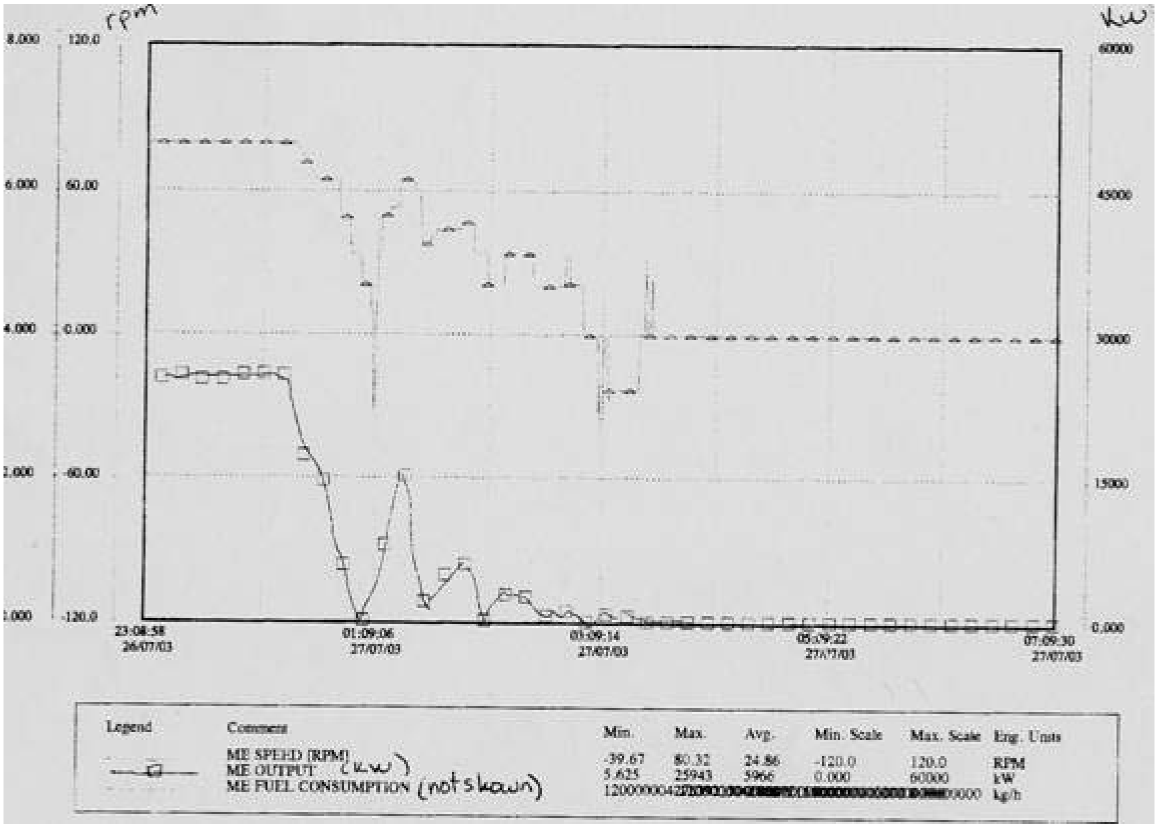
Figure 2.36: Main Engine Power during Arrival, kW



[redacted]

Figure 2.37 belongs to a 5,468 TEU capacity containership with a main engine power of 54,900 kW and four 2,320 kW auxiliary engines. The histogram shows the trend for the main engine rpms and power in kilowatts over a two-day period. This was printed the day after the vessel arrived during a berth visit with the chief engineer, so it shows arrival and the main engine stopped while at berth.

Figure 2.37: Main Engine Power during Arrival and at Berth, rpm, kW



Auxiliary Engine Power

Auxiliary engine characteristics were obtained from a combination of Lloyd's data and information collected during the VBP. Interviews conducted with ship captains, chief engineers, and pilots during the VBP also helped to develop profiles of the characteristics of auxiliary power usage for the various class types. Table 2.18 presents the average number of auxiliary engines, their average size (in kW), and the average total installed auxiliary power. Table 2.19 provides the auxiliary engine load factor assumptions by zone. Note that the "bulk" ship type was used as a surrogate for "general cargo," "miscellaneous," and "other tug," so the load factor assumptions for these vessel types are the same. In this table, 'PZ' designates precautionary zone.

Table 2.18: Auxiliary Engine Data

Type	Average Number	Average kW (each)	Average Aux (kW)
Auto Carrier	2.95	687	2,027
Bulk	3.02	387	1,169
Containership	3.78	1,520	5,746
Cruise	5.00	2,200	11,000
General Cargo	3.08	577	1,777
Miscellaneous	4.00	420	1,680
Other Tug	2.00	125	250
RoRo	2.04	2,447	4,992
Reefer	4.00	325	1,300
Tanker	2.94	675	1,985

Table 2.19: Load Factor Assumptions

	Average Aux Eng Load Factor by Zone			
Type	Hotelling	Mnvring	PZ	Fairway
Auto Carrier	0.24	0.67	0.30	0.13
Bulk	0.22	0.45	0.27	0.17
Containership	0.17	0.50	0.25	0.13
Cruise	0.64	0.80	0.80	0.80
General Cargo	0.22	0.45	0.27	0.17
Miscellaneous	0.22	0.45	0.27	0.17
Other Tug	0.22	0.45	0.27	0.17
RoRo	0.20	0.45	0.30	0.15
Reefer	0.34	0.67	0.34	0.20
Tanker	0.67	0.45	0.27	0.13

The load factors cover the various zones within the study area. The hoteling load is primarily what is needed to meet the power needs of the lights, heating/ventilation/air conditioning (HVAC) systems, radar, communications, computers, ship cranes, pumps, and various other power demands while the vessel is at dock. Maneuvering is generally the highest auxiliary load mode for OGVs as the bow thrusters need to be available and the auxiliary air boosters, pumps, and compressors are used to keep the propulsion engine from stalling during very low load conditions. The precautionary zone is generally where inbound ships bring additional auxiliary engines online to prepare for maneuvering operations. The fairway or open sea is generally where the lowest auxiliary loads are found as additional auxiliary power is not required for maneuvering and many vessels have shaft generators and exhaust turbines that help provide power to the ship in an effort to reduce operating costs (through lower fuel consumption).

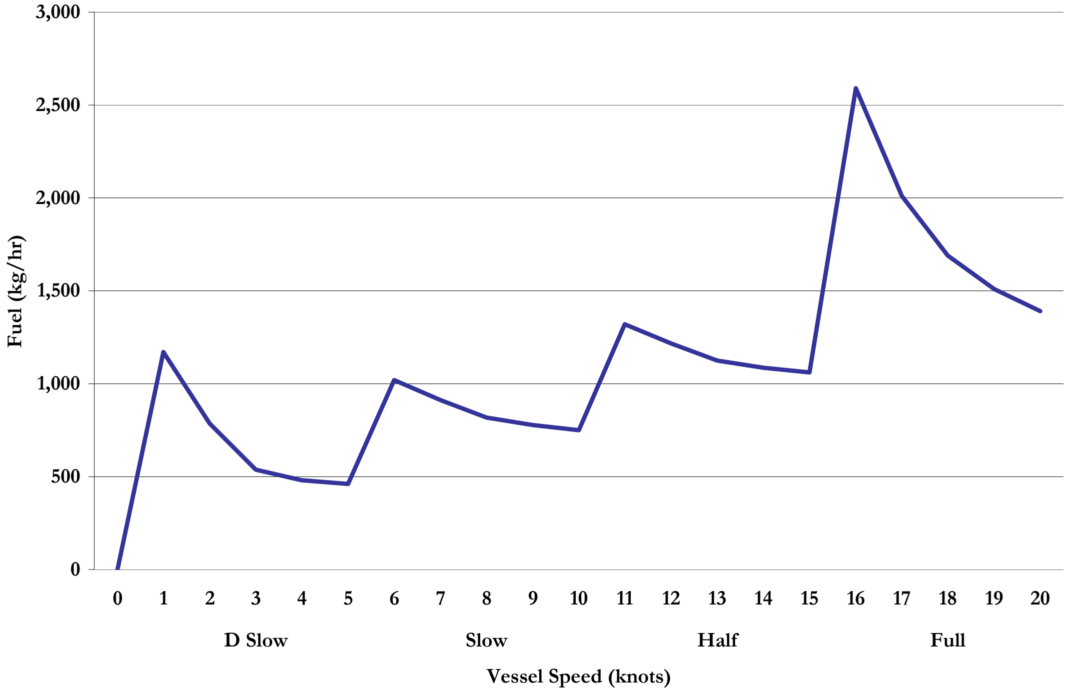
Tanker hoteling load factors were elevated because of the power needed to run the on-board pumps that are used to discharge the bulk-liquid cargo.

Fuel

The majority of the containerships boarded used IFO380 for their propulsion engines. For those vessels that could provide sulfur content information on their most recently purchased fuel, the sulfur content of IFO380 ranged from 1.5% to 3.8%, with an average sulfur content of 2.3%. Thirty three percent of the vessels boarded used only one fuel for the propulsion and auxiliary engines (typically IFO380). The rest used two or three types of fuel for their engines (IFO380 plus marine diesel oil, for example). A query of the Lloyd's database found a similar percentage, with 37% of the containerships using a single fuel for their engines.

One containership provided data on fuel consumption during acceleration. Figure 2.38 illustrates the fuel consumption (kg/hr) for a container vessel (50,000 DWTs and 66,000 hp propulsion engine) during maneuvering starting from stop to a full setting mode. In this figure, 'DSlow' designates 'Dead Slow'.

Figure 2.38: Container Vessel Acceleration Profile



Auxiliary and Main Engine Stacks

Information was obtained for main and auxiliary engine stacks, referred to as funnels to most of the chief engineers interviewed. The chief engineers typically did not have the information on stacks as readily available to them as other data, such as fuel consumption and engine parameters. The following data on the stacks is based on the information available during boardings.

The stacks were 34 to 58 meters above sea level; an average of 47 meters. The orientation of the stacks varied from vessel to vessel from vertical to 45 and 90 degrees to stern. The main engine stack diameters ranged from 0.6 to 2.9 meters, with an average of 1.9 meters. The average diameter of auxiliary engine and boiler stacks was 0.5 meters. The main and auxiliary engines exhaust gas temperature at sea averaged 300° Celsius. The auxiliary engine exhaust gas temperature at port averaged 345° Celsius.

While stack parameters do not affect the calculation of mass emissions, they are important for modeling the spatial allocation of emissions.

2.5 Methodology

The methodology presented in this report describes an activity-based emissions inventory, meaning that the emission estimates are based on the activity levels of the equipment being inventoried, as opposed to other emissions inventory methods such as fuel-based or cargo-based. The fuel-based method is appropriate where precise ship traffic is not known but total fuel consumption estimates are available.[16] The cargo-based method is a hybrid of the activity-based and fuel-based approaches and works reasonably well for offshore OGV estimates but not well for in-port vessel activities;[17] it also tends to miss or understate empty vessel activity. In all cases an activity-based method is considered most accurate.[18]

The activity-based approach was chosen because it makes use of actual location-specific information and can best account for local activity levels. For example, a fuel-based approach might base emission estimates on the amount of marine fuel sold in the vicinity of a particular port, but there would be no way of knowing how much of the fuel was actually burned in the area (as opposed to being burned during a vessel's trip to a distant port). While the total amount of emissions could be estimated, the location of those emissions could not be reliably reported. In contrast, the activity-based approach uses data concerning the operation of the vessels at different points in the Port area, and so is more location-specific.

In developing an activity-based emissions inventory for marine vessels, emissions are estimated as a function of vessel power demand (expressed in kW-hrs) multiplied by an emission factor, where the emission factor is expressed in terms of grams per kilowatt-hour (g/kW-hr). The data, operational information, and observations from the VBP, discussed in Subsection 2.4.4, were used to develop the activity parameters for vessel power demand. Emission factors and emission factor adjustments for low propulsion engine load were then applied to the various activity data. The process for estimating emissions from propulsion engines is depicted as a process flow diagram in Figure 2.39. This diagram indicates the sources of information discussed in the previous subsection and how they are used to develop the components of the emission calculations, as described below.

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[16] Corbett and Fischbeck, 1997.

[17] Corbett and Fischbeck, 2000.

[18] European Commission and ENTEC UK Limited 2002; Corbett and Koehler, 2003.

Equations 1 and 2 show the equations used in estimating emissions, and are labeled in Figure 2.39. Equation 1 is the most basic:

$$E = Energy * EF \qquad \text{Equation 1}$$

Where:

E = Emissions from the engine(s) that are included in the "Energy" term discussed below, usually calculated as grams of emissions per unit of time (e.g., per year), but converted to tons of emissions by dividing by 453.6 grams per pound and 2,000 pounds per ton.

Energy = Energy demand, in kW-hrs, calculated using Equation 2 below as the energy output of the engine (or engines) over the period of time covered by the estimate.

EF = Emission Factor, usually expressed in terms of g/kW-hr, discussed in more detail below.

The "Energy' term of the equation is where most of the location-specific information is used. Energy is calculated using Equation 2:

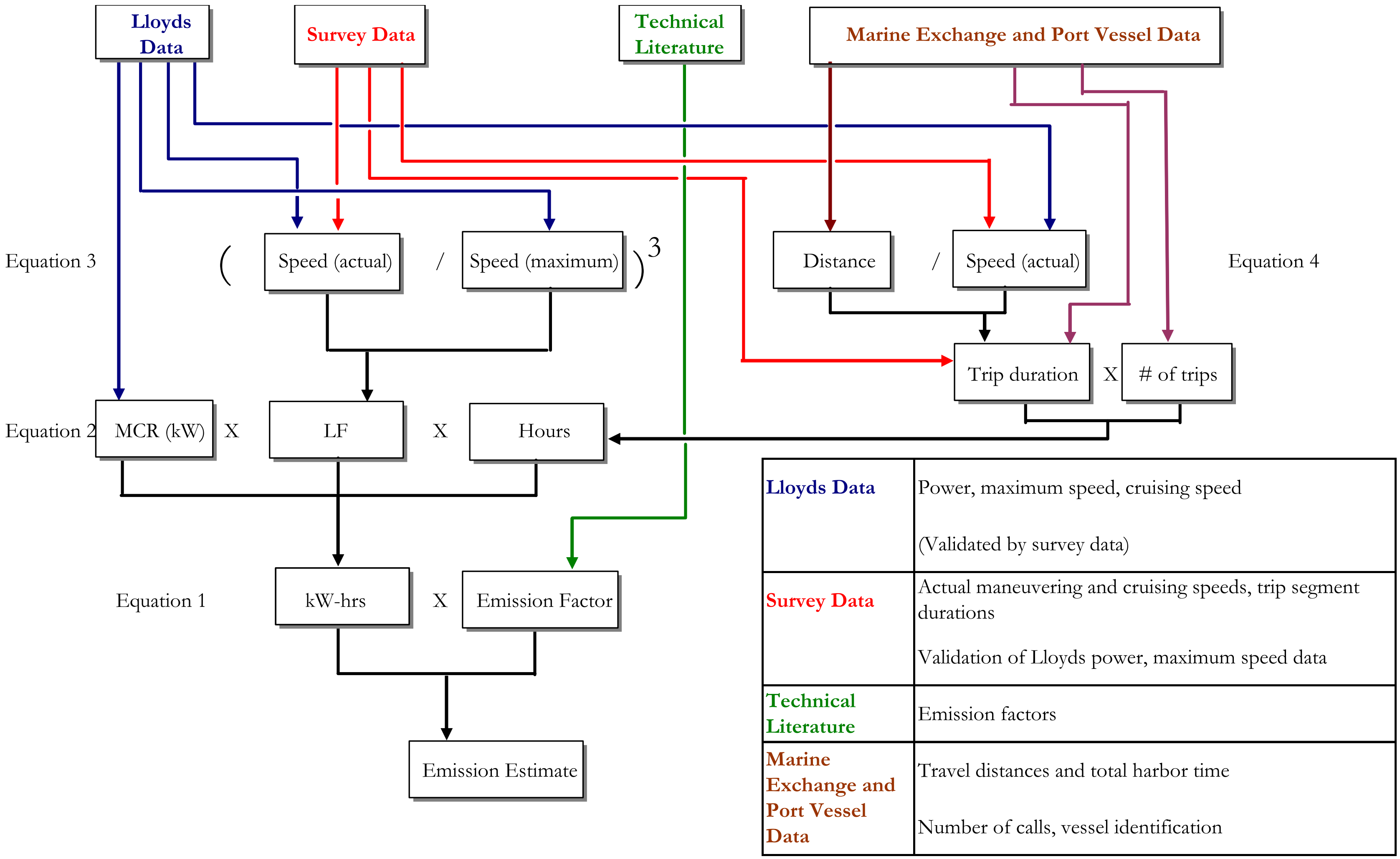
$$Energy = MCR * LF * A \qquad \text{Equation 2}$$

Where:

MCR = Maximum continuous rated engine power, kW
LF = Load Factor (unitless)
A = Activity, hours

These variables are discussed in more detail below.

Figure 2.39: Propulsion Engine Emission Estimation Flow Diagram



Lloyds Data	Power, maximum speed, cruising speed (Validated by survey data)
Survey Data	Actual maneuvering and cruising speeds, trip segment durations Validation of Lloyds power, maximum speed data
Technical Literature	Emission factors
Marine Exchange and Port Vessel Data	Travel distances and total harbor time Number of calls, vessel identification

2.5.1 Maximum Continuous Rated (MCR) Power

MCR power is defined as the manufacturer's tested engine power; for this study, it is assumed that the Lloyd's "power" value is the MCR power, as discussed above. The international specification is to report MCR in units of kilowatts, and it is related to the highest power available from a ship engine during average cargo and sea conditions. However, operating a vessel at 100% of its MCR power is very costly from a fuel consumption and engine maintenance perspective, so most operators limit their "real world" maximum power to about 80% of MCR. This is more fully described in the following subsections. An example of MCR power for a containership might be 20,000 kW.

2.5.2 Propulsion Engine Load Factor

Load factor is expressed as the ratio of a vessel's power output at a given speed to the vessel's MCR power. As suggested above, at normal service speed, a ship probably has a load factor of close to 80%. For intermediate speeds, the Propeller Law is used to estimate ship propulsion engine loads, based on the theory that propulsion power varies by the cube of speed.

$$LF = (AS/MS)^3 \qquad \text{Equation 3}$$

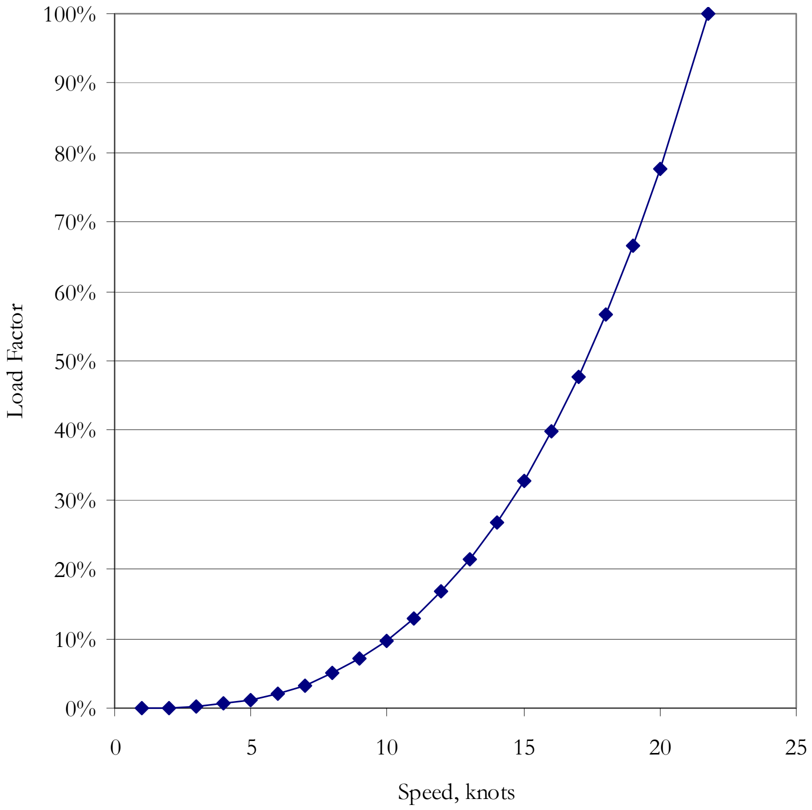
Where:

LF = Load Factor, percent
AS = Actual speed, knots
MS = Maximum Speed, knots

The output from Equation 3 is illustrated in Figure 2.40, showing the load factor curve of a hypothetical ship with 20,000 kW main engine power and a top speed of 22 knots at that power output. The shape of the curve illustrates why vessels typically operate at less than their MCR power – at the top of the curve, the increase in power is much greater than the increase in speed, meaning that the vessel uses a lot more power (and fuel) to get just a small increase in speed.

As an example, at a speed of 20 knots, the hypothetical vessel's engine would be operating with a load factor of 75% [$(20/22)^3$ = 0.75, or 75%]. At 21 knots the load factor would be 87% [$(21/22)^3$ = 0.87, or 87%]. That's an increase of 12% of the vessel's power output for a 1-knot increase in speed. At the lower end of the speed range, at a speed of 10 knots, the hypothetical vessel's engine would be operating with a load factor of 9% [$(10/22)^3$ = 0.09, or 9%]. At 9 knots the load factor would be 7% [$(9/22)^3$ = 0.07, or 7%]; this would give a 1-knot speed increase at an increase of only 2% of the vessel's power output. At 6 knots the load factor would be 2% [$(6/22)^3$ = 0.02, or 2%].

Figure 2.40: Propeller Law Curve of Power Demand



2.5.3 Activity

Activity is measured in hours of operation. In-harbor maneuvering and transit times were developed from Port data and data from the VBP. At-sea transit times were estimated by dividing distance traveled by ship speed.

$$A = D/S \qquad \text{Equation 4}$$

Where:

A = Activity, hours
D = Distance, nautical miles
S = Ship speed, knots

Activity data that was used is detailed above in Subsection 2.4 (Data and Information Acquisition) and below in Subsection 2.6 (Vessel Activity).

2.5.4 Main Engine Emission Factors

The main engine emission factors used in this study were reported in a 2002 ENTEC study[19] and are shown in Table 2.20. All ships are assumed to operate on residual oil (intermediate fuel oil [IFO] 380 or similar specification) with an average sulfur content of 2.7% which consistent with previous studies and not contradicted with VBP findings. Three vessel technologies are reported:

- Slow speed diesel engines, having maximum engine speeds less than 130 rpm based on the EPA definition for ship engines as described in the 1999 Regulatory Impact Analysis.
- Medium speed diesel engines, having maximum engine speeds over 130 rpm (and typically greater than 400 rpm).
- Steam boiler turbines.

Table 2.20: Emission Factors for OGV Main Engines using RO, g/kW-hr

Engine	NO_X	CO[20]	HC	PM_{10}	$PM_{2.5}$	SO_2
Slow speed diesel	18.10	1.40	0.60	1.92	1.54	10.50
Medium speed diesel	14.00	1.10	0.50	0.72	0.58	11.50
Steam turbine	2.10	0.20	0.10	0.72	0.58	16.50

CO emission factors were developed from information provided in the ENTEC appendices because they are not explicitly stated in the text. They were confirmed with IVS Swedish Environmental Research Institute Ltd. Based on a separate report, $PM_{2.5}$ was estimated to be 80% of PM_{10},[21] although this topic continues to be a subject of research and review in the scientific community. (This ratio is different than for the other source categories contained in this EI. This is due to the unique characteristics of marine diesel engines and residual oil.) While the emission inventories for the other source categories included in this Port-wide study (e.g., cargo handling equipment) have presented HC values converted to TOGs to provide more complete estimates of emissions of organic materials, OGV emissions are presented in terms of HC instead of TOGs because no conversion factor is currently available.

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[19] ENTEC, 2002. *Quantification of Emissions from Ships Associated with Ship Movements between Ports in the European Community, Final Report*, July 2002; prepared for the European Commission.

[20] IVL, 2004 David Cooper, IVL Swedish Environmental Research Institute Ltd., 16 January 2004 e-mail correspondence with C.H. Wells, Starcrest Consulting Group, LLC.

[21] Lyyranen et al 1999. 'Aerosol Characterization in Medium-Speed Diesel Engines Operating with Heavy Fuel Oils," *Journal of Aerosol Science* 30:6.

The IMO established OGV propulsion engine standards in Annex VI, which have not yet been ratified but may be within the next few years. The engine standards are baseline standards to prevent "back sliding" on emission levels from 2000 and newer engine models. When ratified, the standard will be applied retroactively to vessels produced in 2000 and after. This 2001 baseline inventory does not take into account any adjustment to the emission factors because the emission factors represent fleet averages, and the average ages of all the vessel classes (as presented in Table 2.33 below) are well beyond one to two years old. It is assumed that in 2001 the IMO standards had very little, if any, impact on the fleet based emission factors.

A study conducted by Energy and Environmental Analysis, Inc (EEAI) for Sierra Research[22] has established a formula for calculating emission factors for low engine load conditions such as those encountered during harbor maneuvering. While mass emissions (e.g., pounds per hour) tend to go down as vessel speeds and engine loads decrease, the emission factors (emissions as a function of power, such as g/kW-hr) increase. The EEAI study used formulas to develop low load emission factors based on EPA emission factors for marine vessels at full load. For this study, "emission factor adjustment factors" were developed from the EEAI formulas to estimate emissions at loads below 20%. The adjustment factors have been multiplied by the base ENTEC emission factors to derive the low-load emission factors listed in Table 2.21. The EEAI formulas were not used directly because they are based on less current emission factors than the ENTEC factors used for this study.

The low-load emission factor adjustment factors have been developed by taking the ratio of the low-load emission factors from EEAI to the calculated emission factor at a load factor of 20%. The EEAI formula is "$EF = a(LF)^{-x} + b$," where EF is the low-load emission factor, and "a," "b," and "x" are variables, with specific values for each pollutant (PM, NO_X, CO, and HC are included). For example, using the EEAI formula, the emission factor for NO_X at 3% load is calculated to be 34.6 g/kW-hr [$0.1255 \times (0.03)^{-1.5} + 10.4496 = 34.6$ g/kW-hr], and at 20% load is 11.85 g/kW-hr [$0.1255 \times (0.20)^{-1.5} + 10.4496 = 11.85$ g/kW-hr].

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[22] U.S. EPA. 2000. *Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data.* EPA420-R-002. February, 2000. Sierra Research work assignment No. 1-10.

The ratio of the low-load EEAI emission factors at 3% and 20% is 34.6/11.85 or 2.92. Therefore, the ENTEC emission factor for NO_X (18.10 g/kW-hr for low-speed engines) will be multiplied by the adjustment factor of 2.92 to calculate a load-specific emission factor for vessels operating at 3% load: 18.10 x 2.92 = 52.85 g/kW-hr. While this appears to be a very high emission factor compared with the base emission factor of 18.10 g/kW-hr, the actual emissions at a load of 3% are lower than at higher loads. For example, a 20,000 kW vessel at 3% load would emit NO_X at a rate of 70 lb/hr [20,000 kW x 0.03 x 52.85 g/kW-hr / 453.6 g/lb = 70 lbs/hr]. By comparison, the same vessel traveling at 80% load would emit NO_X at a rate of 638 lbs/hr [20,000 kW x 0.80 x 18.10 g/kW-hr / 453.6 g/lb = 638 lbs/hr], a rate 9 times higher.[23]

Table 2.21: Low-Load Emission Factor Adjustment Factors

Load	NOx	CO	HC	PM	SO_2
1%	11.47	20.00	89.44	19.17	1.00
2%	4.63	10.00	31.62	7.29	1.00
3%	2.92	6.67	17.21	4.33	1.00
4%	2.21	5.00	11.18	3.09	1.00
5%	1.83	4.00	8.00	2.44	1.00
6%	1.60	3.33	6.09	2.04	1.00
7%	1.45	2.86	4.83	1.79	1.00
8%	1.35	2.50	3.95	1.61	1.00
9%	1.27	2.22	3.31	1.48	1.00
10%	1.22	2.00	2.83	1.38	1.00
11%	1.17	1.82	2.45	1.30	1.00
12%	1.14	1.67	2.15	1.24	1.00
13%	1.11	1.54	1.91	1.19	1.00
14%	1.08	1.43	1.71	1.15	1.00
15%	1.06	1.33	1.54	1.11	1.00
16%	1.05	1.25	1.40	1.08	1.00
17%	1.03	1.18	1.28	1.06	1.00
18%	1.02	1.11	1.17	1.04	1.00
19%	1.01	1.05	1.08	1.02	1.00
20%	1.00	1.00	1.00	1.00	1.00

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[23] The emission factors used in this and similar studies are developed as fleet averages and are not intended to represent any particular individual vessel.

2.5.5 Auxiliary Engine Emission Factors.

The process of estimating emissions from auxiliary engines follows the same logic as for main engines but differs in some details. The process is illustrated in Figure 2.41. The most visible difference is that load factor is not calculated but rather is estimated from reports in the technical literature and from discussions with experts such as ships' engineers. Calculating auxiliary engine load factors from empirical data is theoretically possible but would require detailed fuel consumption data that is not normally available. The ENTEC auxiliary engine emission factors used in this study are presented in Table 2.22.

Table 2.22: Auxiliary Engine Emission Factors, g/kW-hr

Engine	Fuel	NO_X	CO[24]	HC	PM_{10}	$PM_{2.5}$	SO_2
Medium speed diesel	Residual oil	14.70	1.10	0.40	0.80	0.64	12.30
Medium speed diesel	Diesel oil	13.90	1.10	0.40	0.30	0.24	4.30
Medium speed diesel	Gas oil	13.90	1.10	0.40	0.30	0.24	1.10
High speed diesel	Residual oil	11.80	0.90	0.40	0.80	0.64	12.30
High speed diesel	Diesel oil	10.90	0.90	0.40	0.30	0.24	4.30
High speed diesel	Gas oil	10.90	0.90	0.40	0.30	0.24	1.10

2.5.6 Boiler Emission Factors

In addition to the auxiliary engines that are used to generate electricity for on-board uses, most OGVs have boilers used for fuel and engine heating and for producing hot water. The methodology for estimating emissions from on-board boilers is slightly different from that used for auxiliary engines: a fuel demand method is used instead of the power demand method because emission factors have been published in terms of fuel usage rather than power. Auxiliary boiler fuel consumption is estimated (from data collected during the vessel boarding program) to be 0.0125 tonnes of fuel per hour. Emission factors are then applied as being in units of kilograms per tonne of fuel consumed.[24] Auxiliary boiler emission factors are presented in Table 2.23.

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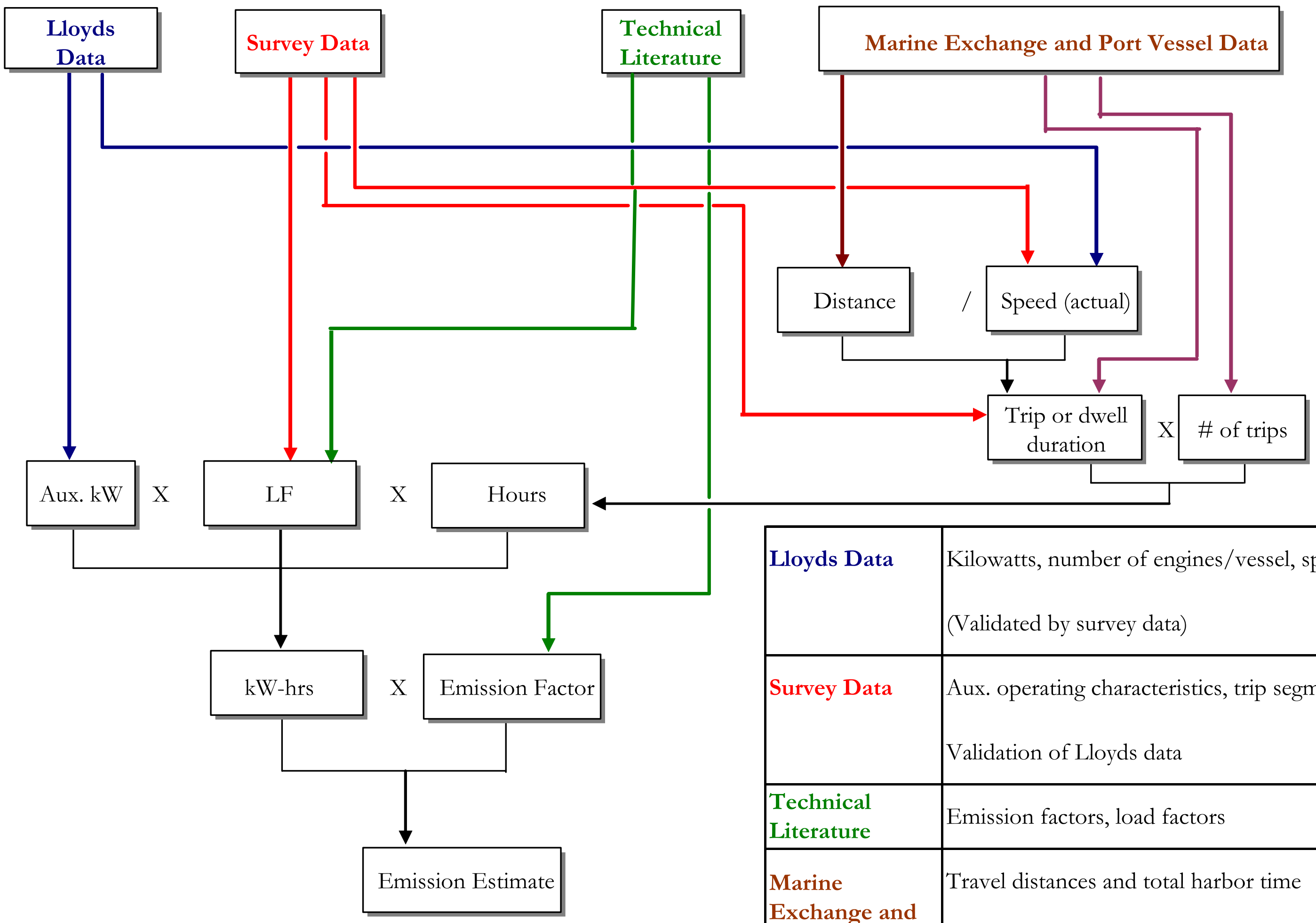
[24] Starcrest, 2000. *Houston-Galveston Area Vessel Emissions Inventory;* prepared for the Port of Houston Authority and the Texas Natural Resource Conservation Commission. Appendix D (relating to emission factors) prepared by Environ Corporation.

Figure 2.41: Auxiliary Engine Emission Estimation Flow Diagram



Lloyds Data	Kilowatts, number of engines/vessel, speeds (Validated by survey data)
Survey Data	Aux. operating characteristics, trip segment durations Validation of Lloyds data
Technical Literature	Emission factors, load factors
Marine Exchange and Port Vessel Data	Travel distances and total harbor time Number of calls, vessel identification

Table 2.23: Auxiliary Boiler Fuel Emission Factors, kg/tonne fuel consumed

Pollutant	kg/tonne
NO_X	12.30
CO	4.60
HC	0.38
PM_{10}	1.30
$PM_{2.5}$	1.04
SO_2	54.00

2.6 Vessel Activity

Vessel activity information relates primarily to the "Activity" term of Equation 4, but also affects the "Load Factor" term for the main engine emission calculations. Activity information includes the number of vessel calls to the Port over the study period, duration of vessel transit and hoteling, and travel speeds over the study area. This subsection explains how the vessel call data were processed, and how vessel performance characteristics were evaluated, aggregated, and used in the calculations.

2.6.1 Data Management

There were over 6,000 OGV movements in the Port during 2001. A movement is a trip to or from the sea, to or from an anchorage, an internal shift between Port docks, or a trip between berths at the Port of Los Angeles and the POLB. A computer program was used to help aggregate OGV movements according to the following assignments:

- Ship codes were correlated with vessel type names (e.g., the ship code 'UCC' corresponds to the containership type).
- Vessels were aggregated into the following DWT groups for the purpose of averaging MCR power. (Individual DWTs were retained in the database of vessel characteristics.)
  - ☐ 5,000 – 10,000 DWT
  - ☐ 10,000 – 25,000 DWT
  - ☐ 25,000 – 50,000 DWT
  - ☐ 50,000 – 75,000 DWT
  - ☐ 75,000 – 100,000 DWT
  - ☐ 100,000 – 200,000 DWT (VLCS)

- Vessels were aggregated to allow a manageable number of emission calculations, and because the emission factors are more appropriate to groups of vessels than to individual ships. Deadweight tonnage was used to aggregate vessels because this is a measure of a vessel's size and is related to the power needed to propel the vessel through the water (and, therefore, related to vessel characteristics such as main engine power).

- The Port's designated berth numbers were matched with the recorded terminals of arrival and departure. To assist in spatial resolution and time-in-mode modeling, three sections of the Port were also identified and recorded for each vessel type:
  - ☐ West Basin - Berths 103 through 151
  - ☐ San Pedro - Berths up to 96, and 226 through 305
  - ☐ East Basin - Berths 153 through 224

- Inbound and outbound trips were then segregated. This resulted in seven different trip types:
  - ☐ Inbound from sea
  - ☐ Inbound from anchorage
  - ☐ Outbound to sea
  - ☐ Outbound to anchorage
  - ☐ Internal shift (from one Port of Los Angeles berth to another)
  - ☐ Port of Los Angeles to POLB
  - ☐ POLB to Port of Los Angeles

- Next, trips involving transit from the sea or from anchorage were assigned directional designations using the MarEx dataset. Internal and inter-port shifts were estimated in separate subsections.
  - ☐ Inbound from the north
  - ☐ Inbound from the east
  - ☐ Inbound from the south
  - ☐ Inbound from the west
  - ☐ Outbound to the north
  - ☐ Outbound to the east
  - ☐ Outbound to the south
  - ☐ Outbound to the west

Vessel hoteling times obtained from the Port's vessel call database were then averaged to obtain an annual average for 2001 according to terminal and ship type. For most combinations of terminal and vessel type, the average hoteling time for the specific terminal and vessel type was used in the emission calculations. However, in a limited number of cases this was not possible. To account for these cases, average hoteling times (in hours) were estimated using the Port's vessel call database and are presented in Table 2.24. These averages represent average hoteling times for specific vessel types and were used only when terminal-specific hoteling times were unavailable.

Table 2.24: Default Hoteling Times, hours

Type	Hoteling Time
Auto carrier	17.35
Bulk	72.16
Containership	42.80
Cruise	10.47
General cargo	39.83
Miscellaneous	114.22
Other tugboat	41.50
Reefer	29.00
Ro-Ro	43.66
Tanker	30.16

All activity metrics were developed in a master table that was then used as a template for further calculations. Table 2.25 shows the initial data table. The numbers in column labeled SEA_LA represent the number of inbound trips from the sea to Port for a given vessel type and destination terminal. The column labeled Anch_LA means an inbound trip from anchorage to Port. The same meaning is applied to the outbound trips, LA_SEA and LA_Anch. For the shifts columns, Int. Shift means an internal shift within the Port berths.

The method used to prepare the template shown above was to create separate source tables for each of the seven trip types and then run a query to count similar vessels by terminal and Port sub-region. In all, 15 groups of trips were prepared for the 73 combinations of terminal and vessel type shown in Table 2.25. The groups were in-bound trips for vessels with slow-speed-engines, medium-speed-engines, and steam-powered ships; out-bound trips for those three types of vessel; and shifts (internal, Los Angeles to Long Beach, and Long Beach to Los Angeles) for each of the three types of vessel.

Table 2.25: Master Vessel Activity Matrix

Terminal			Inbound		Outbound		Shift			
ID	Subregion	Type	Sea_LA	Anch_LA	LA_Sea	LA_Anch	Int. Shift	LA_LB	LB_LA	Total
LAV010	East Basin	Bulk	4	0	4	0	0	0	0	8
LAV010	East Basin	General Cargo	4	0	5	0	2	1	0	12
LAV010	East Basin	Miscellaneous	1	0	1	0	0	0	0	2
LAV010	East Basin	Other Tug	0	0	0	0	3	2	0	5
LAV010	East Basin	Tanker	6	1	7	2	2	5	5	28
LAV020	East Basin	Auto Carrier	145	1	149	0	1	2	1	299
LAV020	East Basin	General Cargo	2	0	2	0	0	0	0	4
LAV020	East Basin	RoRo	1	0	1	0	0	0	0	2
LAV030	East Basin	Bulk	16	7	20	3	1	8	6	61
LAV040	East Basin	Tanker	30	0	14	5	13	29	14	105
LAV050	East Basin	Bulk	53	1	56	1	8	5	4	128
LAV050	East Basin	Containership	1	0	1	0	0	0	0	2
LAV050	East Basin	General Cargo	15	0	21	0	4	1	3	44
LAV050	East Basin	Tanker	1	0	1	0	0	0	0	2
LAV060	East Basin	Containership	121	0	123	0	3	1	0	248
LAV060	East Basin	General Cargo	2	0	0	0	0	0	0	2
LAV060	East Basin	RoRo	26	0	29	0	0	0	0	55
LAV070	East Basin	Bulk	1	0	1	0	2	3	1	8
LAV070	East Basin	Tanker	19	3	8	10	10	17	8	75
LAV080	East Basin	Bulk	0	3	8	0	1	0	4	16
LAV080	East Basin	General Cargo	0	3	11	0	0	1	9	24
LAV090	East Basin	Bulk	0	0	0	0	0	1	1	2
LAV090	East Basin	Other Tug	9	0	8	0	3	0	2	22
LAV090	East Basin	Tanker	13	1	9	0	10	16	4	53
LAV100	East Basin	Bulk	22	0	3	11	20	12	7	75
LAV100	East Basin	General Cargo	2	0	0	1	0	1	0	4
LAV100	East Basin	Tanker	62	2	46	9	12	33	37	201
LAV110	East Basin	Containership	297	0	307	0	37	0	1	642
LAV110	East Basin	General Cargo	1	0	0	0	0	1	0	2
LAV110	East Basin	Miscellaneous	0	0	1	0	3	0	1	5
LAV110	East Basin	Reefer	17	0	5	0	7	1	0	30
LAV120	San Pedro	Containership	412	0	415	4	4	7	2	844
LAV120	San Pedro	General Cargo	3	0	2	0	0	1	0	6
LAV120	San Pedro	Tanker	1	0	0	0	0	1	0	2
LAV130	San Pedro	Bulk	0	0	0	0	0	1	1	2
LAV130	San Pedro	Other Tug	1	0	1	0	0	0	0	2
LAV130	San Pedro	Tanker	12	3	8	3	8	25	19	78

Table 2.25: Master OGV Activity Matrix (cont'd)

Terminal ID	Subregion	Type	Inbound Sea_LA	Anch_LA	Outbound LA_Sea	LA_Anch	Shift Int. Shift	LA_LB	LB_LA	Total
LAV140	San Pedro	Containership	240	0	246	0	0	0	0	486
LAV150	San Pedro	Cruise	317	0	326	0	1	0	0	644
LAV160	San Pedro	Bulk	35	10	53	0	0	4	10	112
LAV160	San Pedro	General Cargo	1	0	1	0	0	0	0	2
LAV170	San Pedro	Containership	0	0	3	0	0	0	3	6
LAV170	San Pedro	Miscellaneous	5	0	7	0	0	0	1	13
LAV180	San Pedro	Bulk	6	0	4	0	8	2	0	20
LAV190	San Pedro	Bulk	13	0	14	0	2	0	1	30
LAV190	San Pedro	Containership	0	0	1	0	0	0	1	2
LAV190	San Pedro	General Cargo	2	0	2	0	1	1	0	6
LAV190	San Pedro	Reefer	1	0	1	0	1	0	0	3
LAV200	San Pedro	Bulk	16	0	17	0	1	0	0	34
LAV200	San Pedro	Cruise	2	0	1	0	0	0	0	3
LAV200	San Pedro	General Cargo	4	0	4	0	1	0	0	9
LAV210	San Pedro	Reefer	34	0	54	0	38	2	2	130
LAV210	San Pedro	Tanker	0	0	0	0	2	0	0	2
LAV220	San Pedro	Bulk	0	0	1	0	1	0	1	3
LAV220	San Pedro	Cruise	1	0	1	0	0	0	0	2
LAV220	San Pedro	Tanker	0	0	2	0	1	0	1	4
LAV230	San Pedro	Tanker	20	1	26	2	3	13	18	83
LAV240	San Pedro	Containership	9	0	6	0	14	0	0	29
LAV250	West Basin	Bulk	0	1	3	0	0	1	4	9
LAV250	West Basin	Other Tug	5	0	4	0	0	1	0	10
LAV250	West Basin	Tanker	64	9	44	13	10	30	25	195
LAV260	West Basin	Other Tug	2	0	4	0	4	0	1	11
LAV260	West Basin	Tanker	22	2	20	4	13	12	7	80
LAV270	West Basin	Bulk	15	0	12	0	1	0	0	28
LAV270	West Basin	Containership	279	0	292	0	11	0	0	582
LAV270	West Basin	General Cargo	21	0	17	1	1	1	2	43
LAV270	West Basin	Miscellaneous	0	1	2	0	0	0	1	4
LAV270	West Basin	Reefer	16	3	10	0	9	1	0	39
LAV270	West Basin	Tanker	4	0	6	0	2	0	1	13
LAV280	West Basin	Bulk	0	0	1	0	0	1	2	4
LAV280	West Basin	Containership	225	0	229	0	27	0	0	481
LAV280	West Basin	General Cargo	4	0	4	0	0	0	0	8
LAV280	West Basin	Reefer	2	0	0	0	0	0	0	2
Totals			**2,665**	**52**	**2,685**	**69**	**306**	**244**	**211**	**6,232**

2.6.2 Vessel Category Characteristics

Average characteristics for nine categories of vessels were developed from Lloyd's data. As discussed previously, averages for maximum power in kilowatts and speed in knots were developed for vessels of different types within discrete DWT ranges. To allow for a manageable set of emission calculations, weighted averages were developed for each vessel type DWT category. The weighting was based on the number of vessels for each of the vessel type categories. Within each type category, the fraction of vessels in each DWT range was multiplied by the average power and speed for that range. The resulting products were summed to arrive at the weighted average power and speed. The results of this process for slow-speed-engined vessels are summarized in Table 2.26. In this table:

- "Type" refers to the type of vessel.
- "DWT Category" refers to the size range, in DWT, of the vessels of the corresponding type (e.g., "DWTA5_10" refers to vessels within a DWT range between 5,000 and 10,000 DWT).
- "Number" refers to the number of vessel calls associated with the corresponding type and size range.
- "Fraction" is the percentage of the size range of a vessel type within the total number of vessels of that type (e.g., 10 auto carriers in the 5,000 to 10,000 DWT range represent 7.2% of the 139 total auto carrier calls recorded for the year).
- "DWT" refers to the average DWT size of the vessels in the corresponding type and size range.
- "DWT Frac" includes the product of "Fraction" and "DWT" for each vessel type and size range and, for each vessel type, the sum of those products, which is the weighted average (shown in bold type in the table).
- "Main Power" refers to the average Lloyd's main engine power value for the vessel type and size range.
- "Main Power Frac" is similar to "DWT Frac" in that the main power value is multiplied by the "Fraction" value and the products are added together to calculate the weighted average power figure.
- "Speed" refers to the average Lloyd's maximum speed value for the vessel type and size range.
- "Speed Frac." is like the other fraction columns in that it illustrates the calculation of the weighted average maximum speed for the vessel type.

Table 2.26: Weighted Average Characteristics for Vessel Type Classes

Type	DWT Category	Number	Fraction	DWT (tons)	DWT frac.	Main Power (kW)	Main Power frac.	Speed	Speed frac.
Auto Carrier	DWTA5_10	10	7.2%	9,024	649	10,604	763	17.96	1.29
Auto Carrier	DWTB10_25	129	92.8%	15,129	14,041	10,689	9,920	18.76	17.41
Sum/averages:		**139**			**14,690**		**10,683**		**18.70**
Bulk	DWTB10_25	4	2.1%	21,852	465	6,036	128	13.80	0.29
Bulk	DWTC25_50	122	64.9%	39,993	25,953	7,342	4,765	14.52	9.42
Bulk	DWTD50_75	39	20.7%	67,680	14,040	8,764	1,818	14.48	3.00
Bulk	DWTE75_100	22	11.7%	84,055	9,836	10,149	1,188	14.32	1.68
Bulk	DWTF100_20(	1	0.5%	142,235	757	10,320	55	13.70	0.07
Sum/averages:		**188**			**51,050**		**7,954**		**14.47**
Containership	DWTB10_25	259	18.0%	18,991	3,418	13,218	2,379	19.40	3.49
Containership	DWTC25_50	473	32.9%	38,682	12,715	24,473	8,044	22.16	7.28
Containership	DWTD50_75	702	48.8%	61,566	30,034	41,552	20,271	24.09	11.75
Containership	DWTE75_100	5	0.3%	77,099	268	55,065	191	26.44	0.09
Sum/averages:		**1,439**	**100.0%**		**46,435**		**30,885**		**22.62**
Cruise	DWTA5_10	273	98.9%	6,439	6,369	39,520	39,091	19.14	18.94
Cruise	DWTB10_25	3	1.1%	13,026	142	43,482	473	25.50	0.28
Sum/averages:		**276**			**6,510**		**39,563**		**19.21**
General Cargo	DWTA5_10	1	1.64%	8,914	146	1,986	33	15.00	0.25
General Cargo	DWTB10_25	4	6.56%	16,748	1,098	13,064	857	16.00	1.05
General Cargo	DWTC25_50	53	86.89%	41,073	35,687	8,275	7,190	15.43	13.41
General Cargo	DWTD50_75	2	3.28%	62,378	2,045	34,000	1,115	21.18	0.69
General Cargo	DWTE75_100	1	1.64%	77,828	1,276	8,378	137	14.30	0.23
Sum/averages:		**61**			**40,252**		**9,331**		**15.63**
MISC	DWTB10_25	1	100.0%	12,928	12,928	6,252	6,252	15.00	15.00
RORO	DWTC25_50	1	100.0%	42,424	42,424	10,993	10,993	14.80	14.80
Reefer	DWTA5_10	18	28.6%	8,901	2,543	8,297	2,371	19.03	5.44
Reefer	DWTB10_25	45	71.4%	11,690	8,350	10,075	7,196	20.53	14.67
Sum/averages:		**63**			**10,893**		**9,567**		**20.10**
Tanker	DWTB10_25	26	11.8%	18,707	2,201	6,660	784	14.34	1.69
Tanker	DWTC25_50	163	73.8%	41,475	30,590	9,679	7,139	14.75	10.88
Tanker	DWTD50_75	22	10.0%	59,578	5,931	10,290	1,024	14.81	1.47
Tanker	DWTE75_100	7	3.2%	95,809	3,035	10,268	325	14.00	0.44
Tanker	DWTF100_20(	3	1.4%	100,038	1,358	10,129	137	14.10	0.19
Sum/averages:		**221**			**43,114**		**9,409**		**14.68**

Auxiliary engine power was also estimated for each type of ship, based on Lloyd's data on ships making local calls, as well as data collected during the VBP. Table 2.27 shows the results of this process.

Table 2.27: Estimation of Installed Auxiliary Power, kW

Type	Average Number	Average kW (each)	Average Aux (kW)
Auto Carrier	2.95	687	2,027
Bulk	3.02	387	1,169
Containership	3.78	1,520	5,746
Cruise	5.00	2,200	11,000
General Cargo	3.08	577	1,777
Miscellaneous	4.00	420	1,680
Other Tug	2.00	125	250
RoRo	2.04	2,447	4,992
Reefer	4.00	325	1,300
Tanker	2.94	675	1,985
Average	3.28	936	

2.6.3 Power and Fuel Demand Calculations

Energy demand for main engines and auxiliary engines is the product of the MCR power, the load factor, and the number of hours of operation. The number of hours of operation, in turn, is based on the number of trips and the time spent during each trip. For boilers, fuel demand was estimated as being the product of the number of trips, the time per trip, and the average fuel consumption rate.

The calculations described in the preceding subsections were performed on Microsoft Excel™ spreadsheets that have been reproduced in Appendix A.

2.7 Vessel Emissions

Tables 2.28 and 2.29 present summaries of the emissions by vessel type for each pollutant in tpy and tpd, respectively. Tables 2.30 through 2.41 present detailed emission estimates by vessel type and power source in tpy and tpd for NO_X, HC, CO, PM_{10}, $PM_{2.5}$, and SO_2, respectively. Ton-per-day estimates were developed by dividing the tpy values by 365 days per year.

Table 2.28: 2001 OGV Emissions by Vessel Type, tpy

	NO_X	HC	CO	PM_{10}	$PM_{2.5}$	SO_2
Auto Carrier	155.7	5.6	12.7	14.4	11.5	91.1
Bulk	273.5	9.2	22.8	22.7	18.2	182.1
Containership	4,271.9	144.9	340.5	365.5	293.1	2,547.8
Cruise	1,443.3	48.1	114.9	99.6	79.9	705.0
General Cargo	87.7	3.0	7.1	7.7	6.2	57.2
Miscellaneous	15.2	0.5	1.2	1.1	0.9	12.3
Other Tug	11.8	0.5	1.0	0.6	0.5	8.6
Reefer	52.2	1.9	4.4	5.0	4.0	34.1
RoRo	34.9	1.1	2.9	4.3	3.5	85.0
Tanker	576.6	18.8	46.4	40.1	32.1	394.3
Total	**6,922.7**	**233.5**	**553.9**	**561.0**	**449.9**	**4,117.5**

Table 2.29: 2001 OGV Emissions by Vessel Type, tpd

	NO_X	HC	CO	PM_{10}	$PM_{2.5}$	SO_2
Auto Carrier	0.43	0.02	0.03	0.04	0.03	0.25
Bulk	0.75	0.03	0.06	0.06	0.05	0.50
Containership	11.70	0.40	0.93	1.00	0.80	6.98
Cruise	3.95	0.13	0.31	0.27	0.22	1.93
General Cargo	0.24	0.01	0.02	0.02	0.02	0.16
Miscellaneous	0.04	0.00	0.00	0.00	0.00	0.03
Other Tug	0.03	0.00	0.00	0.00	0.00	0.02
Reefer	0.14	0.01	0.01	0.01	0.01	0.09
RoRo	0.10	0.00	0.01	0.01	0.01	0.23
Tanker	1.58	0.05	0.13	0.11	0.09	1.08
Total	**18.97**	**0.64**	**1.52**	**1.54**	**1.23**	**11.28**

Figure 2.42: Total 2001 OGV NO_X Emissions by Vessel Type, tpy

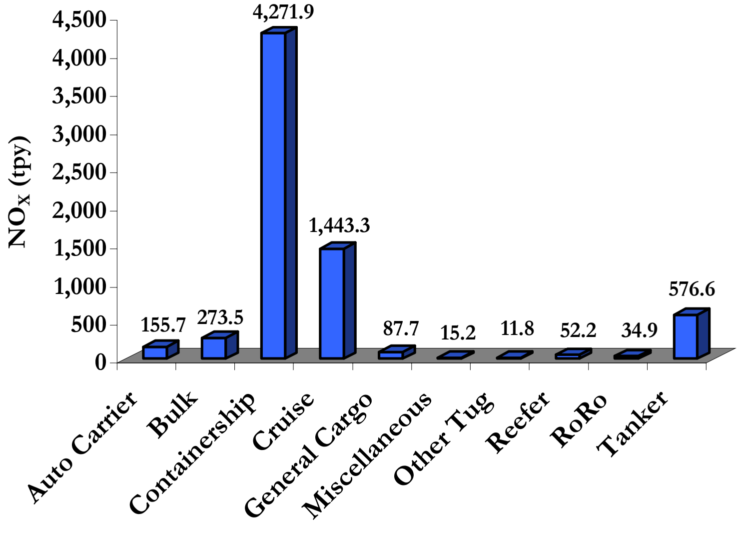


Table 2.30: 2001 OGV NO_X Emissions, tpy

Tons Per Year Type	Main Engines	Auxiliary Transit	Auxiliary Hotelling	Boilers	Total
Auto Carrier	124.6	11.1	19.4	0.6	155.7
Bulk	170.6	8.6	90.2	4.0	273.5
Containership	2,967.6	202.1	1,088.2	13.9	4,271.9
Cruise	838.5	240.0	363.8	0.9	1,443.3
General Cargo	59.8	4.1	23.1	0.7	87.7
Miscellaneous	5.3	0.4	9.2	0.3	15.2
Other Tug	10.6	0.2	1.0	0.0	11.8
Reefer	44.8	0.6	5.9	0.9	52.2
RoRo	9.8	5.7	19.1	0.2	34.9
Tanker	231.9	18.5	323.1	3.0	576.6
Totals	**4,463.7**	**491.4**	**1,943.0**	**24.6**	**6,922.7**

Table 2.31: 2001 OGV NO_X Emissions, tpd

Tons Per Day Type	Main Engines	Auxiliary Transit	Auxiliary Hotelling	Boilers	Total
Auto Carrier	0.34	0.03	0.05	0.00	0.43
Bulk	0.47	0.02	0.25	0.01	0.75
Containership	8.13	0.55	2.98	0.04	11.70
Cruise	2.30	0.66	1.00	0.00	3.95
General Cargo	0.16	0.01	0.06	0.00	0.24
Miscellaneous	0.01	0.00	0.03	0.00	0.04
Other Tug	0.03	0.00	0.00	0.00	0.03
Reefer	0.12	0.00	0.02	0.00	0.14
RoRo	0.03	0.02	0.05	0.00	0.10
Tanker	0.64	0.05	0.89	0.01	1.58
Totals	**12.23**	**1.35**	**5.32**	**0.07**	**18.97**

Figure 2.43: Total 2001 OGV HC Emissions by Vessel Type, tpy

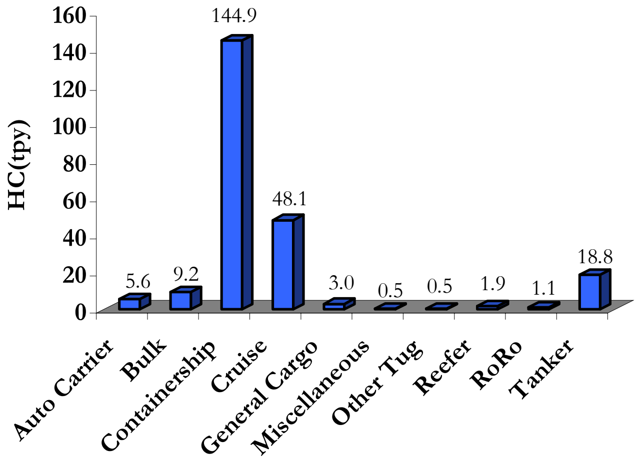


Table 2.32: 2001 OGV HC Emissions, tpy

Tons Per Year Type	Main Engines	Auxiliary Transit	Auxiliary Hotelling	Boilers	Total
Auto Carrier	4.7	0.3	0.5	0.0	5.6
Bulk	6.4	0.2	2.5	0.1	9.2
Containership	108.1	5.7	30.7	0.4	144.9
Cruise	30.8	6.9	10.4	0.0	48.1
General Cargo	2.2	0.1	0.6	0.0	3.0
Miscellaneous	0.2	0.0	0.2	0.0	0.5
Other Tug	0.5	0.0	0.0	0.0	0.5
Reefer	1.7	0.0	0.2	0.0	1.9
RoRo	0.4	0.2	0.5	0.0	1.1
Tanker	9.1	0.5	9.0	0.1	18.8
Totals	**164.0**	**14.0**	**54.8**	**0.8**	**233.5**

Table 2.33: 2001 OGV HC Emissions, tpd

Tons Per Day Type	Main Engines	Auxiliary Transit	Auxiliary Hotelling	Boilers	Total
Auto Carrier	0.01	0.00	0.00	0.00	0.02
Bulk	0.02	0.00	0.01	0.00	0.03
Containership	0.30	0.02	0.08	0.00	0.40
Cruise	0.08	0.02	0.03	0.00	0.13
General Cargo	0.01	0.00	0.00	0.00	0.01
Miscellaneous	0.00	0.00	0.00	0.00	0.00
Other Tug	0.00	0.00	0.00	0.00	0.00
Reefer	0.00	0.00	0.00	0.00	0.01
RoRo	0.00	0.00	0.00	0.00	0.00
Tanker	0.03	0.00	0.02	0.00	0.05
Totals	**0.45**	**0.04**	**0.15**	**0.00**	**0.64**

Figure 2.44: Total 2001 OGV CO Emissions by Vessel Type, tpy

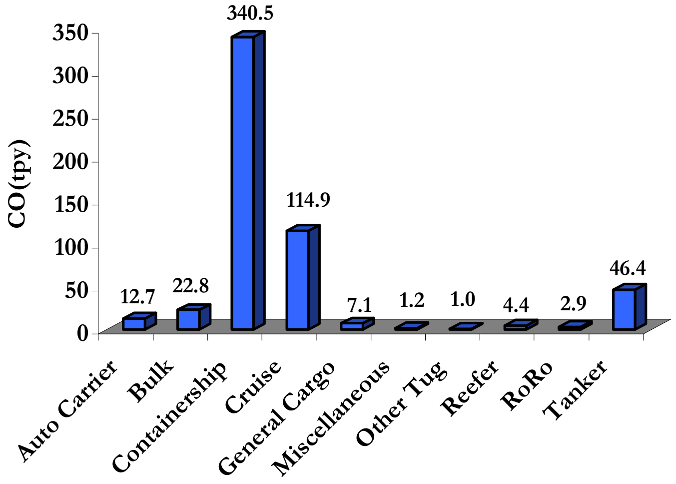


Table 2.34: 2001 OGV CO Emissions, tpy

Tons Per Year Type	Main Engines	Auxiliary Transit	Auxiliary Hotelling	Boilers	Total
Auto Carrier	10.1	0.9	1.5	0.2	12.7
Bulk	13.7	0.7	6.9	1.5	22.8
Containership	235.4	15.7	84.3	5.2	340.5
Cruise	66.9	18.9	28.7	0.3	114.9
General Cargo	4.8	0.3	1.8	0.3	7.1
Miscellaneous	0.4	0.0	0.7	0.1	1.2
Other Tug	0.9	0.0	0.1	0.0	1.0
Reefer	3.6	0.0	0.5	0.3	4.4
RoRo	0.9	0.4	1.4	0.1	2.9
Tanker	19.1	1.4	24.8	1.1	46.4
Totals	**355.7**	**38.4**	**150.6**	**9.2**	**553.9**

Table 2.35: 2001 OGV CO Emissions, tpd

Tons Per Day Type	Main Engines	Auxiliary Transit	Auxiliary Hotelling	Boilers	Total
Auto Carrier	0.03	0.00	0.00	0.00	0.03
Bulk	0.04	0.00	0.02	0.00	0.06
Containership	0.64	0.04	0.23	0.01	0.93
Cruise	0.18	0.05	0.08	0.00	0.31
General Cargo	0.01	0.00	0.00	0.00	0.02
Miscellaneous	0.00	0.00	0.00	0.00	0.00
Other Tug	0.00	0.00	0.00	0.00	0.00
Reefer	0.01	0.00	0.00	0.00	0.01
RoRo	0.00	0.00	0.00	0.00	0.01
Tanker	0.05	0.00	0.07	0.00	0.13
Totals	**0.97**	**0.11**	**0.41**	**0.03**	**1.52**

Figure 2.45: Total 2001 OGV PM_{10} Emissions by Vessel Type, tpy

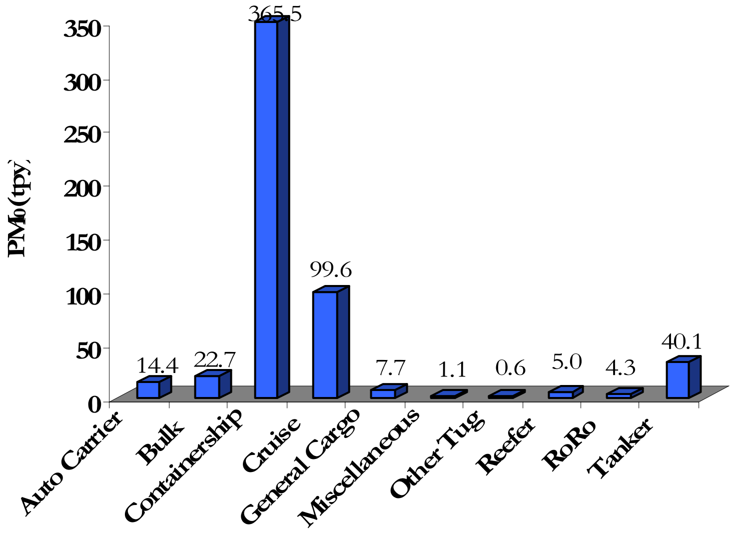


Table 2.36: 2001 OGV PM_{10} Emissions, tpy

Tons Per Year Type	Main Engines	Auxiliary Transit	Auxiliary Hotelling	Boilers	Total
Auto Carrier	13.2	0.4	0.7	0.1	14.4
Bulk	18.0	0.4	3.9	0.4	22.7
Containership	319.8	6.9	37.3	1.5	365.5
Cruise	85.6	5.5	8.4	0.1	99.6
General Cargo	6.3	0.2	1.1	0.1	7.7
Miscellaneous	0.6	0.0	0.5	0.0	1.1
Other Tug	0.6	0.0	0.0	0.0	0.6
Reefer	4.6	0.0	0.2	0.1	5.0
RoRo	2.9	0.3	1.0	0.0	4.3
Tanker	26.0	0.7	13.0	0.3	40.1
Totals	**477.7**	**14.5**	**66.2**	**2.6**	**561.0**

Table 2.37: 2001 OGV PM_{10} Emissions, tpd

Tons Per Year Type	Main Engines	Auxiliary Transit	Auxiliary Hotelling	Boilers	Total
Auto Carrier	0.04	0.00	0.00	0.00	0.04
Bulk	0.05	0.00	0.01	0.00	0.06
Containership	0.88	0.02	0.10	0.00	1.00
Cruise	0.23	0.02	0.02	0.00	0.27
General Cargo	0.02	0.00	0.00	0.00	0.02
Miscellaneous	0.00	0.00	0.00	0.00	0.00
Other Tug	0.00	0.00	0.00	0.00	0.00
Reefer	0.01	0.00	0.00	0.00	0.01
RoRo	0.01	0.00	0.00	0.00	0.01
Tanker	0.07	0.00	0.04	0.00	0.11
Totals	**1.31**	**0.04**	**0.18**	**0.01**	**1.54**

Table 2.38: 2001 OGV $PM_{2.5}$ Emissions, tpy

Tons Per Year Type	Main Engines	Auxiliary Transit	Auxiliary Hotelling	Boilers	Total
Auto Carrier	10.6	0.3	0.6	0.1	11.5
Bulk	14.4	0.3	3.2	0.3	18.2
Containership	256.5	5.5	29.9	1.2	293.1
Cruise	68.7	4.4	6.7	0.1	79.9
General Cargo	5.1	0.2	0.9	0.1	6.2
Miscellaneous	0.5	0.0	0.4	0.0	0.9
Other Tug	0.5	0.0	0.0	0.0	0.5
Reefer	3.7	0.0	0.2	0.1	4.0
RoRo	2.4	0.2	0.8	0.0	3.4
Tanker	20.9	0.6	10.4	0.3	32.1
Totals	**383.2**	**11.6**	**53.0**	**2.1**	**449.9**

Table 2.39: 2001 OGV $PM_{2.5}$ Emissions, tpd

Tons Per Year Type	Main Engines	Auxiliary Transit	Auxiliary Hotelling	Boilers	Total
Auto Carrier	0.03	0.00	0.00	0.00	0.03
Bulk	0.04	0.00	0.01	0.00	0.05
Containership	0.70	0.02	0.08	0.00	0.80
Cruise	0.19	0.01	0.02	0.00	0.22
General Cargo	0.01	0.00	0.00	0.00	0.02
Miscellaneous	0.00	0.00	0.00	0.00	0.00
Other Tug	0.00	0.00	0.00	0.00	0.00
Reefer	0.01	0.00	0.00	0.00	0.01
RoRo	0.01	0.00	0.00	0.00	0.01
Tanker	0.06	0.00	0.03	0.00	0.09
Totals	**1.05**	**0.03**	**0.15**	**0.01**	**1.23**

Figure 2.46: Total 2001 OGV $PM_{2.5}$ Emissions by Vessel Type, tpy

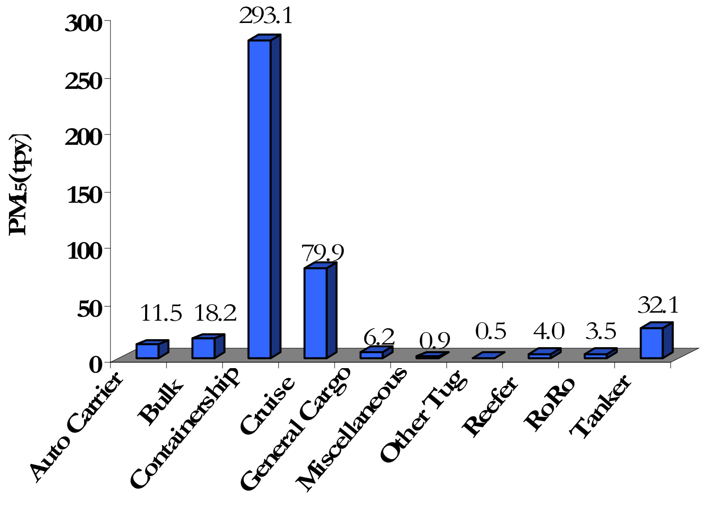


Figure 2.47: Total 2001 OGV SO_2 Emissions by Vessel Type, tpy

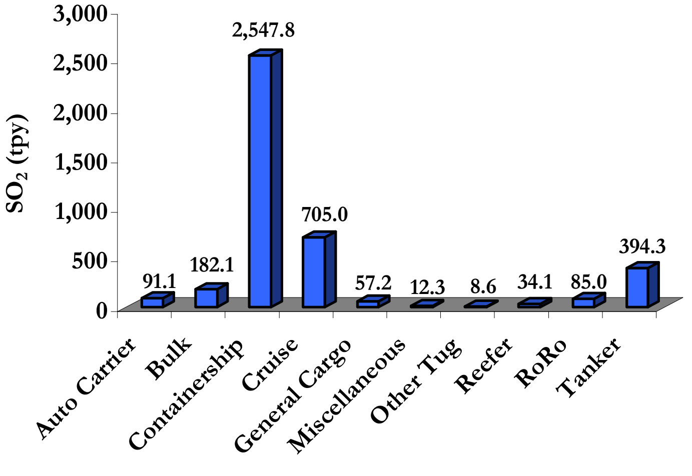


Table 2.40: 2001 OGV SO_2 Emissions, tpy

Tons Per Year Type	Main Engines	Auxiliary Transit	Auxiliary Hotelling	Boilers	Total
Auto Carrier	71.9	6.0	10.5	2.7	91.1
Bulk	98.8	5.7	60.0	17.6	182.1
Containership	1,823.9	103.9	559.1	61.0	2,547.8
Cruise	500.3	79.7	120.9	4.1	705.0
General Cargo	34.5	3.0	16.6	3.1	57.2
Miscellaneous	3.1	0.4	7.7	1.2	12.3
Other Tug	8.2	0.1	0.3	0.0	8.6
Reefer	26.4	0.4	3.5	3.9	34.1
RoRo	63.2	4.7	16.0	1.1	85.0
Tanker	173.7	11.2	196.1	13.3	394.3
Totals	**2,803.9**	**215.1**	**990.6**	**107.9**	**4,117.5**

Table 2.41: 2001 OGV SO_2 Emissions, tpd

Tons Per Day Type	Main Engines	Auxiliary Transit	Auxiliary Hotelling	Boilers	Total
Auto Carrier	0.20	0.02	0.03	0.01	0.25
Bulk	0.27	0.02	0.16	0.05	0.50
Containership	5.00	0.28	1.53	0.17	6.98
Cruise	1.37	0.22	0.33	0.01	1.93
General Cargo	0.09	0.01	0.05	0.01	0.16
Miscellaneous	0.01	0.00	0.02	0.00	0.03
Other Tug	0.02	0.00	0.00	0.00	0.02
Reefer	0.07	0.00	0.01	0.01	0.09
RoRo	0.17	0.01	0.04	0.00	0.23
Tanker	0.48	0.03	0.54	0.04	1.08
Totals	**7.68**	**0.59**	**2.71**	**0.30**	**11.28**

2.8 Quality Assurance Overview

Several efforts were undertaken to ensure the accuracy of emission calculations used in this study. These included:

- Level 1: cell reference checking to ensure the correct activity and emission factor were used.
- Level 2: sum checking at the bottom of selected workbooks to ensure that totals match the line-by-line computations.
- Level 3: programmatic checking to ensure that emissions were estimated in a reasonable manner, following the outline of the report.

2.9 Strengths and Limitations

This subsection presents the strengths and limitations associated with the Port of Los Angeles' OGV baseline emissions inventory.

2.9.1 Strengths

The following are strengths of the baseline inventory that should be considered when reviewing and evaluating the results presented in this section:

- The approach utilized for the baseline inventory was reviewed by, commented on, and coordinated with the ARB and the SCAQMD. This coordination was critical to ensure that the project team utilized approved methods for estimating emissions and that the collected information was used in the appropriate manner.
- The technical approach used to estimate OGV emissions is basically an enhanced version or next generation of the approach utilized in the 1999 Arcadis Study. One of the primary enhancements of the Port's baseline OGV emission estimates is the extensive use of local data and operational knowledge through the ambitious Vessel Boarding Program, which focused on gathering critical information on the following key issues:
  - ☐ Propulsion/main engine loads during harbor maneuvering conditions
  - ☐ Harbor maneuvering time-in-mode and engine power demand
  - ☐ Accuracy of Lloyd's data for OGV physical characteristics (e.g., maximum speed and power)
  - ☐ Auxiliary engine power and operational characteristics
- The information that was collected from the Vessel Boarding Program and operational data from interviews with individuals knowledgeable in the daily activities of OGVs operating in the Port of Los Angeles increased the accuracy of the source activity data used in the emission estimating process.
- The availability and use of several data sets (e.g., Lloyd's, MarEx, Port of Los Angeles, and Vessel Boarding Program) ensured that the baseline conditions in 2001 were properly modeled and thus minimized assumptions on the number, type, and physical characteristics of the OGVs that called on the Port.
- New emission factors were incorporated that have been used in the latest commercial marine inventories developed in the United States and Europe.
- An emission factor adjustment was utilized for propulsion engines to model the effect of physical changes of a compression ignition engine operating at very low loads.

- When assumptions were made regarding activity parameters that are not based on Vessel Boarding Program findings or interviews, these assumptions are conservative.
- The resolution with which the emissions have been estimated by OGV class, engine type, fuel type, and location within the study area allows a more complete picture of where future efforts should be focused to further refine the understanding of this complex transportation system.
- The baseline emissions inventory is not a one time study, but the start of a continuing effort that will focus on continuing to minimize the activity-related assumptions made in this document, through the further engagement of the maritime industry, both within the Port of Los Angeles and among those knowledgeable in the estimation of marine emissions.

2.9.2 Limitations

All data-intensive inventories, including this one, have limitations, which are generally in the assumptions that must be made to make up for lack of complete information or understanding. The following list provides limitations that should be considered when reviewing and evaluating the results presented in the OGV section:

- As with all similar works that attempt to characterize vessel emissions within a limited area, the emission factors and load factors still represent significant areas of uncertainty. The emission factors are based on a relatively small number of vessels world-wide that have undergone emission testing. As such, the emission factors do not represent any particular individual vessel; rather, they have been developed to apply to a fleet of vessels, including the vessels calling on the Port. In addition, a larger sample of vessels, focusing on load factors throughout their transit and hoteling operations within the study, would add additional ground-truthing support to the load factor assumptions.
- While vessel activity data were collected through multiple interviews with captains, chief engineers, and pilots, the number of vessels boarded was limited compared with the number of vessels that call on the Port in a year. While the information collected represents an improvement in the state of knowledge of Port vessel activities, additional interviews would increase confidence in the applicability of the data to the activity of all vessels. This is particularly true with respect to fuel types, including sulfur content used in main and auxiliary engines; auxiliary engine specifications; and operating practices.
- In addition, development of operational profiles and activity parameters in the fairway, precautionary zone and harbor maneuvering zone were focused primarily on containerships, which are the predominant type of OGV calling on the Port. Though this information is assumed to be representative of the other classes of OGVs, it has not been verified with hard data or extensive observations.

- Cruise ship propulsion and auxiliary engine loads are based on a limited data set which may not represent the ever changing configuration and sizes of the cruise ships that call on the Port. Since this class of OGV represents one of the most frequently changing classes (new ships, schedules, ship rotation, etc.), additional information on the configurations and operational characteristics is needed to improve the estimates of emissions from this class.
- Information on the transition from sea speed to the speeds traveled in the precautionary zone and vice versa for both propulsion and auxiliary engines would be benefited from additional follow-up interviews with captains, chief engineers, shipping lines, MarEx, and the Pilots. Further investigation on this complex transitional phase for each OGV class could improve or verify assumptions used in this baseline inventory.

2.10 Comparison with Previous Studies

The current marine vessel emissions inventory for the SoCAB is based on a study conducted in 1996 by Acurex Environmental Corporation[25] (Accurex) and updated in 1999 by Arcadis Geraghty and Miller, Inc.[26] (Arcadis). These studies included a detailed evaluation of the characteristics of marine vessels that relate to air emissions, and of the operations of the Port and POLB as they relate to the activities of marine vessels.

As with all emissions inventories of this type, the data that were evaluated ranged in specificity from very high (e.g., record of every arrival and departure to and from the two ports during the study period) to low (e.g., emission factors based on tests conducted on vessels other than those that called on the two ports during the study period). In addition, these studies developed assumptions to cover areas for which data were unavailable. This is also typical of such large-scale emissions inventories.

Certain features and methods of the Port's 2001 baseline emissions inventory differ from the information and methods presented in the 1996 Accurex and 1999 Arcadis reports. Some of these differences are due to the varying time periods covered by the reports (cargo statistics and port operations can change significantly over a short period of time) while others are due to differences in methods and/or sources of data. This section reviews the major aspects of the methodologies used in the Accurex and Arcadis studies and contrasts and compares these studies and the Port's study.

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[25] Acurex Environmental Corporation, December 1996. *Marine Vessel Emissions Inventory and Control Strategies*

[26] ARCADIS Geraghty and Miller, Inc., September 1999. *Marine Vessel Emissions Inventory – UPDATE to 1996 Report: Marine Vessel Emissions Inventory and Control Strategie*

2.10.1 EI Results

The Accurex and Arcadis reports include forecasts of future years' emissions as well as an estimate based on actual ship call data for a "study year." The study year of the 1996 report is 1993, and the 1999 report updates that to 1997 by using 1997 ship call data. Both reports include a forecast of emissions in the year 2000. A direct comparison of the results of the Accurex/Arcadis EIs with the Port EI is not possible because the Accurex/Arcadis reports cover both the Port of Los Angeles and Long Beach, whereas the Port study focuses only on the Port of Los Angeles. However, an order-of-magnitude comparison of the emission estimates from the two earlier studies is presented are listed in Table 2.42, along with the results of the 2001 baseline Port EI. The table includes the emission estimates for the study year of both Accurex/Arcadis reports (1993 and 1997) as well as the projections for 2000 presented in each of those reports.

Table 2.42: Emissions Inventory Results Comparison

Mode/EI Period	NO_x (tpd)	HC (tpd)	CO (tpd)	PM (tpd)	SO_x (tpd)
Cruising/Maneuvering					
1996 report baseline (for 1993)	15.0	0.7	1.4	1.7	11.8
1999 report baseline (for 1997)	18.1	1.1	1.9	1.9	13.2
1996 report 2000 projection	16.2	0.8	1.5	1.7	11.8
1999 report 2000 projection	20.4	1.1	2.1	2.1	14.6
2001 Port baseline	13.6	0.5	1.1	1.3	8.3
Hoteling					
1996 report baseline (for 1993)	9.1	1.5	1.1	0.5	6.7
1999 report baseline (for 1997)	11.7	2.1	1.6	0.7	8.5
1996 report 2000 projection	10.6	1.8	1.3	0.6	7.8
1999 report 2000 projection	12.7	2.3	1.8	0.8	9.3
2001 Port baseline	5.4	0.2	0.4	0.1	3.0
Total					
1996 report baseline (for 1993)	24.1	2.2	2.4	2.3	18.5
1999 report baseline (for 1997)	29.7	3.2	3.5	2.7	21.7
1996 report 2000 projection	26.8	2.5	2.8	2.3	19.6
1999 report 2000 projection	33.1	3.4	3.9	2.8	23.8
2001 Port baseline	19.0	0.7	1.5	1.4	11.3

Table 2.42 shows that the 1999 update report increased the projection of 2000 emissions by 22% (for SO_2) to 39% for (CO). The NO_x projection increased by 24%, from 26.8 to 33.1 tpd for both ports. The 2001 NO_x estimate for the Port alone is 19.0 tpd. While the estimates from the Arcadis reports cannot be directly compared with the 2001 estimates of Port emissions, the relationship between the 2000 projections from the 1999 report and the 2001 estimates do not seem unreasonable.

One noticeable contrast between the Arcadis estimates and the 2001 Port estimates for which a valid comparison can be made is the distribution of the estimated emissions between transiting (cruising and maneuvering) and hoteling. The Figures 2.48 through 2.52 illustrate the relative proportions of transiting and hoteling emissions in the estimates from the Accurex/Arcadis and Port emissions inventories.

Figure 2.48: NO_x Emissions Distribution – Transiting and Hoteling

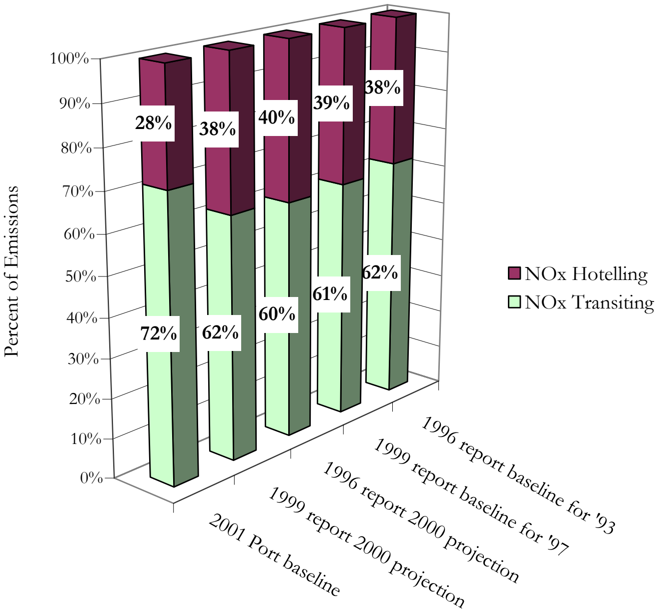


Figure 2.49: HC Emissions Distribution – Transiting and Hoteling

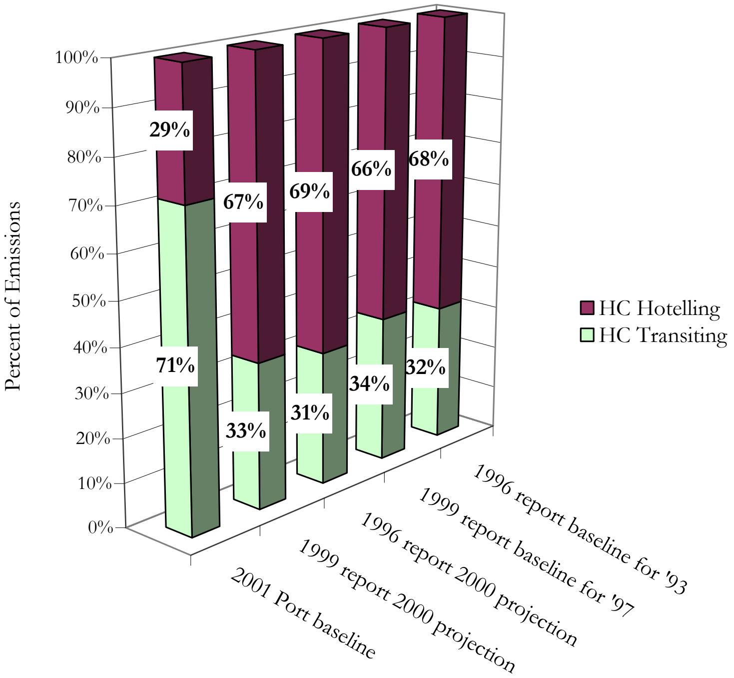


Figure 2.50: CO Emissions Distribution – Transiting and Hoteling

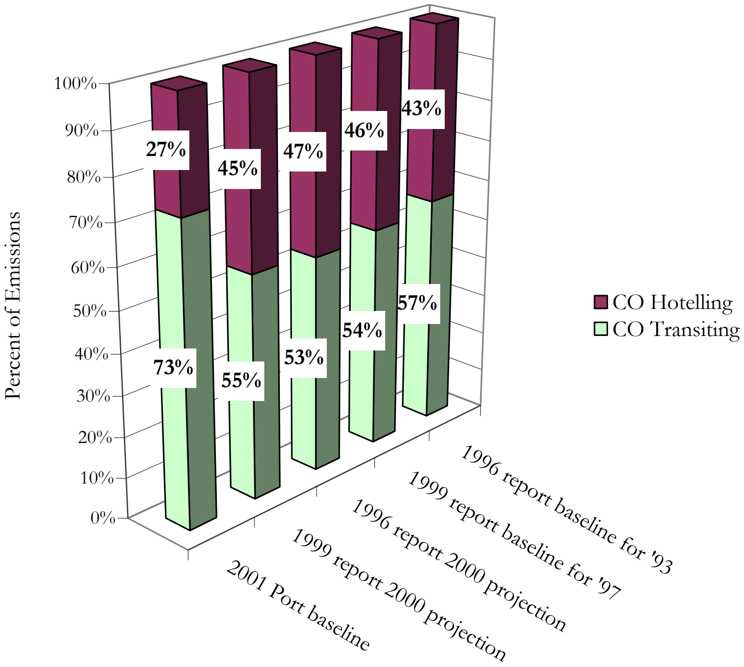


Figure 2.51: PM Emissions Distribution – Transiting and Hoteling

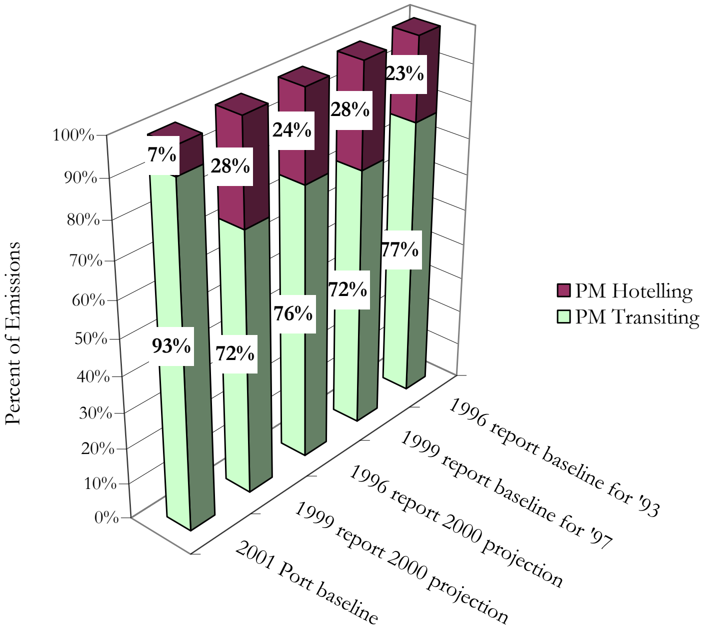
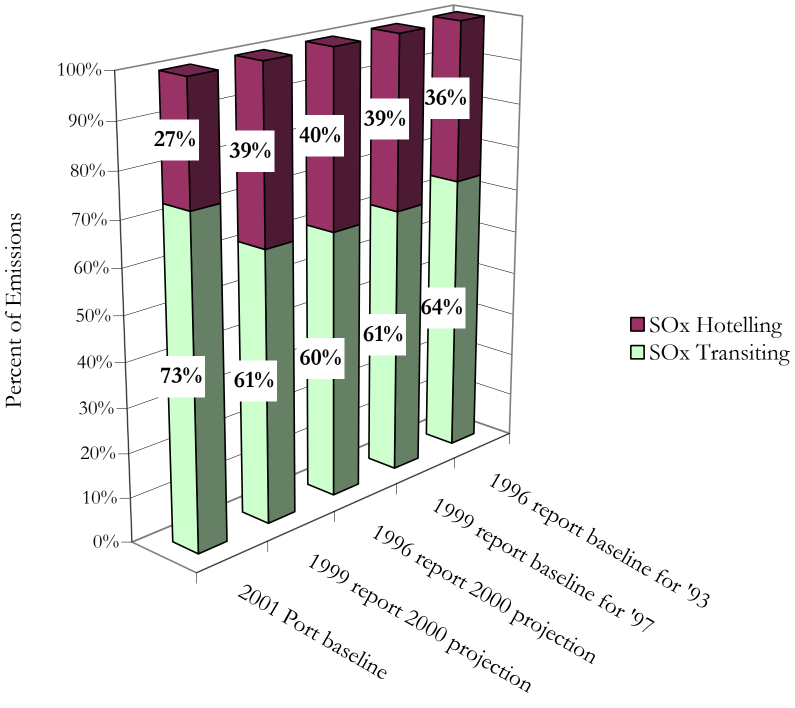


Figure 2.52: SO_x Emissions Distribution – Transiting and Hoteling



The preceding figures show that, for each pollutant, the emissions in the Port EI are biased more toward transiting emissions and less toward hoteling emissions than the Accurex/Arcadis estimates. This results primarily from differences in activity data and assumptions between the Accurex/Arcadis studies and the Port study. Methods, data, and assumptions used by Accurex/Arcadis are discussed below; differences and similarities between these studies and the Port study are also discussed.

2.10.2 Comparison of Methods, Data and Assumptions

Several aspects of the methodology used by Accurex/Arcadis and the Port's consultant in developing their emissions inventories will be discussed. These include:

- Vessel types
- Vessel categorization method
- Energy consumption/power demand estimates
- Emission factors
- Activity estimates

Vessel Types

Table 2.43 shows that, in general, the same ship types were considered by Accurex/Arcadis and the Port's consultant. A small number of ocean-going tugboats and other miscellaneous vessels were identified by the Port's consultant and included as separate vessel types. This probably did not greatly affect the overall emission estimates.

Table 2.43: Vessel Types

Accurex/Arcadis Reports	Port Report
Auto Carrier	Auto Carrier
Bulk Carrier	Bulk Carrier
Container Ship	Containership
General Cargo Vessel	General Cargo Vessel
Passenger Ship	Cruise Ships
Reefer Vessel	Reefers
RoRo Vessel	RoRo
Tanker	Tankers
	Other Tug
	Miscellaneous vessels

Vessel Categorization Method

The Accurex/Arcadis studies categorized vessels by vessel type, as listed above, by propulsion type (motorships and steamships), and by a "design category" value calculated using the following equation:

$$\textbf{Design Category} = \textbf{DWT}^{2/3} \times \textbf{Service Speed}^{3} \times 1{,}000 \qquad \text{Equation 5}$$

Where:

DWT is the reported deadweight tonnage.
Service speed and DWT values were obtained from Lloyd's data.

The formula was reportedly derived from ship design equations that relate to fuel consumption and power requirements. The data worksheets reproduced in the report also list the corresponding DWT categories, so it is unclear what benefit is gained by the "design category" concept.

The Port's EI was similarly developed by categorizing vessels by vessel type, propulsion type, and deadweight tonnage category, without the use of the formula noted above. The Port's EI as well as the Accurex/Arcadis works have separately estimated emissions from motorships and steamships. However, given the decreasing prevalence of steamships among the vessels calling at the Port,[27] this discussion is limited to the variables associated with estimating emissions from motorships.

Energy Consumption/Power Demand Estimates

The 1996 Accurex study based the emission estimates on fuel consumption multiplied by emission factors expressed in terms of pounds of pollutant per thousand gallons of fuel (lb/1,000 gal). Fuel consumption was estimated by multiplying power output by brake specific fuel consumption (BSFC), which is a measure of the mass of fuel required to perform a given amount of work, expressed as grams per horsepower-hour (g/hp-hr). BSFC varies by engine and by engine operating conditions. For their study, Accurex/Arcadis estimated BSFC for each ship type by dividing Lloyd's fuel consumption data by Lloyd's power values. Numerous assumptions and adjustments were made to the Lloyd's data for both fuel consumption and vessel horsepower. This approach was not carried over into the 1999 update. The 1999 update study changed the methodology from fuel consumption to power demand, using the cubic relationship between speed and power of the Propeller Law and emission factors expressed as grams of emissions per horsepower-hour. The Port's 2001 study also uses this approach.

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[27] In the 1996 study, steamship calls in 1993 made up 18% of vessel calls. The 1999 update indicates that steamships made up 9% of calls in 1997, and by 2001 the percentage of steamships among the OGVs calling on the Port was down to 2.3%.

The Arcadis study considered four phases of OGV operations: cruise mode (at normal travel speed); precautionary zone travel; maneuvering; and hoteling. Different assumptions were made regarding engine load conditions in these operating modes.

Cruise Mode

For cruise mode, the Arcadis study seems to have modified the earlier Accurex assumption that vessels typically operate at 80% of MCR power at their maximum cruise speed, but apparently retained the assumption that the Lloyd's data on power represent on average 92% of MCR power. The modified speed assumption, based on a review of 1997 Marine Exchange data, was that vessels normally travel at speeds less than their Lloyd's cruise speed while inside the study area. The overall load factor (referred to as %MCR in the report) at cruise speed was calculated for three general vessel classes as a function of how much slower than the average Lloyd's speed the vessels in that category traveled in the fairway (within the study area but outside the precautionary zone). This change resulted in lower load factors than in the previous report, in which the vessels were thought to travel at the Lloyd's speed while in the study area, at a load factor of 80%. Table 2.44 lists the fairway, precautionary zone, and maneuvering load factors reported in the 1999 Arcadis report. The precautionary zone and maneuvering load factors are discussed below.

Table 2.44: Arcadis Study Load Factors

Vessel Type	Fairway Load Factor	Precautionary Zone Load Factor	Maneuvering Load Factor
Auto Carrier	64%	19% - 64%	15%
Bulk Carrier	64%	30% - 55%	20%
Container Ship	64%	8% - 23%	10%
General Cargo Vessel	64%	10% - 64%	20%
Passenger Ship	29%	16% - 28%	15%
Reefer	64%	13% - 32%	15%
RoRo	64%	15 – 25%	20%
Tanker	61%	39 – 42%	20%

The calculation of fairway load factor, or %MCR, would appear to be straightforward based on the tables and descriptions in the report. For example, the analysis of speed data indicated passenger ships traveled an average of 34% slower than the average Lloyd's speed value of 20.07 kts (for motorships, as opposed to steamships). This results in an assumed average actual speed of 20.07 x (1-0.34) = 13.25 kts. Using the cubic equation, the load factor at that speed would be $(13.25/20.07)^3 = 0.29$, or 29%, which is reflected the Arcadis report's Table 2.5.

Curiously, similar calculations for cargo vessels (which apply to all OGVs except passenger ships and tankers) and tankers do not produce results that match the reported results. For example, tankers were said to travel an average of 11% slower than the average Lloyd's speed value of 15.23 kts. Using the same equation as above, assumed actual speed would be 15.23 x (1-0.11) = 13.55 kts and the load factor would be $(13.55/15.23)^3$ = 0.70 or 70%. The value reported in the Arcadis document is 61%. Similarly, a manual calculation for the cargo vessels results in an estimate of 78%, whereas the study's Table 2.5 reports the value of 64%. There may be aspects to the calculation that are not apparent on reading the information presented in the report.

The Port's 2001 study compares Lloyd's data with information collected during the VBP, and reaches slightly different conclusions regarding the relationship between Lloyd's data and actual operating conditions. First, a comparison of Lloyd's data with data obtained ship-board for MCR power indicates that the discrepancy noted by Accurex in 1996 (based on their comparison of Lloyd's data with results of a 1994 LA Harbor Department survey) no longer exists to a meaningful degree. It now appears that Lloyd's data on power closely approximates actual MCR power as reported by the ships. For this reason, Lloyd's power values have not been adjusted in the Port's EI.

A second comparison, between Lloyd's data for vessel maximum speed and the same information collected from boarded ships, indicates a similarly close relationship between the two sets of values. A third comparison, between vessel-provided maximum and cruising speeds indicates that normal cruise speed averages 94% of maximum speed.

As an example of the effect of the different load factor assumptions, a hypothetical vessel size category having an Lloyd's power value of 100,000 kW would have a power demand calculation using the Arcadis method of:

$$(100{,}000 \text{ hp}/0.92) \times 0.64 = 69{,}565 \text{ kW}$$

Using the methodology followed by the Port EI, the power demand for a similarly sized vessel category would be calculated as:

$$100{,}000 \text{ kW} \times 0.94^3 = 83{,}058 \text{ kW}$$

At this level of power, the Port EI estimates load factors 19% higher than the Arcadis method.

Precautionary Zone

The Arcadis study used an assumption of a 12-knot travel speed for all vessels traveling through the precautionary zone. The load factor calculation was not well explained in the report, but an evaluation of the methodology and the reported data and results indicates that the precautionary zone load factor was calculated using:

$$\%\text{MCR (load factor)} = (12/\text{actual cruise speed})^3 \text{ x cruise load factor}$$

The "actual cruise speed" was calculated by adjusting for the average percentage that vessels were slower than the average Lloyd's speed, as noted above. Based on the understanding of load factor as being related to the cube of the ratio of actual speed to maximum speed, it is not clear why the additional step of multiplying by the cruise speed load factor was taken.

As an example, one category of vessel included in the study was containerships with "design values" between 1,000 and 1,200 (22,100 to 29,100 DWT). The average Lloyd's speed of vessels in this category was reported as 21.21 kts, and the actual cruising speed was calculated to be 19.51 kts [21.21 x (1-0.08) = 19.51]. The precautionary zone load factor (termed %MCR in the report) was listed as 14.89%. The following calculation arrives at this load factor:

$$(12/19.51)^3 \text{ x } 0.64 = 0.1498\text{, or } 14.98\%$$

Where 0.64, or 64%, is the cruising load factor assigned to cargo vessels, as discussed above.

Because the VBP data indicate that Lloyd's speed values now closely approximate actual vessel top speeds, the Port's EI uses a simpler calculation:

$$\text{load factor} = (\text{PZ speed/LLOYD'S speed})^3$$

This calculation using the vessel data cited above would result in a load factor of:

$$(12/12.12)^3 = 0.1811\text{, or } 18.11\%.$$

The Port's EI bases precautionary zone speed on information obtained during the VBP, which indicates vessels typically travel between 9 and 11 knots, depending on vessel type (as listed in Table 2.13). The combination of different speed assumptions and different calculation methodology result in somewhat different load factors between the Arcadis report and the Port study. Table 2.45 presents the load factors used in the different studies. In contrast to the fairway, for which the Arcadis study developed just three load factors for all vessel types and classes, for the precautionary zone the report developed a separate load factor for each size class of vessel. Because the vessel classes vary in average Lloyd's speeds, the load factors vary over a wide range. The average Arcadis load factor has been calculated using the report's methodology and the average Lloyd's and actual speeds listed in the report.

Table 2.45: Comparison of Precautionary Zone Load Factors

Vessel Type	**Arcadis EI range** (12 kts)	**Arcadis EI average** (12 kts)	**Port Baseline EI, wt'd avg** (9 or 11 kts*)
Auto Carrier	19% - 64%	23%	20.3%
Bulk Carrier	30% - 55%	38%	24.1%
Container Ship	8% - 23%	11%	11.5%
General Cargo	10% - 64%	26%	19.1%
Passenger Ship	16% - 28%	22%	18.8%
Reefer	13% - 32%	20%	9.0%
RoRo	15 – 25%	25%	22.5%
Tanker	39 – 42%	42%	23.0%

* Speed is specific to vessel type and location, and is listed in Table 2.8.

It can be seen in Table 2.45 that the precautionary zone load factors developed for the Port EI are somewhat lower than the average Arcadis load factors, except for containerships.

<u>Maneuvering</u>

Maneuvering load factors used in the 1999 Arcadis study were unchanged from the earlier Accurex work. An average maneuvering speed of 5 knts was assumed for maneuvering, and the load factors themselves were based on Lloyd's test data and "engineering judgement," although the precise methodology was not reported. The load factors were 20% for bulk carriers, general cargo ships, and tankers, 10% for containerships and RoRos, and 15% for auto carriers, passenger vessels, and reefers.

As reported in previous subsections, this study developed speed estimates based on observations made during the vessel boarding program, and load factors were calculated using the same methodology as for the other components of vessel transit, with the exception of a 2% load factor minimum for the very low speed operation seen during docking maneuvers, based on an evaluation of propulsion engine operating modes and maneuvering procedures. Table 2.46 presents the load factors used in both studies. The Port EI load factors are lower than the Accurex/Arcadis emission factors in every case, except for out-bound RoRo vessels.

Table 2.46: Comparison of Maneuvering Load Factors

Vessel Type	Arcadis EI	Port Baseline EI		
		Docking	In-Bound	Out-Bound
Auto Carrier	15%	2.0%	5.2%	7.8%
Bulk Carrier	20%	2.0%	4.1%	16.9%
Container Ship	10%	2.0%	3.0%	4.4%
General Cargo	15%	2.0%	4.8%	7.2%
Passenger Ship	20%	2.0%	3.3%	13.4%
Reefer	15%	2.0%	1.5%	6.3%
RoRo	10%	2.0%	3.9%	15.8%
Tanker	20%	2.0%	4.0%	16.2%

Auxiliary Engines

The 1999 Arcadis study did not update the hoteling load assumptions from the 1996 Arcadis report. The earlier report cited the 1994 Port survey of ship operators and a 1989 study conducted by TRC Environmental Consultants(TRC) in establishing auxiliary engine loads for cruising, maneuvering, and hoteling vessels, although the precise methodology was not reported. The Port EI uses information obtained during the vessel boarding program as well as Lloyd's data to develop more detailed estimates of average installed auxiliary power and overall load factor for each vessel type. Table 2.47 presents the assumed kilowatt loads from both studies for cruising, precautionary zone, maneuvering, and hoteling.

Table 2.47: Comparison of Auxiliary Engine Power Output, kW

Vessel Type	Cruising		Precautionary Zone		Maneuvering		Hoteling	
	Arcadis	Port	Arcadis	Port	Arcadis	Port	Arcadis	Port
Auto Carrier	750	270	750	540	1,250	1,358	1,000	481
Bulk Carrier	750	195	750	312	1,250	522	1,000	261
Container Ship	750	718	750	1,436	1,250	2,887	1,000	962
General Cargo	750	296	750	474	1,250	794	1,000	397
Passenger Ship	5,000	7,040	5,000	7,040	5,000	8,800	5,000	7,040
Reefer	750	260	750	436	1,250	871	1,000	436
RoRo	750	749	750	1,498	1,250	2,246	1,000	998
Tanker	750	265	750	529	1,250	886	1,000	1,330

There are similarities and differences between the two sets of load assumptions. Most of the Port EI hoteling loads are lower than the corresponding Arcadis loads, with the exception of passenger (cruise) ships and tankers. The cruise ship loads are likely higher because of the greater size of modern cruise ships, whereas the Port's tanker load takes into account the use of electrically powered on-board pumps that are used to off-load liquid cargo. Containership and RoRo loads are very similar between the two studies, and the remaining vessel types are assigned lower loads in the Port EI than were used in the Arcadis study.

Emission Factors

The 1996 Accurex study used fuel-based emission factors (lb/1,000 gal) from Lloyd's for motorship main engines and, for auxiliary engines, pound-per-hour values derived from the TRC study mentioned previously. The main engine NO_x emission factors were composites developed by Accurex from the Lloyd's data on 2-stroke and 4-stroke engines. In addition, main engine HC and CO emissions were "adjusted" to take into account evidence from the Lloyd's data that lower load emission factors were higher than cruising emission factors. Sulfur content was assumed to be 2.3%, based on Lloyd's and other data.

Main engines

For the 1999 update, Arcadis changed the main engine methodology from fuel-based to power-based, so a different suite of emission factors was developed for propulsion engines. The report states these factors were also derived from Lloyd's data but the methodology is not described in the text. Except for NO_x, they appear to be similar to the emission factors used in the earlier study, converted to grams/kilowatt-hour. NO_X emission factors were changed to those developed by Arcadis for a 1999 emission control strategy study performed for the EPA. These emission factors were developed to help assess the future impact of the IMO emission standards, and include a range of factors that increase with decreasing load factor. The assumption for average fuel sulfur content was increased to 2.8%, based on the result of further research, and auxiliary engine emission factors were unchanged from the 1996 study.

The Port EI uses main engine emission factors published in the 2002 ENTEC study cited previously in this report. The ENTEC emission factors are based on the Lloyd's work plus an evaluation of more recent emission test results. The Port EI does not make adjustments to the emission factors to account for technology mix as in the Accurex and Arcadis studies (which developed composites for the 2-stroke/4-stroke mix). Rather, the engine technologies (in this case, low speed and medium speed engines) are considered separately in developing category averages of power, speed, operating time, and other variables that go into the emission estimates. Additionally, a mechanism has been developed to account for an increase in emission factors at lower loads, down to the 2% minimum load used in the study to represent loads during docking procedures.

For illustrative purposes, Table 2.48 lists the base emission factors from the Arcadis and Port studies for vessels with slow speed engines. The Arcadis NO_x emission factors for these vessels increase with decreasing load factor to a maximum of 28.89 g/kW-hr at 10% load, which is the load factor assumed by that study for maneuvering containerships. By contrast, the Port study establishes three maneuvering load factors, for in-bound and out-bound trips, and for docking procedures. The emission factors for each pollutant (for slow speed engines burning residual fuel) is multiplied by the adjustment factor corresponding to the average load factors for all vessels during each of the three maneuvering segments, resulting in the low load emission factors shown in Table 2.48. The resolution of three discrete maneuvering modes with associated load factors and emission factors will allow the Port study's emission estimates to be more closely allocated geographically than if just one were used.

Table 2.48: Base and Low Load Emission Factors, g/kW-hr

Study (mode)	NO_X	CO	HC	PM	SO_2
Arcadis (base)	17.06	1.600	0.500	1.370	11.760
Port (base)	18.10	1.40	0.60	1.92	10.50
Arcadis (all maneuvering)	28.89	1.600	0.500	1.370	11.760
Port (maneuvering – in)	33.12	5.60	4.80	4.68	10.50
Port (maneuvering – out)	19.19	1.86	0.92	2.13	10.50
Port (docking)	83.80	14.00	18.97	14.00	10.50

Auxiliary Engines

Auxiliary engine emission factors in the Accurex/Arcadis reports are reported in terms of lbs/hr, derived from the previously cited TRC study and from a Booz Allen Hamilton (BAH) report. In the Accurex/Arcadis calculations the emission factors are "adjusted" to take into account the differences in auxiliary power between the source studies (TRC and BAH) and the assumption used by Accurex/Arcadis. To compare these adjusted emission factors with the ENTEC emission factors used in the Port study, the lb/hr values have been converted into g/kW-hr using the power assumptions shown in Table 2.49. The calculation is (lb/hr x 453.6 g/lb)/kW = g/kW-hr. The two sets of factors are presented in Table 2.49.

Table 2.49: Comparison of Auxiliary Engine Emission Factors, lb/hr

Study	NO_X	CO	HC	PM	SO_2
Arcadis	13.3	1.4	2.5	0.5	7.3
Port	14.7	1.1	0.4	0.3-0.8	12.3

The Port study's more recent emission factors are higher for NO_X and SO_2, lower for CO, HCs; PM is approximately the same, the Accurex/Arcadis reports used a single value of 0.5, while the Port study uses different values for distillate and residual fuel oils (see Table 2.22).

Activity Estimates

Cruising/Transit

Activity estimates primarily relate to speeds and times in mode. Table 2.50 presents average Lloyd's speeds and fairway cruising speeds for each vessel type for the Arcadis report and the Port study. These are averages of the values developed for specific size categories of the different types of vessels. The differences do not appear to be significant, particularly with regard to the most common ship types visiting the Port – containerships, bulk carriers, and tankers. However, it is interesting to refer back to Table 2.44, which summarizes the Arcadis load factor assumptions associated with these fairway speeds. For most vessel types (all except passenger ships and tankers), the assigned load factor is 64%, although the cubic equation as normally applied would result in an estimate of (using containerships as an example): $(21.54/23.31)^3 = 78\%$. The other vessels produce similar results. The 64% used in the Arcadis study (as well as 61% for tankers and 29% for passenger ships) is significantly lower than the 83% used in the Port study, which is based on the finding from the vessel boarding program that vessels' cruise speeds average 94% of their LLOYD'S speeds.

Because the speeds are similar the times in mode for the fairway would be similar, also. However, the load factor differences would result in significantly lower estimates from the Arcadis assumptions.

Table 2.50: Comparison of Lloyds and Cruise Speeds, kts

Vessel Type	Lloyds Avg. Speed		Avg. Cruise Speed	
	Arcadis	Port	Arcadis	Port
Auto Carrier	18.28	18.70	16.82	17.58
Bulk Carrier	15.49	14.47	14.25	13.60
Container Ship	23.31	22.62	21.45	21.26
General Cargo	17.67	15.63	16.26	14.69
Passenger Ship	20.07	21.02	13.25	19.76
Reefer	19.24	20.10	17.70	18.90
RoRo	17.80	14.80	16.38	13.91
Tanker	15.23	14.68	13.55	13.80

Precautionary Zone

As previously noted, the Arcadis study assumed a uniform precautionary zone speed of 12 knots, although a large number of category-specific load factors were derived from the category cruise speed assumptions and the cruising load factors. The Port study used precautionary zone speeds based on vessel boarding observations, either 9 or 11 knots depending on vessel type. Time in the precautionary zone was assumed in the Arcadis study to be within a 0.9 to 1.1 hour range, whereas the Port study calculated the time (based on speed and distance) to be approximately two-thirds of an hour, depending on vessel speed in the precautionary zone.

Maneuvering

Maneuvering times for the Accurex/Arcadis and the Port studies were based on evaluation of Marine Exchange data and Pilot on-board/off-board times. The Accurex and Arcadis works were based on 1994 data and developed an average maneuvering time for each vessel type. The Port EI uses 2001 data and develops in-bound, out-bound, and docking time estimates for each vessel type and each berth. Table 2.51 presents the average maneuvering times for each study (the times in the Accurex study were unchanged in the Arcadis report so only one set of values is shown in the table). For the Port EI, the total of in-bound, out-bound, and docking time estimates is shown. It should be remembered that the Accurex/Arcadis studies involved both ports, so maneuvering times are not directly comparable because of different distances to berths in the two ports.

Table 2.51: Comparison of Average Maneuvering Times, hours

	Accurex		Port		
Vessel Type	/Arcadis	In-Bound	Out-Bound	Docking	Total
Auto Carrier	1.5	1.15	0.88	0.25	2.28
Bulk Carrier	2.5	1.21	0.78	0.25	2.24
Container Ship	1.9	0.58	0.60	0.41	1.59
General Cargo	1.8	1.07	0.79	0.25	2.11
Passenger Ship	2.5	0.74	0.50	0.25	1.49
Reefer	1.8	0.77	0.76	0.25	1.78
RoRo	1.5	1.37	1.12	0.25	2.74
Tanker	1.5	1.37	0.81	0.25	2.44

Hoteling

Hoteling times as reported by the Accurex/Arcadis reports were also drawn from data related to both ports. The 1999 Arcadis update compared the calculated hoteling times for the two studies and speculated on the reasons for the significant increases seen for some of the ship types. Table 2.52 continues this tradition by presenting the hoteling times for all three of the studies. The Port EI hoteling times are weighted averages of the separate terminal-specific hoteling times that were developed. Once again, it should be stressed that the Port study data relate to one port while the other studies were concerned with both ports in the harbor, so terminal and cargo differences may have affected the average hoteling times for particular ship types. However, it can be seen that hoteling times in 2001 were, for most ship types, less than in 1997.

Table 2.52: Comparison of Hoteling Times, hours

Vessel Type	Hoteling 1994	Hoteling 1997	Hoteling 2001	% Change 1997-2001
Auto Carrier	26.3	26.4	17.3	-34%
Bulk Carrier	73.3	102.8	72.2	-30%
Container Ship	37.6	51.1	42.8	-16%
General Cargo	47.4	51.1	39.8	-22%
Passenger Ship	11.0	9.5	10.5	11%
Reefer	47.4	38.5	29.0	-25%
RoRo	26.3	43.3	43.7	1%
Tanker	59.7	62.2	30.2	-51%

Auto carriers, which had remained unchanged between the 1994 study and the later update, had significantly shorter times in 2001. The average hoteling time for bulk carriers was almost the same between the 1994 and 2001 data, both being significantly lower than the 1997 data. Passenger ship and RoRo times in 2001 were similar to 1997, while tanker stays were significantly shorter in 2001 than either of the two previous reports.

It is difficult to speculate on the differences between the hoteling times found in the Port study and those of the previous works. The most likely potential reasons are intrinsic differences between terminals and/or cargo types at the Port of Los Angeles versus the POLB, and efficiency improvements in off-loading and loading cargo. The great difference in tanker hoteling times is most likely a function of average vessel size calling on the Port compared with the average calling on both ports.

Overall, average hoteling times representing the vast majority of vessel calls to the Port are significantly lower than the earlier estimates for 1997. This would result in hoteling emission estimates correspondingly lower and may explain some of the relative difference between transit and hoteling emission noted at the beginning of this subsection.

2.10.3 Conclusions

There are numerous differences between the Accurex and Arcadis studies, and between the Arcadis study and the Port EI in terms of assumptions and methodology. There are also several fundamental similarities, including the underlying use of a power-based approach and the cubic relationship between speed and power, the use of LLOYD'S data to establish basic operating criteria for the vessels, and the use of Marine Exchange and port databases to develop ship call frequencies and durations.

Most of the differences relate to improvements in the Port study in the understanding of local operating conditions and the geographical specificity of the emission estimates. The Port study included the collection of detailed information during the vessel boarding program that has previously been described. Enhancements from of the data collected during the boarding program included an:

- Updated understanding of the relationships between Lloyd's data and vessels' reported power ratings.
- Updated understanding of the relationships between Lloyd's data on speed and vessels' stated cruising speeds.
- Updated understanding of maneuvering speeds and load factors.

In addition, the Port study's methodology included identifying cruising, maneuvering, and hoteling emissions associated with individual Port terminals, for improved resolution of geographical distribution of emissions.

The effect of the differences in methodology on the magnitude of the emission estimates is difficult to estimate. Each step of either methodology requires a considerable amount of data analysis, and to attempt to estimate emissions using both methodologies on the same data sources would be time prohibitive. However, the relative effect of the differences can be evaluated based on the descriptions provided in this subsection.

Cruising (Fairway) Emissions

The cruising emission factors do not differ significantly (see Table 2.48) but, other factors being equal, the Port EI emission estimates would be slightly higher for NO_X, HC, and PM emissions and lightly lower for CO and SO_2 emissions compared with estimates prepared using the emission factors used in the Arcadis study. Most of the vessel speeds (see Table 2.50) are also not significantly different between similar types of vessels.

A more significant difference with regard to cruising emissions in the fairway is the estimate of load factor. The Port EI's analysis supports the earlier Accurex study's assumption that vessels cruise at approximately 80% of their MCR power. (The Port EI's load factor assumption is 83%.) The Arcadis study, however, reduced this estimate to 64% for most vessels, 61% for tankers, and 29% for cruise (passenger) ships. As noted in the discussion of fairway load factors above, the methodology and vessel speeds described in the Arcadis report would appear to predict a load factor of 78%, which is also consistent with the "approximately 80% load" assumption, but the calculations are performed with the lower load factors stated above. This difference would cause the Arcadis emission estimates to be significantly lower than the Port study method's estimates.

Precautionary Zone Emissions

The precautionary zone is a relatively small segment of the transit from sea to port and back out, so differences here would not produce a pronounced difference in overall emission estimates. However, load factors and time-in-mode are lower for the Port EI (see Table 2.45 for load factors), so Port EI estimates would be expected to be somewhat lower than Arcadis method estimates.

Maneuvering Emissions

Maneuvering is one of the areas most enhanced by the findings of the vessel boarding program, in terms of speeds, load factors, and operating practices. The load factors are generally lower in the Port EI than in the Arcadis study (see Table 2.46). However, the use in the Port EI of factors that increase emission factors as load factors decrease would tend to cancel out the effect of lower load factors, particularly with respect to the pollutants other than NO_X, for which the Arcadis study also used a low load adjustment (Table 2.48).

The benefit of the Port EI approach with respect to maneuvering emissions is greater spatial resolution of the emissions.

Hoteling Emissions

Hoteling emission estimates are a function of auxiliary power usage, emission factors, and hoteling times. Compared with the Accurex and Arcadis studies, the Port study vessel boarding program was used to refine the assumptions regarding auxiliary power, newer emission factors were used, and the same data sources were analyzed for times spent at dock.

Auxiliary power use figures are another major refinement of the Port's EI. Separate average power output assumptions were developed for each vessel type (see Table 2.47), which improve the spatial allocation of hoteling emissions. There is no consistent pattern to the differences between the Port EI information and the Accurex/Arcadis assumptions – some are higher, some lower, and some essentially the same. With regard to emission factors (Table 2.49), the Port EI emission factors are slightly higher for NO_X and SO_2 and lower for CO, HC, and PM. It would be difficult to estimate the effect of these differences on overall hoteling emission estimates.

More significant differences were found for the times vessels spent at berth (see Table 2.52). In most cases, 2001 hoteling times were found to be considerably less than the 1997 times presented by the Arcadis report. Even though some of the differences may be attributable to differences between the terminals at the two ports included in the 1999 study, the differences in hoteling times would be enough to result in the relatively lower hoteling estimates seen in the Port EI.

Summary
In sum, the factors that most likely influence the differences in relative distributions of transiting and hoteling emissions between the Arcadis and Port EIs are the lower fairway load factors and the longer hoteling times used in the Arcadis study.

The combination in the Port EI of relatively higher transiting emission and relatively lower hoteling emissions reflects the patterns presented in Figures 2.48 through 2..52 at the beginning of this subsection.

SECTION 3 HARBOR CRAFT

This section describes the emissions for commercial marine vessels, other than OGVs, which were discussed in Section 2. The geographic area covered by the harbor craft survey is described in Section 2.2. While many of the harbor vessel companies work within both the Port and the POLB, this emissions inventory reflects harbor vessel activity during 2001 within the Port harbor area only.

3.1 Vessel Types and Operational Characteristics

Harbor vessels are commercial vessels that spend the majority of their time within or near the Port and harbor. The Port harbor vessels are divided into the following major categories:

- Assist tugboats
- Towboats/push-boats/tugboats
- Ferries and excursion vessels
- Crew boats
- Work boats
- Government vessels
- Dredges and dredging support vessels
- Commercial fishing vessels
- Recreational vessels

These category classifications follow, to some extent, the categories used in ARB's 2002 Statewide Commercial Harbor Craft Survey and other port commercial marine vessel inventories. Description of the vessel types follow.

3.1.1 Assist Tugboats

Assist tugboats help OGVs maneuver in the harbor during arrival, departure, and shifts from berth. In general, the assist tugboats escort the ships from the breakwater to the berth upon their arrival, and accompany them from the berth to the breakwater upon departure. As part of their escort duty, assist tugboats help vessels in making turns and reducing speed, in providing low-speed propulsion, and in docking. Assist tugboats may also do "tugboat escort" for tankers, which means the tugboats are positioned "in proximity of a vessel as it transits into the Port to provide immediate assistance should a steering or propulsion failure develop".[28]

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[28] Port of Los Angeles, 2003. *Mariners Guide*

The Port *Mariners Guide* lists the standard number of tugboats required for vessels, which is based in part on the DWT of the OGV. In general, vessels with a DWT of 20,000 tons or less use one tugboat and vessels with a DWT above 20,000 tons use two tugboats when moving inside the breakwater.

Three companies do the majority of the assist tugboat operations in the Los Angeles harbor. Most of the tugboats have an approximate total engine power of 3,000 to 6,000 hp, with single screw, twin screw, Z-drive, or Voith-Schneider propulsion. Tugboats with single or twin-screw engines have a conventional propeller and rudder. A Z-drive is an integrated unit that enables the tugboat to pull or push in any direction. A Voith-Schneider drive is made up of a series of blades on a plate that rotates, giving the tugboat greater force and maneuverability.

Due to the unique role that assist tugboats play at the Port, the assist tugboats have been separated from the towboat/push-boat/tugboat category discussed in 3.1.2. The emissions have been calculated and presented separately from the other tugboats.

3.1.2 Towboats/Push-boats/Tugboats

Towboats, push-boats, and tugboats are self-propelled vessels that tow or push barges. They engage in two common operations, line haul and unit tow, and may work outside the harbor as they tow barges to other ports.

Unit tow movements include hauling of bulk materials such as rock, sand, or gravel, bunkering moves (refueling of OGVs), hauling of scrap metal, and bulk liquid inventory shifts. An example is the activity of a certain company that tows two barges daily from the Los Angeles harbor to Catalina Island to deliver supplies and equipment.

Fleeting, a subset of unit tow, is the moving and positioning of barges around the harbor and usually involves the smaller tugboats. Fleeting makes up a large proportion of the unit tow movements made by the towboats, tugboats and push-boats. Some of the tugboats that perform assist tugboat operations also do unit tow movements within the harbor. These vessels were included in this category with their annual hours of operation based on the percentage of their work done in this category.

Line haul operations include movement outside of the harbor to and from other ports; some of these vessels may have a home port other than the Port of Los Angeles. Line haul operations have been separated from unit tow operations for estimating emissions since line haul towboats are larger than the vessels typically used for unit tows and can also be ocean-going. The line haul towboats fall in a category between typical harbor vessels and OGVs. Because they are not in the same engine size category as the typical OGVs, line haul towboats are included in this section of the report. In 2001, there were approximately 17,000 towboat movements within the Port, not including OGV assists, piloted tugboats, or dredged material transit movements.

3.1.3 Ferries and Excursion Vessels

There are a number of ferries and excursion vessels operating out of the Los Angeles Harbor. The excursion vessels include the harbor cruises and the charter vessels that are for hire by the general public. Included in the ferry category are vessels that transport people and property to the nearby islands. There are daily ferry trips from San Pedro to Avalon and Two Harbors on Catalina Island that take approximately one hour and 30 minutes to transit each way.

The excursion vessels include daily 45-minute harbor cruises, and seasonal (January through March) whale watching cruises just outside the breakwater. Some excursion boat operators have specific routes and times and also may use their smaller boats on demand for burials at sea and to help film crews shoot films. In general, there are fewer excursion trips during the winter months. Some excursion vessels are also used for diving near the coast of Catalina and for taking groups on field trips near the harbor. Charter vessels are used seasonally and the inventory includes the charter boats operated by the local charter companies based in or operating from the Port. Sport-fishing charters include half-day boat trips and overnight trips. They usually travel 25 miles from the coast for local fishing, including Catalina Island, or as far as 100 miles to sea to fish for tuna.

3.1.4 Crew Boats

Crew boats and supply boats are used for carrying personnel and supplies to and from off-shore and in-harbor locations. They may go to vessels at anchorage, construction sites, and off-shore platforms.

3.1.5 Work Boats

Work boats are vessels that perform numerous duties within the harbor, such as utility inspection, survey, spill/response, research, training and construction. Diving boats are used five days a week inside the harbor to survey piers and underground obstructions.

3.1.6 Government Vessels

Several federal, state and local governments operate vessels within the study area. The governmental agencies included in this report were the U.S. Coast Guard, the California Department of Fish and Game, the City of Los Angeles Fire Department and Harbor Department, and the Port Police. The two pilot boats used to take the Port pilots to the arriving vessels and to pick up pilots from the departing vessels are included in this category.

3.1.7 Dredges and Dredging Support Vessels

Dredging operations in 2001 included a dredge and a variety of support vessels such as tender/positioning tugboats, survey boats, dredged material towboats/pushboats, and crew boats. There are two types of dredging operations that occur at the Port: maintenance and new work/deepening dredging. Maintenance dredging generally involves smaller clamshell or excavator dredges whose function is to remove silt buildup that collects in existing channels. New work/deepening dredging involves either the dredging of new channels within the Port or deepening existing channels such that ships with deep drafts can access areas of the Port.

3.1.8 Commercial Fishing Vessels

Commercial fishing vessels are dedicated to procuring fish for the purpose of sale at market. There are approximately 260 commercial fishing vessels in the Los Angeles harbor, primarily docked at one of two locations within the Port harbor, at Terminal Island and at Berth 73.

3.1.9 Recreational Vessels

Recreational vessels include private boats owned by the general public, including powerboats and sailboats. Over 3,000 recreational boats are docked at the various marinas at the Los Angeles Harbor. Personal water craft, such as water jet skis, are not included in the emission estimates since they are not stored within the Port harbor.

3.2 Methodology

The methodology section is divided into data acquisition and emission estimation. The emission factors, engine load factors, and emission equations can be found in the emission estimation subsection.

3.2.1 Data Acquisition

The approach taken to collecting data for the harbor vessel inventory was to identify and interview the vessel owners and operators to determine key operating parameters of interest. The operating parameters of interest included the following:

- Hours of operation (annual and average daily, plus schedules if relevant and available)
- Percent of time in operational modes (idling, half power, full power, etc.)
- Vessel characteristics
- Number, type and horsepower (or kilowatts) of main engine(s)
- Number, type and horsepower (or kilowatts) of auxiliary engines
- Other operational parameters such as fuel consumption rates, dredging volumes

- Qualitative information regarding how the vessels are used in service
- Information on percentage of time operating within harbor, and within 25 and 50 mile ranges

The 2002 Statewide Commercial Harbor Craft Survey[29] was reviewed and the data specific to the Port commercial harbor craft were included in this inventory with refinements based on interviews with each participant. Specifically, refinements were made to annual operating hours to reflect hours of use for Port work in 2001. Many of the harbor vessel companies work jobs in both the Port and POLB harbors and this emissions inventory reflects work performed during 2001 within the Port harbor only. A list of South Coast vessels re-powered through the Carl Moyer program provided by ARB was also reviewed to ensure the new re-powered engines were included in the Port inventory. From the Carl Moyer program, 22 main engines and 20 auxiliary engines were included in this inventory.

With the exception of recreational vessels and commercial fishing boats, the local commercial harbor craft companies that were identified and contacted provided relevant information on their vessels for this inventory. The methodology used for commercial fishing and recreational vessels is described at the end of this section.

Owners and operators throughout the Port were interviewed during the collection of activity and operational data for harbor craft based out of or working in the Port. Fuel suppliers were interviewed for the typical sulfur content of fuel sold locally to the Port harbor vessels. In addition, engine manufacturers were contacted to discuss more detailed engine specifications that the Port harbor vessel operators could not provide, such as the per-cylinder displacement of main engines in order to distinguish between Category 1 and 2 engines. Most of the harbor vessels inventoried for 2001 were equipped with Category 1 engines, which are engines having a displacement of less than five liters per cylinder. Eight of the assist tugboats, two other tugboats used for unit tows and ten of the line haul towboats for which engine specifications were provided were equipped with Category 2 engines (displacing between 5 and 30 liters per cylinder). (See section 3.2.2 *Emission Factors* for further definition of categories.) For the engine models inventoried at the Port, the Caterpillar 3606, EMD (GM)12-645, and EMD (GM)16-645 are Category 2 engines. All other engine models inventoried are Category 1, such as the Caterpillar 3516 and the Detroit Diesel engines found in the larger vessels.

Tables 3.1 and 3.2 summarize the main and auxiliary engine data, respectively, for each vessel category. The individual vessel information can be found in the Appendix B tables. The tables below do not include every harbor vessel at the Port, only those that provided specific engine data. The harbor craft EI is based on these vessels and other estimates that were made for commercial fishing vessels,

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[29] ARB, 2002, *Statewide Commercial Harbor Craft Survey*.

recreational vessels and line haul towboats. The commercial fishing category in the tables below includes only the vessels that had specific survey data and does not include all the commercial fishing vessels at the Port. In addition, recreational vessels and line haul towboats are not included in the table below.

Table 3.1: Main Engine Data by Vessel Category

		Propulsion Engine								
	Number			Avg. No./		Horsepower			Annual Operating Hours	
Vessel Category	Vessels	Common Type	Number	Vessel	Minimum	Maximum	Average	Minimum	Maximum	Average
Assist Tug	18	CAT 3516B	36	2.0	1,500	2,500	2,053	300	1,900	1,043
Tugboat (Unit Tow)	24	Detroit	47	2.0	200	2,200	1,210	100	2,500	654
Ferry	9	Detroit	18	2.0	340	2,300	1,077	350	2,500	1,672
Excursion	27	Lugger	50	1.9	82	530	335	480	6,600	1,971
Crew boat	17	Detroit	36	2.1	200	645	381	100	1,000	606
Work boat	17	Detroit	34	2.0	80	800	357	0	2,000	345
Government	24	Cummins	30	1.3	24	764	318	1	1,100	413
Commercial Fishing	26	Detroit	34	1.3	50	940	274	0	5,000	1,647

Table 3.2: Auxiliary Engine Data by Vessel Category

		Auxiliary Engines								
	Number			Avg. No./		Horsepower			Annual Operating Hours	
Vessel Category	Vessels	Common Type	Number	Vessel	Minimum	Maximum	Average	Minimum	Maximum	Average
Assist Tug	18	CAT 3304	35	1.9	67	180	110	130	2,900	1,207
Tugboat (Unit Tow)	24	Detroit	38	1.5	22	180	75	70	2,500	859
Ferry	9	Northern Lights	12	1.3	18	95	33	125	2,500	1,616
Excursion	27	Isuzu	27	1.0	7	375	55	480	6,600	2,199
Crew boat	17	Northern Lights	14	0.8	17	300	97	100	1,000	700
Work boat	7	Northern Lights	12	0.9	10	83	31	0	2,000	618
Government	24	Varies	10	0.4	54	525	236	100	300	156
Commercial Fishing	26	Detroit	17	0.7	10	200	69	0	5,000	1,932

During the survey interviews, the proportion of time spent within three zones (the Port harbor, up to 25 miles, and from 25 to 50 miles) was discussed with the vessel operators. Based on the interviews, percentages were given for each vessel type and emissions for each of the pollutants were estimated for each zone. Table 3.3 summarizes the average percent of time spent by each category of harbor vessel in the three zones. These percentages can be used with average annual operating hours data by vessel type presented below to derive annual average hours by zone.

Table 3.3: Average Time Spent in Zone, percent

	Percent Time in Zone		
Category	**Harbor**	**25 Miles**	**50 Miles**
Assist Tug	100%	0%	0%
Tugboat (Unit Tow)	81%	15%	4%
Ferry	35%	51%	14%
Excursion	25%	65%	9%
Crew boat	52%	48%	0%
Work boat	66%	34%	0%
Government	74%	14%	12%
Commercial Fishing	10%	50%	40%
Recreational Vessel	40%	38%	22%
Dredge and Dredging Support	100%	0%	0%
Line Haul Towboat	60%	20%	20%
	58.5%	**30.5%**	**11.0%**

Assist Tugboats

As shown in Tables 3.1 and 3.2, in 2001 the three harbor assist tugboat companies operated a total of 18 diesel-powered boats. The majority of the assist tugboats had two main engines with each engine having a horsepower between 1,500 and 2,500 hp. The most common main engine model found was Caterpillar 3516B. The annual operating hours for main propulsion engines ranged from 300 to 1,900 hours, with an average of 1,043 hours. The average assist tugboat had two 110 hp auxiliary engines used to supply on-board power, navigation systems, and air conditioning/heating for the crew. The most common type of auxiliary engine among assist tugboats was the Caterpillar 3304. The auxiliary engines ranged from 67 to 180 hp. The annual hours of usage for auxiliary engines ranged from 130 to 2,900 hours, with an average of 1,200 hours. One harbor assist tugboat company started using shore power after 2001 for its tugboats while they are at the company's docks. The average hourly fuel consumption for assist tugboats was 39 gallons per hour. Approximately 44% of the assist tugboats had Category 2 main engines.

Towboats/Push Boats/Tugboats

As mentioned earlier, unit tow and line haul operations can be performed by towboats, push boats or tugboats. Unit tow and line haul emissions were estimated separately since the line haul operations are accomplished by ocean-going towboats that are operated by companies mostly based outside the Port. Local companies provided the information for the unit tows. Twenty-four tugboats and push boats were found to operate unit tows at the Port. These vessels each have two main engines; each engine has between 200 and 2,200 hp, averaging 1,210 hp. Detroit Diesel was the most prominent manufacturer of main and auxiliary engines. The annual hours of use ranged from 100 to 2,500 hours, with an average of 654 hours. The vessels each had one or two auxiliary engines with horsepower ranging from 22 to 180 hp, with an average of 75 hp. The annual hours of use for auxiliary engines ranged from 70 to 2,500 hours, with an average of 859 hours. Approximately 25% of the tugboats had category 2 main engines.

Line Haul Towboats

For the line-haul (ocean going) towboat emissions, a combination of USACE data for towboat activity (half of the total towboat moves) and actual data from company interviews was used since not every towboat movement could be accounted for based solely on the harbor company interviews. The total horsepower range for the line haul towboats taken from the USACE data is 2,250 to 8,000 hp, with an average of 4,500 hp. The engine horsepower reflects the power of both engines, for those towboats that have more than one engine. The year built ranged from 1954 to 2002, and 1976 was the average. Towboats usually have two auxiliary engines, with an average horsepower of 110 hp. From the actual engine specifications received, GM and EMD engines were the most prominent auxiliary and main engine manufacturer, respectively. Approximately 80% of the 17 line haul towboats that provided engine specifications had Category 2 main engines.

Ferries and Excursion Vessels

Nine ferries and twenty-seven excursion vessels were inventoried in the Port harbor. The ferries had two main engines, with a horsepower range of 340 to 2,300 hp per engine. The average main engine power was 1,077 hp and the most prominent main engine manufacturer was Detroit Diesel. The main engine annual hours of use ranged from 350 to 2,500 hours, with an average of 1,672 hours. Most of the ferries had one auxiliary engine with the most prominent auxiliary engine manufacturer being Northern Lights. The auxiliary engine horsepower ranged from 18 to 95 hp, with an average of 33 hp. The annual hours of usage for auxiliary engines ranged from 125 to 2,500 hours, with an average of 1,616 hours. The ferries and excursion vessels burn non-road EPA diesel fuel according to the operators and area fuel suppliers that were interviewed. The Catalina Island ferries traveled at speeds up to 32 knots and were launched between 1986 and 1994.

On average, the twenty-seven excursion vessels had two main engines with an engine power range of 82 to 530 hp each. The average main engine power was 335 hp and the most prominent main engine manufacturer was Lugger. The main engine annual hours of use ranged from 480 to 6,600 hours, with an average of 1,971 hours. The excursion vessels each had one auxiliary engine ranging in horsepower from 7 to 375 hp. The average horsepower was 55 hp and the most prominent auxiliary engine manufacturer was Isuzu. The annual hours of use ranged from 480 to 6,600 hours, with an average of 2,199 hours.

Crew Boats

Seventeen crew boats were inventoried for 2001. Most crew boats have two main engines with a horsepower range of 200 to 645 hp each, averaging 381 hp per engine. The most prominent main engine manufacturer was Detroit Diesel. The annual hours of use ranged from 100 to 1,000 hours, with an average of 606 hours. On average, the crew boat had one auxiliary engine and the most prominent manufacturer was Northern Lights. The engine power ranged from 17 to 300 hp, with an average of 97 hp. The annual hours of use ranged from 100 to 1,000 hours, with an average of 700 hours.

Work Boats

Seventeen work boats were inventoried, ten of which belong to a spill response company. The work boats had two main engines and Detroit Diesel was the most prominent engine manufacturer. The engine power ranged from 80 to 800 hp each, with an average of 357 hp. The annual hours of use ranged from none to 2000 hours, with an average of 345 hours. The work boats had one auxiliary engine and Northern Lights was the most prominent auxiliary engine manufacturer. The engine power ranged from 10 hp to 83 hp, with an average of 31 hp. The annual hours of use ranged from none to 2,000 hours, with an average of 618 hours.

Government Vessels

Twenty-four government vessels were inventoried. The majority of the vessels had one Cummins main engine. The horsepower ranged from 24 to 764 hp, with an average of 318 hp. The annual hours of use ranged from one to 1,100 hours, with an average of 413 hours. Most government vessels did not have an auxiliary engine, but the auxiliary power of those that were so equipped ranged from 54 to 525 horsepower. The annual hours of use ranged from 100 to 300 hours, with an average of 156 hours.

Dredges and dredging support vessels

One dredging company did the maintenance dredging work at the Port in 2001 and used clamshell dredges. A clamshell dredge is a mechanical crane-type dredge that uses a single bucket attached to the dredge crane with cables. The dredge operates by lifting the bucket, dropping it into the bottom sediments, lifting the bucket and dredged material and emptying the dredged material into a nearby disposal site or onto barges for transportation to a disposal site. The clamshell dredge is used in tight quarters around docks or piers.

The two clamshell dredges each had one main engine and one auxiliary engine. The main engine of a dredge is not a propulsion engine, but is used to operate the bucket during actual dredging. The power of the main engines ranged from 1,650 to 2,600 hp, with an average of 2,052 hp. The smaller auxiliary engines had an engine power range from 205 to 500 hp, with an average of 287 hp. The annual hours of use for the clamshell dredge engines ranged from 65 to 612 hours, with an average of 372 hours.

Since dredge companies own their own dredge support vessels, the emissions from support vessels have been included in the dredge operations category. The emissions attributed to the dredge operations support vessels are listed under "tenders" in the dredge operations emissions results later in this section. A dredge vessel, positioning tenders, and scow barges are typically used for a clamshell dredge project. The five scows used in 2001 had engines ranging in horsepower from 250 to 350 hp, with an average of 284 hp. The annual hours of operation ranged from 210 to 315 hours, with an average of 248 hours. Two tugboats were used to push the scow barges to unload the dredged material. The tugboats each had two main engines and one auxiliary engine. The main engines ranged from 800 to 1,800 hp, with an average of 1,300 hp. The main engine hours of use for the Port dredging projects in 2001 ranged from eight to 21 hours. The auxiliary engines for the tugboats ranged from 110 to 124 hp, with an average of 117 hp. The hours of use ranged from 336 to 888 hours, with an average of 612 hours. The project work boat had two 700 hp main engines that were used 70 hours in 2001. The most prominent manufacturer for main and auxiliary engines for the dredge project vessels was Caterpillar.

Commercial Fishing Vessels

The commercial fishing vessels proved to be a challenging category to inventory since the fishing boat operators were not available to interview. The president of a local fishing cooperative was interviewed but did not provide detailed data for the fishing vessels. A total of 260 commercial fishing vessels are estimated to dock at the harbor based on information from the Port, although it is not known whether all of these vessels are operational. Since activity based data were not collected from the local fishermen, ARB's 2002 Statewide Commercial Harbor Craft Survey was used as an information source. The operators of only 26 of the 260 local fishing boats (10%) submitted information to ARB's 2002 Statewide Commercial Harbor Craft Survey. Therefore, average horsepower and hours for main and auxiliary engines were taken from the 488 statewide commercial fishing boats that submitted information to ARB's 2002 Survey. It was assumed that the vessels had one propulsion engine each and that half the vessels had one auxiliary engine, the other half, none. The average horsepower and hours for propulsion and auxiliary engines based on ARB's survey results for commercial fishing are listed in Table 3.4.

Table 3.4: Commercial Fishing Vessel Activity Averages

Commercial Fishing Vessel	Engine Type	Count	Power (hp)	POLA Hours 2001
260 vessels	propulsion	260	230	1,600
	auxiliary	130	71	1,300

Recreational Vessels

Each marina manager in the Port was interviewed either by phone or in person. Individual recreational vessel owners were not interviewed due to the difficulty of locating each individual and getting a response in a timely manner. The only information marina managers were able to provide was the number of slips, number of live-aboards, percentages of sailboats and powerboats, and whether the marinas were at full capacity. Based on the interviews, the slip count assumes every slip is occupied by a recreational vessel since most marinas were at full capacity with approximately every slip rented. Live-aboards, or houseboats, are recreational vessels used by people who live in their boats year-round. In general, these boats lack an operational main engine and are not used for recreational purposes, therefore they were not included as part of the inventory. The harbor vessel count column represents the number of recreational vessels occupying berths at the marinas minus the houseboats. Table 3.5 summarizes the data gathered at the various Port harbor marinas.

For the Island Yacht #1 Marina, only the recreational boats anchored in the Los Angeles harbor were taken into account since the marina lies on the boundary line of the Los Angeles and Long Beach harbors.

The marina managers stated that the recreational vessels, when used, stayed mostly within a 25-mile range since the owners typically take them out for only a few hours at a time. The avid sport fishermen may go out 90 miles to the Cortez bank, to the Catalina outer banks, or to Santa Barbara and the Channel Islands. It was assumed that the only recreational vessels that enter and leave the Port harbor are the ones berthed at the marinas. Other marinas outside the Port harbor attract more tourists and their recreational vessels. One marina manager stated sailboats only use their engines within the harbor to maneuver in and out of the marina. This information was used to calculate an average percentage of time spent within the harbor, 25 miles out, and up to 50 miles out.

The marina managers were not able to provide particular information on engine horsepower or hours of operation. A local experienced marine appraiser/surveyor was contacted and interviewed for information, such as average engine sizes for the sailboats and power boats. He stated that power boats could typically range from 150 to 450 hp and sailboat engines could range from 10 to 120 hp, but that it would be difficult to be more precise without sending out a survey questionnaire to each boat owner.

Table 3.5: Marinas at Los Angeles Harbor

Marina Name	Location	Slips Count	Live Aboard Count	Harbor Vessels Count
Al Larson's Marina	Fish Harbor	128	14	114
Cabrillo Beach Yacht	Cabrillo	160	27	133
California Yacht Marina	Cabrillo	868	46	822
Holiday Harbor	Cabrillo	300	15	285
Cabrillo Way Marina	Cabrillo	560	35	525
San Pedro Marina	Main Channel	96	39	57
California Yacht	East Basin	266	60	206
Cerritos Yacht Anchor.	East Basin	85	8	77
Colonial Yacht Anchor.	East Basin	135	20	115
Holiday Harbor	East Basin	180	20	160
Island Yacht #1	East Basin	22	5	17
Island Yacht #2	East Basin	210	36	174
Leeward Bay Marina	East Basin	185	20	165
Lighthouse Yacht Land.	East Basin	70	25	45
Newmarks Yacht Ctr.	East Basin	245	40	205
Pacific Yacht Landing	East Basin	180	20	160
Yacht Haven	East Basin	163	30	133
Totals		**3,893**	**460**	**3,393**

An attendant was interviewed at a marina fuel dock that services the recreational vessels at the Cabrillo marinas, which comprise almost 50% of the recreational vessels at the Port harbor. She stated that fuel sale to recreational vessels is seasonal, with the peak months being April through October. Although a fuel-based method is not used to estimate emissions in this inventory, the information is included here for future reference. Based on information provided, Table 3.6 presents gallons of diesel and gasoline sold for a peak season month and an off-peak month in 2003.

Table 3.6: Amount of Fuel Sold During Typical Peak Season and Off-season Month

Season	Diesel (gallons)	Gasoline (gallons)
One Month in peak season	16,531	7,280
One Month in off-season	6,342	3,755

3.2.2 Emission Estimation

The flow chart in Figure 3.1 graphically summarizes the steps taken to estimate the majority of harbor vessel emissions. A slightly different approach was taken for line haul towboats and recreational vessels (see Figures 3.3 and 3.4 for emission estimation flow charts for line haul towboats and recreational vessels, respectively).

Emission Factors

Based on the best available data, the following sources for emission factors were used:

- 1999 EPA *Regulatory Impact Analysis*[30] (RIA) for Category 1 main and auxiliary engines
- 2002 ENTEC Study[31] for Category 2/medium speed main engines
- ARB's Pleasure Craft Exhaust Emissions Inventory[32] (PCEEI) for the recreational vessels' main and auxiliary engines

In the 1999 RIA, EPA defined three categories for commercial marine vessel main propulsion engines and auxiliary engines:

- Category 1: 1-5 liters per cylinder displacement
- Category 2: 5-30 liters per cylinder displacement

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[30] EPA, 1999. *Final Regulatory Impact Analysis: Control Emissions from Compression-Ignition Marine Engines,* EPA420-R-99-026.

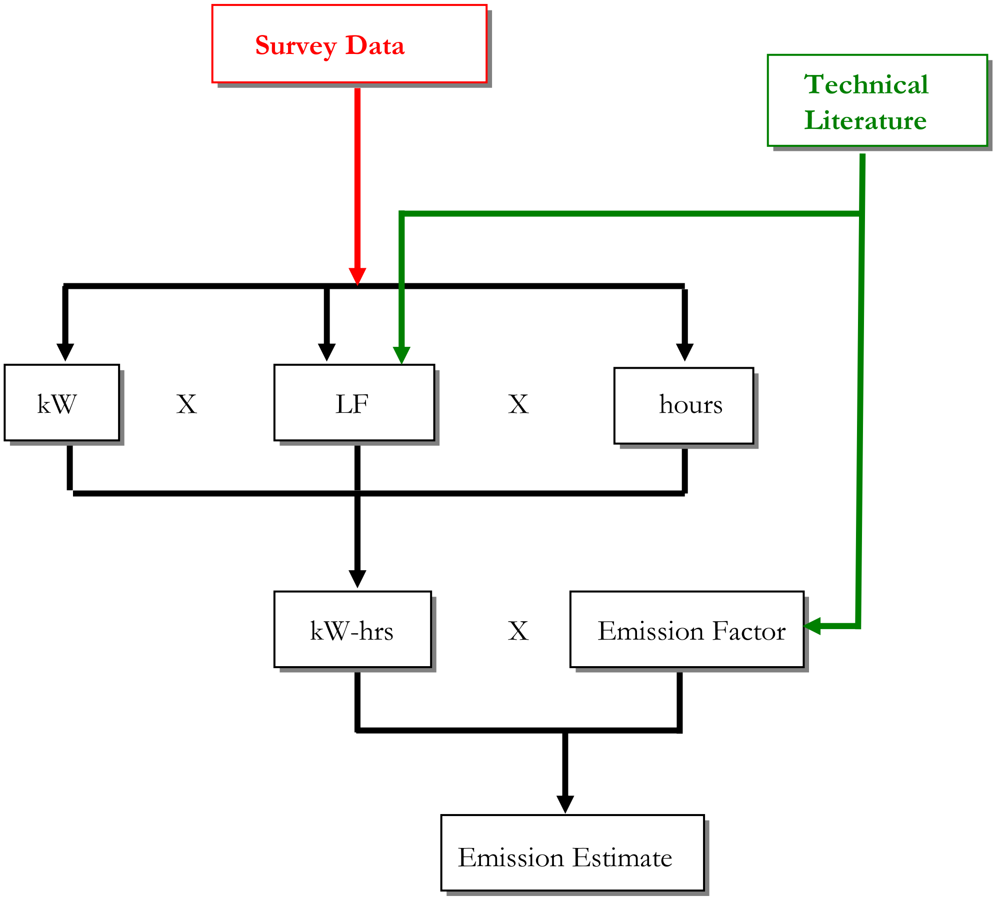
[31] Entec, 2002. *Quantification of Emissions from Ships Associated with Ship Movements between Ports in the European Community, Final Report.*

[32] ARB, 1998. *Proposed Pleasure Craft Exhaust Emissions Inventory*, MSC 98-14, Tables 3a and 3b.

- Category 3: over 30 liters per cylinder displacement

The majority of the harbor vessel engines fall under Category 1, although the ocean going towboats and some of the assist tugboats have Category 2 engines.

Figure 3.1: Harbor Craft Emission Estimation Flow Chart



Technical Literature - Emission factors and load factors

Survey Data - number of engines, power, LF for assist tugs only, activity hours

The EPA RIA emission factors used for Category 1 engines were developed specifically for commercial marine engines and are based on a blend of pre-1999 new and old marine engines. The EPA RIA emission factors are listed in Table 3.7 by engine horsepower for diesel-fueled main propulsion and auxiliary engines, Category 1 (<5 liters/cylinder).

Table 3.7: Category 1 Harbor Craft Emission Factors

Minimum		g/kW-hr				
kW	HP	NO_X	CO	HC	PM_{10}	SO_2
37	50	11.0	2.0	0.27	0.9	0.81
75	101	10.0	1.7	0.27	0.4	0.81
130	174	10.0	1.5	0.27	0.4	0.81
225	302	10.0	1.5	0.27	0.3	0.81
450	603	10.0	1.5	0.27	0.3	0.81
560	751	10.0	1.5	0.27	0.3	0.81
1,000	1,341	13.0	2.5	0.27	0.3	0.81

PM_{10} is assumed to be 100% of PM and $PM_{2.5}$ is assumed to be 92% of PM.[33] Deterioration rates are not taken into account for commercial marine engine emission factors due to the lack of activity based information on deterioration rates. EPA's list of emission factors did not include a SO_2, emission factor, so one was estimated based on the sulfur content of the diesel fuel sold to the harbor vessels in the Port harbor.

Emission factors for Category 2 engines have not been as clearly defined in previous studies and there is limited research on Category 2 U.S. marine engines. Since it is a transitional category, either the EPA RIA Category 1 emission factors for engines rated over 1,000 kW or the 2002 ENTEC emission factors for medium speed engines could potentially be used. The ENTEC factors were chosen because the Category 2 vessels inventoried had medium speed engines. The ENTEC emission factors are higher than the RIA emission factors for all pollutants except for CO; their use results in an 11% and 40% increase in total harbor vessel emissions for HC and PM_{10}, respectively, compared with the RIA emission factors. Therefore, the use of the ENTEC factors produces conservatively high emission estimates.

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[33] EPA, NONROAD Model.

Table 3.8: Emission Factors for Medium Speed Diesel Engines

		g/kW-hr		
NO_X	CO	HC	PM_{10}	SO_2
13.20	1.10	0.50	0.72	0.81

The CO emission factor shown in Table 3.8 was developed from the ENTEC appendices because they are not explicitly stated in the text. They were confirmed with IVS Swedish Environmental Research Institute Ltd, previously cited.

The emission factor for SO_2 from diesel-powered engines was estimated to be 0.81 g/kW-hr. The harbor vessels at the Port obtain their fuel mostly from two suppliers that mainly sell diesel fuel with a typical sulfur content of 300 ppm (0.03%) by weight and maximum 500 ppm (0.05%) by weight. One of the suppliers occasionally sells diesel fuel with a maximum sulfur content of 5,000 ppm (0.5%) by weight. Since the diesel with the higher sulfur content is placed in the same tank as the lower sulfur content diesel, the typical sulfur content is not known for the second supplier. Averages for each fuel sulfur content (350 ppm and 3,500 ppm) were used to calculate an average emission factor for SO_2. The values 350 ppm and 3,500 ppm were chosen based on past experience and discussions with local suppliers. This approach is conservative since the majority of the time the harbor vessels may be buying the lower sulfur diesel fuel. It was also assumed that the line haul tugboats would use the same fuel as the other harbor vessels. (One of the line haul tugboat operators interviewed stated that their ocean tugboat, used to haul rock barges from Mexico, fueled at the Port). The sulfur content of the fuel used by harbor vessels could be further studied in order to arrive at a more fuel-specific SO_2 EF. It is important to note that the average annual sulfur content will change year to year as it is dependant on the characteristics of the fuel purchased. EPA has a document called "In-Use Marine Diesel Fuel" that lists the specifications for both "on-highway" and "off-highway" No. 2 diesel fuel and explains that "diesel fuel for marine applications depend on three things: engine used, cost and availability".[34]

The emission factor for SO_2 was calculated from the assumed sulfur content using the following calculation:

$$\frac{350 \text{ g S}}{1{,}000{,}000 \text{ g fuel}} \times \frac{210 \text{ g fuel}}{\text{kW-hr}} \times \frac{2 \text{ g } SO_2}{\text{g S}} = 0.147 \text{ g}SO_2\text{/kW-hr}$$

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[34] EPA, 1999. *In Use Marine Diesel Fuel,* EPA420-R-99-027, Table 2.

The first term, 350 g S/1,000,000 g fuel, is another way of expressing 350 parts per million. The second expression, 210 g fuel/kW-hr, is a typical value for the BSFC of a diesel engine. The 2002 ENTEC[35] study lists a BSFC range of 194-226 g fuel/kW-hr for slow and medium speed vessels based on information from Lloyd's and engine tests. BSFC is the amount of fuel input required for a certain amount of engine output – in this case, the amount of fuel in grams and the engine output in kW-hrs. The third term in the calculation reflects the fact that a molecule of SO_2 weighs twice as much as a molecule of S (because of their molecular weights of 64 and 32, respectively) so an input of one g S results in emissions of 2 g SO_2. A similar calculation for a sulfur content of 3,500 ppm yields an emission factor of 1.47 g/kW-hr; the average of the two is (1.47 + 0.147)/2 = 0.81 g/kW-hr. Therefore, an emission factor of 0.81 g/kW-hr was used to estimate SO_2 emissions for all the Port's commercial harbor craft.

Engine Load Factors

Engine load factor represents the load applied to an engine or the percent of rated engine power that is applied during the engine's operation. Depending on the duration period that is being estimated, the load factor can represent the hourly average, daily average, or annual average load applied to an engine while it is operating. Table 3.9 summarizes the average engine load factors that were used in this inventory for the various harbor vessel types for their propulsion and auxiliary engines.

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[35] ENTEC, 2002. *Quantification of Emissions from Ships Associated with Ship Movements between Ports in the European Community, Final Report*, July 2002; prepared for the European Commission.

Table 3.9: Engine Load Factors

Harbor Vessel Type	Engine LF
Assist Tug	31%
Tugboat (Unit Tow)	43%
Line Haul Towboat	43%
Ferry / Excursion	43%
Crew boat	43%
Work boat	43%
Government	43%
Dredges	43%
Dredge tenders	69%
Commercial Fishing	43%
Recreational	21%
Recreational, auxiliary	32%
All other auxiliary engines	43%

The 43% engine load factors were defaults obtained from the EPA NONROAD model[36] which used some direct measurements and has been used in previous studies.[37] Until better engine load data becomes available, the 43% load factor is a reasonable choice to use for both main and auxiliary marine engines. Other default load factors were considered, such as the ones found in the 1999 EPA RIA, with a load factor range from 70% to 80%. That high load factor would mean a boat is at full speed the majority of the time, which is unrealistic based on experience and interviews with the vessel operators. It is recommended in later inventories that additional engine load data be collected such that use of default load factors is minimized. The recreational vessels' engine load factors are from ARB's PCEEI, Attachment D.

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[36] EPA, *Median Life, Annual Activity, and Load Factor Values for Nonroad Engine Emissions Modeling,* EPA 420-P-02-014.

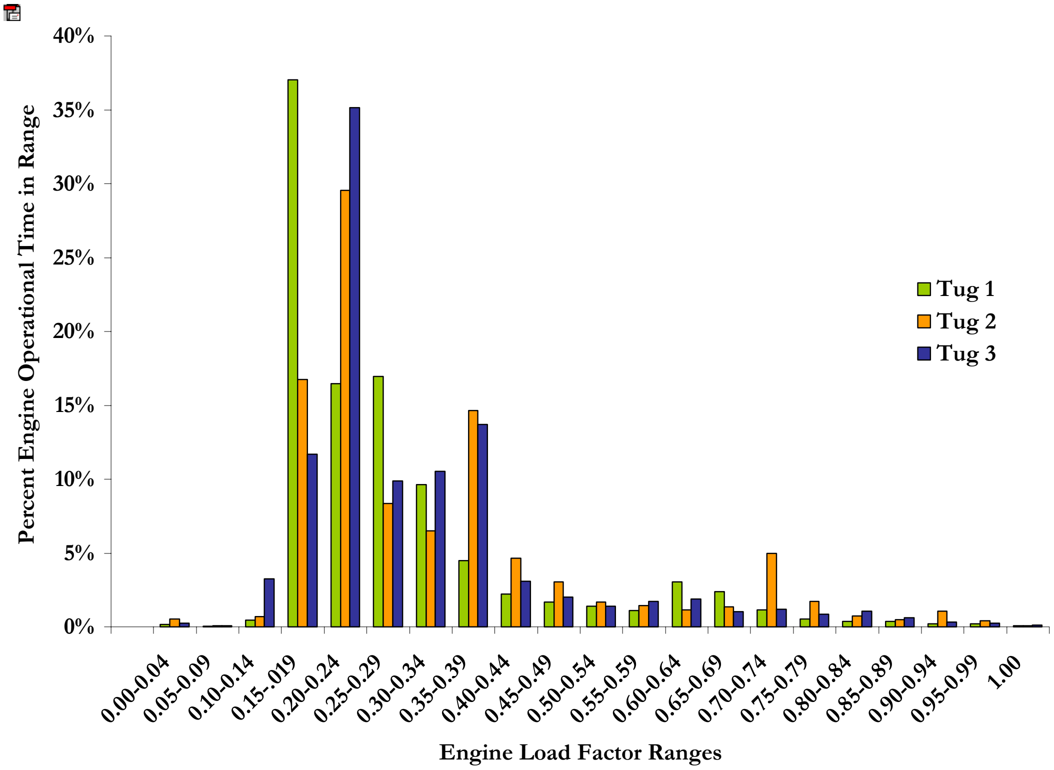
[37] Starcrest Consulting Group, LLC under subcontract to ERG, LLC, January 2004. *Update to the Commercial Marine Inventory for Texas to Review Emission Factors, Consider a Ton-mile EI Method, and Revise Emissions for the Beaumont-Port Arthur Non-Attainment Area;* prepared for the Houston Advance Research Council

The engine load for assist tugboats is based on actual vessel engine load readings. For assist tugboats, a 31% average engine load factor was used since detailed data for assist tugboats was collected from the three main companies that operate the ship assist tugboats in the Los Angeles harbor. The assist tugboat companies were most helpful and forthcoming with information during the initial interview and follow-up meetings. Some of the companies allowed Port consultant personnel to board the tugboats during a regular day shift to observe the engine load during typical operations while another provided engine load data from engine histograms.

Figure 3.2 compares the engine loads over a period of time that spans an average 10,000 operating hours for three Port harbor assist tugboats and percentage spent at each load point. Table 3.10 shows the calculation of the weighted average load factor for assist tugboats. The composite weighted average engine load factor was calculated to be 31%.

The average engine load for towboats, tugboats, and push-boats was assumed to be 43%, as per the EPA NONROAD model for harbor vessels. An industry expert reported that the engine load for tugboats and towboats inside the harbor with similar horsepower as assist tugboats may have average engine loads of 31%. Often the same tugboat can operate both as an assist tugboat or a towboat, with the distinction that towboats are used to haul or push barges. Since the tugboat and towboat category has vessels with varying horsepower, the more conservative 43% engine load was used.

Figure 3.2: Percent of Operational Time Spent at Engine Load Ranges



An engine load factor of 43% was used for the main engines and auxiliary engines of the clamshell dredges, as well as the support vessels used in conjunction with the dredging projects, such as scows and work boats. A load factor of 69% was used for the tenders that move the scow barges and clamshell dredges. These engine load factors have been used for other projects when estimating dredge emissions and are based on numerous interviews with dredging companies.[38]

An engine load factor of 43% was used for the propulsion and auxiliary engines of ferries, government vessels, excursion vessels, crew boats and work boats.

The average engine load factor used for recreational vessels was 21% for main engines and 32% for auxiliary engines. The average load factors for main engines are discussed in Attachment D of the PCEEI. The load factor for auxiliary engines was taken from Table 7 of ARB's MSC 98-34.

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[38] Starcrest, April 2003. *The New York, Northern New Jersey, Long Island Nonattainment Area Commercial Marine Vessel Emissions Inventory.*

Table 3.10: Estimation of Average Assist Tugboat Load Factor

Load Factor		Time in Mode			Results		QA
Load Range	**Midpoint**	**Tug 1**	**Tug 2**	**Tug 3**	**Average**	**Weighted**	**Std Dev**
0%-4%	2%	0.16%	0.52%	0.23%	0.30%	0.01%	0.19%
5%-9%	7%	0.06%	0.07%	0.07%	0.07%	0.00%	0.01%
10%-14%	12%	0.45%	0.72%	3.23%	1.47%	0.18%	1.53%
15%-19%	17%	37.03%	16.76%	11.68%	21.82%	3.71%	13.41%
20%-24%	22%	16.46%	29.56%	35.15%	27.06%	5.95%	9.59%
25%-29%	27%	16.96%	8.37%	9.86%	11.73%	3.17%	4.59%
30%-34%	32%	9.64%	6.51%	10.52%	8.89%	2.84%	2.10%
35%-39%	37%	4.47%	14.64%	13.69%	10.93%	4.04%	5.62%
40%-44%	42%	2.22%	4.63%	3.10%	3.32%	1.39%	1.22%
45%-49%	47%	1.70%	3.04%	2.01%	2.25%	1.06%	0.70%
50%-54%	52%	1.38%	1.67%	1.42%	1.49%	0.78%	0.16%
55%-59%	57%	1.10%	1.44%	1.71%	1.42%	0.81%	0.31%
60%-64%	62%	3.04%	1.17%	1.89%	2.03%	1.26%	0.94%
65%-69%	67%	2.40%	1.35%	1.02%	1.59%	1.07%	0.72%
70%-74%	72%	1.16%	5.00%	1.19%	2.45%	1.77%	2.21%
75%-79%	77%	0.54%	1.73%	0.85%	1.04%	0.80%	0.62%
80%-84%	82%	0.37%	0.75%	1.05%	0.72%	0.59%	0.34%
85%-89%	87%	0.38%	0.48%	0.61%	0.49%	0.43%	0.12%
90%-94%	92%	0.23%	1.06%	0.31%	0.53%	0.49%	0.46%
95%-99%	97%	0.19%	0.42%	0.25%	0.29%	0.28%	0.12%
100%	102%	0.08%	0.10%	0.14%	0.11%	0.11%	0.03%
					100.00%	30.73%	2.14%

Emission Equations

The basic equation used to estimate harbor vessel emissions is:

$$E = kW \text{ x } Act \text{ x } LF \text{ x } EF \qquad \text{Equation 6}$$

Where:

E = Emission, g/year
kW = Kilowatts
Act = Activity, hours/year
LF = Load Factor
EF = Emission Factor, g/kW-hr

The EPA emission factors are in g/kW-hr, so the engine horsepower was converted to kilowatts by dividing the horsepower by 1.341 (one horsepower is equal to 0.746 kilowatts). The hours are annual hours of use in 2001 within the Port. The total annual hours were used to calculate the Port harbor craft emissions. For emission estimates inside the breakwater, within 25 miles, and up to 50 miles, the total annual hours were multiplied by the percentage of time spent within each zone (see Table 3.3). The calculated emissions were converted to tons per year by dividing the emissions by 2,000 lb/ton and 453.6 g/lb.

TOG from diesel engines was calculated by multiplying the HC emissions value by a factor of 1.07.[39] All of the vessels included in the emissions inventory use diesel fuel, with the exception of the recreational vessels, some of which use gasoline. For recreational vessels that use gasoline, TOG was calculated to be 4% higher than HC emissions.[40] DPM was calculated by subtracting the non-diesel (i.e., gasoline) emissions from the PM_{10} emissions estimates.

Line Haul Towboats

The previous calculations relate to most of the harbor vessel types. However, emissions from line haul towboats have been estimated using a modified approach, described below.

The data received from the local harbor companies was not sufficient for a complete emissions inventory for oceanic towboats because, as learned from local towboat operator interviews, some of the oceanic towboats are based at other ports. Therefore, the number of towboat trips to and from the Port were obtained from the USACE's Waterborne Commerce Statistics Center to supplement the activity-based data. The 50 piloted ocean-going tugboats that are included in the OGV inventory were subtracted from the USACE data, as were the harbor tugboats, push boats, and towboats that were already included in the harbor craft inventory.

Emissions from oceanic towboats were estimated using the activity-based method for the towboats for which specific information was available, and by using the trip method based on the number of trips as described in the USACE data for 17,593 trips.

Based on interviews with the towboat operators, it was assumed the inbound, outbound and shift moves were each one third of the total moves. It was estimated that it took 4.5 hours for inbound vessels to travel from the SoCAB water boundary (see Geographical Extent, Section 2.2), and four hours for outbound vessels based on an average speed of 10 knots. The shifts were estimated to be one hour. The

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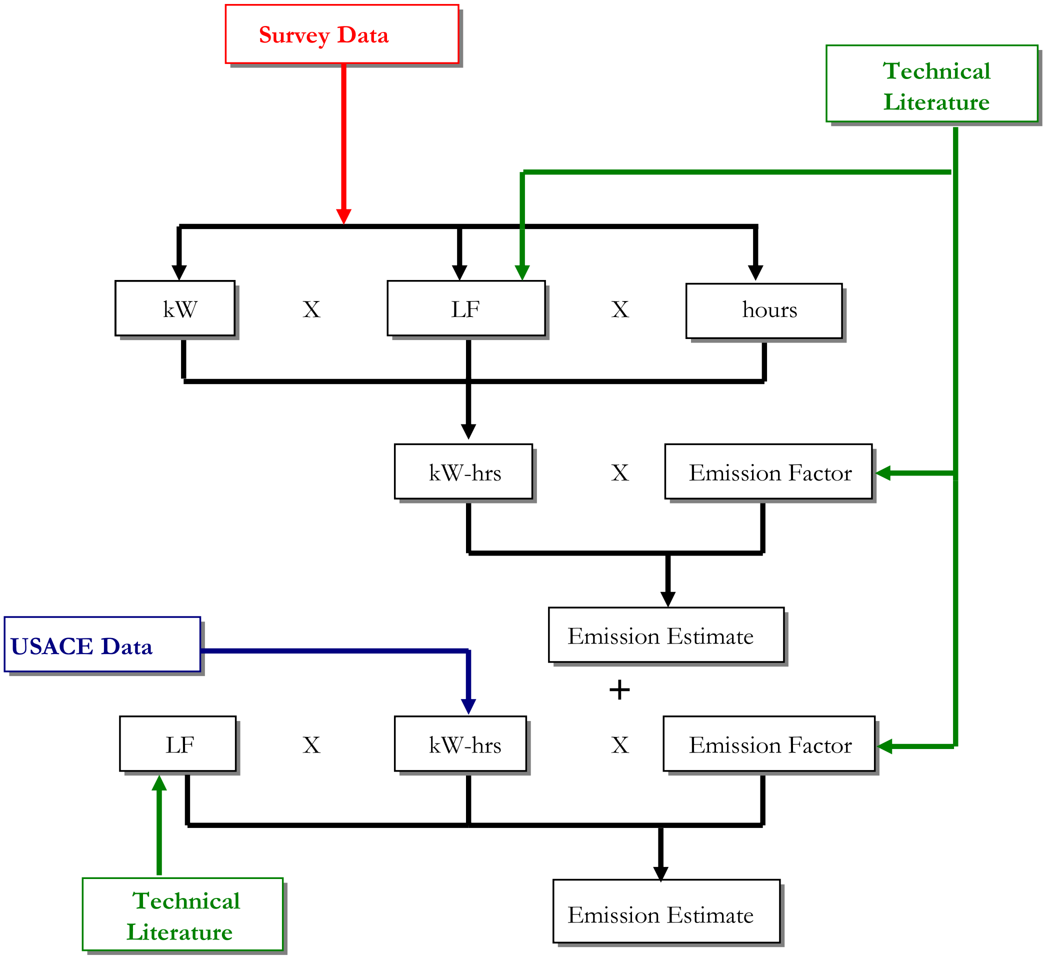
[39] EPA, "Conversion Factors for Hydrocarbon Emission Components", May 2003.
[40] *Ibid.*

total kW-hours for inbound, outbound, and shift were calculated and multiplied by the load factor and emission factor. The emission estimates using the USACE data were added to the emission estimates for the towboats that had specific information provided by towboat operators. Figure 3.3 provides a flow chart summarizing the emission estimation methods used.

Figure 3.3: Line Haul Towboat Emission Estimation Flow Chart



Technical Literature - emission factors and load factors
Survey Data for activity based method - number of engines, power, activity hours
USACE Data for total kW-hrs for those towboats that activity data was not available

Recreational Vessels

Recreational vessels represent another harbor vessel type for which a modified approach to estimating emissions was taken, as described below.

ARB's PCEEI, along with the attachments and public notices, were reviewed to determine average horsepower, average annual usage hours and load factors. Average horsepower, annual activity hours and load factors were taken from Attachment D of the PCEEI. Average horsepower for outboards was taken from Table 4 of the PCEEI.

The 2002 Southern California recreational vessel population contained in the ARB PCEEI was used to estimate the percentages of different types of engines on recreational vessels at the Port marinas. The percentages were than multiplied by the total number of recreational boats found at the Port. For example, the ARB inventory found 49% of the South Coast recreational vessels were vessels with outboards (2-stroke, gasoline) and the next most common were vessels with stern drive engines (4-stroke, gasoline). Jet skis were not included in the 2001 Port emission estimates since the jet skis are not stored at any of the marinas within the harbor and it is difficult to accurately estimate the number of jet skis that visit the Port harbor.

The emissions factors were given in grams per horsepower-hour in Tables 8a and 8b of ARB's PCEEI, except for the SO_2 EF which was estimated. For calculating the SO_2 EF, 30 ppm was assumed for gasoline sold in California[41] and a brake-specific fuel consumption of 796 g/kW-hr was assumed for 2-stroke engines[42] and 429 g/kW-hr for 4-stroke engines. The resulting SO_2 EFs were 0.05 g/kW-hr for 2-stroke and 0.03 g/kW-hr for 4-stroke engines. Since the other emission factors for the recreational vessels were given in g/hp-hr, the estimated SO_2 emission factors were converted to g/hp-hr.

ARB uses the OFFROAD model to estimate emissions for recreational vessels and uses deterioration factors and fuel correction factors. The emissions listed in Table 3.21 were estimated manually and the deterioration factor was not used due to lack of activity-based information on deterioration rates. A fuel correction factor is used in the model to account for changes in emissions attributed to clean burning fuel which was introduced by the State of California in phases. The fuel correction factor (FCF) is 1 for pre-1992 gasoline powered boats and pre-1993 diesel powered boats. These vessels were assumed to have a median engine age of 13 years, so the FCF of 1 applies.

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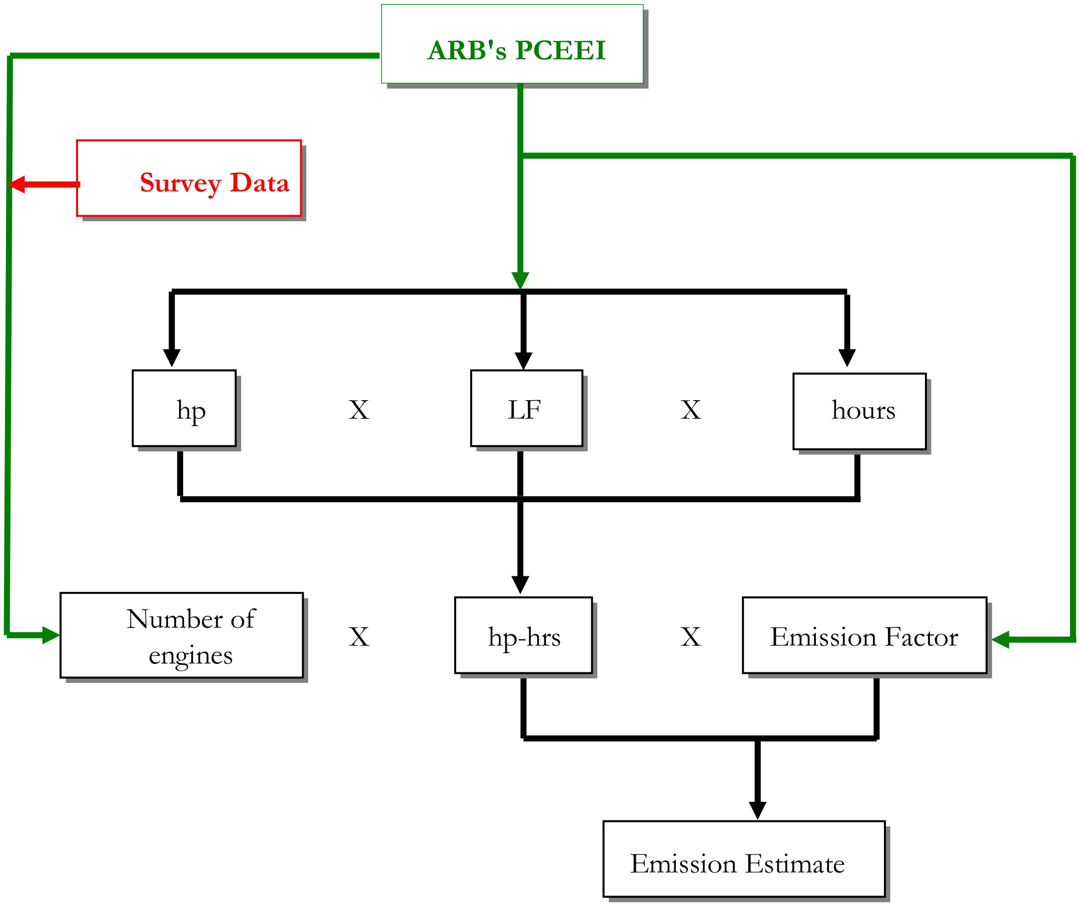
[41] California Reformulated Gasoline Regulations, 13 CCR 2250-2273, amended June 16, 2000.

[42] EPA, NONROAD Emissions Model.

The flow chart in Figure 3.4 graphically summarizes the steps taken to estimate recreational vessel emissions as discussed above.

Figure 3.4: Recreational Vessel Emission Estimation Flow Chart



ARB's PCEEI - Avg horspower, activity hours, load factor, % of types of engines

Survey Data - number of recreational vessels at Port, type of fuel used for SO_2 EF

Using data from the ARB PCEEI, Table 3.21 below summarizes the load factors, average horsepower, hours of operation, and emission factors used for the 2001 Port inventory. 'G2' is 2-stroke gasoline engine, 'G4' is 4-stroke gasoline engine, and 'D' is for diesel engine.

Table 3.11: Average LF, HP, Hours, EF for Recreational Vessel

Vessel Type		POLA Population	LF	HP (avg.)	Hours (avg. annual)	Total (hp-hrs)	NO_x EF (g/bhp-hr)	CO EF (g/bhp-hr)	HC EF (g/bhp-hr)	PM EF (g/bhp-hr)	SO_2 EF (g/bhp-hr)
Vessels w/Outboard Engines	G2	1,656	21%	95	48	1,586,129	1.1	213	107	7.1	0.04
Sailboat Auxiliary Outboard Engines	G2	26	32%	27	10	2,250	1.1	215	107	7.1	0.04
Vessels w/Inboard Engines	G4	355	21%	211	93	1,461,594	5.4	151	9.1	0.07	0.02
Vessels w/Outboard Engines	G4	80	21%	36	48	29,160	5.4	151	9.1	0.07	0.02
Vessels w/Sterndrive Engines	G4	1,006	21%	211	73	3,254,300	5.4	151	9.1	0.07	0.02
Sailboat Auxiliary Inboard Engines	G4	20	32%	27	10	1,698	5.4	151	9.1	0.07	0.02
Vessels w/Inboard Jet Engines	G4	137	21%	211	73	441,764	5.4	151	9.1	0.07	0.02
Vessels w/Inboard Engines	D	61	21%	211	88	238,422	11.3	4.7	2.6	0.34	0.60
Sailboat Auxiliary Inboard Engines	D	52	32%	27	10	4,502	11.3	4.7	2.6	0.34	0.60

3.3 Emission Estimates

The following subsection reports the estimated emissions for main and auxiliary engines for each vessel type, and a summary of estimated emissions for all harbor vessels by vessel type. Due tp rounding errors, totals may vary slightly from the sums of the tons reported. Detailed emission calculations and the harbor vessel inventory can be found in Appendix B.

Tables 3.12 and 3.13 show the estimated 2001 Port emissions from main and auxiliary engines on assist tugboats and on other tugboats and push boats, respectively.

Table 3.12: 2001 Assist Tugboat Emissions, tons

Assist Tugs	NOx	TOG	CO	PM_{10}	$PM_{2.5}$	DPM	SO_2
Main Engines	253.8	7.6	37.1	9.2	8.5	9.2	15.7
Auxiliary Engines	15.8	0.4	2.7	0.8	0.8	0.8	1.2
Total, tpy	**269.6**	**8.1**	**39.8**	**10.1**	**9.3**	**10.1**	**17.0**
Total, tpd	**0.74**	**0.02**	**0.11**	**0.03**	**0.03**	**0.03**	**0.05**

Table 3.13: 2001 Tugboat Emissions, tons

Tugboats (Unit Tow)	NOx	TOG	CO	PM_{10}	$PM_{2.5}$	DPM	SO_2
Main Engines	151.3	4.8	20.6	5.7	5.2	5.7	10.4
Auxiliary Engines	9.7	0.3	1.7	0.6	0.5	0.6	0.7
Total, tpy	**161.0**	**5.0**	**22.3**	**6.2**	**5.7**	**6.2**	**11.1**
Total, tpd	**0.44**	**0.01**	**0.06**	**0.02**	**0.02**	**0.02**	**0.03**

Table 3.14 presents the estimated 2001 Port emissions from line haul towboats using the activity-based method and the USACE data, as discussed above.

Table 3.14: 2001 Line Haul Towboat Emissions, tons

Line Haul Towboats	NOx	TOG	CO	PM_{10}	$PM_{2.5}$	DPM	SO_2
Activity-based	112.5	4.1	12.3	5.4	4.9	5.4	7.0
Inbound	1,014.4	41.1	84.5	55.3	50.9	55.3	62.2
Outbound	901.7	36.5	75.1	49.2	45.2	49.2	55.3
Shift	212.2	8.6	17.7	11.6	10.6	11.6	13.0
Total, tpy	**2,240.7**	**90.3**	**189.6**	**121.4**	**111.7**	**121.4**	**137.6**
Total, tpd	**6.14**	**0.25**	**0.52**	**0.33**	**0.31**	**0.33**	**0.38**

Estimated emissions from Port ferries, excursion boats, crew boats, work boats, government boats, dredging equipment, commercial fishing vessels, and recreational vessels are presented in Tables 3.15 through 3.22, respectively.

Table 3.15: 2001 Ferry Emissions, tons

Excursion Vessels	NOx	TOG	CO	PM_{10}	$PM_{2.5}$	DPM	SO_2
Main Engines	131.5	3.8	19.8	4.3	3.9	4.3	10.6
Auxiliary Engines	15.3	0.4	2.6	1.0	0.9	1.0	1.2
Total, tpy	**146.8**	**4.2**	**22.4**	**5.2**	**4.8**	**5.2**	**11.8**
Total, tpd	**0.40**	**0.01**	**0.06**	**0.01**	**0.01**	**0.01**	**0.03**

Table 3.16: 2001 Excursion Boat Emissions, tons

Excursion Vessels	NOx	TOG	CO	PM_{10}	$PM_{2.5}$	DPM	SO_2
Main Engines	131.5	3.8	19.8	4.3	3.9	4.3	10.6
Auxiliary Engines	15.3	0.4	2.6	1.0	0.9	1.0	1.2
Total, tpy	**146.8**	**4.2**	**22.4**	**5.2**	**4.8**	**5.2**	**11.8**
Total, tpd	**0.40**	**0.01**	**0.06**	**0.01**	**0.01**	**0.01**	**0.03**

Table 3.17: 2001 Crew Boat Emissions, tons

Crew Boats	NOx	TOG	CO	PM_{10}	$PM_{2.5}$	DPM	SO_2
Main Engines	30.4	0.9	4.6	1.0	1.0	1.0	2.5
Auxiliary Engines	4.9	0.1	0.8	0.2	0.2	0.2	0.4
Total, tpy	**35.3**	**1.0**	**5.3**	**1.3**	**1.2**	**1.3**	**2.9**
Total, tpd	**0.10**	**0.00**	**0.01**	**0.00**	**0.00**	**0.00**	**0.01**

Table 3.18: 2001 Work Boat Emissions, tons

Work Boats	NOx	TOG	CO	PM_{10}	$PM_{2.5}$	DPM	SO_2
Main Engines	19.8	0.6	3.0	0.6	0.6	0.6	1.6
Auxiliary Engines	1.7	0.04	0.3	0.1	0.1	0.1	0.1
Total, tpy	**21.5**	**0.6**	**3.3**	**0.8**	**0.7**	**0.7**	**1.7**
Total, tpd	**0.06**	**0.002**	**0.01**	**0.002**	**0.002**	**0.002**	**0.005**

Table 3.19: 2001 Government Vessel Emissions, tons

Government Vessels	NOx	TOG	CO	PM_{10}	$PM_{2.5}$	DPM	SO_2
Main Engines	19.3	0.6	2.9	0.6	0.6	0.6	1.6
Auxiliary Engines	1.2	0.03	0.2	0.05	0.04	0.05	0.1
Total, tpy	**20.5**	**0.6**	**3.1**	**0.7**	**0.6**	**0.7**	**1.7**
Total, tpd	**0.06**	**0.002**	**0.01**	**0.002**	**0.002**	**0.002**	**0.005**

Emissions from the vessels associated with dredging operations were estimated separately from the dredge vessel and are listed under tenders, which include the scows, work boats, and tugboats associated with the dredge.

Table 3.20: 2001 Dredge Operations Emissions, tons

Dredges	NOx	TOG	CO	PM_{10}	$PM_{2.5}$	DPM	SO_2
Dredges	15.2	0.4	2.8	0.4	0.4	0.4	1.0
Tenders	2.1	0.5	0.3	0.1	0.1	0.1	0.2
Total, tpy	**17.3**	**0.9**	**3.1**	**0.5**	**0.4**	**0.5**	**1.2**
Total, tpd	**0.05**	**0.002**	**0.01**	**0.001**	**0.001**	**0.001**	**0.003**

Table 3.21: 2001 Commercial Fishing Emissions, tons

Commercial Fishing Vessels	NOx	TOG	CO	PM_{10}	$PM_{2.5}$	DPM	SO_2
Main Engines	338.2	9.8	50.7	10.1	9.3	10.1	273.9
Auxiliary Engines	46.7	1.23	8.5	3.8	3.5	3.8	34.4
Total, tpy	**384.8**	**11.0**	**59.2**	**14.0**	**12.8**	**14.0**	**308.3**
Total, tpd	**1.05**	**0.03**	**0.16**	**0.04**	**0.04**	**0.04**	**0.84**

Table 3.22: 2001 Emissions for Recreational Vessel, tons

Recreational Vessels	NOx	TOG	CO	PM_{10}	$PM_{2.5}$	DPM	SO_2
Main Engines	35.8	249.4	1,237.0	12.9	11.9	0.1	0.3
Auxiliary Engines	0.1	0.3	0.8	0.02	0.02	0.002	0.003
Total, tpy	**35.8**	**249.7**	**1,237.8**	**12.9**	**11.9**	**0.1**	**0.3**
Total, tpd	**0.10**	**0.68**	**3.39**	**0.04**	**0.03**	**0.0002**	**0.001**

The 2001 emissions for each harbor vessel type in tons per year and tons per day are presented in Table 3.23.

Table 3.23: 2001 Total Harbor Vessel Emissions, tpy

Harbor Vessel Type	NOx (tpy)	TOG (tpy)	CO (tpy)	PM10 (tpy)	PM2.5 (tpy)	DPM (tpy)	SO2 (tpy)
Assist Tug	269.6	8.1	39.8	10.1	9.3	10.1	17.0
Tugboat (Unit Tow)	161.0	5.0	22.3	6.2	5.7	6.2	11.1
Ferry	197.2	4.5	37.0	4.9	4.5	4.9	12.7
Excursion	146.8	4.2	22.4	5.2	4.8	5.2	11.8
Crew boat	35.3	1.0	5.3	1.3	1.2	1.3	2.9
Work boat	21.5	0.6	3.3	0.8	0.7	0.8	1.7
Government	20.5	0.6	3.1	0.7	0.6	0.7	1.7
Commercial Fishing	384.8	11.0	59.2	14.0	12.8	14.0	308.3
Recreational Vessel	35.8	249.7	1,237.8	12.9	11.9	0.1	0.3
Dredges	17.3	0.9	3.1	0.5	0.4	0.5	1.2
Line Haul Towboat	2,240.7	90.3	189.6	121.4	111.7	121.4	137.6
Total, tpy	**3,530.6**	**376.0**	**1,622.9**	**177.9**	**163.7**	**165.1**	**506.3**
Total, tpd	**9.67**	**1.03**	**4.45**	**0.49**	**0.45**	**0.45**	**1.39**

To estimate emissions inside the breakwater, within 25 miles of the Port, and up to 50 miles from the Port, the total estimated emissions were multiplied by the percentage of time spent by each vessel category within each zone (see Table 3.3) and then summed by pollutant. The results are summarized in Table 3.24 below:

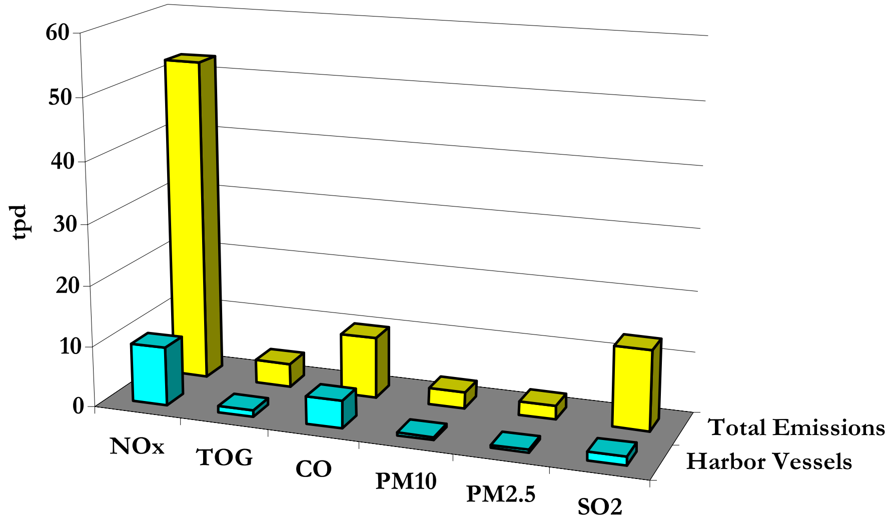
Table 3.24: Emissions by Zone, tpy

Pollutant	Harbor (tpy)	25 Miles (tpy)	50 Miles (tpy)	Total
NO_X	1,968.0	902.3	660.4	**3,530.6**
CO	701.5	576.1	345.2	**1,622.9**
TOG	172.2	124.5	79.3	**376.0**
PM_{10}	99.7	44.0	34.3	**177.9**
$PM_{2.5}$	91.7	40.5	31.5	**163.7**
DPM	94.6	39.1	31.4	**165.1**
SO_2	152.0	199.9	154.5	**506.3**

3.4 Conclusions

Figure 3.5 compares the total harbor vessel emissions in tons per day with the Port's total emissions. The line haul towboat emissions are included in the harbor vessel emissions. The Port's total emissions include on-port and off-port emissions from the categories included in the EI: cargo handling equipment, locomotives, on-road trucks, commercial ocean-going vessels and harbor vessels.

Figure 3.5: Comparison of Harbor Vessel Emissions to the Port's Total Emissions, tpd



Strengths
A strength of the harbor craft inventory is that, for most vessel types, emissions were estimated for vessels on an individual basis. This will prove beneficial for updating the fleet in future inventories. Since the commercial harbor craft companies frequently expand and reorganize their fleets, new vessels can readily be added and vessels no longer used at the Port can easily be removed from the inventory. Engine models and horsepowers can also be updated as the main and auxiliary engines are repowered or retrofitted. With the Carl Moyer Program and other local, state and federal programs, the vessels' engines are expected to continue to be repowered and retrofitted with newer, cleaner engines. Emission factors for each individual engine can also be updated as new information becomes available.

Limitations
The limitations of the harbor craft inventory include the inability to collect comprehensive activity data (including load factor) with the exception of assist tugboats. Instead, EPA load factors were used for most vessel types, averages from ARB's PCEEI were used for the recreational vessels, and ARB's 2002 Statewide Commercial Harbor Craft Survey was used for commercial fishing vessels.

SECTION 4 CARGO HANDLING EQUIPMENT

This section discusses the Port facilities and their cargo handling equipment as identified through the inventory process. This section also provides detail of the emission estimating methodology and results/findings for this source category.

4.1 Terminal and Equipment Types

The EI for CHE includes container terminals; dry bulk and break bulk terminals; liquid bulk terminals; other terminals such as auto terminals and a cruise ship terminal; and smaller facilities located within Port boundaries. The CHE EI also includes an area located northeast of the Port which also belongs to the Port. Figure 4.1 presents a map illustrating the geographic boundaries of the CHE EI.

The names of the terminals inventoried and the categories they were placed in are as follows:

Container Terminals:[43]

- Berths 121-131: Yang Ming Line
- Berths 136-146: Trans Pacific Container Services Corp. (Trapac)
- Berths 206-209: Matson Terminal
- Berths 212-225: Yusen Terminals Inc (YTI)
- Berths 226-236: Evergreen
- Berths 302-305: APL Container Terminal

Bulk Terminals:

- Berths 49-53 and 87-89: Pasha Stevedoring and Terminals
- Berths 54-55: Stevedore Services of America (SSA)
- Berths 153-155: Crescent Warehouse Company
- Berths 210-211: Hugo Neu-Proler Company
- Berth 301: Los Angeles Export Terminal (LAXT)

Liquid Terminals:

- Berths 70-71: Westway
- Berths 118-120: Kinder Morgan
- General Petroleum

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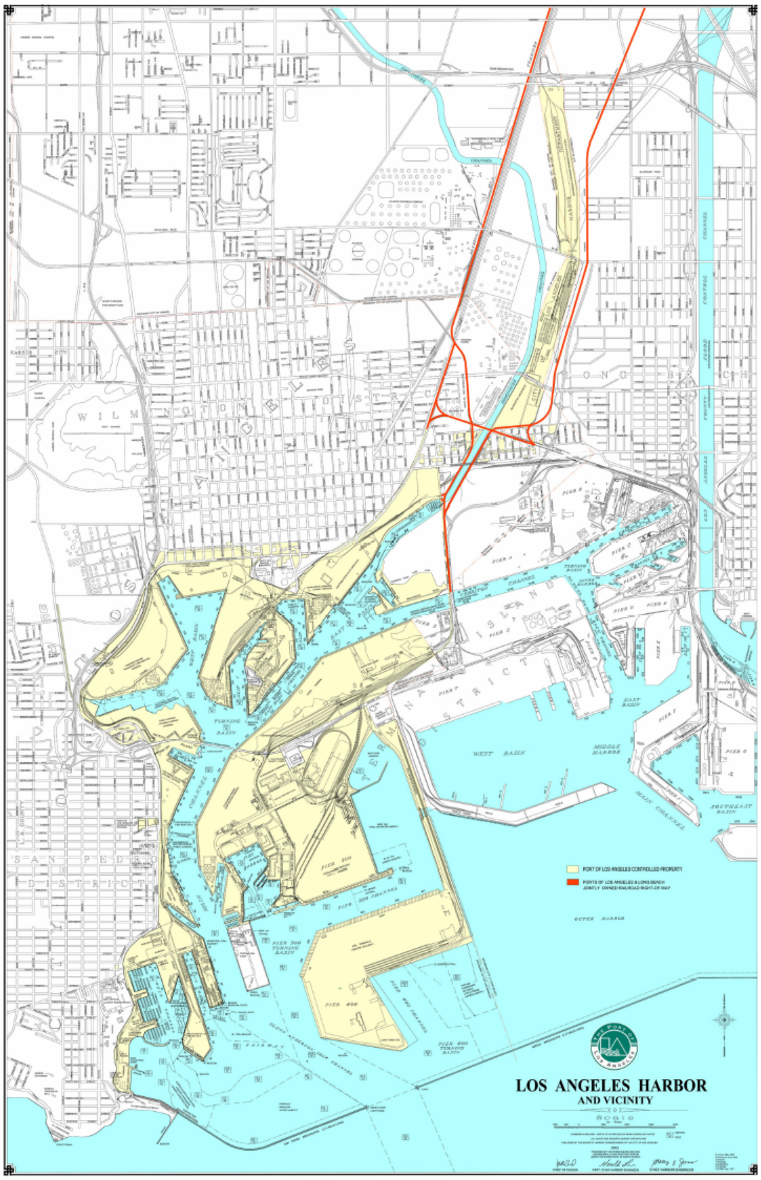
[43] Late in 2002, APM Pier 400 terminal opened and Matson terminal moved to POLB.

Figure 4.1: CHE EI Geographic Boundaries



Auto Terminals:

- Berths 195-199: Distribution & Auto Service (DAS)
- Berth 200A: Auto Warehousing

Other Terminals/Facilities:

- Berths 90-93: Pacific Cruise Ship Terminals (PCST)
- Five small facilities/tenants (Southern California Marine Institute, Southern California Ship Services, Tri-Marine Fish Company, U.S. Coast Guard, Harbor Ice)
- Cal Sulfur
- LA Grain
- Union Pacific Intermodal Containers Transfer Facility (ICTF)
- Vopak

Following approved protocol, facilities identified in the methodology were contacted and/or visited to determine whether they had cargo handling equipment. Some facilities contacted were not included in the inventory because they had no CHE or an insignificant amount of equipment.

There are a wide range of equipment types found at the Port due to the diversity of cargo. Container terminals have the most extensive use of CHE, followed by the intermodal truck to rail yard, and break and dry bulk terminals. Liquid bulk and auto terminals have minimal use of CHE. The majority of the equipment can be classified into one of the following equipment types:

- Crane
- Forklift
- Reach stacker
- Rubber tired gantry (RTG) crane
- Rubber tired loader

- Side handler
- Skid loader
- Sweeper
- Top handler
- Yard tractor

A detailed equipment inventory is presented in Appendix C. An identification number was assigned to each piece of CHE to maintain confidentiality regarding terminal-specific information on numbers and types of equipment. The equipment types are described below based on the type of terminal operation in which they are used.

Figure 4.2 presents the distribution of the 1,121 pieces of equipment inventoried at the Port for 2001. Of the equipment inventoried at all Port facilities for 2001, 53% were yard tractors, 28% were fork lifts, seven percent were top handlers, six percent were other equipment (not typical cargo handling equipment), three percent were side handlers, and three percent were cranes, including rubber tired gantry (RTG) cranes.

The most common type of engine identified in the equipment inventory is the Cummins C5.9, with 21% of the CHE being equipped with this model engine. Next in prevalence are the Cummins B5.9, in 17% of the CHE; the Cummins ISC, in 14% of the CHE; and the Cummins C8.3 in 13% of the CHE. Table 4.1 lists the types of CHE equipped with the most common engines, along with the range of horsepower (HP range) of these engines, and the number installed in the different pieces of equipment.

Figure 4.2: Distribution of 2001 Port CHE by Equipment Type

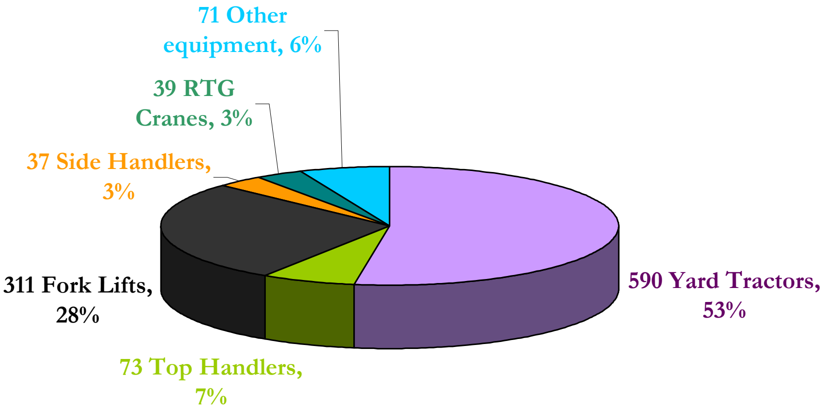


Table 4.1: Most Common CHE Engine Manufacturers

Equipment Type	Engine Make	Model	HP Range	Count	Percentage of all CHE
Forklifts	Cummins	C5.9	150-210	13	
Side Loaders	Cummins	C5.9	170-210	19	
Yard Trucks	Cummins	C5.9	145-175	202	
Total	**Cummins**	**C5.9**	**145-210**	**234**	**21%**
Forklifts	Cummins	B5.9	150-200	3	
Side Loaders	Cummins	B5.9	150-170	16	
Yard Trucks	Cummins	B5.9	170-205	166	
Total	**Cummins**	**B5.9**	**150-205**	**185**	**17%**
Yard Trucks	Cummins	ISC	230-240	153	
Total	**Cummins**	**ISC**	**230-240**	**153**	**14%**
Forklifts	Cummins	C8.3	215-240	2	
Top Handlers	Cummins	C8.3	330	7	
Side Loaders	Cummins	C8.3	170	2	
Yard Trucks	Cummins	C8.3	215	138	
Total	**Cummins**	**C8.3**	**170-330**	**149**	**13%**

4.1.1 Container Terminals

Containerized cargo is any kind of cargo that is packed in standardized boxes for transport and handling. The Port of Los Angeles and other West Coast ports are the major ports of entrance for containerized cargo coming from the Far East to the U.S. The Port of Los Angeles ranks first as the busiest container Port in the U.S. and eighth in the world.[44] Together with POLB, the Port of Los Angeles serves the Los Angeles Basin, Southern California and other destinations in the continental U.S. OGVs transport refrigerated cargo, consumer goods and other unique product cargo in containers. For the Port, leading imports include furniture, apparel, toys, computer equipment, and footwear. The top five exports include wastepaper, synthetic resins, fabric, animal feed and scrap metal.[45]

The 2001 container throughput for Port terminals was approximately 5.18 million TEUs,[46] with a range from 500,000 TEU to 1,600,000 TEU per terminal. The ratio between TEUs and actual container lifts averaged 1.7 at the Port terminals, based on

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[44] *http://www.portoflosangeles.org.*

[45] *http://www.portoflosangeles.org*

[46] *http://www.portoflosangeles..org.*

conversations with the various terminal operators. The number of TEUs is not equivalent to the number of actual containers because container lengths include 20 feet, 40 feet, and other sizes. The container terminals had an average of 490,000 container lifts each per year. Operating hours ranged from 10 to 24 hours per day, for five to seven days per week.

In 2001, six container terminals using 55 berths served the sea to land link for container transport, as listed in Table 4.2.

Table 4.2: Container Terminals at the Port of Los Angeles, 2001

Terminal	Berths	Size (acres)
Yang Ming	121-131	186
Trapac	136-146	173
Matson	206-209	91
YTI	212-225	185
Evergreen	226-236	205
APL	302-305	292

Operational Characteristics

The basic layout of a container terminal consists of docks where vessels berth, an area alongside the docks for cranes to load/unload a vessel, a container storage area where CHE moves and organizes cargo, gates for trucks that are delivering or picking up containers, and an intermodal rail yard.

The operation of a container terminal is dependant on the amount of land the terminal has to operate on. There are three basic types of operations that can be found in Port container terminals: wheeled, grounded, and combination. These represent how the containers are physically stored and kept on a terminal. Wheeled operations are generally the most efficient operations as all the containers are kept on chassis and can be moved anywhere on or off the terminal by the use of a yard tractor or HDV. Grounded operations are where containers are stored onsite in “stacks” that can be several containers wide by two to four containers high, thus requiring the use of RTG, top handlers and side handlers to move the containers to/from and within the stacks. RTG cranes are cranes that can move about the stacks and straddle the containers to lift them up and move them around. Top and side handlers are equipment used to pick up the full and empty containers. Most terminals employ a mix of wheeled and grounded operations as land permits.

Wheeled operations have low container per acre densities and thus require significantly more land than grounded operations, which have high container densities, however they are the most efficient and require less CHE than a grounded operation. Grounded operations use a mixture of RTG cranes, top handlers, side handlers and yard tractors versus just yard tractors for wheeled operations and therefore the emissions per container generally increase. The type of operation at any specific terminal is generally dictated by the amount of land available and the number of containers that the terminal processes per year.

Some containers are used to transport perishable goods such as fruits and meats, and therefore are equipped with a refrigeration unit that has a small diesel generator that can provide power to the cooling system when external power is not available. These refrigerated container units (reefers) were investigated during the course of data collection for this inventory to determine their potential air quality impact from ship to yard to distribution. Through the interviews, it was found that there are no emissions associated with the diesel units on the containers. While on board ships, reefers are powered by the ship's auxiliary generators, and once ashore, reefers that are stored for any length of time in the terminal are plugged into the utility grid at special slots designated for reefers. A reefer that is removed from an external power source, such as when it is loaded onto a trailer for truck transport, will hold its temperature for approximately eight hours before the diesel generator would need to be operated to power the refrigeration unit. Therefore, it is reasonable to conclude that the containers' diesel generators are not turned on within the Port boundary or when traveling within the study area because truck travel time within the study area is far less than eight hours.

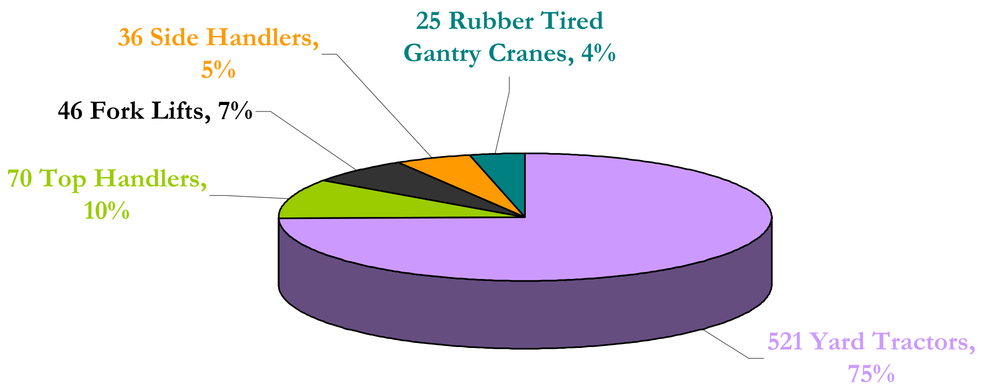
Equipment Types

The equipment inventoried for the container terminals are mostly diesel-powered landside equipment and not licensed for highway use. One of the six container terminals listed four liquefied petroleum gas (LPG) powered forklifts in their equipment inventory, and these were included in the emissions inventory. The major types of cargo handling equipment found at the container terminals include:

- Yard tractors
- Top handlers
- Side handlers
- RTG cranes
- Forklifts

The equipment used directly in handling cargo at container terminals consists mainly of yard tractors, top handlers, and forklifts. Figure 4.3 presents the breakdown by type of the 699 pieces of equipment used by the container terminals. Yard tractors accounted for three-quarters of the equipment inventoried. Top handlers were the next largest category with 10%, followed by forklifts at 7%, side handlers at 5% and RTG cranes at 4%.

Figure 4.3: Distribution of Container Terminal CHE by Equipment



Images of various equipment types were obtained from the Internet to aid in the description of the equipment, and to distinguish between the types of equipment inventoried as part of this EI. The equipment images shown in the figures are not photographs of actual pieces of equipment used at the surveyed terminals.

Yard Tractors

The equipment inventory showed that yard tractors, also known as terminal tractors and yard hustlers, accounted for 75% of the CHE used at the container terminals. The typical off-road yard tractor is a close relative of the on-road truck tractor chassis, however it has an off-road engine and can not drive on public roads (the engine does not meet EPA standards to be registered for public roads). It is designed for the movement of containers throughout the terminal in both stacked and wheeled operations. Common uses of yard tractors are to move containers to and from the ship, move containers within the terminal, move reefer containers into position, and move containers to RTGs for placement or removal from the stacks. Yard tractors are used throughout the terminal and the majority of their hours are worked when a ship is at dock being loaded/unloaded. When a vessel is at dock, the yard tractors line up next to the vessel and a crane places an unloaded container on the yard tractor while another crane lifts a container from another yard tractor to load the vessel. The yard tractors are in constant motion from the dock to the container storage area. They work primarily between the ship and the locations of stacked containers or chassis'. Yard tractors are also used for intermodal rail container transfers.

At the container terminals, yard tractor model years ranged from 1972 to 2002, with an average model year of 1996. Engine power ranged from 182 hp to 240 hp, with an average of 191 hp. Annual operating time ranged from zero to 7,793 hours, with an average of 2,400 hours. Most of the yard tractors identified in the inventory were manufactured by Ottawa. Figure 4.4 shows a typical yard tractor.

Figure 4.4: Yard Tractor

Top Loaders

Approximately ten percent, or 70 pieces, of the equipment inventoried were diesel powered top loaders, also known as top handlers by the terminal operators. Top loaders move, stack and load containers using an overhead telescopic boom. They can be used in place of or in conjunction with RTGs to lift heavy containers within a terminal. Model years ranged from 1987 to 2001, with an average model year of 1996. Engine power ranged from 174 hp to 330 hp, with an average of 278 hp. Annual operating time ranged from zero to 4,500 hours, with an average of 1,732 hours. Figure 4.5 shows a typical top loader.

Figure 4.5: Top Loader

Forklifts

The container terminals had 46 forklifts, accounting for 7% of the equipment inventoried at container terminals. The forklifts at the container facilities may be used for cargo and non-cargo handling activities. Forklifts use an under lift principle to move loads of varying sizes depending on their capacity. The forklifts used at the container terminals had model years ranging from 1972 to 2001, with 1986 being the average model year. Engine power ranged from 45 hp to 230 hp, with an average of 150 hp. Annual operating hours ranged from zero to 4,000 hours, with an average of 1,173 hours. Only 4 of the 46 forklifts at the container terminals used LPG instead of diesel fuel and for modeling purposes, 1995 was used as their default model year. Figure 4.6 illustrates a typical forklift.

Figure 4.6: Forklift

Side Handlers

Side picks, side handlers and side loaders are the various names of the cargo handling equipment that typically move and stack the empty containers at a terminal and therefore do not have horsepower comparable to a top handler. Five percent, or 36 units, of the equipment inventoried were side handlers. Model years ranged from 1986 to 2002, with an average model year of 1997. Engine power ranged from 152 hp to 300 hp, with an average of 183 hp. Annual operating time ranged from zero to 2,400 hours, with an average of 1,407 hours. Figure 4.7 presents a Taylor side handler.[47]

Figure 4.7: Side Handler

Rubber Tired Gantry Cranes

The 25 RTG cranes made up four percent of the equipment inventoried for container terminals. The diesel-powered RTG crane moves containers to and from the container stacks in a grounded operation; it is designed like a ship-loading crane without the horizontal extended boom. The RTG straddles the stacks of containers and has room for a HDV truck/yard tractor to pull under, and moves containers to and from stacks. It is also used to consolidate the stacks weekly as containers are added and removed from the terminal. The low operating hours for some of the RTG cranes may be due to operational decisions (for example, moving more containers to a wheeled operation if land permits) made by the container terminals not to use their RTGs. Model years ranged from 1972 to 2000, with an average model year of 1995. Engine power ranged from 185 hp to 625 hp, with an average of 388 hp. The annual operating hours ranged from 1 hour to 2,080 hours, with an average of 1,000 hours. Figure 4.8 illustrates a typical RTG (in gray).

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[47] *http://www.cal-lift.com.*

Figure 4.8: Rubber Tired Gantry Crane

4.1.2 Break Bulk and Dry Bulk Terminals

Break bulk cargoes include steel, lumber, large machinery and other large product cargo. Break bulk terminals generally receive cargo that is not shipped via container ships and therefore the cargo has to be unloaded from a ship's hold and then assembled/disassembled on the dock for distribution. Steel products, such as plates or rolls are placed in a ship's hold and have to be removed one by one, if for example the steel is being imported. Large machinery may also be carried with special RoRo vessels with large roll-on/roll-off ramps suitable for driving equipment on and off the ship directly via a large ramp that is part of the ship. Lumber and lumber products are often carried by dedicated vessels and barges that are designed to carry their cargo. Some vessels that call on break bulk terminals may mix containerized cargo and break bulk cargo and are called "combination" ships, where the break bulk cargo is stored in the below deck in holds and containers are stacked on the hatch covers that cover the cargo holds during sailings. In general, the ships that call at break bulk terminals are much smaller than the ships that call at the container terminals.

Due to their weight and characteristics, heavy lift machines are used for handling bulk cargo on the terminal and for loading rail or truck. Cargo is discharged either by the vessel's own cranes which are powered by the ship's auxiliary engines or ship-to-shore cranes or large boom cranes that operate on the dock and are highly mobile and move into position based on the ship's configuration. Most break bulk cargo leaves the terminals by truck. Dry bulk includes fine, grain-like cargo that can be processed by bucket loaders, screw loaders, conveyors or suction and that are temporarily stored in piles, warehouses, or silos on the terminals. The most common break bulk and dry bulk cargos at the Port include scrap metal, paper and petroleum coke.

Five break bulk and dry bulk terminals at the Port had diesel-powered CHE in 2001 and were included in this inventory. Table 4.3 lists the terminals, along with their berth and size.

Table 4.3: Break and Dry Bulk Terminals at the Port of Los Angeles, 2001

Terminal	Berths	Size (acres)
Pasha	49-53 and 87-89	24 and 25
SSA	54-55	11
Crescent Warehouses	153-155	13
Hugo Neu-Proler	210-211	22
Los Angeles Export	301	120

The equipment found at the Port's dry and break bulk terminals consisted mainly of forklifts, rubber tired loaders, yard tractors, cranes, and sweepers.

Figure 4.9 shows the distribution of the 163 pieces of equipment inventoried at the dry and break bulk terminals. The majority of the equipment surveyed is diesel powered, with a few exceptions noted below. The equipment at the various break and dry bulk terminals was inventoried by the Port's consultant and ARB[48] (some of the equipment information was not given such as equipment make and model year).

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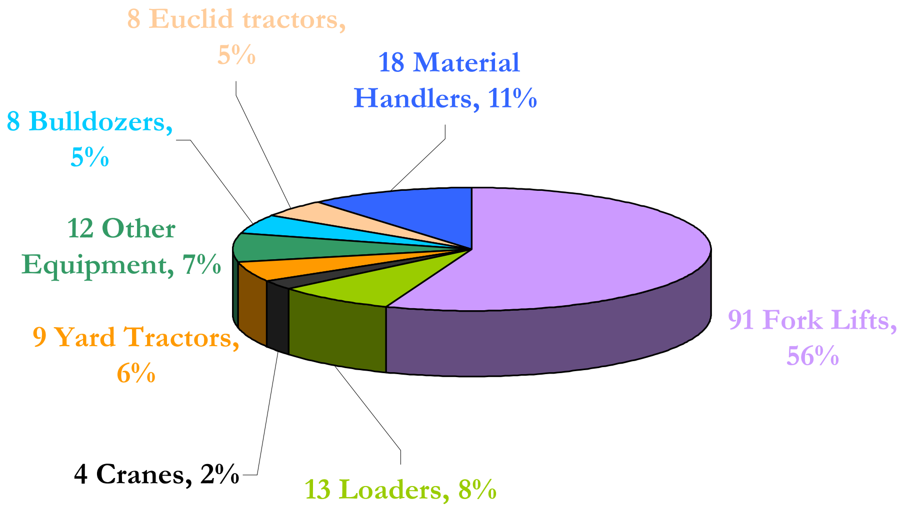
[48] The ARB collected data from smaller Port facilities in supportof an ARB study of the Wilmington area currently under development.

Figure 4.9: Distribution of Dry and Break Bulk CHE Equipment Type



Forklifts

The most numerous type of equipment found at the dry and break bulk terminals was the forklift, with 91 pieces identified, representing 56% of the CHE. At one bulk terminal, the forklifts were used to move palletized cargo from the dock to the warehouse, organize the cargo within the warehouse, and load cargo to trucks. Their model years ranged from 1979 to 2002, with an average model year of 1991. The engine power ranged from 35 hp to 280 hp, with an average of 130 hp. Annual operating time ranged from 120 hours to 2,250 hours, with an average of 790 hours. The majority (78%) of the forklifts at the dry and break bulk terminals were powered by LPG. The rest of the forklifts were diesel powered and four forklifts used gasoline. See Figure 4.6 for a forklift photograph.

Material Handlers, Top Loaders, Side Loaders

Approximately 11% of the equipment inventoried was material handlers, including one side handler and two top loaders. These loaders and handlers are used on an as needed basis at the bulk terminals when general cargo vessels are loaded/unloaded with containers along with break bulk materials. The material handlers may also be used for heavier cargo that cannot be moved by the forklifts. The material handlers' engine power ranged from 80 to 930 hp, with an average of 342 hp. Annual operating hours ranged from 100 to 2,860 hours. 1995 was used as the default model year. Since the "material handlers" did not list equipment make or model and no more description was given, it is difficult to show a figure that resembles a typical material handler. Previous figures show photographs of a typical top loader (Figure 4.5) and side handler (Figure 4.7). The two top loaders had model years of 1979 and 1989. The engine powers were 174 hp and 250 hp, with annual operating times of 200 hours and 380 hours.

Loaders
Approximately 8% of the equipment used at the dry and break bulk terminals was listed as loaders and were mostly found at a metal recycling facility. The loaders are used in conjunction with the bulldozers and Euclid haul trucks to move the recycled metal within the metal recycling facility. For the loaders, engine power ranged from 54 hp to 430 hp, and annual operating hours from 60 hours to 2,450 hours. The default model year, 1995, was used.

Bulldozers
Approximately 8%, or five units, were bulldozers, mostly found at the metal recycling facility. The bulldozers' engine power ranged from 120 hp to 460 hp, with an average of 198 hp. Annual operating hours ranged from 40 to 1,800 hours. The model year was 1995.

Yard tractors
Approximately 6%, or nine pieces of the equipment at the dry and break bulk terminals were yard tractors. Yard tractors are also used infrequently at the bulk facilities whenever the type of shipment warrants their use. For the yard tractors, model years ranged from 1980 to 2000, with an average model year of 1982. Engine power ranged from 174 hp to 210 hp, with an average of 178 hp. Annual operating time ranged from 300 hours to 404 hours. See Figure 4.4 for a photograph of a yard tractor.

Euclids
Approximately 5% of the equipment was listed as a Euclid, which is the manufacturer name for haul trucks. The trucks are used for hauling recycled scrap metal at a recycling facility at the Port. Engine power averaged 546 hp. The default model year, 1995, was used.

The "other equipment" included an aerial lift, sweeper, a skid steer loader, rail car movers and rail ramps. All of the "other" equipment, except for the sweeper, had a default model year of 1995. The rail car movers had an engine power ranging from 120 hp to 370 hp and an annual operating time range of 56 hours to 480 hours. The rail ramps had an engine power of 50 hp and an annual operating time of 120 hours each.

The aerial lift had an engine power of 85 hp and 40 hours. Figure 4.10 shows a JLG aerial lift. An aerial lift, typically used for maintenance purposes, allows individuals to be lifted to reach high areas without the need for scaffolding. The sweeper had a model year of 1998, with an engine power of 48 hp and annual operating time of 495 hours. Figure 4.11 shows an Elgin sweeper with a 100 hp engine. The skid steer loader, a small loader used in tight spaces, had an engine power of 40 hp and 800 hours. Figure 4.12 shows a Komatsu skid steer loader.

Figure 4.10: Aerial Lift

Figure 4.11: Elgin Sweeper

Figure 4.12: Skid Steer Loader

4.1.3 Liquid Bulk Terminals

Liquid bulk terminals predominately import petroleum products to California. The liquid bulk terminals require minimal CHE for their operations. The various liquid bulk terminals at the Port handle crude oil, finished and semi-finished petroleum products, chemicals, petrochemicals, and vegetable oils.

Compared to other types of terminals, liquid bulk cargo operations use limited diesel-powered terminal equipment. Liquid cargo is transported using loading/unloading arms, flexible hoses and valves, and/or booms to load/unload product from the vessels to/from onshore facilities. The emissions from the vessel loading and unloading are not included in the CHE inventory since the landside pumps are stationary and not considered CHE. The ship's diesel/bunker-powered auxiliary and propulsion engines emissions are included in the marine vessel emissions inventory portion of this report.

Only three LPG forklifts were found at the liquid terminals. Model years ranged from 1995 to 1998, with an average model year of 1996. The engine power was 122 hp for each one, and annual operating time ranged from 24 hours to 780 hours, with an average of 336 hours.

4.1.4 Automobile Terminals

The U.S. is a major importer of motor vehicles and California is an important market. West Coast ports are a port of entry for many automobiles manufactured in Asia and Europe. The Port has two automobile terminals, which serve mostly the local California market. In the year 2001, the Port handled approximately 300,000 automobiles. Mostly Nissan and Mercedes passenger cars were imported through the Port automobile terminal, with a small percentage of sport utility vehicles (SUVs) and diesel pickup trucks. Loading and unloading does not require the use of heavy cargo handling equipment. The self propelled vehicles are discharged (or loaded) by driving them off (or on) the vessel. The terminal workers drive the cars to dedicated parking areas on the terminal. The automobiles are parked on the ground. The emissions from the new automobiles are included in the inventory and presented in Section 4.3, along with the CHE emissions.

Five LPG forklifts were inventoried at the automobile terminals. Each forklift had a model year of 1999 and engine power of 122 hp, with annual operating time of 780 hours. Information on the two automobile terminals is presented in Table 4.4.

Table 4.4: Automobile Terminals, 2001

Terminal	Berths	Size
Distribution and Auto Services	195-199	129
Auto Warehousing Company	200A	19

4.1.5 Other Terminals and Facilities

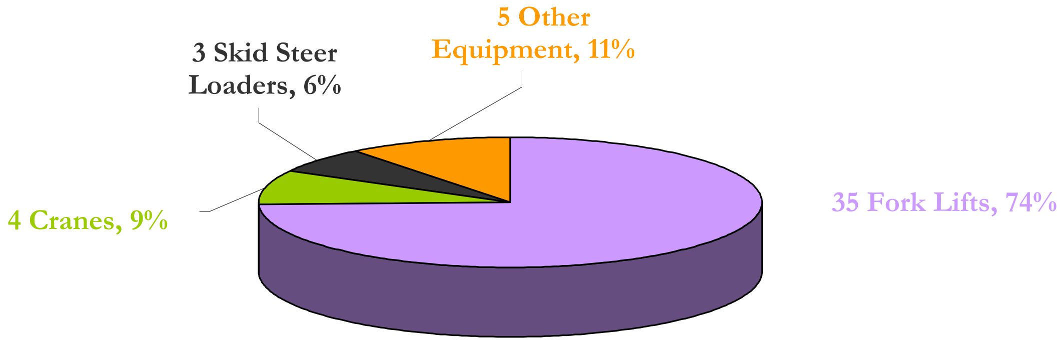
There were several facilities within the Port boundary that were included in this inventory that did not fit into the container, dry bulk, break bulk, liquid bulk, or auto terminal categories listed above. Although these facilities are unique among themselves, they have been put together in this category for the purpose of summarizing the CHE data.

Other Terminals/Facilities:

- Pacific Cruise Ship Terminals (PCST)
- Five small facilities/tenants - Southern California Marine Institute, Southern California Ship Services, Tri-Marine Fish Company, the U.S. Coast Guard (USCG), and Harbor Ice

The Port of Los Angeles is ranked first on the west coast for cruise traffic and is the fourth busiest port in the nation with 1.08 million passengers in 2001. For this reason, equipment is frequently used to manage the passengers' luggage at the cruise terminal. Mainly forklifts are used to load and unload the passengers' luggage from the cruise ship to the terminal. Figure 4.13 presents the distribution of CHE by equipment type.

Figure 4.13: Distribution of Equipment at Other Port Terminals/Facilities by Equipment Type



Forklift
Forklifts accounted for 74% of the equipment found at the cruise terminal and the smaller facilities at the Port. Approximately 44% of these forklifts run on LPG. Model years ranged from 1979 to 1999, with an average model year of 1992. The engine power ranged from 56 hp to 210 hp, and annual operating time ranged from 50 hours to 1,460 hours, with an average of 723 hours.

Crane
Nine percent of the equipment at these facilities were cranes with an engine power range of 43 hp to 185 hp. The default model year of 1995 was used, and annual operating time ranged from 400 hours to 1,200 hours, with an average of 650 hours.

Skid Steer Loaders
Skid steer loaders were six percent of the equipment found at these facilities. The default model year, 1995, was used. The engine power ranged from 37 hp to 85 hp, and annual operating time ranged from 62 hours to 125 hours, with an average of 96 hours.

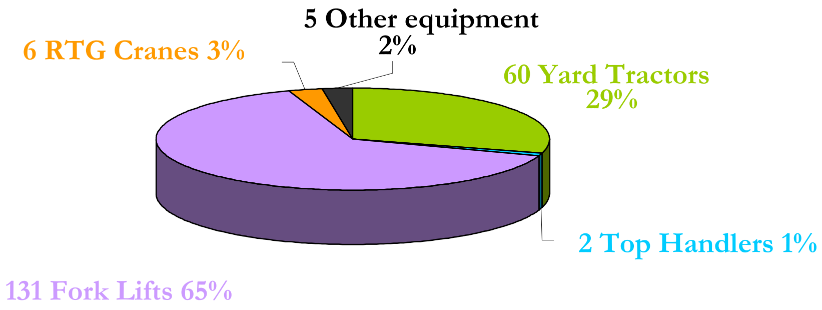
Other Equipment
For the remainder of the "other equipment" the default model year of 1995 was used. Other equipment included two utility trucks with 80 hp and average annual operating time of 140 hours; one pay-loader with 350 hp and 25 hours of annual operating time; one truck with 230 hp and 63 hours; and one man lift with 80 hp and 150 hours for annual operating time.

4.1.6 Additional Facilities

Some additional facilities are located on Port-owned property not contiguous to the main Port area. This northeastern area of the Port, between the cities of Wilmington and Long Beach (see Figure 4.1), mainly serves as an intermodal truck to rail yard for the Port and POLB. Vopak, Cal Sulfur and LA Grain also have facilities in this area.

Figure 4.14 shows the CHE equipment found in the northeastern area which is mostly used to move containers on and off railcars at the intermodal yard.

Figure 4.14: Distribution of Equipment at Additional Northeastern Facilities



Forklifts

Forklifts accounted for 65% of the equipment found at the additional sites on Port-owned land. The vast majority of these forklifts are run on LPG,, with the exception of three diesel forklifts. The engine power averaged 57 hp, and annual operating time averaged 2,080 hours.

Yard tractors

Approximately 29% of the equipment at the additional sites on Port-owned land were yard tractors. These yard tractors had an average model year of 1998. Engine power ranged from 147 hp to 250 hp, with an average of 155 hp. Annual operating time averaged 2900 hours.

Cranes

Three percent of the equipment at these facilities were RTG cranes with an engine power average of 300 hp. The model year ranged from 1988 to 1997, with an average model year of 1994, and annual operating time ranged from 1,787 hours to 4,576 hours, with an average of 3,638 hours.

Other equipment

Four front end loaders, two top handlers and one sweeper were inventoried at the facilities located northeast of the Port. The front end loaders had an average power of 233 hp and an average annual operating time of 695 hours. The top handlers had an average power of 340 hp and an average annual operating time of 905 hours.

4.2 Methodology

This section presents both how the equipment and operational data was acquired and how the emission estimates were developed based on the data collected.

4.2.1 Data Acquisition

Each terminal at the Port (identified in Section 4.1) was contacted for information. Initial in-person interviews were conducted with terminal owners, equipment operators, and others having first hand knowledge of equipment details or operational parameters. The larger terminals were visited more than once to gather the detailed operational data needed. Additional information was also requested during the interviews, or by telephone after the initial information was reviewed. The terminals provided information in one or more formats, including a questionnaire developed especially for this effort, their own written or electronic format, or in a conversational setting, either by telephone or in person. The collected information was compared with information collected from similar operations at other locations as a "reasonableness check" and also submitted back to each terminal for quality assurance.

The CHE equipment details requested for each piece of equipment included the following:

- Equipment type
- Equipment identification number
- Equipment make and model
- Engine make and model
- Rated horsepower
- Model year
- Type of fuel used
- Annual hours of operation
- Equipment load data

4.2.2 Emissions Estimation

The ARB has developed the OFFROAD model to estimate emissions from off-road equipment fleets in the State of California, including industrial equipment such as CHE; therefore, this model was used to estimate emissions for this emission inventory. Because the ARB has not developed a publicly available version of the OFFROAD model, the agency ran the model using the data collected by the Port from the terminal operators and augmented by data provided to ARB in support of the Wilmington Children's Environmental Health Air Quality Study.

For pieces of equipment where the model year was not identified (primarily smaller, non-container terminals), ARB assigned a model year of 1995 at the suggestion of the Port's consultant, because the average age of the CHE at the Port is model year 1995.

Before submitting the CHE data file to ARB, the data was pre-processed as follows:

- Data provided by ARB for facilities ARB had contacted were incorporated into the data file.
- A terminal identification number was added to protect the anonymity of facilities.
- Horsepower and hours-of-use data gaps were filled by using category averages. For example, a forklift for which horsepower was not available would be assigned a horsepower value equal to the Port-wide average forklift horsepower.
- The OFFROAD equipment type corresponding to the reported terminal equipment type was added to each record. The survey equipment type is the name commonly used by the terminal operators, whereas the OFFROAD equipment type is used by the model to assign variable values such as load factor.
- Each matched equipment category had an assumed load factor in the OFFROAD model. These assumptions were compared to information gathered in the interview process on specific engines and equipment types to determine reasonableness.

Table 4.5 shows the OFFROAD categories used for each piece of equipment.

Table 4.5: Terminal and OFFROAD Equipment Type Cross-Reference

Survey Equipment Type	OFFROAD Equipment Type	OFFROAD Category
Crane	Crane	Construction
Forklift	Forklift	Industrial
Reach stacker	Other general industrial equipment	Industrial
RTG crane	Crane	Construction
Rubber tired loader	Rubber tired loader	Construction
Side loader	Other general industrial equipment	Industrial
Skid loader	Skid steer loader	Construction
Sweeper	Sweeper/Scrubber	Industrial
Top loader	Other general industrial equipment	Industrial
Yard tractor	Off highway truck	Construction

The modeling procedures discussed below are as reported by ARB. ARB stated in their model output summary that: "the emissions calculations were consistent with the OFFROAD methodology; averages for horsepower and usage were taken within the terminal, fuel type, and horsepower group for each equipment type; usage rates were assumed to be constant for each year; and, the sulfur content was assumed to be 500 ppm for diesel fuel." The diesel fuel actually used by the Port terminals may have lower sulfur content, but it was agreed to use the 500 ppm in the diesel calculation as a default for the 2001 baseline year. Additional research into the sulfur content of in-use fuels may refine the estimate of sulfur dioxide emissions for future inventories.

ARB has also separately confirmed that the model was run in "by-model year" mode, meaning that the model took into account emission factors for specific model year groups, and the number of pieces of equipment in each of these subgroups. The emission factors differ, for example, as emission standards have changed for more recent model years.

The ARB grouped each piece of equipment according to terminal, fuel type, and horsepower range using the following ranges:

- up to 25 hp
- 26 – 50 hp
- 51 – 120 hp
- 121 – 175 hp
- 176 – 250 hp
- 251 – 500 hp
- 501 – 750 hp
- 751 hp and up

Within the groups, ARB then averaged the horsepower and annual hours of use, and ran OFFROAD using these averages instead of the corresponding default OFFROAD values.

In general, off-road equipment emissions for a population of equipment would be estimated using the following equation. This equation is consistent with the publicly available model-related data that has been reviewed. The basic equation is:

$$E = EF * HP * LF * Act * FCF \qquad \text{Equation 7}$$

Where:

E = Emissions, in short tons
EF = Emission Factor, grams of pollutant per horsepower-hour (g/hp-hr)
HP = Average rated horsepower for the equipment type and horsepower category
LF = Load Factor (assumed average percentage of full load)
Act = Equipment activity, hours of use per year
FCF = Fuel Correction Factor

The emissions for a given year were internally calculated by multiplying the emission factor for the particular pollutant times the equipment horsepower times the load factor times the annual equipment hours of use for that year. The fuel correction factor which accounts for changes in the emission rates due to the use of Clean Diesel Fuel is applied, when applicable.

The emission factor can be reconstructed as a combination of the base emission factor for the equipment model year (g/hp-hr) plus a deterioration factor. The emission factor is calculated using Equation 8 below:

$$EF = EF_{BASE} + DF \qquad \text{Equation 8}$$

Where:

EF = Emission Factor, g/hp-hr

EF_{BASE}= Base Emission Factor for a given horsepower category and model year
DF = Deterioration Factor (estimate of emissions increase as an engine ages, expressed as g/hp-hr)

The deterioration factor is a means of accounting for changes in the emissions from engines as they accumulate hours of operation, and is based on certification testing of similar engines designed for on-road use. The equation for the deterioration factor is:

$$DF = DF_{BASE} * Act * Age \qquad \text{Equation 9}$$

Where:

DF = Deterioration Factor (expressed as g/hp-hr)
DF_{BASE} = Base Deterioration Factor (expressed as g/hp-hr^2)
Act = Equipment activity, hours of use per year
Age = Age of equipment in years

Model Output

The OFFROAD output file received from ARB consisted of several worksheets, one for each pollutant, plus a summary sheet. For each pollutant, the emissions were listed by equipment type, horsepower category, and terminal. The ARB provided emission estimates for the following pollutants for each terminal by equipment type and horsepower category:

- NO_X
- CO
- SO_2
- PM
- HC

The OFFROAD output reported emissions in grams per day (g/day) for each type of equipment by terminal and horsepower category. These were summed and the totals were converted from g/day to tons/day. Appendix C includes the OFFROAD output received from ARB with columns added for conversion to tons/day.

The terminals were separated into the various groups (container, dry/break bulk, liquid bulk, automarine, miscellaneous) in order to be able to summarize results for each type of terminal. The tons/year values are calculated by multiplying the tons/day values by 365 days/year. $PM_{2.5}$ has been estimated to be 92% of PM_{10}, and diesel particulate matter was estimated by subtracting the non-diesel emissions from the PM_{10} emission estimates. According to ARB, the HC value reported in the OFFROAD output is the value for total organic gases, TOG. Therefore, no conversion factor was applied to the reported HC value.

Note on OFFROAD/NONROAD Difference

The OFFROAD model was chosen for this study because it is the modeling tool used in California to estimate emissions from fleets of off-road equipment. The model is designed to estimate emissions based on average equipment activity for the entire State of California or subdivisions such as counties or air basins. In this study it was used to estimate emissions from a particular subset of equipment (i.e, port cargo handling equipment used at individual terminals) and, in some cases, the model predicted disproportionately high emissions for certain terminals when compared with other similarly sized terminals. This is believed to be largely due to the deterioration function. Container terminal cargo handling equipment fleets are high activity fleets, and pieces of equipment may be operated for up to 12 years with the same engine, at much higher annual utilization rates than seen in most off-road equipment. These kinds of fleets have advanced engine maintenance/servicing programs so as to keep the engines in service well beyond the certification/warranty requirements (e.g., over about 10,000 hours). The EPA's NONROAD model is designed to cap the increases in emissions due to deterioration after an engine reaches its median age, but the ARB's OFFROAD model will continue to deteriorate (increase) emissions for a longer period of time which may not be reflective of real conditions. (Median age is roughly equivalent to 50% of the engine's expected useful life, in hours, based on operation at 100% load factor.) At this time, there is insufficient in-use emissions data to determine whether the deterioration factor is more accurate in NONROAD versus OFFROAD.

In the course of this study, the NONROAD model was used to evaluate emissions from some of the same terminals as the OFFROAD model, and the NONROAD results were somewhat lower (an average 40% lower for the higher-activity fleets). Because of these model differences, it will be difficult to compare the Port's cargo handling equipment emissions estimates with those of a port in a different state that has used the EPA model for estimating emissions. However, the emission estimates will be comparable with other California ports that have used OFFROAD.

4.3 Emission Estimates

Based on the data collected and the methodology described above, emission estimates were developed by terminal type. The emission estimates for each pollutant are presented in tons per year and tons per day. The tons per day are an average annual day (i.e., tons per year divided by 365 days per year). A summary of the total CHE emission estimates by terminal type for the year 2001 is presented in Table 4.6.

Table 4.6: CHE Emissions by Terminal Type, tons

Terminal Type	NO_X	TOG	CO	PM_{10}	$PM_{2.5}$	DPM	SO_2
Container	1,513.9	163.3	520.9	91.4	84.1	91.4	36.5
Bulk	115.5	13.2	96.5	4.5	4.1	4.3	2.6
Liquid	1.3	0.2	2.3	0.01	0.01	0.0	0.03
Auto	1.8	0.4	4.2	0.01	0.0	0.0	0.04
Other	230.2	27.5	101.6	15.6	14.4	15.6	5.0
Totals, tpy	**1,862.6**	**204.5**	**725.5**	**111.6**	**102.6**	**111.4**	**44.1**
Totals, tpd	**5.10**	**0.56**	**1.99**	**0.31**	**0.28**	**0.31**	**0.12**

In addition to the Cruise terminal and the smaller facilities, the "Other" terminal type in the table above also includes the CHE emissions from the additional facilities northeast of the Port that are on Port-owned land. Since the northeastern sites are not contiguous to the Port, the CHE emissions are also separately summarized below.

Table 4.7: CHE Emissions for Additional Sites, tpy

Northern Site	NO_X	TOG	CO	PM_{10}	$PM_{2.5}$	DPM	SO_2
Totals, tpy	**215.1**	**25.7**	**88.5**	**15.0**	**13.8**	**15.0**	**4.7**
Totals, tpd	**0.59**	**0.07**	**0.24**	**0.04**	**0.04**	**0.04**	**0.01**

The automobile terminal includes emissions from cargo handling equipment and for the new cars that were unloaded from the vessels in 2001. The table below shows the total emissions from the new automobiles, which included 222,717 gasoline light duty autos (LDA), 33,205 gasoline light duty trucks (LDT-Gas), and 500 diesel light duty trucks (LDT-DSL).

Table 4.8: New Automobile Emissions, tpy

Vehicle Class	NO_X (tpy)	TOG (tpy)	CO (tpy)	PM_{10} (tpy)	$PM_{2.5}$ (tpy)	SO_2 (tpy)
LDA	0.1	0.1	0.8	0.0004	0.0003	0.001
LDT-Gas	0.03	0.05	0.5	0.0003	0.0003	0.0002
LDT-DSL	0.0004	0.0001	0.0003	0.00002	0.00002	0.00001
Totals	**0.11**	**0.14**	**1.33**	**0.001**	**0.0006**	**0.001**

The new vehicles travel an average of 0.5 miles at 15 mph from the ship to the parking area, to the shop for accessories or custom paint job, and to the loading area where they are parked until they are ready to be loaded unto trucks or rail. The following tables summarize the running and starting emission factors from the EMFAC2002 model.

Table 4.9: Running Emission Factors, grams/mile

Vehicle Class	NO_X (g/mi)	TOG (g/mi)	CO (g/mi)	PM_{10} (g/mi)	SO_2 (g/mi)
LDA	0.384	0.686	6.152	0.003	0.008
LDT-Gas	1.432	2.672	26.189	0.015	0.010
LDT-DSL	1.462	0.183	0.994	0.089	0.029

Table 4.10: Starting Emission Factors, grams/start

Vehicle Class	NO_X	TOG	CO	PM_{10}	SO_2
LDA	0.131	0.022	0.342	0.000	0.000
LDT-Gas	0.131	0.023	0.348	0.000	0.000
LDT-DSL	0.000	0.000	0.000	0.000	0.000

Table 4.11 below lists the evaporative emission factors used for TOG emissions for the new autos.

Table 4.11: Evaporative Emission Factors, grams/start and grams/mile

Vehicle Class	Start (g/start)	Run (g/mile)
LDA	0.002	0.001
LDT-Gas	0.003	0.001
LDT-DSL	0.000	0.000

The following sections present a breakdown of the various equipment contributions and further detail the findings of each of the above pollutants. CHE emissions were calculated by off-road equipment type however, the tables and figures in the following sections are organized by survey equipment type, the description commonly used by terminal operators. A cross-reference of off-road equipment type to survey equipment type appears in the previous Table 4.4. The figures are not as detailed as the corresponding tables, but offer a graphic summary of the main survey equipment types. The sweepers, skid steer loaders and aerial lifts have been grouped under miscellaneous equipment in the pie charts, but are presented individually in the tables. The emissions for cranes and RTG cranes cannot be shown separately since the model estimated the emissions by equipment type and these are in the same equipment type category. The majority of the cranes inventoried were RTG cranes (see Appendix C).

4.3.1 NO_x Emission Estimates

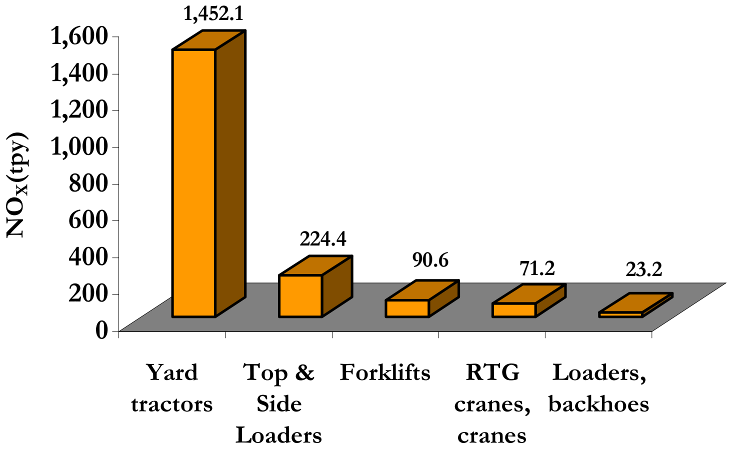
A breakdown of the NO_X emissions by survey equipment types for all the equipment inventoried is presented in Table 4.12 and Figure 4.14. The percentages in the table were rounded, and therefore do not add to 100%.

Table 4.12: CHE NO_X Emissions by Survey Equipment Types

Survey Equipment Types	NO_X (tpy)	NO_X (%)
Yard tractors	1,452.1	78
Top and Side loaders	224.4	12
Forklifts	90.6	5
RTG cranes, cranes	71.2	4
Loaders, backhoes	23.2	1
Sweepers	0.8	0.04
Skid loaders	0.2	0.01
Aerial lifts	0.1	0.01
Total	**1,862.5**	

The yard tractor emissions account for approximately 78% of the total NO_X emissions. Side loaders, top loaders, and reach stackers account for 12% of the total NO_X emissions. RTGs and conventional cranes account for approximately 4% of the total NO_X emissions. The NO_X emissions for forklifts comprise 5% of the total NO_X emissions. Tractors/loaders/backhoes account for approximately 1% of the total NO_X emissions. Less than 1% of the NO_X emissions are attributed to sweepers, skid steer loaders, and aerial platforms.

Figure 4.15: CHE NO_X Emissions by Major Survey Equipment Types, tpy



4.3.2 PM_{10}, $PM_{2.5}$, and DPM Emission Estimates

Yard tractors account for approximately 82% of the total PM emissions. Side loaders, top loaders, and reach stackers account for 10% of the PM emissions. LPG, gasoline and diesel powered forklifts account for 3% of the PM emissions. RTGs and other cranes account for just 3% of the PM emissions. Tractors, loaders, and backhoes account for approximately 1% of the PM emissions. Sweepers, skid loaders, and aerial lifts account for less than 1% of the total PM emissions. A breakdown of the PM_{10} and $PM_{2.5}$ emissions by survey equipment type inventoried is presented in Table 4.13 and Figures 4.16 and 4.17. The percent PM emissions in the table were rounded, and therefore may not add up to 100%.

Table 4.13: CHE PM Emissions by Survey Equipment Types, tpy

Survey Equipment Types	PM_{10} (tpy)	$PM_{2.5}$ (tpy)	DPM (tpy)	All PM (%)
Yard tractors	91.5	84.2	91.5	82
Top and Side loaders	11.2	10.4	11.2	10
Forklifts	3.8	3.5	3.5	3
RTG cranes, cranes	3.6	3.3	3.6	3
Loaders, backhoes	1.3	1.2	1.3	1
Sweepers	0.04	0.04	0.04	0.04
Skid loaders	0.02	0.02	0.02	0.02
Aerial lifts	0.005	0.004	0.005	0.004
Total	**111.4**	**102.5**	**111.2**	

Figure 4.16: CHE PM_{10} Emissions by Survey Equipment Type, tpy

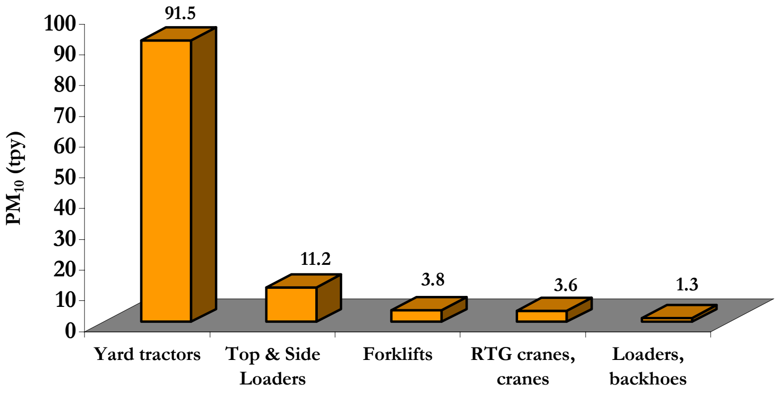
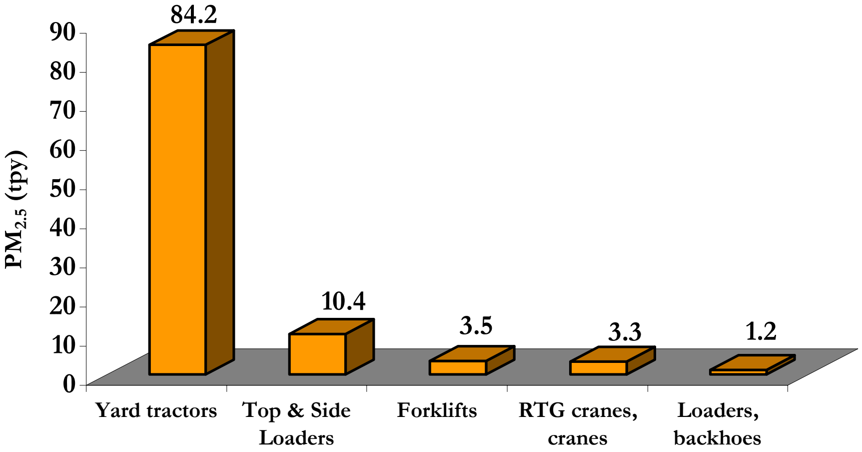


Figure 4.17: CHE $PM_{2.5}$ Emissions by Survey Equipment Type, tpy



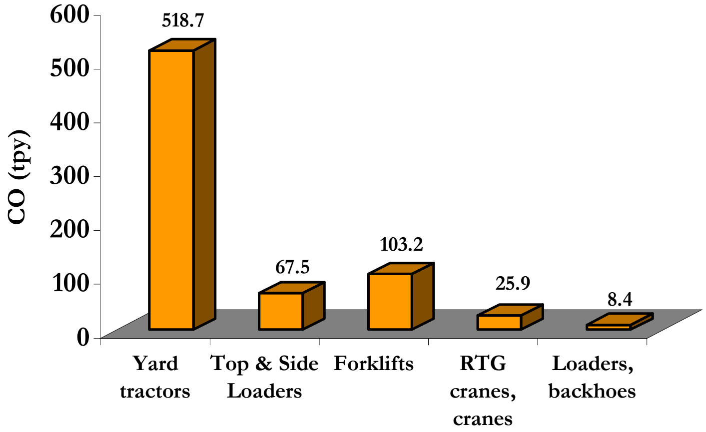
4.3.3 CO Emission Estimates

A breakdown of the CO emissions by survey equipment type category for all the equipment inventoried is presented in Table 4.14 and Figure 4.18. The percent CO emissions were rounded, and therefore do not add up to 100%.

Table 4.14: CHE CO Emissions by Survey Equipment Types, tpy

Survey Equipment Types	CO (tpy)	CO (%)
Yard tractors	518.7	72
Top and Side loaders	67.5	9
Forklifts	103.2	14
RTG cranes, cranes	25.9	4
Loaders, backhoes	8.4	1
Sweepers	0.3	0.05
Skid loaders	0.2	0.03
Aerial lifts	0.03	0.004
Total	**724.2**	

Figure 4.18: CHE CO Emissions by Survey Equipment Type, tpy



The yard tractor emissions account for approximately 72% of the total CO emissions. Side loaders, top loaders, and reach stackers account for approximately 9% of the total CO emissions. RTGs and conventional cranes account for approximately 4% of the total CO emissions. The CO emissions for forklifts comprise 14% of the total CO emissions. Tractors/loaders/backhoes account for approximately 1% of the total CO emissions. Less than 1% of the CO emissions are attributed to sweepers, skid steer loaders, and aerial platforms.

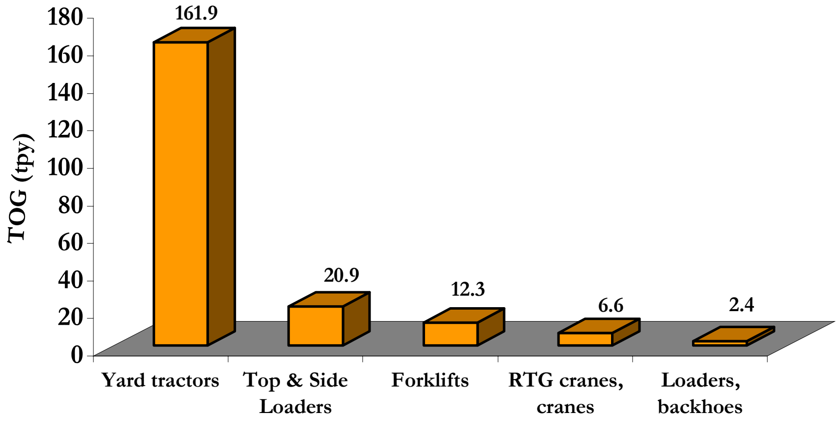
4.3.4 TOG Emission Estimates

A breakdown of the TOG emissions by survey equipment type for all the equipment inventoried is presented in Table 4.15 and Figure 4.19. The percent TOG emissions were rounded, and therefore do not add up to 100%.

Table 4.15: CHE TOG Emissions by Survey Equipment Types, tpy

Survey Equipment Types	TOG (tpy)	TOG (%)
Yard tractors	161.9	79
Top and Side loaders	20.9	10
Forklifts	12.3	6
RTG cranes, cranes	6.6	3
Loaders, backhoes	2.4	1
Sweepers	0.1	0.1
Skid loaders	0.1	0.05
Aerial lifts	0.0	0
Total	**204.4**	

Figure 4.19: CHE TOG Emissions by Survey Equipment Type, tpy



The yard tractor emissions account for approximately 79% of the total TOG emissions. Side loaders, top loaders, and reach stackers account for approximately 10% of the total TOG emissions. RTGs and conventional cranes account for approximately 3% of the total TOG emissions. The TOG emissions for forklifts comprise 6% of the total TOG emissions. Tractors/loaders/backhoes account for approximately 1% of the total TOG emissions. Approximately 1% of the TOG emissions are attributed to sweepers, skid steer loaders, and aerial platforms.

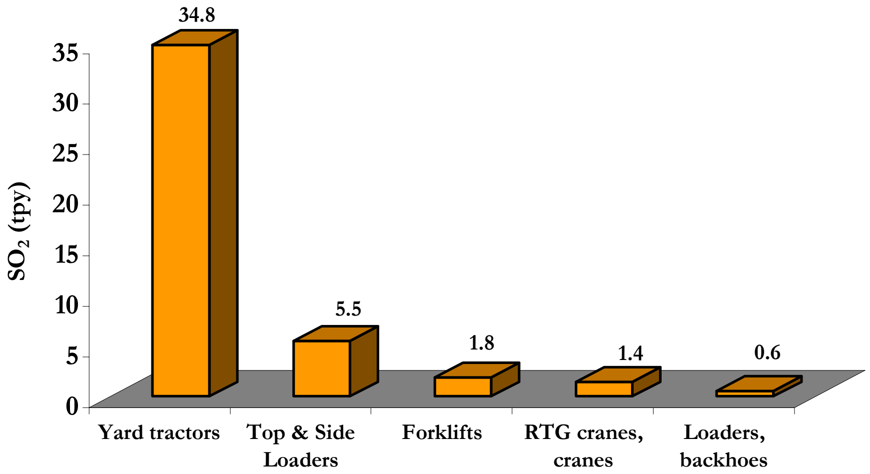
4.3.5 SO_2 Emission Estimates

A breakdown of the SO_2 emissions by survey equipment type for all the equipment inventoried is presented in Table 4.16 and Figure 4.20. The percent SO_2 emissions were rounded, and therefore do not add up to 100%.

Table 4.16: CHE SO_2 Emissions by Survey Equipment Types, tpy

Survey Equipment Types	SO_2 (tpy)	SO_2 (%)
Yard tractors	34.8	79
Top and Side loaders	5.5	12
Forklifts	1.8	4
RTG cranes, cranes	1.4	3
Loaders, backhoes	0.6	1
Sweepers	0.02	0.05
Skid loaders	0.01	0.02
Aerial lifts	0.002	0.005
Total	**44.1**	

Figure 4.20: CHE SO_2 by Survey Equipment Types, tpy

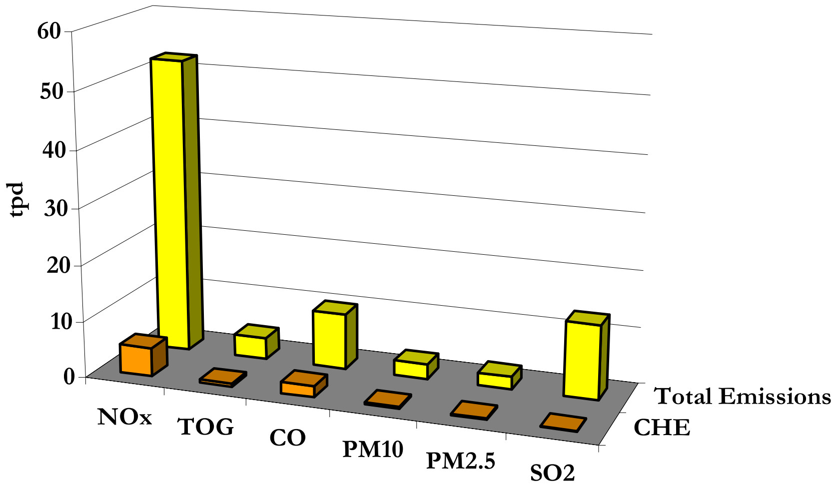


The yard tractor emissions account for approximately 79% of the total SO_2 emissions. Side loaders, top loaders, and reach stackers account for approximately 12% of the total SO_2 emissions. RTGs and conventional cranes account for approximately 3% of the total SO_2 emissions. The SO_2 emissions for forklifts comprise 4% of the total SO_2 emissions. Tractors/loaders/backhoes account for approximately 1% of the total SO_2 emissions. Less than 1% of the SO_2 emissions are attributed to sweepers, skid steer loaders, and aerial platforms.

4.4 Conclusions

Figure 4.21 compares the total CHE emissions in tons per day with the Port's total emissions. The Port's total emissions include the on-port and off-port emissions from the categories included in the EI: cargo handling equipment, locomoting, on-road trucks, commercial ocean-going vessels and harbor vessels. Cargo handling equipment operates only on port, whereas the other categories have off-port emissions associated with transporting Port-related cargo.

Figure 4.21: Comparison of CHE Emissions to the Port's Total Emissions, tpd



Attempting to estimate emissions from hundreds of pieces of off-road equipment, all operating under varying conditions, times, and operators has inherent limitations. This section discusses the strengths and limitations of the CHE portion of the emissions inventory.

Strengths

The greatest strength of the CHE EI was the level of granularity used in the collection of activity data. The activity data collection process was modified several times to help develop a high level of robustness. In addition, the overall approach is consistent with previous inventories of similar equipment found in California, such as those using the OFFROAD model.

Limitations

A key component of the emission calculations is the annual activity (hours of operation) of the equipment. This variable is used in two places in the emission calculations. One of these is Equation 7 presented in subsection 4.2.2: $E = EF * HP * LF * Act * FCF$, where "Act" is the annual hours of operation. The other is in the calculation of the deterioration factor that is added to the base emission factor, Equation 9 is also presented in subsection 4.2.2: $DF = DF_{BASE} * Act * Age$. One limitation of this method is the assumption that a piece of equipment has operated the same number of hours over its lifetime when, in fact, annual usage for any particular piece of equipment may vary. Another limitation relates to the deterioration factor equation – this equation assumes that the emission increase due to deterioration continues in a linear fashion for the life of the equipment. In equipment that is used intensively, such as much of the container terminals' CHE, this may result in unrealistically high emission estimates. In order to maximize the use of their equipment and achieve the high utilization reported by the terminals (up to 4,000 hours per year for some equipment), the terminals have implemented effective maintenance programs that enable the equipment to operate for longer lifetimes than the typical off-road equipment fleets for which the OFFROAD model was developed. Additional in-use emission testing is required to accurately modify the deterioration factor equation.

While the activity-based approach utilized for this emissions inventory helps to minimize uncertainties in such parameters as equipment population, activity, horsepower, and age, the emission factors and load factors may not precisely reflect the parameters of specific engines included in the Port terminals' equipment fleets. However, more specific information on emission factors and load factors was not available.

SECTION 5 RAILROAD LOCOMOTIVES

This section discusses the rail systems that operate in and around the Port, including the types of activities performed, the equipment used, and the methods of estimating emissions. Different methods have been used for different types of activity to make best use of the information that was made available by the various railroads operating in the Port. This section provides further details of the emission estimating methodology and results/findings for this source category.

5.1 Description of Rail System and Locomotives

Railroad operations are typically described in terms of two different types of operation, line haul and switching. Line haul refers to the movement of cargo over long distances (e.g., cross-country) and occurs within the Port as the initiation or termination of a line haul trip, as cargo is either picked up for transport to destinations across the country or is dropped off for shipment overseas. Switching refers to the assembling and disassembling of trains at various locations in and around the Port, sorting of the cars of inbound cargo trains into contiguous “fragments” for subsequent delivery to terminals, and the short distance hauling of rail cargo within the Port. It is important to recognize that “outbound” rail freight is cargo that has arrived on vessels and is being shipped to locations across the U.S., whereas “inbound” rail freight is destined for shipment out of the Port by vessel. This is contrary to the usual port terminology of cargo off-loaded from vessels referred to as “inbound” and that loaded onto vessels as “outbound.”

Locomotives used for line haul operations are typically large, powerful engines of 3,000 hp or more, while switch engines are smaller, typically having 1,200 to 3,000 hp. Older line haul locomotives have often been converted to switch duty as newer line haul locomotives with more horsepower have become available.

The Port is served by three railway companies:

- Burlington Northern and Santa Fe (BNSF)
- Union Pacific (UP)
- Pacific Harbor Line (PHL)

These railroads transport dry bulk, liquid bulk, car-load (box car), and intermodal (containerized) freight. PHL performs most of the switching operations within the Port, while BNSF and UP provide line haul service to and from Port and also provide limited switching services at their off-port locations.

The locomotive section of the EI presents an estimate of emissions associated with Port-related activities of the locomotives operating within the Port and outside the Port to the boundary of the SoCAB. Information regarding these operations has been obtained through interviews with railroad operators and others with knowledge of rail activities associated with the Port.

Figure 5.1 illustrates the rail track system serving both ports, and Figure 5.2 presents a broader view of the major rail routes in the air basin that are used to move Port-related intermodal cargo.

Figure 5.1: Port Area Rail Lines

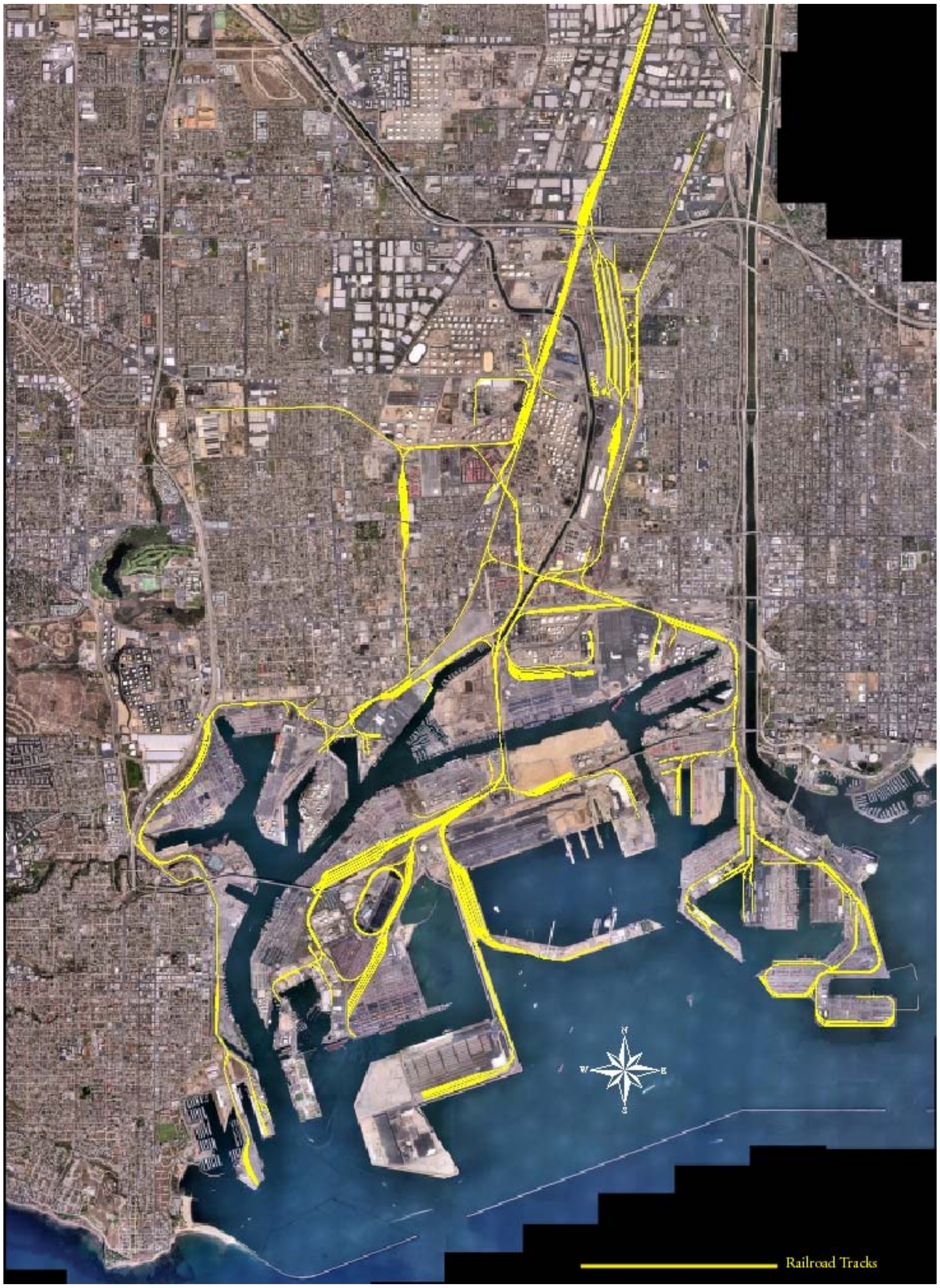


Figure 5.2: Air Basin Major Intermodal Rail Routes

5.1.1 Rail System Description and Operational Characteristics

The rail system is described below in terms of the activities that are undertaken by locomotive operators. Specifically, descriptions are provided for the assembly of outbound trains, the disassembly of inbound trains, and the performance of switching operations, as well as a detailed listing of the activities of line haul and switching operations.

Outbound Trains

The assembly of outbound trains occurs in one of three ways. Container terminals with sufficient track space build trains on-terminal, using flat cars that have remained on site after the off-loading of inbound containers or those brought in by one of the railroads. Alternatively, containers can be trucked (drayed) to an off-terminal transfer facility where the containers are transferred from truck chassis to railcar. A third option is for the terminal to store individual railcars or build a partial train on-terminal, to be collected later by a railroad (typically PHL) and moved to a rail yard with sufficient track to build an entire train.

Within the Port, complete trains can be built at the terminals servicing Yang Ming and American Presidents Line (APL). In addition, the Terminal Island Container Transfer Facility (TICTF) is shared by NYK and Evergreen as a location to build trains. Trains are also built outside of the Port at the Watson Yard, the Dolores Yard, and the Manuel Yard, and at locations within the POLB. If containers to be transported by rail are not loaded onto railcars at the Port, they are typically hauled by truck (drayed) to off-port locations operated by the line haul railroads. The containers are loaded onto railcars at these locations.

Inbound Trains

In-bound trains that carry cargo (or empty containers) that are all destined for the same terminal are delivered directly to the terminal by the line haul railroad if the receiving terminal has the track space to accommodate all of the cars at one time (i.e., the TICTF). Trains carrying cargo that is bound for multiple terminals with one or both Ports are staged by the line haul railroads at several locations, where they are broken up, typically by PHL, and delivered to their destination terminals. Inbound trains are also dropped off at the Watson Yard, the ICTF, the Dolores Yard, and the Manuel Yard.

Switching

Switching locomotives deliver and pick up railcars transporting containers, liquid and dry bulk materials, and general cargo to and from terminals at the Port. Switching operations take place around the clock, seven days per week, although weekend activity is generally lower than weekday or weeknight activity.

PHL is the primary switching railroad at the Port. PHL operations are organized into scheduled shifts, each shift being dispatched to do specified tasks in shift-specific areas. For example, there is a daily shift that operates on the west side of the Port, servicing liquid bulk terminals and storage facilities in that area. As another example, another daily shift operates in the POLB servicing the Toyota import terminal and various other non-container terminals in the POLB. Other shifts move empty or laden container flat cars to and from container terminals. Much of the work involves rearranging the order of railcars in a train to organize cars bound for the same destinations (inbound or outbound) into contiguous segments of the train, and to ensure proper train dynamics. Train dynamics can include, for example, locating railcars carrying hazardous materials the appropriate minimum distance from the locomotives, and properly distributing the train's weight. Although there is a defined schedule of shifts that perform the same basic tasks, there is little consistency or predictability to the work performed during a given shift or at a particular time.

Specific Activities

Locomotive activities of the line haul railway companies consist of:

- Delivering inbound trains (and/or empty railcars) to terminals or to the nearby rail yards, using line haul locomotives.
- Picking up trains from the terminals or nearby rail yards and transporting them to destinations across the country, using line haul locomotives.
- Breaking up inbound trains and sorting rail cars into contiguous fragments, and delivering the fragments to terminals, using switch locomotives.

Locomotive switching activities consist of:

- Breaking up inbound trains and sorting railcars into contiguous fragments, and delivering the fragments to terminals.
- Delivering empty container flat cars to terminals.
- Delivering rail cars to non-container facilities, and removing previously delivered rail cars. For example, delivering full tank cars to a terminal that ships product and removing empties, or delivering empty tank cars to a terminal that receives product and removing full ones.
- Rearranging full and empty railcars to facilitate loading by a terminal. For example, one break bulk terminal has two loading tracks and two storage tracks. BNSF delivers empty flat cars and positions four equal sets of the empty cars on the four tracks. After the terminal has loaded cargo onto the cars located on the loading tracks, PHL switches the full cars onto the storage tracks and the empty cars onto the loading tracks. After the terminal has completed loading the second set of empty rail cars, BNSF returns and picks up the train for transport out of the Port.
- Picking up outbound containers in less than full train configuration and transporting them to a yard for assembly into full trains to be transported out of the Port by one of the line haul railroads.

5.1.2 Description of Locomotives

Physical and operational characteristics of the locomotives operating at the Port are discussed in the following paragraphs. Locomotives operate differently from other types of mobile sources with respect to how they transmit power from engine to wheels. While most mobile sources use a physical coupling such as a transmission to transfer power from the engine to the wheels, a locomotive's engine turns a generator or alternator powering an electric motor that, in turn, powers the locomotive's wheels. The physical connection of a typical mobile source means that the engine's speed is dictated by the vehicle's speed through a fixed set of gear ratios, resulting in the highly transient operating conditions (particularly engine speed and load) that characterize mobile source operations. In contrast, the locomotive's engine and drive system operate more independently, such that the engine can be operated at a particular speed without respect to the speed of the locomotive itself. This allows operation under more steady-state load and speed conditions, and as a result locomotives have been designed to operate in a series of discrete throttle settings called notches, ranging from notch positions one through eight, plus an idle position.

Many locomotives also have a feature known as dynamic braking, in which the electric drive engine operates as a generator to help slow the locomotive, with the resistance-generated power being dissipated as heat. While the engine is not generating motive power under dynamic braking, it is generating power to run cooling fans, so this operating condition is somewhat different from idling. Switch engines typically do not feature dynamic braking.

Line Haul Locomotives

Line haul locomotives are operated in the Port by BNSF and UP. Because the function of line haul locomotives is to transport freight to and from destinations across the country, there is no readily identifiable "fleet" of line haul locomotives that call on the Port other than the railroads' nation-wide fleets.

The characteristics of BNSF line haul locomotives operating within the Port have been estimated from a sampling of BNSF locomotives that called on the Port area in 2001 – BNSF provided this sample of locomotives as being representative of their line haul locomotives calling on the Port. The sample of locomotives, primarily the 6-axle GE C44-9W (also known as Dash 9s) has an average of 4,256 hp.

Basic specifications of UP locomotives have been obtained from the railroad's Internet website.[49] The UP website lists approximately 6,500 line haul locomotives in the company's nation-wide fleet, with an average power rating of 3,655 horsepower. Most of the locomotives (78%) are six-axle units, the remainder (22%) being 4-axle units. Six-axle locomotives are generally more powerful than four-axle locomotives. Most of the UP locomotives calling on the POLB are six-axle, 4,000-horsepower Electromotive Division (EMD) SD70s.

Line haul locomotives are typically operated in groups of two to five units, with three or four units being most common, depending on the power requirements of the specific train being pulled and the horsepower capacities of available locomotives. Thus, two higher-horsepower locomotives may be able to pull a train that would take three units with lower power outputs. Locomotives operated in sets are connected such that every engine in the set is operated in unison by an engineer in one of the locomotives.

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[49] See *http://www.uprr.com.*

Switching Locomotives

Most switching within the Port is conducted by PHL. The line haul companies also conduct switching at their off-port locations. At times, PHL personnel operate BNSF or UP switch locomotives. PHL's fleet in 2001 consisted of 13 switch engines ranging from 1,200 to 2,000 hp, with an average of 1,573 hp. While the PHL fleet consists of several models, all are powered by 12- or 16-cylinder EMD engines.

The other railroads also operate switch engines in and around the POLB, primarily at their switching yards outside of the Port. Table 5.1 lists the switch engines that have been reported as working in the area. They are typically powered by EMD engines, with an average power rating of 2,167 hp.

Table 5.1: Typical On and Off-Port Switching Locomotives

Locomotive Model	Engine Mfr	Engine Model	Horsepower (each)
SW-1200	EMD	12-567-C	1,200
SW-1200	EMD	12-567-BC	1,200
GP-7	EMD	16-567-BC	1,500
GP-9	EMD	16-567-C	1,750
SD-18	EMD	16-567-D3	1,800
SD-20	EMD	16-567-D1	2,000
SD-20	EMD	16-645-CE	2,000
GP-7	EMD	not known	1,500
GP-9	EMD	not known	1,750
GP-30	EMD	not known	2,250
GP-38	EMD	not known	not known
GP-39-2	EMD	not known	2,300
SD-40	EMD	not known	3,000

5.2 Methodology

The following section provides a discussion of how railroad and locomotive data were collected and a detailed description of the methods used to estimate emission. Additional information is provided in Appendix D.

5.2.1 Data Collection

PHL provided data in the form of files downloaded from their locomotives' electronic event recorders. Similar to the "black boxes" installed in aircraft, the event recorders maintain a record of several locomotive operating parameters on a second-by-second basis, including throttle notch setting, locomotive speed, and direction of travel. The recorders have limited storage capacity and typically maintain two to three days of data with the oldest data being overwritten as new data is accumulated. PHL provided a download from each of its locomotives covering the same approximate 2-day period of operation.

In addition to providing event recorder data, PHL also allowed access to their switch engines as they operated. The Port's consultant rode along with the switching crew on seven of the 24 shifts, covering all hours of operation and most areas of the Port to gain an understanding of the work performed and the types of cargo handled.

The line haul railway companies also provided information on their switch engines, including representative fuel usage, as well as emissions data, limited throttle notch data for switching and line haul locomotives, and detailed out-of-Port cargo information (in terms of tons of cargo and fuel usage). In addition, railroad personnel were interviewed for an overview of their operations in the area. As stated previously, certain information related to line haul locomotive fleets has been obtained from railroad companies' Internet websites. Additionally, terminal operators have provided information on their rail operations that provides an additional level of understanding of overall line haul rail operations.

5.2.2 Emission Estimation

Emissions have been estimated using the information provided by the railroads and the terminals, and from information sources such as the EPA's Regulatory Support Document (RSD) published as background to EPA's locomotive rule-making process.[50] For in-Port switching operations, the throttle notch data and schedule/operational information provided by the switching companies has been used along with EPA data on emission rates by throttle notch. Off-Port switching emissions have been estimated using throttle notch, emissions, and fuel use data provided by one of the railroad companies. For the limited line haul operations in the Port, emission estimates have been based on schedule and throughput information provided by terminal operators and on EPA operational and emission factors. Off-Port line haul emissions have been estimated using detailed cargo movement and fuel use information provided by the line haul railroads.

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[50] EPA Office of Mobile Sources, April 1998, revised. *Locomotive Emission Standards Regulatory Support Document.*

The throttle notch setting approach to estimating locomotive emissions has been selected as the preferred method because it is expected to provide better spatial resolution than alternative approaches, which will enhance the value of the emission estimates for subsequent use in health assessments. However, specific throttle notch information has only been provided for switching operations. Therefore, throttle notch information published by EPA and described below has been used to estimate line haul emissions.

A detailed explanation of emission calculation methods is presented in the following section, and back-up data tables are presented in Appendix D.

5.3 Emission Estimates

A summary of estimated emissions from locomotive operations in the Port is presented below in Table 5.2. These emissions include operations within the Port and port-related emissions out to the boundary of the SoCAB, including the Watson, Dolores, and Manuel Yards and the ICTF.

Table 5.2: Port Locomotive Operations Estimated Emissions

	NO_X	TOG	CO	PM_{10}	$PM_{2.5}$	DPM	SO_2
In-port Switching	171.9	7.2	16.5	3.7	3.4	3.7	1.0
Out-of-Port Switching	121.4	7.5	12.8	3.1	2.8	3.1	0.7
In-Port Line Haul	274.0	9.8	33.1	6.2	5.7	6.2	2.1
Out-of-Port Line Haul	1,898.5	75.2	187.0	47.1	43.3	47.1	86.0
Totals (tpy)	**2,465.8**	**99.8**	**249.4**	**60.1**	**55.3**	**60.1**	**89.8**
Totals (tpd)	**6.76**	**0.27**	**0.68**	**0.16**	**0.15**	**0.16**	**0.25**

In the table above, "In-Port Switching" refers to emissions from switch locomotives operating within the Port boundaries, and "Out-of-Port Switching" includes emissions from switch locomotives operated at rail yards close to the Port, such as the Watson, Dolores, and Manuel yards. "In-Port Line Haul" refers to emissions from locomotives of the line haul railroads as they operate within the Port boundaries. "Out-of-Port Line Haul" refers to emissions from line haul locomotives moving cargo to or from Port within the SoCAB.

In relation to total land-based on-port emissions, locomotive emissions make up approximately 14% of NO_X emissions, and less than 10% of the emissions of the other pollutants evaluated in this study. When comparing port-related emissions within the air basin, locomotive emissions make up approximately 28% of NO_X emissions, over half the SO_2 emissions, and between 14% and 25% of the emissions of the other pollutants. Emissions of SO_2 are relatively higher than SO_2 emissions from the other segments of the inventory because it has been assumed that line haul locomotives burn a percentage of regular high-sulfur off-road diesel fuel (because they may be fueled outside California before coming to the Port). The sulfur content of regular off-road diesel fuel has been assumed to average 3,300 ppm, while California diesel has been assumed to average 330 ppm. One of the line haul railroads reported that they purchase 35% California diesel and 65% regular diesel, although this percentage is not limited to the fuel actually used in the Port area. However, in the absence of more detailed information, this breakdown of high- versus low-sulfur fuels has been used to develop the line haul emission estimates.

Daily on-port emissions of the three land-based components of the emissions inventory are presented in Table 5.3, while Table 5.4 presents daily Port-related emissions within the air basin. The data presented in these tables is illustrated in Figures 5.3 and 5.4.

Table 5.3: Comparison of Estimated-on-Port Emissions, tpd

	NO_X	TOG	CO	PM_{10}	$PM_{2.5}$	DPM	SO_2
On-Port Rail	1.22	0.05	0.14	0.03	0.02	0.03	0.01
On-Road	2.39	0.14	0.68	0.07	0.06	0.07	0.01
Off-Road (CHE)	5.10	0.56	1.99	0.31	0.28	0.31	0.12
Totals, tpd	**8.71**	**0.75**	**2.80**	**0.40**	**0.37**	**0.40**	**0.14**
Rail % of totals	**14%**	**6%**	**5%**	**7%**	**7%**	**7%**	**6%**

Figure 5.3: Comparison of Estimated On-Port Emissions, tpd

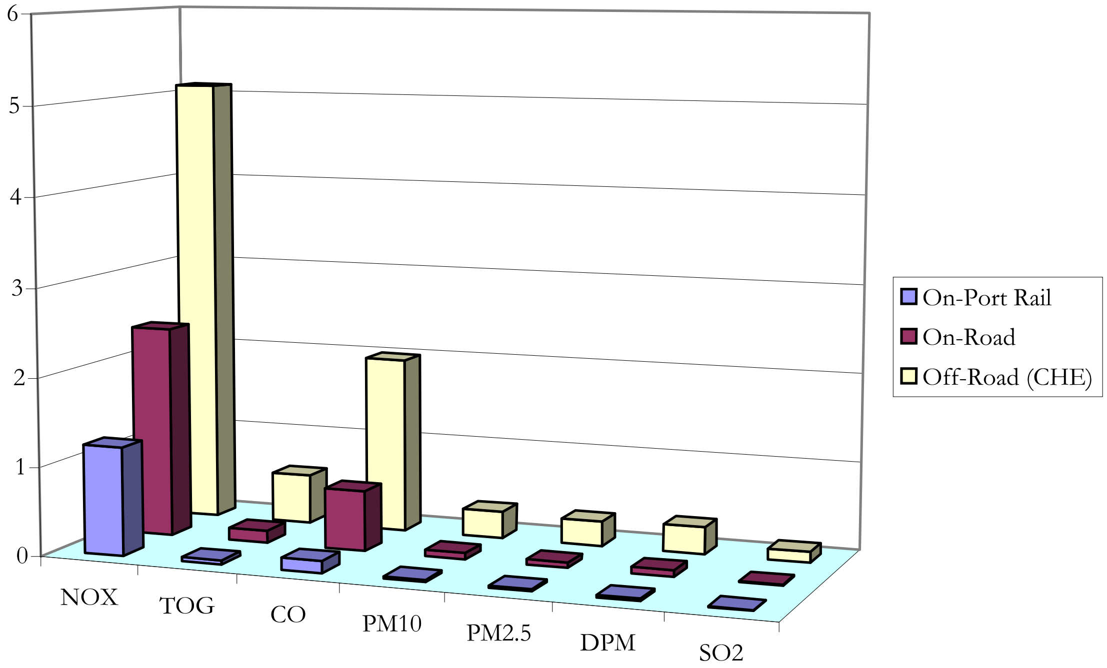
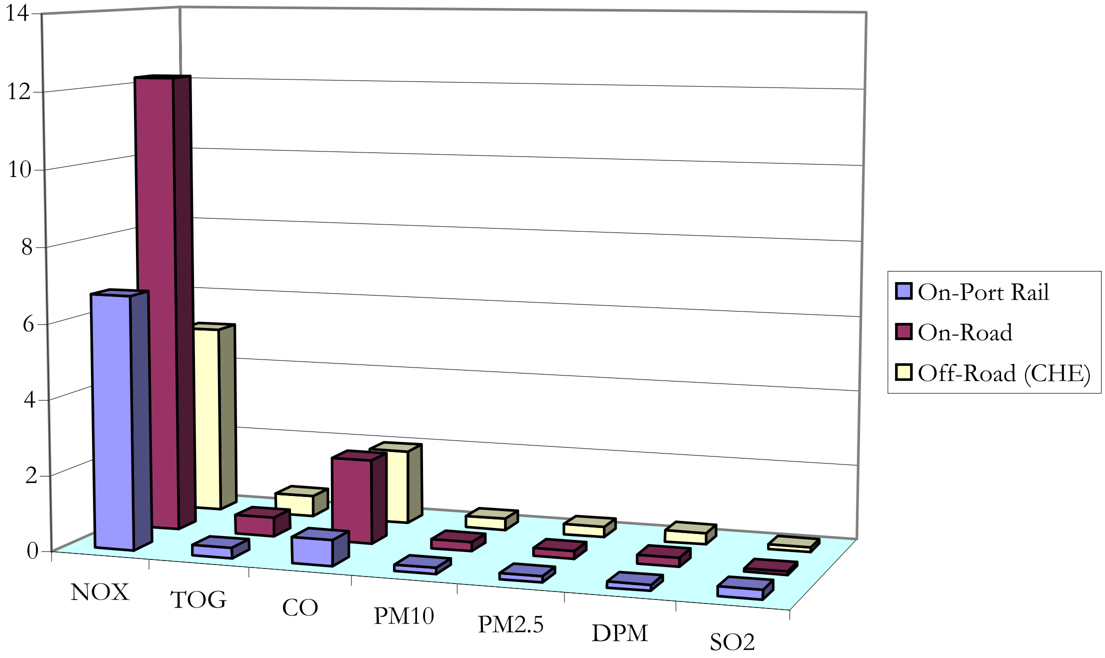


Table 5.4: Comparison of Estimated Port Emissions in Air Basin, tpd

	NO_X	TOG	CO	PM_{10}	$PM_{2.5}$	DPM	SO_2
Rail	6.76	0.27	0.68	0.16	0.15	0.16	0.25
On-Road	12.23	0.51	2.23	0.24	0.21	0.24	0.09
Off-Road (CHE)	5.10	0.56	1.99	0.31	0.28	0.31	0.12
Totals, tpd	**24.09**	**1.34**	**4.91**	**0.71**	**0.65**	**0.71**	**0.46**
Rail % of totals	**28%**	**20%**	**14%**	**23%**	**23%**	**23%**	**54%**

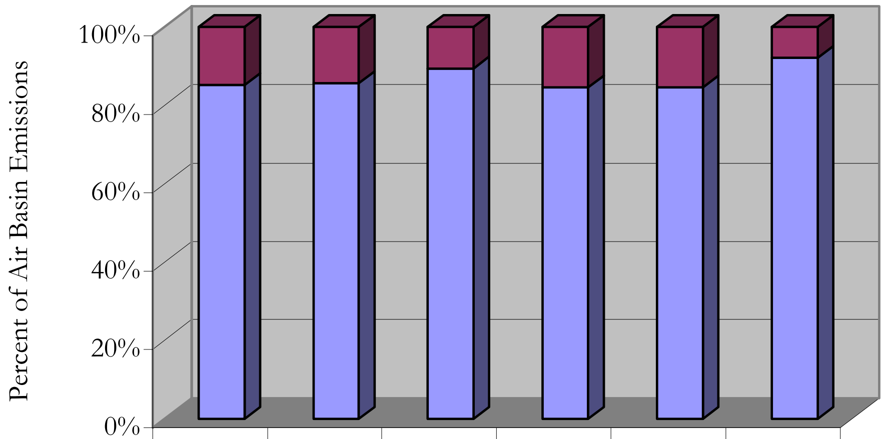
Figure 5.4: Comparison of Estimated Port Emissions in Air Basin, tpd



As a general comparison, Figure 5.5 shows the estimated total Port-related locomotive emissions as a percentage of the estimated basin-wide locomotive emissions included in the SCAQMD's 1997 baseline emissions inventory.[51] The percentages range from 18% for PM_{10} and $PM_{2.5}$ to 9% for SO_2. The lower percentage of SO_2 may be due to different fuel mix assumptions or it may be due to changes in the fuel sulfur content between the 1997 baseline period and the 2001 Port study period. Additional study of recent and current locomotive fuel use in the Los Angeles area would help to clarify this difference.

The comparison shown in Figure 5.5 relates 2001 estimated emissions with the 1997 baseline, so the actual percentages may have been somewhat different in 2001. In addition, the Port-related emissions shown in the figure are only those associated with the Port of Los Angeles.

Figure 5.5: Port-Related Locomotive Emissions Compared with Air Basin Locomotive Emissions



	NOx	TOG	CO	PM10	PM2.5	SO2
Port-Related Emissions (2001)	6.76	0.27	0.68	0.16	0.15	0.25
AQMP 1997 Baseline Emissions	38.86	1.64	5.79	0.907	0.834	2.88

Emissions from rail operations have been calculated using information provided by the railroads and the terminals, and from published EPA documents including the RSD (previously cited) and *Technical Highlights – Emission Factors for Locomotives.*[52] These publications were issued in support and clarification of EPA's locomotive emissions rule.

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[51] SCAQMD, August 2003. *Final 2003 Air Quality Management Plan (AQMP), Appendix III, Attachment F, Table F-1*; see *http://www.aqmd.gov/aqmp/AQMD03AQMP.htm*

[52] EPA Office of Mobile Sources, December 1997. *Technical Highlights – Emission Factors for Locomotives,* EPA420-F-97-051

Different calculation methods were required because different types of information were provided for different activities. For example, an activity and throttle notch-based approach has been used for one company's switching emissions, whereas a fuel use-based approach has been used for another. These methods are described below.

5.3.1 Switching Emissions

Separate emission estimates have been prepared for the companies that provide switching services within and near the Port based on the information each company provided. Estimation methods differ because the companies provided different types of information, as described below.

Switching Emission Estimation Method 1

Emissions from the first company's switching operations have been based on the railroad company's schedule of operations and site-specific throttle notch frequencies, and emission factors from the EPA documents cited above.

First, the characteristics of the railroad company's fleet operating in 2001 were evaluated to develop a fleet average horsepower rating. Because several locomotives normally operate as coupled pairs, these pairs were considered as one "locomotive" when developing the averages. Table 5.5 lists the "in-use" rated horsepower characteristics of this company's 2001 fleet.

Table 5.5: In-use Horsepower Characteristics of Switch Locomotives

Locomotive Model	Number	Horsepower Each	Horsepower Total
Pair of SW-1200s	2	2,400	4,800
Single SW-1200	1	1,200	1,200
SD-18	4	1,800	7,200
SD-20	2	2,000	4,000
GP-7/GP-9 Pair	1	3,250	3,250
Total	10		20,450
Average locomotive horsepower:			**2,045**

Next, the average notch-specific horsepower values for the "average" switch locomotive operated by this company have been calculated by multiplying the average rated horsepower value by notch-specific percentages derived from the EPA's RSD cited above. The percentages represent the fraction of total rated horsepower that is produced in each throttle setting. This process is illustrated in the example below, for throttle notch setting 1, with results for all throttle settings shown in Table 5.6.

83 hp / 1,750 hp = 0.047, or 4.7%

2,045 hp x 0.047 = 96 hp

In this example, the average notch 1 power in the RSD data is 83 hp, which is divided by the average rated power of the locomotives tested for the RSD, 1,750 hp. The result is 0.047, or 4.7%; this means that 4.7% of the power of the average locomotive (in the RSD dataset) is used at throttle notch position 1. The next step is to multiply the average horsepower rating of the locomotives doing switch duty at the Port (2,045 hp) by the percentage of power used by the RSD locomotives. This result is 96 hp, meaning that the switch engines in use at the Port use an average of 96 hp while in throttle notch position 1.

This calculation is repeated for each throttle notch position, as shown in Table 5.6.

Table 5.6: Calculation of Notch-Specific In-Use Horsepower

Notch	RSD Power in Notch, bhp	% of Avg. Rated bhp	Avg. in-use Power, bhp
DB	67	3.8%	78
Idle	14	0.8%	16
1	83	4.7%	96
2	249	14.2%	290
3	487	27.8%	569
4	735	42.0%	859
5	1,002	57.3%	1,172
6	1,268	72.5%	1,483
7	1,570	89.7%	1,834
8	1,843	105.3%	2,153
Average RSD hp:	1,750	Avg. local hp:	2,045

(Note: in these tables, “DB” refers to “dynamic braking,” a feature of some locomotives’ operation that does not apply to this switching locomotive fleet. The term is included because it is part of the published EPA data set.)

The next step is to develop notch-weighted hourly emission rates, first by using the in-use horsepower values described above to convert the RSD average switching emission rates from grams per horsepower-hour (g/hp-hr) to pounds per hour (lbs/hr). The conversion is calculated as follows:

$$(\text{g/hp-hr} \times \text{hp}) / (453.6\ \text{g/lb}) = \text{lb/hr}$$

The two sets of emission rates (g/hp-hr and lb/hr) are presented in Tables 5.7 and 5.8, where the values in Table 5.8 have been obtained by multiplying those in Table 5.7 by the in-use horsepower figures presented in Table 5.6.

For example, for NO_X emissions and throttle notch setting 1, the Table 5.7 value of 17.92 g/bhp-hr is multiplied by the notch position 1 horsepower value of 96 hp in Table 5.6 and divided by 453.6 g/lb to result in an estimate of 3.79 lb/hr as shown in Table 5.8. This calculation is repeated for each throttle notch position, as shown in Table 5.8.

Table 5.7: Horsepower-Based Emission Factors from RSD

Notch	HC g/bhp-hr	CO g/bhp-hr	NO_x g/bhp-hr	PM g/bhp-hr
DB	2.68	6.76	41.48	0.84
I	7.44	15.47	74.47	2.30
1	1.27	2.50	17.92	0.32
2	0.48	1.28	12.47	0.33
3	0.33	0.75	13.40	0.31
4	0.30	0.54	14.45	0.24
5	0.32	0.50	15.30	0.23
6	0.33	0.62	16.05	0.28
7	0.37	1.25	16.16	0.25
8	0.40	2.74	15.76	0.28

Table 5.8: Hourly Notch-Specific Emission Rates

Notch	HC lb/hr	CO lb/hr	NO_X lb/hr	PM lb/hr	SO_2 lb/hr
DB	0.46	1.16	7.13	0.14	0.02
Idle	0.26	0.55	2.63	0.08	0.004
1	0.27	0.53	3.79	0.07	0.02
2	0.30	0.82	7.97	0.21	0.06
3	0.41	0.94	16.81	0.39	0.13
4	0.56	1.02	27.36	0.46	0.19
5	0.81	1.28	39.52	0.59	0.26
6	1.08	2.03	52.46	0.92	0.33
7	1.50	5.05	65.34	1.03	0.41
8	1.90	12.98	74.78	1.35	0.48

Table 5.8 also includes hourly emission rates of SO_2 that have been estimated on the basis of a mass balance approach and a typical fuel sulfur content of 350 ppm by weight. The mass balance approach assumes that the sulfur (S) in the fuel is converted to SO_2 and emitted during the combustion process. The following example shows the calculation for throttle notch position 1.

$$\frac{350\text{ lbs S}}{1{,}000{,}000\text{ lbs fuel}} \times \frac{0.336\text{ lbs fuel}}{\text{hp-hr}} \times \frac{2\text{ lbs SO}_2}{\text{lb S}} \times 96\text{ hp} = 0.02\text{ lbs SO}_2/\text{hr}$$

In this calculation, 330 ppm S is written as 350 lbs S per million lbs of fuel. The value of 0.336 lbs fuel/hp-hr is an average brake-specific fuel consumption derived from EPA's technical literature on locomotive emission factors. Two pounds of SO_2 is emitted for each pound of sulfur in the fuel because the atomic weight of sulfur is 32 while that of SO_2 is 64, meaning that the weight doubles when expressed as SO_2. Finally, the average in-use horsepower value for throttle notch position 1 is 96 hp, as presented in Table 5.6. This calculation was carried out for each throttle notch position; the results are shown in Table 5.8.

A notch-weighted average emission rate is estimated using time-in-notch percentages developed from the event recorder data provided by the switching company. Each hourly value in Table 5.8 is multiplied by the percentage corresponding to the respective notch setting. The percentages and resulting fractional emission rates are shown in Table 5.9. Because the time-in-notch fractions together represent all of the locomotives' operating time, the products obtained from the multiplication of pounds per hour by time fraction can be summed to provide a notch-weighted hourly emission rate that is representative of the average locomotive (or pair of locomotives) operating with an average site-specific throttle notch distribution.

Continuing the example of NO_X emissions for throttle notch position 1, the 3.79 lb/hr from Table 5.8 is multiplied by the notch position 1 percentage of 5.9% (or 0.059) listed in Table 5.9 under "wt'd avg % in mode" to obtain the value of 0.22.

$$3.79 \text{ lb/hr} \times 0.059 = 0.22$$

Each of the hourly rates in Table 5.8 is similarly multiplied by the percentage corresponding to each throttle notch position. The results are summed for each pollutant to calculate weighted average emission rates.

Table 5.9: Time-in-Notch and Weighted Average Emission Rates

Notch	wt'd avg % in mode	HC % x lb/hr	CO % x lb/hr	NO_X % x lb/hr	PM % x lb/hr	SO_2 % x lb/hr
DB	0.0%	0.00	0.00	0.00	0.00	0.000
Idle	67.4%	0.18	0.37	1.77	0.05	0.002
1	5.9%	0.02	0.03	0.22	0.004	0.001
2	7.7%	0.02	0.06	0.61	0.02	0.005
3	6.7%	0.03	0.06	1.13	0.03	0.008
4	5.3%	0.03	0.05	1.44	0.02	0.010
5	3.0%	0.02	0.04	1.19	0.02	0.008
6	2.0%	0.02	0.04	1.07	0.02	0.007
7	0.9%	0.01	0.05	0.60	0.01	0.004
8	1.1%	0.02	0.14	0.82	0.01	0.005
Weighted average lb/hr		**0.35**	**0.85**	**8.87**	**0.19**	**0.05**

An estimate of the operating hours of these switching locomotives has been developed by evaluating the number and duration of work shifts. The schedule of shifts is well defined, with 23 shifts per day during the week, and 20 per day on weekends. While shifts may last up to 12 hours (the federally mandated limit for railroad crews) they are usually shorter. An average of 8 hours per weekday shift has been assumed based on an evaluation of shift duration records. Because weekend shifts are reportedly shorter, 4 hours has been assumed for Saturday and Sunday shifts because weekend shifts are reportedly shorter than weekday shifts. These assumptions provide the basis of an estimate of annual hours of locomotive operation, as presented in Table 5.10. (Company staff has noted that locomotives are shut off when they are not in use, so shift operations represent the appropriate measure of operating time.)

Table 5.10: Estimate of Annual Switching Locomotive Hours of Operation

	Operating Shifts/day	Approx. Operating hours/shift	Operating hours/day (shifts/day x hours/shift)
Weekdays	23	8	184
Saturdays	20	4	80
Sundays	20	4	80
Operating hrs/week			1,080
Operating hrs/year (52 wks/year)			**56,160**

PHL operates within both the Port of Los Angeles and the Port of Long Beach. While some of the shifts are focused on activities in only one of the ports, such as the 17:00 West Basin shift that normally switches non-container railcars on the west side of the Port, other shifts may work in either or both ports depending upon the day's needs for switching services. Therefore, it is not possible to clearly designate which shifts operate solely within the Port of Los Angeles so a method is required for apportioning emissions between the two ports. To do this, the shifts have been evaluated as to whether they are likely to work in either port exclusively or in both ports. If a shift could work in both ports it is assumed that, on average, each port receives an equal amount of time. In this manner, a value of "1" "0.5" or "0" has been assigned to each port for each shift, as shown in Table 5.11. The sum of the values for each port was used to estimate the distribution of activity between the two ports.

Table 5.11: Estimate of Distribution of Emissions Between Ports

Shift Name	Start Time	Days	Port of Los Angeles	Port of Long Beach
BNSF	0:01	Every day	0.5	0.5
UP	0:01	Every day	0.5	0.5
APL	1:30	Every day	1	0
BNSF	2:00	Every day	0.5	0.5
Pier A / IC switcher	3:00	Mon-Sat (off Sun)	1	0
Pier A switcher	8:00	Every day	1	0
BNSF dock	8:00	Sat/Sun	0.5	0.5
Hanjin	10:00	Mon-Fri (off Sat/Sun)	0	1
BNSF dock	10:00	Every day	0.5	0.5
Yang Ming	10:00	Tues-Sun (03:00 Monday)	1	0
BNSF dock / Pier 400	10:30	Every day	1	0
NYK	10:30	Sun-Fri (off Sat)	1	0
TICTF	10:30	Every day	1	0
UP	12:01	Every day	0.5	0.5
Long Beach	13:00	Mon-Fri (off Sat/Sun)	0	1
APL	14:00	Every day	1	0
BNSF dock	14:30	Every day	0.5	0.5
BNSF dock	15:30	Every day	0.5	0.5
West Basin	17:00	Every day	1	0
Manual / Terminal Island	18:00	Mon-Fri (off Sat/Sun)	0.5	0.5
NYK switcher	20:00	Sat-Thur (off Fri)	1	0
DAS switcher	20:00	Every day	1	0
BNSF dock	22:30	Every day	0.5	0.5
UP dock	22:30	Every day	0.5	0.5
Total			16.5	7.5
Percentage of emissions apportioned to each port:			**69%**	**31%**

=As the final step, emissions from the locomotives attributable to the Port have been calculated by multiplying the hourly notch-weighted emission rates shown in Table 5.9 by the annual operating hours shown in Table 5.10 and the Port activity percentage from Table 5.11. The results are shown in Table 5.12. For example, the CO emission rate of 0.85 lb/hr multiplied by 56,160 hours/year (from Table 5.10) and the 69% Port fraction (from Table 5.11), and divided by 2,000 lbs/ton, results in the 16.5 tons per year shown in Table 5.12.

$$\frac{0.85\ \text{lb/hr} \times 56{,}160\ \text{hr/yr} \times 0.69}{2{,}000\ \text{lb/ton}} = 16.5\ \text{tpy}$$

The HC emission rate presented in Table 5.9 has been converted to total organic gases using a conversion factor of 1.07 (HC x 1.07 = TOG), as recommended by EPA, FTNT in (EPA420-P-03-002, *Conversion Factors for Hydrocarbon Emission Components*, May 2003). In addition, while EPA's RSD does not include emission factors for SO_2, Table 5.12 also includes an estimate of SO_2 emissions based on PHL's reported use of EPA on-road diesel fuel, which has been assumed to have a sulfur content of 330 ppm.

Table 5.12: Estimated Switching Emissions for the Port

	NO_X	TOG	CO	PM_{10}	$PM_{2.5}$	DPM	SO_2
Totals (tpy)	**171.9**	**7.2**	**16.5**	**3.7**	**3.4**	**3.7**	**1.0**
Totals (tpd)	**0.47**	**0.02**	**0.05**	**0.01**	**0.01**	**0.01**	**0.003**

Note: All particulate emissions are assumed to be PM_{10} and diesel particulate matter (DPM); $PM_{2.5}$ emissions have been estimated as 92% of PM_{10} emissions.

To evaluate the relative accuracy of these estimates, the amount of fuel that would be required to operate the estimated number of hours was calculated and compared with the switching company's reported fuel usage of approximately 45,000 gallons per month. Expected fuel consumption was determined by multiplying the number of hours per year by the estimated in-use horsepower and by a fuel consumption factor derived from EPA's *Technical Highlights* document cited previously. The in-use horsepower was estimated by multiplying the notch-specific horsepower estimates presented in Table 5.6 by the percent time-in-notch values in Table 5.9 – and summing the notch-specific results. This procedure estimated an average of 229 hp as illustrated in Table 5.13.

Table 5.13: Calculation of Average In-Use Horsepower

Notch	wt'd avg % in mode	Avg. in-use Power, bhp	% x bhp
DB	0.0%	79	0.0
Idle	67.4%	16	11.0
1	5.9%	97	5.7
2	7.7%	291	22.4
3	6.7%	569	38.2
4	5.3%	859	45.3
5	3.0%	1,171	35.4
6	2.0%	1,482	30.3
7	0.9%	1,835	16.9
8	1.1%	2,154	23.5
Weighted average horsepower			**229**

The fuel-use factor (gallons of fuel per horsepower-hour, gal/hp-hr) was derived from the EPA emission factors by dividing their gram/horsepower-hour emission factors by their gram/gallon emission factors. The results were consistently 0.048 gal/hp-hr. (Although these fuel use factors, known as brake-specific fuel consumption, or BSFC, vary by engine type and by engine operating conditions, this value is typical of diesel engine BSFC values.)

The product of annual hours, in-use horsepower, and BSFC predict the annual and monthly fuel consumption amounts illustrated in Table 5.14. The predicted monthly amount is approximately 14% higher than the 45,000 gallon-per-month figure provided by the switching company, indicating fairly good agreement and a conservatively high emission estimate.

Table 5.14: Fuel Use Estimate for In-Port Switching

Factor	Value	Explanation
Weighted avg. operating horsepower	228	(sum of hp in notch x % time in notch)
Brake-specific fuel consumption, gal/hp-hr	0.048	(derived from EPA's technical literature on locomotive emission factors)
Estimated fuel use, gals/year	614,615	(hp x operating hours x gal/hp-hr)
Estimated fuel use, gals/month	51,218	(annual fuel use estimate /12 months/year)
Reported actual fuel use, gals/month	45,000	(reported by switching railroad)
Difference, %	14%	(estimated - reported) /reported

Switching Emission Estimation Method 2

BNSF and UP operate switching locomotives at their off-port rail yards to help make up the trains that are hauled out of the air basin.

One railroad provided a refueling record of two to three months for their locomotives operating in the off-Port yard and elsewhere in the air basin. Expected annual fuel use has been extrapolated from this record and the average annual per-locomotive estimated fuel usage has been used to estimate emissions from the locomotives operating in the off-port rail yards. The refueling record and estimate of annual fuel use are presented in Table 5.15. Annual fuel use was estimated for each locomotive individually, then summed to estimate fuel usage for all 12 of this company's locomotives. The following method was used to estimate annual fuel use:

1) The number of days between refueling events was calculated by subtracting the dates of each two consecutive refueling events; for example, a fueling event on 6/20 followed by a fueling event on 6/27 would be calculated as 7 days of use between fueling events.

2) The amount of fuel presumed to be used during the period between refueling events was calculated by subtracting the "pre-fill" volume of each refueling event from the "ending" volume of the previous refueling event; for the 7 days mentioned above, the pre-fill volume of zero gallons on 6/27 (empty tank) was subtracted from the 6/20 ending volume of 900 gallons, to indicate that 900 gallons of fuel was used over the seven days between 6/20 and 6/27. (The locomotive's fuel tank held 900 gallons after being filled on 6/20 and held 0 gallons by 6/27 when it was refilled.) In a few cases, the ending volume was less than the following pre-fill volume, for unknown reasons. These anomalies were not factored into the fuel use estimates, but are indicated in Table 3.14 by grey shading.

3) The average daily volume of fuel used for each period was calculated by dividing the volume of fuel (step 2) by the number of days (step 1);

4) The average daily volume for each locomotive was calculated by dividing the sum of the volumes for that locomotive by the sum of the days; for example, a locomotive was indicated by the record to use 4,920 gallons over 50 days – the average daily usage for that locomotive was calculated to be 4,920/50 = 98.4 gallons per day.

5) The projected annual volume for each locomotive was calculated by multiplying the average daily volume by 365 days per year; for the locomotive discussed above, the annual rate would be calculated as 98.4 x 365 = 35,916 gallons per year.

The projected annual fuel use values for the 12 locomotives for which data was provided were added together to provide an estimate of fuel usage for the 12 locomotives. Six locomotives are shown as being primarily or exclusively fueled in the off-port rail yard– it has been assumed that six locomotives normally operate within this yard although not necessarily the same six. This is seen as a reasonable method of apportioning activity based on fuel consumption without access to detailed locomotive movement information. The estimated fuel usage per locomotive was calculated as the total for all 12 locomotives divided by 12.

It should be noted that the estimated fuel usage of one locomotive, the SD-40 listed last in Table 5.15, is much higher than is considered to be normal switch engine fuel use. This estimate is approximately 127,000 gallons per year, whereas normal fuel use is considered to be around 45,000 gallons per year per locomotive. No cause for this anomaly has been identified and the number has been used in the calculation of the overall average. This may mean that the estimated average fuel consumption may be biased high, producing higher emission estimates.

Rail cargo from both the Port of Los Angeles and the Port of Long Beach are handled at this off-Port yard, and the complexities of the rail system are such that apportionment of activity (and emissions) between the two ports is difficult. However, an evaluation of port cargo throughputs indicates that approximately 55% of the containers passing through the off-port rail yards are associated with the Port of Los Angeles. This assumption can be refined as additional information on rail activities becomes available. Regardless of apportionment, the sum of the two ports' emissions represents all of the estimated switching emissions from locomotives operated at the off-Port rail yard.

Table 5.15: Off-Port Rail Yard Locomotive Fuel Use Record

Locomotive	Date	Location	Pre-Fill (Gallons)	Ending	Days of Use	Gallons Used	Gallons per Day	Projected Gals per Year
EMD GP-7	7/25/03	POLA/POLB area		1,200				
1500 HP	7/29/03	POLA/POLB area	750		4	450	113	
					total:		average:	
					4	450	113	41,063
EMD GP-7	6/25/03	POLA/POLB area		700				
1500 HP	7/1/03	POLA/POLB area	800	1,600	6	-100		
	7/8/03	POLA/POLB area	0	850	7	1,600	229	
	7/15/03	POLA/POLB area	200	500	7	650	93	
	7/19/03	POLA/POLB area	0	1,265	4	500	125	
	7/31/03	POLA/POLB area	200		12	1,065	89	
					total:		average:	
					30	3,815	127	46,416
EMD GP-9	6/9/03	POLA/POLB area		900				
1750 HP	6/15/03	POLA/POLB area	200	1,200	6	700	117	
	6/20/03	POLA/POLB area	200	900	5	1,000	200	
	6/27/03	POLA/POLB area	0	1,100	7	900	129	
	7/7/03	POLA/POLB area	0	1,100	10	1,100	110	
	7/25/03	POLA/POLB area	705	1,200	18	395	22	
	7/29/03	POLA/POLB area	375		4	825	206	
					total:		average:	
					50	4,920	98	35,916
EMD GP-30	4/6/03	Kaiser		1,800				
2250 HP	4/13/03	Kaiser	600	1,400	7	1,200	171	
	5/14/03	Riverbank	700	2,100	31	700	23	
	7/29/03	POLA/POLB area	1,335		76	765	10	
					total:		average:	
					114	2,665	23	8,533
EMD GP-39-2	6/9/03	POLA/POLB area		2,000				
2300 HP	6/15/03	POLA/POLB area	1,200	2,300	6	800	133	
	6/20/03	POLA/POLB area	1,600	2,000	5	700	140	
	6/27/03	POLA/POLB area	1,200	2,200	7	800	114	
	7/3/03	POLA/POLB area	1,600	2,100	6	600	100	
	7/7/03	POLA/POLB area	1,800		4	300	75	
					total:		average:	
					28	3,200	114	41,714
EMD GP-39-2	5/2/03	Stockton		1,800				
2300 HP	5/19/03	POLA/POLB area	2,355	2,900	17	-555		
	6/24/03	POLA/POLB area	200	2,200	36	2,700	75	
	7/1/03	POLA/POLB area	600	1,500	7	1,600	229	
	7/15/03	POLA/POLB area	200	2,200	14	1,300	93	
	7/19/03	POLA/POLB area	2,085		4	115	29	
					total:		average:	
					61	5,715	94	34,196
EMD GP-39-2	4/6/03	Kaiser		2,200				
2300 HP	4/13/03	Kaiser	1,600	2,400	7	600	86	
	4/27/03	Kaiser	1,350	2,400	14	1,050	75	
	5/11/03	Kaiser	2,500	3,200	14	-100		
	5/18/03	Kaiser	2,050	2,600	7	1,150	164	
	5/25/03	Kaiser	200	400	7	2,400	343	
	6/19/03	POLA/POLB area	2,200	2,400	25	-1,800		
	6/28/03	POLA/POLB area	1,050	2,350	9	1,350	150	
	7/14/03	POLA/POLB area	400		16	1,950	122	
					total:		average:	
					60	8,500	142	51,708

Table 5.15: Off-Port Rail Yard Locomotive Fuel Use Record (cont'd)

Locomotive	Date	Location	Pre-Fill (Gallons)	Ending	Days of Use	Gallons Used	Gallons per Day	Projected Gals per Year
EMD GP-30	6/23/03	San Bernadino		2,200				
2250 HP	7/12/03	San Bernadino	1,500	3,550	19	700	37	
	7/16/03	San Bernadino	1,750	2,300	4	1,800	450	
	7/20/03	San Bernadino	1,400		4	900	225	
					total:		average:	
					27	3,400	126	45,963
EMD GP-30	5/25/03	Kaiser		2,200				
2250 HP	6/1/03	Kaiser	1,750	2,400	7	450	64	
	6/8/03	Kaiser	1,350	2,300	7	1,050	150	
	6/15/03	San Bernadino	1,400	2,300	7	900	129	
	6/22/03	Kaiser	1,000	1,000	7	1,300	186	
	6/29/03	Kaiser	1,600	2,400	7	-600		
	7/6/03	Kaiser	1,500	2,300	7	900	129	
	7/13/03	Kaiser	1,400	2,300	7	900	129	
	7/20/03	Kaiser	1,200		7	1,100	157	
					total:		average:	
					49	6,600	135	49,163
EMD GP-39-2	4/2/03	POLA/POLB area		3,000				
2300 HP	4/16/03	POLA/POLB area	500	2,600	14	2,500	179	
	4/27/03	Kaiser	1,700	3,000	11	900	82	
	5/11/03	Kaiser	2,350	3,300	14	650	46	
	5/18/03	Kaiser	2,350	3,000	7	950	136	
	5/25/03	Kaiser	2,900	3,100	7	100	14	
	6/1/03	Kaiser	2,800	3,500	7	300	43	
	6/8/03	Kaiser	2,100	2,500	7	1,400	200	
	6/15/03	San Bernadino	2,000	2,500	7	500	71	
	6/22/03	Kaiser	1,700	3,000	7	800	114	
	6/29/03	Kaiser	2,400	3,000	7	600	86	
	7/6/03	Kaiser	2,600	3,000	7	400	57	
	7/13/03	Kaiser	1,900		7	1,100	157	
					total:		average:	
					102	10,200	100	36,500
EMD GP-39-2	4/25/03	Corona		2,600				
2300 HP	5/8/03	Corona	1,000	2,200	13	1,600	123	
	5/31/03	Corona	350	2,500	23	1,850	80	
	6/19/03	Corona	700		19	1,800	95	
					total:		average:	
					55	5,250	95	34,841
EMD SD-40	4/3/03	San Bernadino		3,600				
3000 HP	4/6/03	San Bernadino	1,500	2,800	3	2,100	700	
	4/14/03	San Bernadino	0	1,700	8	2,800	350	
	4/15/03	San Bernadino	1,950	2,900	1	-250		
	4/18/03	San Bernadino	2,500	3,600	3	400	133	
	4/28/03	San Bernadino	600	3,200	10	3,000	300	
	5/4/03	San Bernadino	400	3,300	6	2,800	467	
	5/9/03	San Bernadino	2,200		5	1,100	220	
					total:		average:	
					35	12,200	349	127,229
Total								**553,242**

Emission factors based on fuel use have been obtained from EPA's *Locomotive Rule Technical Highlights*, Table 3. These are EPA's "baseline" emission factors that do not take into account the effects of EPA's recent locomotive emission control rules affecting new and rebuilt locomotives. These appear to be the appropriate emission factors since switch engines are generally older, and lacking detailed information from the railroads the assumption must be made that the locomotives have not been rebuilt to meet the new standards.

A second switching yard operates north of the Port. The company operating this yard has reported that three sets of two locomotives work at the yard. In the absence of more detailed information, it has been assumed that these locomotives perform at a level of activity equivalent to as the switching locomotives at the other yard and that their fuel usage and emission levels are equivalent. Table 5.16 illustrates the factors going into the estimate of fuel use for off-Port switching activity apportioned to the Port, for both railroads, while Table 5.17 shows the emission factors and estimated emissions.

Table 5.16: Switching Activity – Fuel Use at the Off-Port Rail Yard

Factor	Value	Notes
Projected fuel use for 12 locomotives:	553,242	gals/year
Average per-locomotive fuel use:	46,104	gals/year
Locomotives working rail yard	6	(based on fuel use record)
Annual switching yard fuel use:	276,621	gals/year
Percentage supporting Port of LA	55%	based on what is known of terminals served
Annual fuel apportioned to Port of LA	152,142	gals/year
Extrapolation to 2nd line haul railroad	152,142	gals/year additional

Table 5.17: Estimated Off-Port Rail Yard Emissions

	NO_X	TOG	CO	PM_{10}	$PM_{2.5}$	DPM	SO_2
Baseline EFs, g/gal	362	22.5	38.1	9.2	na	na	2.2
Emissions, tpy	**121.4**	**7.5**	**12.8**	**3.1**	**2.8**	**3.1**	**0.7**
Emissions, tpd	**0.33**	**0.02**	**0.04**	**0.01**	**0.01**	**0.01**	**0.00**

The emission estimates listed above were calculated by multiplying the emission factor listed in Table 5.17 by the total estimated annual fuel use shown for both railroads in Table 5.16. The resulting emission estimates (in grams per year) were divided by 453.6 grams per pound and 2,000 pounds per ton to produce the ton-per-year estimates, which were then divided by 365 days per year to produce the daily emission estimate.

For example, for CO emissions within the rail yard:

$$\frac{38.1\text{ g/gal} \times (152{,}142 + 152{,}142)\text{ gal/year}}{453.6\text{g/lb} \times 2{,}000\text{ lb/ton}} = 12.8\text{ tpy}$$

The HC emission rate published by EPA has been converted to TOG using a conversion factor of 1.07 as previously noted.

5.3.2 Line Haul Emissions

Emissions from line haul locomotives operating in the Port have been estimated on an activity basis, i.e., estimates of the number and characteristics of locomotives that arrive and depart with cargo. The information used in developing these estimates has been obtained from the line haul railroad companies and the Port terminals.

The number of locomotive trips in the Port has been estimated by evaluating cargo movements, percentage of cargo transported by rail, and typical number of locomotives per train. Locomotive characteristics were primarily obtained from the locomotive information discussed in Subsection 5.1.2 of this report, and from information reported by the line haul railroad companies.

Emission factors have been taken from EPA's RSD throttle notch-specific data, as shown on Table 5.18. This table also lists the average percentage of rated power in each throttle notch setting for the locomotives listed in the RSD. These percentages represent the fraction of total rated horsepower that is produced in each throttle setting.

Table 5.18: EPA Line Haul Locomotive Data

Notch	RSD Average Line Haul Locomotive EFs NO_x g/bhp-hr	HC g/bhp-hr	CO g/bhp-hr	PM g/bhp-hr	RSD % of Power in Notch, bhp
DB	53.65	6.89	9.90	2.82	2.1%
Idle	90.68	14.71	27.86	4.67	0.4%
1	13.68	1.05	1.47	0.45	5.0%
2	11.98	0.47	0.95	0.37	11.4%
3	11.49	0.36	0.93	0.37	23.5%
4	11.90	0.27	1.15	0.26	34.3%
5	12.05	0.25	1.41	0.22	48.1%
6	11.86	0.24	1.57	0.23	64.3%
7	11.72	0.25	1.46	0.20	86.6%
8	11.32	0.25	1.22	0.21	102.5%

The average notch-specific horsepower values for a typical line haul locomotive calling on the Port have been calculated by multiplying the assumed typical rated horsepower value by the RSD notch-specific percentages (shown on Table 5.18). The results of this process are illustrated in Table 5.19. This table also shows the result of converting the RSD average line haul emission rates from g/hp-hr to lbs/hr for the locomotive horsepower noted on Table 5.19.

The equation described for the switch engine calculations (Method 1) was used. For example, RSD data indicate line haul locomotives use 5.0% of their rated hp at notch position 1. This percentage is multiplied by the 4,250 hp of the typical line haul locomotive to estimate the 213 horsepower shown for notch position 1 on Table 5.19. Next, the CO notch 1 value of 1.47 g/hp-hr in Table 5.18 is multiplied by 213 hp and divided by 453.6 g/lb to produce the estimate of 0.69 lb/hr shown in Table 5.19 for notch position 1 under CO. These calculations are carried out for each of the throttle notch positions and pollutants to produce notch-specific emission rates.

Table 5.19: Port Notch-Specific Emission Rates

Notch	Power in Notch, bhp	NO_x lb/hr	HC lb/hr	CO lb/hr	PM lb/hr	SO_2 lb/hr
DB	89	10.53	1.35	1.94	0.55	0.02
Idle	17	3.40	0.55	1.04	0.18	0.00
1	213	6.42	0.49	0.69	0.21	0.05
2	485	12.81	0.50	1.02	0.40	0.11
3	999	25.31	0.79	2.05	0.81	0.22
4	1,458	38.25	0.87	3.70	0.84	0.32
5	2,044	54.30	1.13	6.35	0.99	0.45
6	2,733	71.46	1.45	9.46	1.39	0.61
7	3,681	95.11	2.03	11.85	1.62	0.82
8	4,356	108.71	2.40	11.72	2.02	0.97

Based on: 4,250 horsepower per line haul locomotive

In the next step, a notch-weighted average emission rate is estimated using time-in-notch percentages published by EPA in their RSD. It should be noted that the published throttle notch percentages for line haul activity probably include more time at the higher notch settings than is representative of in-port operation. More representative throttle notch percentages could be used to improve these calculations but this information has not been available from the railroads.

Each hourly value in Table 5.19 has been multiplied by the time percentage corresponding to the respective notch setting. The percentages and resulting fractional emission rates are shown in Table 5.20. Because the time-in-notch fractions represent all of the locomotive operating time, the products obtained from the multiplication of pounds per hour by time fraction can be summed to provide a notch-weighted hourly emission rate that is representative of the average line haul locomotive operating with an average throttle notch distribution.

For example, the 0.69 lb/hr value for CO in notch position 1 shown in Table 5.19 is multiplied by the 6.5% shown in Table 5.20 for notch position 1; the result is 0.04 as shown in Table 5.20 in the CO column in the notch position 1 line. The same calculation is carried out for all the pollutants and notch positions. For each pollutant, these numbers are summed to calculate the weighted or composite emission rates shown at the bottom of Table 5.20.

Table 5.20: Line Haul Time-in-Notch and Weighted Average Emission Rates

Notch	RSD avg. % in mode	NO_X lb/hr x %	HC lb/hr x %	CO lb/hr x %	PM lb/hr x %	SO_2 lb/hr x %
DB	12.5%	1.32	0.17	0.24	0.07	0.00
Idle	38.0%	1.29	0.21	0.40	0.07	0.00
1	6.5%	0.42	0.03	0.04	0.01	0.00
2	6.5%	0.83	0.03	0.07	0.03	0.01
3	5.2%	1.32	0.04	0.11	0.04	0.01
4	4.4%	1.68	0.04	0.16	0.04	0.01
5	3.8%	2.06	0.04	0.24	0.04	0.02
6	3.9%	2.79	0.06	0.37	0.05	0.02
7	3.0%	2.85	0.06	0.36	0.05	0.02
8	16.2%	17.61	0.39	1.90	0.33	0.16
Composite Emission Rates:		**32.17**	**1.07**	**3.89**	**0.73**	**0.25**

An estimate of the number of hours that line haul locomotives from both line haul railroads spend in the Port has been based on terminal throughputs, percentages of cargo by rail, and the railroad's descriptions of their operations. This estimate is presented in Table 5.21.

Table 5.21: Port Line Haul Locomotive Activity Estimate

Activity Measure	Inbound	Outbound	Totals
# of Trains per Year	1,402	2,597	3,999
# of Locomotives per Train	3	2.6	
Hours on Port per Trip	1.0	1.9	
Hours on Port per Year	4,205	12,831	17,036

Emission estimates have been calculated by multiplying the total number of locomotive hours per year by the hourly composite per-locomotive emission rates presented in Table 5.20. These estimates are presented in Table 5.22.

For example, the CO composite rate is 3.88 lbs/hr, which is multiplied by 17,035 hours per year and divided by 2,000 lbs/ton, resulting in the CO emission estimate of 33.1 tpy shown in table 5.22.

The HC emission rate presented in Table 5.20 has been converted to TOG using a conversion factor of 1.07 as previously noted.

Table 5.22: In-Port Line Haul Locomotive Emission Estimates

	NO_X	TOG	CO	PM_{10}	$PM_{2.5}$	DPM	SO_2
Emission rates, lb/hr	32.17	1.14	3.89	0.73	0.67	0.73	0.25
Totals (tpy)	**274.0**	**9.8**	**33.1**	**6.2**	**5.7**	**6.2**	**2.1**
Totals (tpd)	**0.75**	**0.03**	**0.09**	**0.02**	**0.02**	**0.02**	**0.01**

Out-of-Port Line Haul Emissions

Out-of-port line haul emission estimates have been developed on the basis of detailed tonnage and fuel use estimates provided by BNSF and UP. The railroads provided detailed data sets that report the distance, fuel consumption, and freight tonnage between mileposts, eastbound and westbound, on their line segments within the SoCAB. The line segments leading to and from the Port and the boundary of the air basin at Cajon Pass were included in the emission estimates.

The fuel consumption and freight tonnage data includes all freight that was transported, whether port-related or not. However, freight carried on tracks that originate or terminate at the ports is assumed to be associated with either the Port or POLB. In addition, a certain amount of freight added in central LA is port-related freight that has been drayed from both ports. Emissions have been calculated for line haul to/from both ports, then apportioned between the two ports based on what is known of cargo throughput percentages.

Table 5.23 summarizes the freight figures for both railroads over the routes used to transport intermodal freight out of the air basin. This table shows, for each railroad, a section of track, its distance in miles, the average tonnage (total and port-related) hauled over that distance during 2001, and the total ton-miles associated with the section of track. The tonnage is shown as millions of gross tons (MMGT), which includes the weight of cargo plus rail equipment such as railcars and locomotives. The overall measure of freight transport is millions of gross ton-miles (MMGTM), which is calculated by multiplying MMGT by miles.

In 2001, BNSF transported freight to and from the Port over a route that runs from the Port toward Torrance and El Segundo, then curves back to central LA and BNSF's intermodal yard, where additional containerized freight is loaded onto railcars. From there, the route goes to San Bernardino, then out of the air basin to the north over Cajon Pass, approximately following the route of Interstate Highway 40 out of California to the east. The railroads do not differentiate the specific port of origin or destination of the tonnage in these records, so at this stage of the evaluation freight associated with both ports is included. The freight hauled between the Port and central LA is assumed to be originating or terminating at either the Port or the POLB (14.5 MMGT eastbound, or out of the ports, and 10.4 MMGT westbound, or into the ports).

Table 5.23: Line Haul Distance and Tonnage Summary

Railroad	Route	Track Length Miles	Avg. Total Eastbound MMGT	Avg. Total Westbound MMGT	Ports Avg. Eastbound MMGT	Ports Avg. Westbound MMGT	Ports Total MMGTM
BNSF	Ports to Central LA	28.4	14.5	10.4	14.5	10.4	707
BNSF	Central LA to San Bernardino	62.9	35.5	35.2	27.8	20.1	3,013
BNSF	San Bernaardino to Cajon Pass	18.7	47.2	53.2	27.8	20.1	896
UP	Ports to Central LA (San Pedro Sub)	18.0	18	14	18.0	14.0	576
UP	Central LA to W. Riverside	55.0	20	33	18.0	14.0	1,760
UP	W. Riverside to Cajon Pass*	29.3	20	33	18.0	14.0	938
UP	Wilmington Subdivision	11.7	3.0	6.0	3.0	6.0	105
UP	Central LA to W. Colton	55.7	13	28	3.0	6.0	501
UP	W. Colton to Cabazon	35.7	38	36	3.0	6.0	321
UP	MetroLink	28.8	7.3	4.7	0.9	0.6	41
UP	MetroLink	4.6	31	31	3.7	3.7	34
* On BNSF track						***Total gross ton-miles***	8,892

The total freight tonnage between central LA and San Bernardino is higher than the tonnage between central LA and the ports because of the addition of freight at BNSF's intermodal yard and the addition of freight unrelated to either port. An evaluation of cargo throughput was developed to estimate the freight tonnage added at BNSF's intermodal yard. More details regarding this analysis are included in Appendix D. These eastbound and westbound estimates have been added to the MMGT figures for the track leading to San Bernardino and out of the basin. It can be seen in Table 5.23 that there was an additional change in freight tonnage at San Bernardino. This change is unrelated to port operations so the port-related tonnage from San Bernardino to Cajon Pass is the same as the previous tonnage.

The route taken by UP trains hauling freight into and out of the Port in 2001 was primarily the line designated the "San Pedro Subdivision," which runs between the ports and central LA to the east of the 710 Freeway. This line meets another line that runs east to Riverside. At this point, UP freight is transported over BNSF rail lines through San Bernardino and out of the air basin over the same route taken by BNSF trains. A second line runs between LA in the west and West Colton in the east, from where trains run southeasterly to Yuma, Arizona and points east.

The freight hauled over the San Pedro Subdivision is assumed to be originating or terminating at either the Port or the POLB (18 MMGT eastbound and 14 MMGT westbound). This total is also assumed to be transported over the line to West Colton and out of the basin over the BNSF line. An additional amount of port-related freight running on the line to and from Yuma is taken from the tonnage reported for a line designated the "Wilmington Subdivision" which runs north and south between central LA and the port area. While it has not been confirmed that all of this tonnage was port-related, the total on this line was included in the gross ton-mile(GTM) calculations to provide an estimate of the port-related freight that was carried over the Yuma rail line. In addition, a portion (approximately one train in eight) of the tonnage reported on the MetroLink rail (operated by the Southern California Regional Rail Authority) consisted of empty container transport, according to UP. Therefore, 12% of the average tonnage reported for the relevant segments of that railroad's tracks has been included in the calculations.

In addition to the track mileage and associated tonnage for 2001, Table 5.23 shows the gross ton-miles calculated by multiplying the total (eastbound and westbound) gross tons for each section of track by the length in miles of that section. Each of the railroads uses a conversion factor to estimate fuel consumption from gross ton-miles. The factor, in terms of gallons of fuel per thousand gross ton miles (gal/1,000 GTM) is multiplied by the tonnage to arrive at an estimated volume of fuel consumed while transporting the given volume of freight. Table 5.24 summarizes the results of this calculation for each of the railroads, and provides an estimate of total fuel used by both railroads in transporting port-related freight out of the air basin. In addition, the table also shows the fraction of that fuel usage that has been apportioned to freight associated with the Port of Los Angeles. This apportionment was based on the cargo throughput analysis, which indicated that approximately 54% of rail cargo is associated with the Port (the remaining 46% being associated with the POLB).

Table 5.24: Estimated Out-of-Port Fuel Use, gals/year

	Ports Total MMGT-miles	Fuel Factor (gal/1,000 GTM)	Ports Total (gals)
BNSF	4,616	1.315	6,070,040
UP	4,201	1.343	5,641,943
Total	8,817		11,711,983
Port of Los Angeles*			6,324,471

* Based on throughput analysis indicating that the Port of Los Angeles contributes 54% of the rail cargo volume.

To estimate emissions, the estimated amount of fuel has been multiplied by an emission factor for each pollutant. EPA has published baseline emission rates for locomotives in the *Technical Highlights* document accompanying their locomotive emission rule, cited previously. "Baseline" refers to emissions from the then-existing fleet without taking into account new locomotives meeting the standards being promulgated (and that were effective with the 2002 model year locomotives). These emission factors, published in terms of grams per gallon of fuel used, have been used in the out-of-port line haul emission calculations and are summarized in Table 5.25. Table 5.25 also lists annual and daily estimated emissions for out-of-port haul rail operations.

Table 5.25: Estimated Out-of-Port Line Haul Emissions

	NOX	TOG	CO	PM10	PM2.5	DPM	SO2
Emission Factors,* g/gal	270.0	10.7	26.6	6.7	6.2	6.7	12.2
Emissions, tpy	1,898	75.2	187.0	47.1	43.3	47.1	86.0
Emissions, tpd	5.20	0.21	0.51	0.13	0.12	0.13	0.24

* EPA420-F-97-051 Locomotive Rule Technical Highlights, Dec. 1997, Table 3

5.4 Conclusions

This section provides a discussion of the strengths and limitations of the data and results, as well as opportunities for improvement.

Strengths

The project team held regular discussions with ARB, SCAQMD, and EPA personnel regarding the scope of the study, the emission estimating protocols that were followed, and project status. This close involvement by regulatory authorities has helped to ensure that the most appropriate and approvable methods have been used in the development of this EI. Additional strengths of this inventory include:

- A considerable amount of information was provided by PHL, the Port area switching railroad and, as a result, the emission estimates seem to be fairly robust. A cross-check, detailed in the text, between estimated fuel usage based on activity assumptions and the railroad's reported monthly fuel consumption agree to within 14%, indicating that assumptions about activities and locomotive operating characteristics are close to the mark.
- Detailed information regarding out-of-port locomotive activity and fuel consumption was provided by BNSF and UP Railroads. This information has been invaluable in estimating emissions from the locomotives once they leave the Port area.
- All of the railroads provided information that has been useful in developing the emission estimates, and all seem interested in providing additional data as their time and resources permit.

Limitations

As with any emissions inventory, there are areas that would benefit from further study or additional information. Some of these areas are discussed below.

- The preferred approach to estimating emissions for this study was the use of throttle notch data, which was only obtained for in-port switching operations. Alternate methods were substituted where throttle notch data was not available. It would be preferable to base estimates of similar types of emissions on similar types of data.

- Off-port switching emission estimates were based on information provided by the railroads but the source data was not of the same level of detail as for on-port switching.

- Fuel sulfur content is based on assumptions about the mix of California and standard (higher sulfur) fuel, and about the average sulfur content of both fuels.

- Estimates of line haul locomotive emissions within the Port have been based on terminal throughput information, as well as train arrival and departure information that has been provided by the line haul railroads. The throughput information is quite good for the container terminals but less detailed for other types of terminals. However, an effort has been made to combine the quantitative nature of the throughput information with the more "average" or "typical" nature of the information provided by the railroads.

- As noted in the text, the EPA's line haul throttle notch percentages used in the on-port line haul locomotive emission calculations probably include more time at the highest notch settings than would be seen in actual in-port operation. Since emission rates increase at the highest settings, this has probably resulted in an overestimate of in-port line haul locomotive emissions.

SECTION 6 HEAVY-DUTY DIESEL-FUELED VEHICLES

This section provides estimates of the emissions from heavy-duty vehicles (HDVs) that transport Port-related cargo. The section also describes the operations of these trucks, which are almost exclusively diesel-fueled, and discusses the methodologies used to estimate vehicle activities and emissions.

6.1 Operational Modes and Vehicle Types

6.1.1 Operational Modes

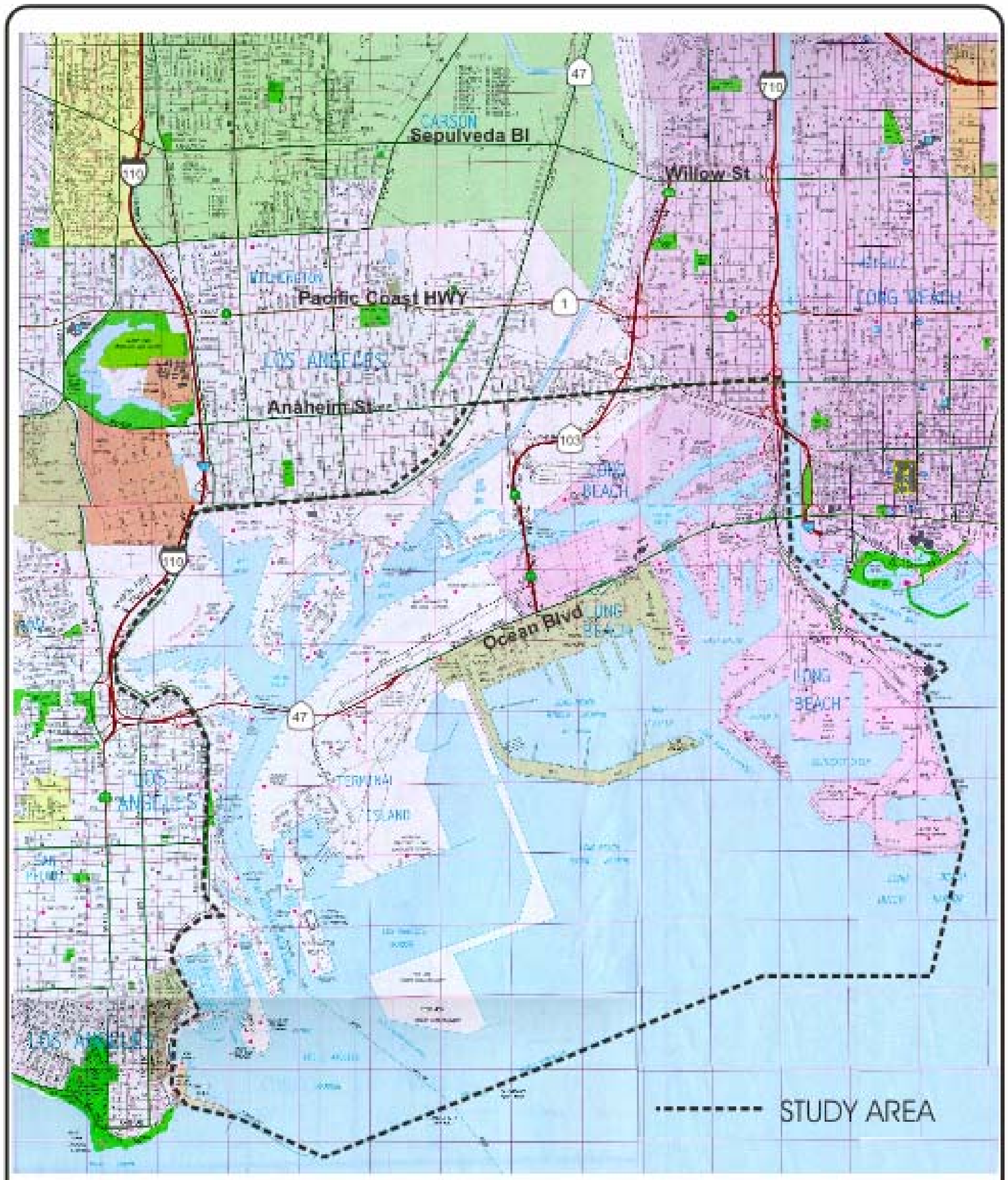
As described in Section 1 (Introduction), trucks are used extensively to move cargo, particularly containerized cargo, to and from the terminals that serve as the bridge between land and sea transportation. Trucks deliver cargo to local and national destinations, and they also transfer containers between terminals and off-port railcar loading facilities, an activity known as draying. In the course of their daily operations, trucks are driven onto and through the terminals, where they deliver and/or pick up cargo. They are also driven on the public roads within the Port boundaries, and on the public roads outside the Port.

To develop emission estimates, truck activities have been evaluated as having three components:

- On-terminal operations, which include waiting for terminal entry, transiting the terminal to drop off and/or pick up cargo, and departing the terminals.
- Off-terminal Port operations, consisting of travel on public roads within the Port jurisdictional boundaries.
- Highway operations outside the Port boundaries but within the SoCAB.

Figure 6.1, on the following page, illustrates the roadways in and around the Port that the HDVs use in daily operations. The figure presents the scope of a traffic study that evaluated traffic patterns in both the Port of Los Angeles and the Port of Long Beach. This study, and its use in developing the HDV emission estimates presented in this report, are discussed in more detail in the following subsections. An excerpt from the report detailing the modeling methods and how they were developed is included in Appendix E.

Figure 6.1: Port and Near-Port Roadways



Meyer, Mohaddes Associates, Inc.
An Iteris Company

PORTS OF LONG BEACH / LOS ANGELES
TRANSPORTATION STUDY

Study Area

Exhibit 1

6.1.2 Vehicle Types

The ARB distinguishes among three types of heavy-duty trucks: light heavy-duty, medium heavy-duty, and heavy heavy-duty. These categories are based on the gross vehicle weight rating (GVWR) of the truck, including its trailer if so equipped.

- Light HDV: 10,000 to 14,000 pounds
- Medium HDV: 14,000 to 33,000 pounds
- Heavy HDV: over 33,000 pounds

This report deals exclusively with diesel-fueled HDVs, as there are few, if any, gasoline-fueled counterparts. The most common configuration of HDV is the articulated tractor-trailer (truck and semi-trailer) having five axles, including the trailer axles. The most common type of trailer in the study area is the container trailer, built to accommodate standard-sized cargo containers. Additional trailer types include tankers, boxes, and flatbeds. A tractor traveling without an attached trailer is called a "bobtail." A tractor pulling an unloaded container trailer chassis is known simply as a "chassis." These vehicles are all classified as heavy HDVs regardless of their actual weight because the classification is based on GVWR, which is a rating of the vehicle's total carrying capacity. Therefore, the emission estimates do not distinguish among the different configurations.

As examples of typical HDVs, Figure 6.2 shows a container truck transporting a container in a terminal, and Figure 6.3 shows a bobtail. The equipment images shown in the figures are not photographs of actual pieces of equipment used at the surveyed terminals but are for illustrative purposes only.

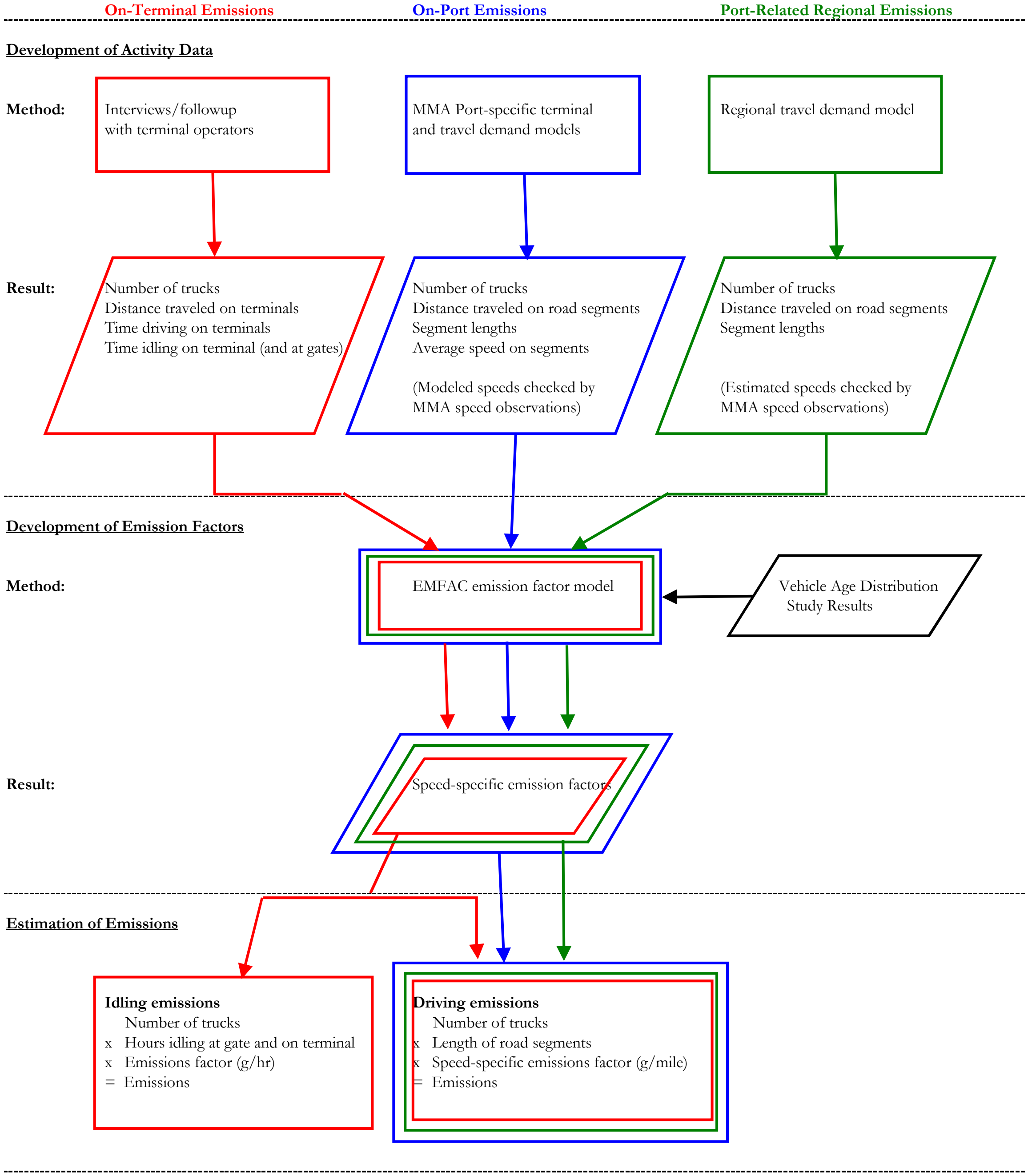
Figure 6.2: Truck with Container

Figure 6.3: Bobtail Truck

6.2 Methodology

This section discusses how the information used in estimating activity and emissions was acquired and how the emission estimates were developed based on the data collected. Figure 6.4 illustrates this process in a flow diagram format for the three components of the HDV evaluation previously discussed (on-terminal, on-Port, and regional components).

Figure 6.4: HDV Emission Estimating Process



6.2.1 Data Acquisition

Data for the HDV emission estimates came from two basic sources: terminal interviews and computer modeling of on-road HDV volumes, distances, and speeds. These information sources are discussed below.

Recently implemented limits on off-terminal idling have made this study's estimates of off-terminal idling emissions less relevant, since these emissions are no longer occurring to the same extent as during the study year. The estimated benefit of these idling limits will be included in future inventory updates.

On-Terminal

The Port and their consultant collected information regarding on-terminal truck activity during in-person and telephone interviews with terminal personnel. This information included their gate operating schedules, on-terminal speeds, time and distance traveled on terminal while dropping off and/or picking up loads, and time spent idling at the entry and exit gates. Most terminals were able to provide estimates of these activity parameters, although few keep detailed records of information such as gate wait times and on-terminal turn-around time. However, the reported values appear to be reasonable and have been used in estimating on-terminal emissions, except as noted in the following text.

Table 6.1 illustrates the range and average of reported characteristics of on-terminal truck activities at Port container terminals. The total number of trips was calculated using a trip generation model, discussed below.

Table 6.1: Summary of Reported Container Terminal Operating Characteristics

	Operation (hrs/day)	Speed (mph)	Distance (miles)	No. Trips (per year)	Gate In (hours)	On-Terminal (hours)	Gate Out (hours)
Maximum	24	15	1.5	NA	0.2	0.75	0.1
Minimum	10	10	0.75	NA	0	0.5	0
Average	12	11	1.2	NA	0.12	0.55	0
Total				**2,933,702**			

The average speeds and distances shown in the table above were used to develop an operational profile to help estimate on-terminal VMT and idling times, especially when the data for a particular terminal was missing or thought to be unreliable or anomalous.

Off-Terminal
The Port retained MMA to develop estimates of on-road truck activity inside and outside the Port. To do this, MMA used trip generation and travel demand models they have used in previous Port transportation studies[53] to estimate the volumes (number of trucks) and average speeds on roadway segments between defined intersections.

The trip generation model was derived from a computer model designed to forecast truck volumes that was developed by Moffatt & Nichol Engineers (M&N), who were team members on the 2001 Port Transportation Study. MMA developed and validated the trip generation model using terminal gate traffic count data. MMA reported in their traffic study report that the model validation confirmed that the model was able to predict truck movements to within 2 to 10% of actual truck counts for all the container terminals combined, and to within 15% or better for the majority of individual terminals. (MMA, 2001) These were considered to be excellent validation results considering the variability of operating conditions and actual gate counts on any given day. The main input to the trip generation model for this study consisted of the average daily container throughput for the most active month in 2001.

The results of the trip generation model were input to a port-area travel demand model also developed by MMA. This model was based on the regional model used for transportation planning by the Southern California Association of Governments (SCAG), the federally designated Metropolitan Planning Organization for the Los Angeles area. MMA incorporated port-specific truck travel information from the trip generation model, as well as the results of an origin/destination survey of approximately 3,300 port-area truck drivers, into the port-area travel demand model. An excerpt from the 2001 Port Transportation Study describing the origin/destination survey in included in Appendix E.

The travel demand model produced estimates of truck traffic volumes and speeds over defined Port roadway segments. These estimates are reproduced in Appendix E. The traffic volumes and distances were combined to produce estimates of vehicle miles of travel, VMT, which in turn were used with the speed-specific EMFAC 2002 emission factors (discussed below) to estimate on-road driving emissions.

The same model was used to produce estimates of Port-related truck traffic traveling through the POLB, such as toward the 710 Freeway across Terminal Island. Additional truck traffic outside the Port area was estimated by a regional analysis that modeled Port-related trucks bi-directionally on highways and major thoroughfares within the Los Angeles area until the trucks leave the highways and enter city streets.

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[53] Meyer, Mohaddes Associates, Inc., June 2001. *Ports of Long Beach/Los Angeles Transportation Study*, and Meyer, Mohaddes Associates, Inc., April 2004. *Port of Los Angeles Baseline Transportation Study.*

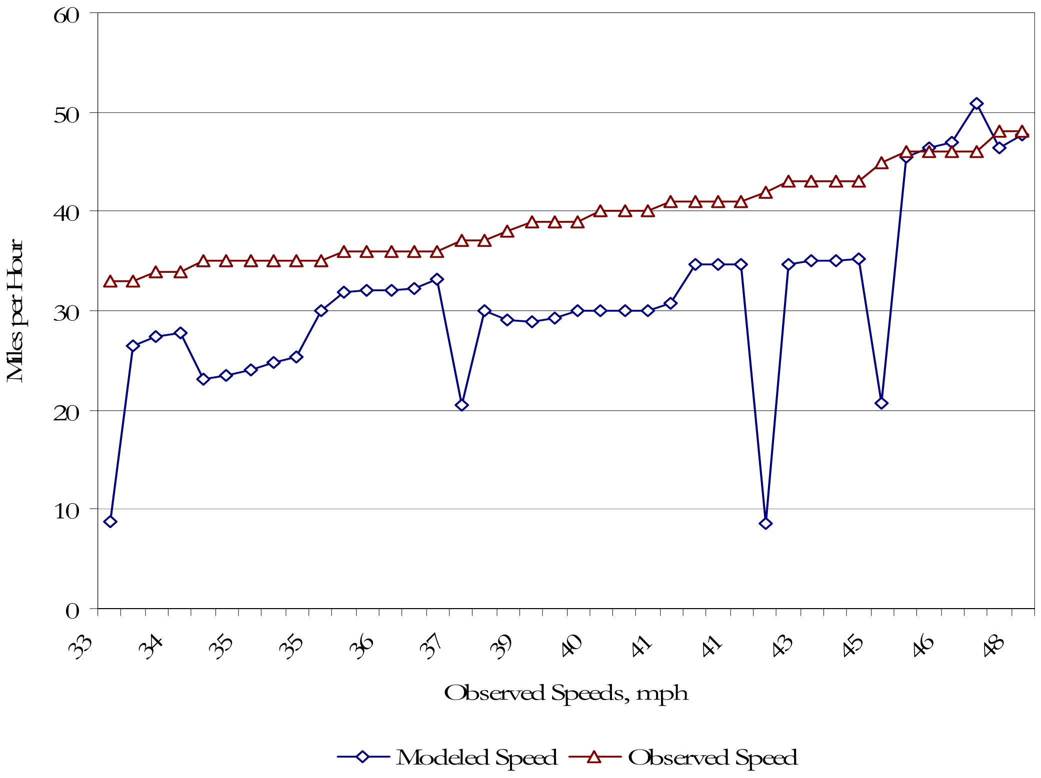
The intent was to model Port-related trucks on their way from the Port until they make their first stop, whether for delivery of a container to a customer or to a transloading facility. Transloading is the process of unloading freight from its overseas shipping container and re-packing it for overland shipment to its destination.

Speed Evaluations

To evaluate how well the model estimates on-road speeds, the Port requested MMA to conduct speed observations on Port roads. Speeds were measured over 40 sections of roads and, consistent with standard traffic study methodology, the speed value representing the 85th percentile value was reported as the speed for that road section. The 85th percentile value is determined by making 100 individual speed measurements, ranking them in order of speed from low to high, and reporting the 85th value from the lowest (or 15th from the highest).

Figure 6.5 illustrates the results of the speed observations in comparison with the modeled speeds for the corresponding sections or road. It can be seen that most of the modeled speeds are lower than the observed speeds by 5 to 10 miles per hour (mph), with 4 modeled values being lower than observed by about 20 to 30 mph, and one modeled value being higher than observed.

Figure 6.5: Observed vs Modeled Speeds



It is important to remember that the model estimates average speed along a segment of road, including acceleration, deceleration, and idling at stops, whereas the observed speeds are observations of relatively steady-state motion (i.e., between intersections). Therefore, the modeled speeds may be expected to be somewhat lower than observed speeds, which is what Figure 6.4 shows. After evaluating the results of the speed observations and the comparison presented in Figure 6.4, the decision was made that the modeled speeds adequately represent the average speeds for on-Port truck traffic. In addition to the reason cited above for expecting actual average speeds to be slightly lower than observed steady-state speeds, any bias on the slow side would result in conservatively high emission estimates because, in the range of speeds seen in on-Port traffic, the emission factors generally increase with decreasing speeds. This can be seen in Figures 6.6 and 6.7 below for NO_X and PM_{10}, respectively.

Figure 6.6: NO_X Emission Factors at Various Speeds

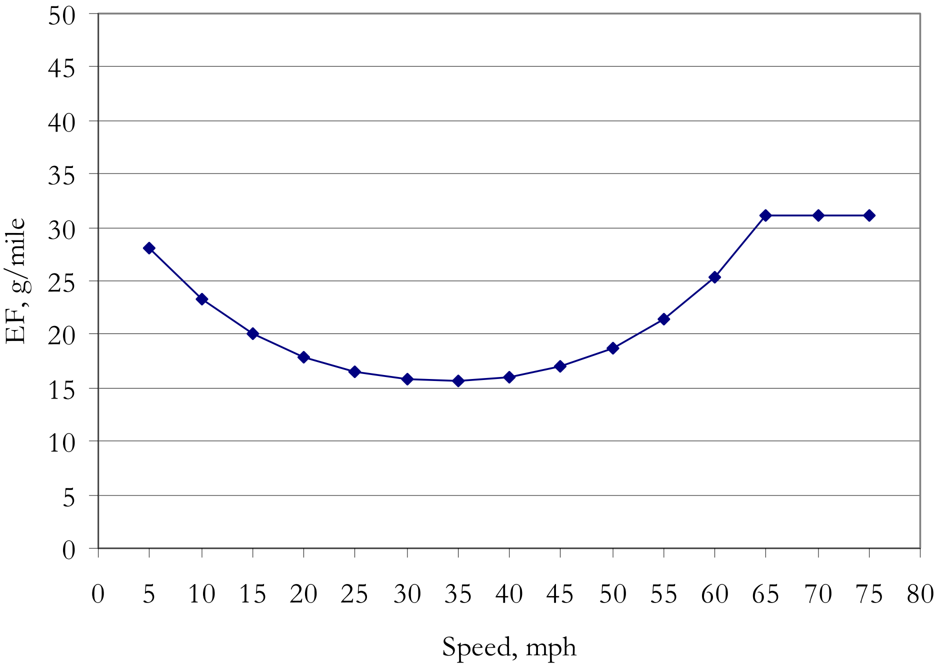
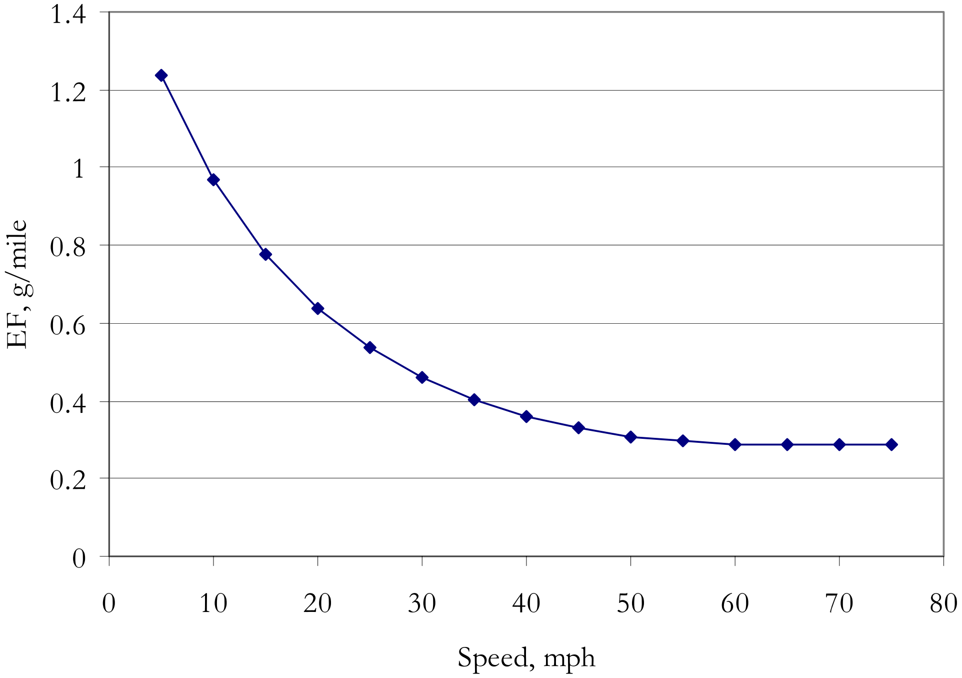


Figure 6.7: PM_{10} Emission Factors at Various Speeds



Additionally, a set of speed measurements was made on the area freeways used to enter and leave the Port (I-110 and I-710). These measurements were made because the version of the travel demand model used to estimate truck traffic volumes on area freeways outside the Port does not estimate travel speeds accurately. The results of these measurements are presented in Table 6.2.

Table 6.2: Highway Truck Speed Measurements

Freeway	AM Peak	MD Peak	PM Peak	Night Time
I-110 Freeway				
- Northbound	59	58	58	Not measured
- Southbound	54	58	60	Not measured
I-710 Freeway				
- Northbound	51	38	36	Not measured
- Southbound	50	48	53	Not measured

These results show that much of the truck traffic on the two freeways connecting the Port with the rest of the Los Angeles area and the routes out of the air basin travels between 50 and 60 mph. However, outbound traffic on the 710 freeway slows to between 35 and 40 mph during the midday and P.M. periods. As shown above in Figures 6.6 and 6.7, the emission factors change in different ways with decreasing speeds. At 35 mph, NO_X is 27% lower than at 55 mph, whereas PM is 36% higher.

6.2.2 Emission Estimates

The general form of the equation for estimating vehicle emissions is:

$$E = EF * A \qquad \text{Equation 10}$$

Where:

E = Emissions
EF = Emission Factor
A = Activity

There are two types of activity: engine running with vehicle moving at a given speed, and engine idling with vehicle at rest. Running emission factors are expressed in terms of grams per mile while idling emission factors are expressed in terms of grams per hour. Therefore, the activity measure used for estimating running emissions is miles (known specifically as vehicle miles of travel, VMT) and the activity measure used for estimating idling emissions is hours. The emission factor (g/mi or g/hr) is multiplied by the activity measure (VMT or hours) to estimate grams of emissions, which are then converted to pounds or tons as appropriate. The time period covered by the emission estimate corresponds to the time period of the activity measure. For example, an annual VMT figure (miles per year) multiplied by a gram/mile emission factor results in a gram-per-year emission estimate.

EMFAC Model

The ARB has developed a computer model that calculates emission factors for fleets of vehicles. The EMFAC2002[54] model has EPA approval for use in California, and was recommended for use in this study by the ARB. Because EMFAC2002 estimates emission factors only, the actual emission calculations (emission factor multiplied by activity measure) have been carried out using custom-designed spreadsheets.

The EMFAC2002 model was used for this study. The model contains three different output options:

- BURDEN
- EMFAC
- CALIMFAC

Of the three options, EMFAC is the most appropriate tool for this emissions inventory. The BURDEN program is more appropriate as an agency tool for planning inventories based on a standard population of vehicles, with little control over applying emission factors, while the CALIMFAC program is not currently suitable for a diesel-only vehicle population. (It assumes that a certain percentage of vehicles are gasoline fueled.)

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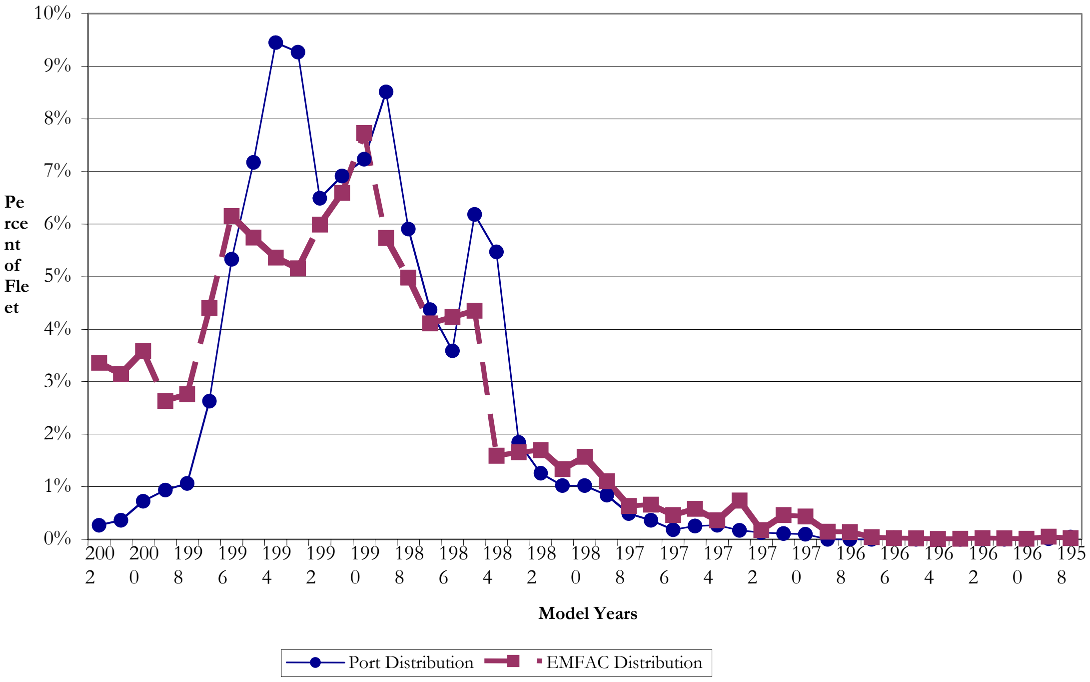
[54] California ARB, EMFAC2002, 2003. See *http://www.arb.ca.gov/msei/msei.htm*. The emission factor model approved by EPA for use in estimating emissions for on-road vehicles in California; it is not approved for off-highway CHE or for emissions outside California.

The distribution of model years in the fleet of trucks operating at the Port was developed with the assistance of the ARB and the SCAQMD, who ran several thousand license plate numbers obtained from several Port (and POLB) terminals through the California Department of Motor Vehicle's vehicle registration database. This Port-specific model year distribution was used with the EMFAC2002 emission factors to estimate HDV emissions. Model year distribution of the HDVs is an important input parameter because the emissions magnitude per VMT is based on the age of the truck or age distribution of the fleet. Approximately 7,200 license plate numbers were included in this age distribution analysis. Model years ranged from 1958 to 2002.

Figure 6.8 graphically illustrates the model year distribution of the Port-related trucks as well as the age distribution of diesel trucks used as a default by the EMFAC2002 model (representing area diesel trucks in general). Appendix E contains more detailed information regarding the model year data, including a comparison of the individual datasets that have gone into the composite model year distribution presented in this subsection.

Figure 6.8: HDV Model Year Distributions



The peak in model year percentage at 1993/1994 that is apparent in the Port study results is not as pronounced in the EMFAC2002 distribution. However, the number of 1998 and newer trucks is proportionately greater in the EMFAC2002 distribution than in the Port distribution. To further compare the distributions, the weighted average age was calculated for the Port-specific fleet and the EMFAC2002 distribution. To do this, the number of vehicles of each age (in years) was multiplied by the age in years (starting with 2002 models = 1 year old). The products were summed and the sum was divided by the total number of vehicles in the fleet to calculate the weighted average age. This was done separately for the two fleets. These calculations indicate that the average age of the Port-specific fleet is 12.9 years and the average age of the EMFAC2002 fleet is 12.2 years.

The EMFAC2002 model was configured for this study to estimate emission factors by "speed bin" where each bin represents a five mph increment between zero (idling) and 65 mph. For example, if there are speeds between 5 and 10 mph, the output would reflect emissions in this bin. The highest average speed output by the model is 65 mph, so modeled or observed speeds over this limit were effectively capped at the 65 mph level.

Technical inputs to the EMFAC2002 model include selections for:

- Los Angeles County
- 2001 annual emissions
- EMFAC model
- Program constants editing for:
  - ☐ Addition of zero mph speed bin
  - ☐ Population by vehicle and fuel type

Emission Factor Output

Emission factors in grams per hour (idling) and grams per mile (traveling) from the EMFAC2002 model are presented in Table 6.3. Note that the same suite of emission factors was used for on-terminal and off-terminal activities. Off-terminal speeds modeled using EMFAC2002 have been limited to 65 mph because it is likely that high-speed emission factors for diesel HDV would not be reasonable or valid. This is because the Federal Testing Protocol (FTP) on which the standards and models are based does not go above 57 mph, and to exceed that speed by a large margin would produce results of uncertain validity. The detailed EMFAC2002 model output is included in Appendix E.

Table 6.3: EMFAC Output for HDV

Speed (mph)	TOG	CO	NO_X	SO_2	PM_{10}
0	5.014	26.285	80.655	0.340	2.445
5	3.142	17.189	29.752	0.180	1.420
10	2.466	11.852	24.684	0.180	1.115
15	1.979	8.553	21.219	0.180	0.894
20	1.624	6.459	18.900	0.180	0.734
25	1.362	5.105	17.442	0.180	0.615
30	1.167	4.223	16.679	0.180	0.528
35	1.023	3.656	16.525	0.180	0.462
40	0.916	3.312	16.965	0.180	0.414
45	0.839	3.140	18.045	0.180	0.379
50	0.786	3.116	19.888	0.180	0.355
55	0.752	3.236	22.712	0.180	0.340
60	0.735	3.517	26.873	0.180	0.332
65+	0.735	4.000	32.947	0.180	0.332

The EMFAC2002 results for $PM_{2.5}$ are 92% of PM_{10}, so this percentage has been used to estimate $PM_{2.5}$ emissions by multiplying PM_{10} values by 0.92. This size fraction has been confirmed by ARB personnel to be a feature of the EMFAC2002 model. DPM is assumed to be 100% of exhaust PM_{10} because DPM is defined as PM emitted from diesel engines and all of the vehicles studied are diesel vehicles. It should be noted that the 92% size fraction of $PM_{2.5}$ in PM_{10} means that 92% of DPM falls in the $PM_{2.5}$ size range while 100% of DPM is PM_{10}. Fugitive or non-exhaust emissions such as from brake wear or roadway dust were not estimated by the EMFAC2002 model.

6.3 Emission Estimates

On-terminal emissions have been estimated by terminal, whereas off-terminal emissions were summarized in four time periods of the day reflecting two peak traffic periods (6:00 – 9:00 a.m. and 3:00 – 7:00 p.m.) and two longer interim periods reflecting mid-day and night-time activity. Idling was separately estimated for the terminals only, since the off-terminal traffic modeling analysis reported only volumes, distances, and average speeds, which were used to estimate VMT. This is a valid approach because average speeds include estimates of normal traffic idling times and the emission factors are designed to take this into account.

6.3.1 On-Terminal

Since annual activity was used for the on-terminal analysis, emissions were calculated as tons per year, with idling and transit activities estimated separately. Table 6.4 summarizes the two modes of operation by terminal. A detailed presentation of the data used to estimate these activity levels is provided in Appendix E.

Table 6.4: 2001 VMT and Idling Hours by Terminal ID

Terminal ID	Total Hours Idling (all trips)	Total Miles Traveled
LAC030	200,760	394,350
LAC090	272,600	564,000
LAC010	491,920	1,341,600
LAC060	282,375	941,250
LAC020	303,317	437,477
LAO060	1,950	2,438
LAO060	1,073	7,150
LAO230	1,560	780
LAO230	780	390
LAO100	998	499
LAO130	260	130
LAO110	52	26
LAO120	22,651	5,148
LAO130	285,180	679,000
LAO131	12,000	10,000
LAO132	2,990	2,600
LAO133	0	104
LAO134	27,375	11,406
LAO135	520	6,500
Totals	**1,908,361**	**4,404,847**

The container terminals (denoted with "LAC" as a prefix) and some stevedore cargo terminals have relatively high activity levels, whereas the oil, bulk, and miscellaneous terminals have much lower levels of activity (stevedore cargo, oil, bulk and miscellaneous terminals are denoted with "LAO" as a prefix).

Emissions were calculated by multiplying the activity value by the relevant emission factor. For on-terminal travel NO_x emissions, for example, the total mileage, 4,404,847 VMT, was multiplied by the 10 mph NO_x emission factor, 24.684 g/mi:

$$\frac{4{,}404{,}847 \text{ miles/yr} \times 24.684 \text{ g/mile}}{453.6 \text{ g/lb} \times 2{,}000 \text{ lb/ton}} = 119.9 \text{ tons/yr}$$

Similarly, for idling emissions:

$$\frac{1{,}908{,}361 \text{ hours/yr} \times 80.665\text{g/hour}}{453.6 \text{ g/lb} \times 2{,}000 \text{ lb/ton}} = 169.7 \text{ tons/yr}$$

Results for all terminals combined are presented in Table 6.5 and Figure 6.9 in terms of short tons per year. By-terminal breakdowns of on-terminal driving and idling emissions are included in Appendix E.

Table 6.5: Summary of On-Terminal Emissions, tpy

Mode	NO_X	TOG	CO	PM_{10}	$PM_{2.5}$	DPM	SO_2
Transit	119.9	12.0	57.5	5.4	5.0	5.4	0.9
Idling	169.7	10.5	55.3	5.1	4.7	5.1	0.7
Totals	**289.5**	**22.5**	**112.8**	**10.6**	**9.7**	**10.6**	**1.6**

Figure 6.9: On-Terminal HDV Emissions Breakdown, tpy

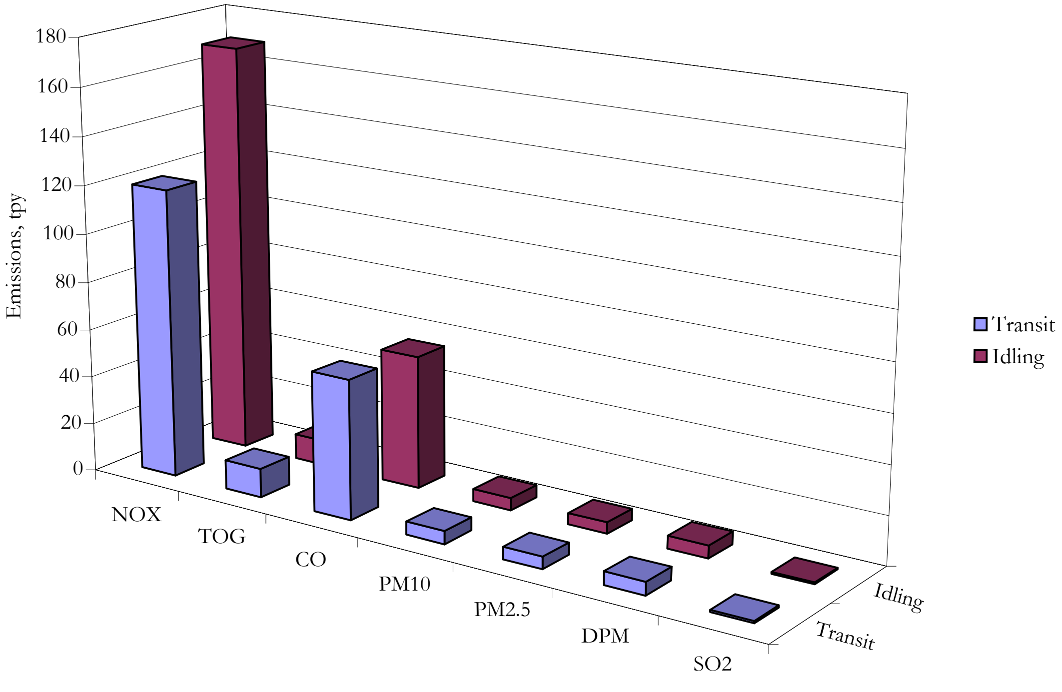


Table 6.6 reports average daily emissions calculated as annual emissions divided by 365 days per year. Where appropriate for this emission inventory, the assumption of consistent daily emissions throughout the week should be evaluated for the purposes of emission estimates for dispersion and risk assessment modeling. While many terminals report being open on weekends, their levels of activity may be lower, in terms of hours of operation and/or vehicle throughput.

Table 6.6: Average Daily Emissions, On-Terminal Activities, tpd

Mode	NO_X	TOG	CO	PM_{10}	$PM_{2.5}$	DPM	SO_2
Transit	0.33	0.03	0.16	0.01	0.01	0.01	0.002
Idling	0.46	0.03	0.15	0.01	0.01	0.01	0.002
Totals	**0.79**	**0.06**	**0.31**	**0.03**	**0.03**	**0.03**	**0.004**

6.3.2 Off-Terminal

Unlike the on-terminal HDV emissions, off-terminal emissions were estimated based on average weekday activity (Monday-Friday), and then summed to produce annual totals. The benefit of the activity data prepared by MMA is that it separates the average weekday into four time periods: morning peak (AM, 6:00 a.m. to 9:00 a.m.), mid-day (MD, 9:00 a.m. to 3:00 p.m.), evening peak (PM, 3:00 p.m. to 7:00 p.m.), and nighttime (NT, 7:00 p.m. to 6:00 a.m.). This provides a level of temporal resolution, although weekend traffic volumes were not included in the MMA modeling because the SCAG model on which MMA's model is based does not have a provision for including the different traffic patterns that occur on weekends.

Off-terminal HDV emission estimates have been prepared for trucks driving on roads within the boundaries of the Port of Los Angeles, and on roads and highways outside the Port. The out-of-Port estimates are based on the results of two modeled components, within the POLB and outside the areas of both ports. The out-of-Port estimates were prepared this way because MMA was able to run the same detailed traffic demand model for trucks traveling through the POLB (to and from the Port of Los Angeles) as for trucks traveling within the Port, whereas truck highway travel was estimated using a different version of the model. The emission estimating method is the same for each of these components.

For each period of time, the travel model estimated the number of trucks traveling each direction over defined road segments within the area of interest (i.e., within the Port of Los Angeles, within the POLB, or on the highways of the SoCAB). For travel within the two ports, the model also reported the average travel speed for the period and the length of the road segment.

A calculation spreadsheet was developed that multiplied the distance of the road segment by the number of trucks traveling over that segment and by the emission factors appropriate to the average speed for that segment to calculate the emissions for that segment of road over the time period. For example, if 100 trucks passed over a 1-mile road segment at an average speed of 30 mph, the calculation for NO_X would be:

$$\frac{100 \text{ trucks } \times \text{ 1 mile } \times \text{ 16.679 g/mile}}{453.6 \text{ g/lb } \times \text{ 2,000 lb/ton}} = 0.0018 \text{ tons}$$

where 16.679 g/mile is the 30-mph emission factor for NO_X as shown in Table 6.3. This calculation has been repeated for each road segment identified in the travel model, with the emissions for each time period being totaled for all of the road segments. The detailed calculation spreadsheets are reproduced in Appendix E. Summaries are presented below.

Travel on Port of Los Angeles Roads
Table 6.7 presents the emission estimates for roadways within the Port of Los Angeles.

Table 6.7: Off-Terminal Port Transit Emissions, tpd

Period	NO_X	TOG	CO	PM_{10}	$PM_{2.5}$	DPM	SO_2
AM	0.20	0.01	0.04	0.004	0.004	0.004	0.002
MD	1.03	0.06	0.25	0.025	0.023	0.025	0.008
PM	0.27	0.01	0.06	0.006	0.006	0.006	0.002
NT	0.09	0.004	0.02	0.002	0.002	0.002	0.001
Totals	**1.60**	**0.08**	**0.37**	**0.038**	**0.035**	**0.038**	**0.012**

The emissions reported in Table 6.7 are higher than those in Table 6.6 because the distances trucks travel outside the terminals is much greater than the distances traveled on-terminal; despite lower emission factors at the higher speeds, the off-terminal component has much higher VMT.

Travel outside of the Port of Los Angeles
Emissions outside of the Port have been estimated for trucks traveling to or from Port terminals on public roads within the POLB and on a broader scale, including major highways in the SoCAB. In addition to the port travel demand modeling on which the traffic estimates for the two ports are based, MMA prepared detailed highway maps, using origin/destination survey data, showing estimated truck volumes during the same daily time periods as for the port modeling. These volumes were transcribed into a spreadsheet designed to estimate VMT for each highway segment between major interchanges. These VMTs were, in turn, used to estimate on-road emissions.

Table 6.8 on the following page summarizes the regional emission estimates.

Table 6.8: Regional HDV Emissions, tpd

Period	NO_X	TOG	CO	PM_{10}	$PM_{2.5}$	DPM	SO_2
AM	1.25	0.05	0.19	0.02	0.02	0.02	0.01
MD	6.17	0.23	1.00	0.11	0.10	0.11	0.05
PM	1.83	0.07	0.28	0.03	0.02	0.03	0.01
NT	0.59	0.02	0.09	0.01	0.01	0.01	0.00
Totals	**9.84**	**0.36**	**1.56**	**0.17**	**0.15**	**0.17**	**0.08**

For the area freeways, emission factors for an average speed of 55 mph were used because the MMA model does not provide highway speed estimates. While the MMA speed observations (discussed in Section 6.2) indicate that 55 mph is not always maintained on the freeway segments closest to the Port, this was seen as a reasonable estimate of average traveling speeds, allowing for speeding up, slowing down, and travel delays as well as occasional higher speeds.

Midday emissions (MD, 9:00 a.m. to 3:00 p.m.) are the highest, in part because the midday period is the longest, but also because truck traffic volumes are highest. The daily emissions are an order of magnitude higher than those for on-terminal or in-Port areas, because of the greater travel distances.

Summary
The totals of on-terminal, on-Port, and regional emission estimates are presented in Table 6.9. For planning purposes, these emissions have been converted into annual emissions by multiplying by 365 (days per year), and are presented in Table 6.10. Figure 6.10 illustrates the contribution of the three components (on-terminal, on-Port, and regional) to the total Port-related HDV emissions, on a percentage basis.

The truck traffic volume estimates were prepared for average weekday travel. While weekend truck travel is not as extensive as on weekdays, many terminals have weekend gate hours, at least seasonally. Therefore, the use of 365 days per year to extrapolate from daily to annual emissions is reasonable but somewhat conservative in that it assumes all days are equivalent in terms of truck traffic volume.

Table 6.9: Port HDV Emissions, tpd

Location	NO_X	TOG	CO	PM_{10}	$PM_{2.5}$	DPM	SO_2
On-Terminal	0.79	0.06	0.31	0.03	0.03	0.03	0.004
Port On-Road	1.60	0.08	0.37	0.04	0.03	0.04	0.01
Regional On-Road	9.84	0.36	1.56	0.17	0.15	0.17	0.08
Totals	**12.23**	**0.51**	**2.23**	**0.24**	**0.21**	**0.24**	**0.09**

Table 6.10: Port HDV Emissions, tpy

Location	NO_x	TOG	CO	PM_{10}	$PM_{2.5}$	DPM	SO_2
On-Terminal	290	22.5	112.8	10.6	9.7	10.6	1.6
Port On-Road	583	30.6	133.2	13.8	12.7	13.8	4.5
Regional On-Road	3,591	132.4	569.3	63.5	55.5	63.5	27.5
Totals	**4,464**	**185.5**	**815.4**	**87.8**	**77.9**	**87.8**	**33.7**

Figure 6.10: Percentage Breakdown of HDV Emissions

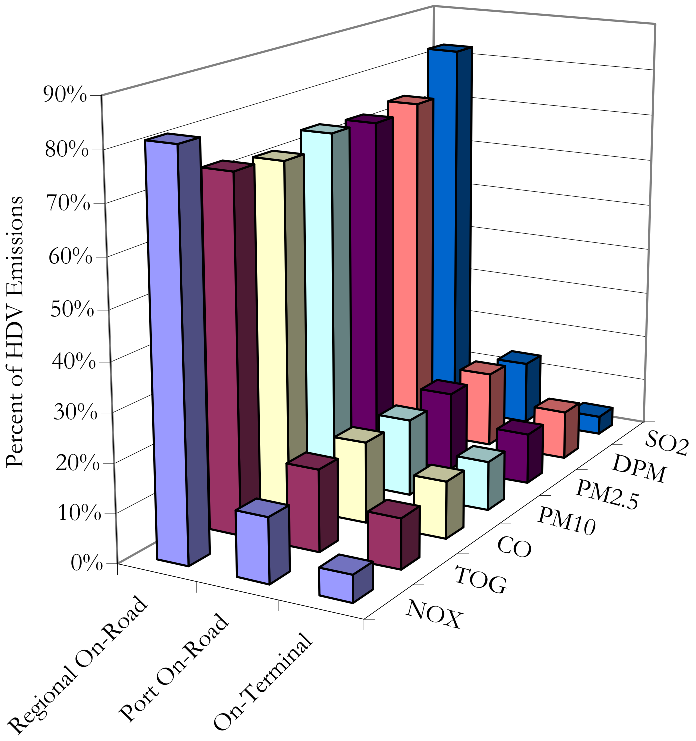
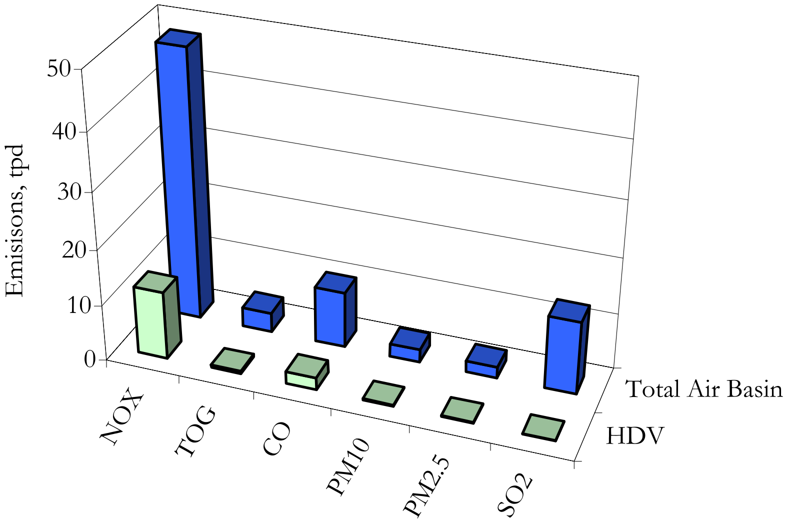


Figure 6.11 illustrates the contribution of Port-related HDV emissions to all Port-related emissions estimated by this study, on an annual basis. This shows the relative magnitude of HDV emissions compared with Port emissions as a whole. Further comparisons are presented in Section 1.

Figure 6.11: Comparison of HDV Emissions with Port's Total Air Basin Emissions, tpd



6.4 Conclusions

This section also provides a discussion of the strengths and limitations of the data and results.

Strengths

During the course of the project, consultants and/or Port staff visited or evaluated all of the Port terminals, and interviewed the terminal operators. This type of resource investment increases the accuracy of the data obtained and thus the emission estimates.

In addition, the project team held regular discussions with ARB, SCAQMD, and EPA personnel regarding the scope of the study, the emission estimating protocols that were followed, and project status. This close involvement by regulatory authorities has helped to ensure that the most appropriate and approvable methods have been used in the development of this EI. Additional strengths of this inventory include:

- The development and use of a site-specific diesel truck model year distribution from actual license plate records from Port of Los Angeles and other (POLB) local terminals.

- The incorporation of modeling methods from local transportation planning consultants having specific experience with Port of Los Angeles traffic modeling for off-terminal truck traffic. One of these consultants, MMA, also provided a technical peer review of this (HDV) section of the baseline emissions inventory.

- The use of terminal-specific information provided by terminal operators.

- The use of the ARB-developed EMFAC2002 model for developing driving and idling emission factors.

Limitations
The limitations of this inventory include:

- The terminal gate wait times are based largely on operators' estimates because the operators did not maintain actual records. While operator knowledge is often a very useful source of information, off-terminal wait time is not a parameter a terminal operator would have been expected to track, until the advent of the off-terminal idling legislation recently enacted (after the time period covered by this study).

- The on-terminal analysis is based on estimates of average time on terminal, which does not account for peaking, a phenomenon where queue lines could be longer than normal, thus potentially increasing idling times on the terminal.

- The off-terminal traffic models were constructed as a function of Monday through Friday activity, and do not address weekend activity. Weekend HDV activity is less than weekday activity because terminal gate opening times are shorter, but there is HDV activity on weekends. Annual emission estimates have been based on weekday emissions occurring seven days per week, which will over-estimate annual emissions to some extent.