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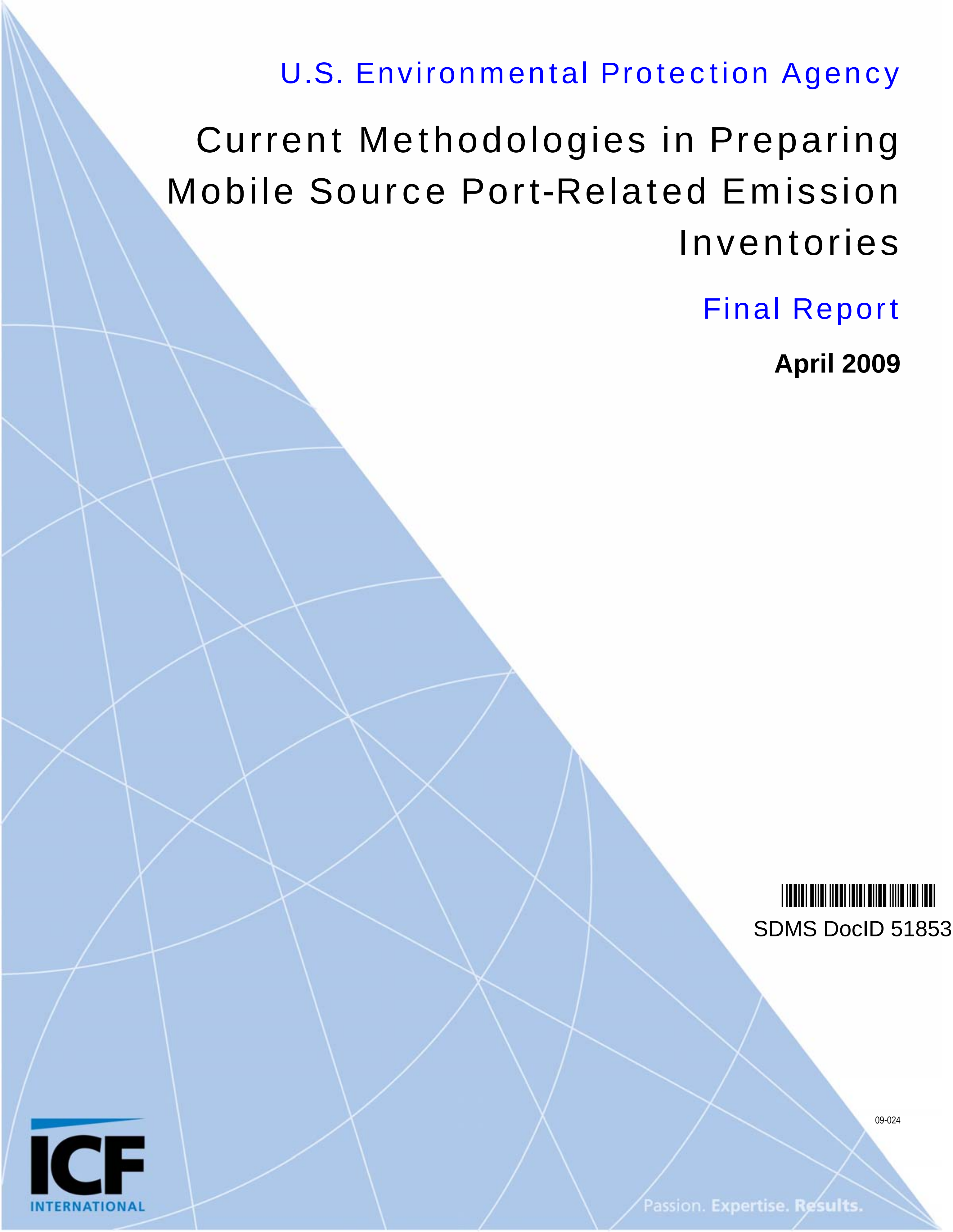

U.S. Environmental Protection Agency

Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories

Final Report

April 2009

09-024

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Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories

Final Report

April 2009

Prepared for
U.S. Environmental Protection Agency
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Sector Strategies Program
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List of Acronyms

AAPA	American Association of Port Authorities
ACES	Air Consulting and Engineering Solutions
AIS	automated identification system
ARB	(California) Air Resources Board
AS	actual speed
ATB	articulated tug-barge
CAA	Clean Air Act
CEQA	California Environmental Quality Act
CH_4	methane
CHE	cargo handling equipment
CNG	compressed natural gas
CO	carbon monoxide
DOT	(United States) Department of Transportation
DWT	dead weight tonnage
DPM	diesel particulate matter
EC	elemental carbon (also known as black carbon)
EEA	Energy and Environmental Analysis Inc.
EEZ	exclusive economic zone
EIR	environmental impact report
EIS	environmental impact statement
EPA	(United States) Environmental Protection Agency
GHG	greenhouse gas emissions
g/kWh	grams per kilowatt-hour
GT	gas turbine
HC	hydrocarbons
hp	horsepower
hrs	hours
HSD	high-speed diesel
IMO	International Maritime Organization
ITB	integrated tug-barge
kg	kilograms
kW	kilowatts
LADCO	Lake Michigan Air Directors Consortium
LF	load factor
LNG	liquefied natural gas
LPG	liquefied petroleum gas
MCR	maximum continuous rating
MDO	marine diesel oil
MEPA	Marine Exchange/Port Authority
MGO	marine gas oil
MISLE	Marine Information for Safety and Law Enforcement
MOVES	MOtor Vehicle Emission Simulator
mp	modeled port
MPO	metropolitan planning organization
MS	maximum speed
MSD	medium-speed diesel
MY	model year
N_2O	nitrous oxide

NAAQS	National Ambient Air Quality Standard
NATA	National Air Toxics Assessment
NEI	National Emissions Inventory
NEPA	National Environmental Policy Act
NOx	nitrogen oxides
OGVs	oceangoing vessels
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
PoLA	Port of Los Angeles
ppm	parts per million
PWD	pier/wharf/dock
RO	residual oil
ROG	reactive organic gases
RoRo	Roll-on/Roll-off (ships)
RPM	revolutions per minute
SCC	Source Classification Codes
SIPs	State Implementation Plans
SOx	sulfur oxides
SSD	slow-speed diesel
ST	steam turbines
TEU	twenty-foot equivalent unit representing a standard shipping container 20 feet long and 8 feet wide
TOG	total organic gases
tp	typical port
USACE	United States Army Corp of Engineers
USCG	United States Coast Guard
VIUS	Vehicle Inventory and Use Survey
VMT	vehicle miles traveled
VDS	Vessel Documentation System
VTS	Vessel Traffic System
VOC	volatile organic compound

Executive Summary

This report describes current methodologies used for preparation of a port-related emission inventory. An emission inventory is necessary for port authorities, those doing business at ports (such as terminal operators, tenants, and shipping companies), state and local entities, or other interested parties to understand and quantify the air quality impacts of current port operations, and to assess the impacts of port expansion projects or growth in port activity. An inventory provides the baseline from which to create and implement emission mitigation strategies and track performance over time. This report focuses on mobile emission sources at ports, including oceangoing vessels (OGVs), harbor craft, and cargo handling equipment (CHE), as well as other land-side mobile emission sources at ports, such as locomotives and on-highway vehicles. For this report we reviewed current information on port emission inventory preparation and summarized the most current practices.

This report was prepared for the U.S. Environmental Protection Agency's (EPA's) Sector Strategies Program, which works with several industry sectors, including ports, to address the most significant impediments to better environmental performance in each sector. EPA, in partnership with the American Association of Port Authorities (AAPA), is encouraging ports to proactively address air quality issues. This report is intended to help port authorities and others who want to prepare a port mobile source emission inventory and thereby quantify current emissions. The inventory can then be used to develop strategies to minimize current and projected emissions and to quantify progress. An emission inventory can inform regulatory requirements such as those in State Implementation Plans (SIPs), the National Environmental Policy Act (NEPA), and the California Environmental Quality Act (CEQA), and also inform voluntary initiatives such as a collaborative regional air toxics assessment or development of a port environmental management system (EMS).

This report expands on and adds to the previous *Current Methodologies and Best Practices in Preparing Port Emission Inventories* report[1] published in 2006. The new report adds methodologies which have evolved since the last report and includes updated emission and load factors as well as adds significant detail on calculating emissions from harbor craft, cargo handling equipment, rail and on-road vehicles serving ports and calculation of greenhouse gas (GHG) emissions. In addition, for each source category, both detailed and streamlined calculation methodologies are discussed.

Ports can be large sources of nitrogen oxides (NOx), particulate matter (PM), sulfur oxides (SOx), toxic emissions and GHGs, therefore, more detailed and accurate emission inventories are needed. Port inventory methodologies have been improving over the last several years, as reflected in the newer port inventories. However, there is still little guidance on preparing port inventories for ports with fewer resources.

Because the rationale and resources to prepare inventories vary between ports, this report provides a range of preparation approaches to provide the appropriate level of detail to meet ports' needs. The two approaches presented in this report are:

- A *detailed approach* in which each ship trip into and out of a port is quantified. Harbor craft and land-side emissions are estimated in detail.

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[1] ICF Consulting, *Best Practices and Current Methodologies in Preparing Port Emission Inventories, Final Report*, Prepared for U.S. Environmental Protection Agency Sector Strategies Program, April 2006.

- A *streamlined approach* in which ship trips are averaged by ship type and dead weight tonnage, and then average trip characteristics are calculated. Harbor craft and land-side emissions also can be averaged by type of ship or equipment.

The report concludes with seven recommendations for further study that will lead to improvements in port emission inventory development.

It should be noted that this guidance document reflects current best practices and is not intended to be the last word in port inventory development methodology. To better understand current techniques, the reader should continually look for new inventory methodologies being developed by ports. The AAPA will likely be able to provide contact information for a specific port[2].

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[2] http://www.aapa-ports.org

1. Introduction

An emission inventory is a quantification of all emissions of criteria and other pollutants (including toxics and greenhouse gases) that occur within a designated area by their source. Emissions sources are categorized broadly as mobile sources, point sources (e.g., a refinery), and area sources (e.g., agricultural tilling). Mobile sources are further categorized as on-road sources (e.g., automobiles, trucks, buses) and non-road sources (e.g., construction equipment, cranes, yard trucks, locomotives, and marine vessels).

Mobile source port-related emissions are generated by marine vessels and by land-based sources at ports. Marine emissions come primarily from diesel engines operating on oceangoing vessels (OGVs), tugs and tows, dredges, and other vessels operating within a port area. Land-based emission sources include cargo handling equipment (CHE) such as terminal tractors, cranes, container handlers, and forklifts, as well as heavy-duty trucks and locomotives operating within a port area. . In port-related emission inventories, emissions are generally characterized by the activity sector generating the emissions. That is, the mode of transportation. Figure 1-1 shows approximate contributions to total port complex emissions from the various activity sectors. [3]

Both land- and sea-based sources are likely to have diesel engines. Diesel emissions of concern are discussed in Section 1.3. Stationary emission sources at ports also need to be included in total port emissions, but are beyond the scope of this report.

Examples of Emission Sources at Ports	
Oceangoing vessels	- Container ships - Tanker ships - Bulk carrier ships - Cruise ships - Reefer ships - Roll-on/Roll-off ships - Vehicle carrier ships
Harbor vessels	- Tugboats and pushboats - Ferries - Excursion vessels - Fishing vessels - Dredging equipment
Cargo handling equipment	- Terminal tractors - Top and side loaders - Forklifts - Wharf cranes - Rubber tire gantry cranes - Skid loaders
Locomotives	- Line haul locomotives - Switch yard locomotives
Vehicles	- On-road trucks - Buses - Other port vehicles

This report is intended to help port authorities, those doing business at ports (such as terminal operators, tenants, and shipping companies), state and local air quality agencies, and other interested parties who want to prepare mobile source port-related emission inventories.

1.1. Background

Ports can be a major contributor to regional NOx, SOx, toxics, PM, and GHG emissions. Without an inventory of the port as an entity, it is difficult to assess opportunities for emission reductions and to quantify reductions over time. In addition, a port emission inventory is necessary to properly assess the impacts of port improvement projects or growth in marine activity, as well as to plan mitigation strategies.

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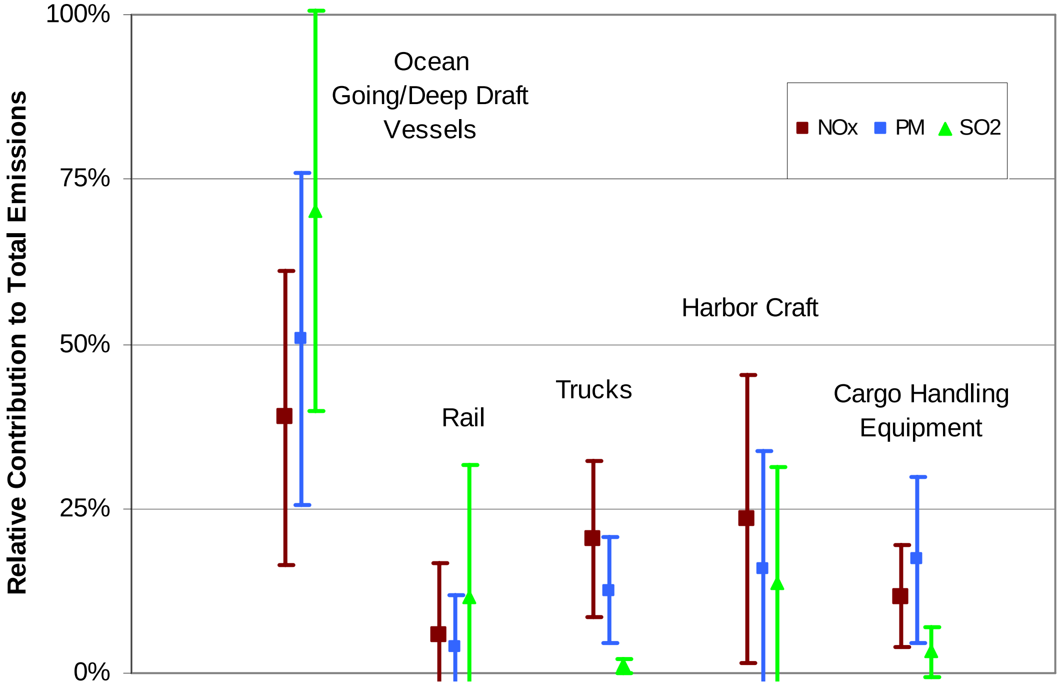
[3] Determined as the mean and standard deviation of values from $PM_{2.5}$, NO_x, and SO_2 emissions from 88 ports across the North Pacific, South Pacific, Gulf Coast, East Coast, and Great Lake regions. Emissions were calculated for the 2005 baseline year. Values are intended only to estimate the range of contributions expected by sector. Results at individual ports will vary.

Figure 1-1. Typical Emission Contribution by Transportation Mode at Ports



Estimating emission inventories generally involves applying emission factors[4] to measures of port activity across a range of activity sectors. Currently, the U.S. Environmental Protection Agency (EPA) offers only limited guidance regarding the development of port emission inventories, and most small and mid-size ports do not have extensive resources to devote to inventory development. As a consequence, many current emission inventories suffer from poor quantification of port activity and use of outdated emission factors. This report discusses current methods of determining emissions from ports and offers recommendations for improvements.

Historically, port emissions developed by state and local air quality agencies have not been evaluated as a sector but as part of engine classifications. As such, emissions emanating from a port could not be easily quantified. In addition, emission factors for OGVs have been developed from very limited data sets.

More recently, a number of port authorities have made detailed estimates of their emissions inventories. Most of the recent inventories listed in Table 1-1 represent recent bottom-up, activity-driven inventories; many of these represent the current best practice in creating emission inventories. Other ports are in the process of preparing detailed inventories. Some shown in Table 1-1 (e.g., the Lake Michigan and Alaskan inventories) rely on scaling or other

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[4] An emission factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. Marine emission factors are usually expressed as the weight (commonly measured in grams) of pollutant divided by the energy (commonly measured in kilowatt-hours (kWh)) of the engine used to produce that emission.

external data sources and may be considered more streamlined inventories. Still other ports have used more streamlined methods for preparing port emission inventories or prepared inventories for a specific terminal or industry. While not considered “best practice,” they can provide reasonable estimates from limited amounts of information available.

Table 1-1: Summary of Recent Port Inventories

Port	Year Published	Data Year	Oceangoing Vessels	Harbor Craft	Land-Side Emissions	Pollutants[a]	Contractor[b]
Selected Alaska Ports	2005	2002	Yes	Yes	No	SO_2, NOx, PM_{10} $PM_{2.5}$, CO, NH_3, VOC	Pechan
Beaumont/Port Arthur	2004	2000	Yes	Yes	No	NOx, CO, HC, PM_{10}, SO_2	Starcrest
Charleston	2008	2005	Yes	Yes	Yes	NOx, TOG, CO, PM_{10}, $PM_{2.5}$, SO_2	Moffatt & Nichol
Corpus Christi	2002	1999	Yes	Yes	Yes[c]	NOx, VOC, CO	ACES
Houston/Galveston	2000	1997	Yes	Yes	No	NOx, VOC, CO, PM_{10}	Starcrest
Houston/Galveston	2003	2001	No	No	Yes	NOx, VOC, CO	Starcrest
Houston	2009	2007	Yes	Yes	Yes	NOx, VOC, CO, PM_{10}, $PM_{2.5}$, SO_2, CO_2	Starcrest
Great Lakes (Ports of Cleveland, OH, and Duluth, MN)	2006	2004	Yes [d]	Tugs only	No	HC, NOx, CO, PM_{10}, $PM_{2.5}$, and SO_2	Lake Carriers Assoc.
Lake Michigan Ports	2007	2005	Yes	Yes	No	NOx, PM_{10}, $PM_{2.5}$, HC, CO, SOx	ENVIRON
Los Angeles	2005	2001	Yes	Yes	Yes	NOx, TOG, CO, PM_{10}, $PM_{2.5}$, SO_2, DPM	Starcrest
Los Angeles	2007	2005	Yes	Yes	Yes	NOx, TOG, CO, PM_{10}, $PM_{2.5}$, SO_2, DPM	Starcrest
Los Angeles	2008	2007	Yes	Yes	Yes	NOx, TOG, CO, PM_{10}, $PM_{2.5}$, SO_2, DPM. CO_2, CH_4, N_2O	Starcrest

Continued

Table1-1: Summary of Recent Port Inventories *(continued)*

Port	Year Published	Data Year	Oceangoing Vessels	Harbor Craft	Land-Side Emissions	Pollutants[a]	Contractor[b]
Long Beach	2004	2002	No	No	Yes	NOx, TOG, CO, PM_{10}, $PM_{2.5}$, SO_2, DPM	Starcrest
Long Beach	2007	2005	Yes	Yes	Yes	NOx, TOG, CO, PM_{10}, $PM_{2.5}$, SO_2, DPM	Starcrest
Long Beach	2009	2007	Yes	Yes	Yes	NOx, TOG, CO, PM_{10}, $PM_{2.5}$, SO_2, DPM. CO_2, CH_4, N_2O	Starcrest
New York/New Jersey	2003	2000	Yes	Yes	No	NOx, VOC, CO, PM_{10}, $PM_{2.5}$, SO_2	Starcrest
New York/New Jersey	2003	2002	No	No	Yes	NOx, VOC, CO, PM_{10}, $PM_{2.5}$, SO_2	Starcrest
New York/New Jersey	2005	2004	No	No	Yes	NOx, VOC, CO, PM_{10}, $PM_{2.5}$, SO_2	Starcrest
New York/New Jersey	2008	2006	Yes	Tugs only	Yes	NOx, VOC, CO, PM_{10}, $PM_{2.5}$, SO_2, CO_2, N_2O, CH_4	Starcrest
Oakland	2008	2005	Yes	Yes	Yes [e]	NOx, ROG, CO, PM, SOx	ENVIRON
Portland	2007	2004	Yes	Yes	Yes	NOx, HC, CO, SOx, PM_{10}, $PM_{2.5}$, CO_2, 9 Air Toxics	Bridgewater Consulting
Puget Sound[f]	2007	2005	Yes	Yes	Yes	NOx, TOG, CO, PM_{10}, $PM_{2.5}$, SO_2, DPM. CO_2, CH_4, N_2O	Starcrest
San Diego	2007	2006	Yes	Yes	Yes	NOx, TOG, CO, PM_{10}, $PM_{2.5}$, SO_2, DPM	Starcrest

a NOx = oxides of nitrogen, TOG = total organic gases, ROG = reactive organic gases, VOC = volatile organic compound, HC = hydrocarbons, CO = carbon monoxide, PM_{10} = particulate matter < 10 microns, $PM_{2.5}$ = particulate matter < 2.5 microns, SO_2 = sulfur dioxide, DPM = diesel particulate matter, CO_2 = carbon dioxide, CH_4 = methane, N_2O = nitrous oxide

b Starcrest = Starcrest Consulting Group LLC, ACES = Air Consulting and Engineering Solutions; ENVIRON = ENVIRON International Corp.

c Truck and rail only

d Both Lakers and Salties

e Although definitive results are not included for Cargo Handling Equipment

f Includes the Ports of Anacortes, Everett, Olympia, Port Angeles, Seattle and Tacoma

Additional national inventories worth noting are the National Emissions Inventory (NEI) and the National Air Toxics Assessment (NATA), which include emissions from various activity sectors at ports. Additional references and inventory methods can be found in the reference section at the end of this report.

Many of the recent inventories listed in Table 1-1 have been done by Starcrest Consulting Group, LLC. As such, there has been consistency in methodology for detailed port emission inventories, although the methodology keeps evolving. However, there is little specific guidance on preparing less detailed inventories; thus, methodologies vary. In most cases, simplified inventories are prepared based upon fuel use or cargo moved. This report attempts to point out the most recent discoveries and best practices regarding port inventory preparation to encourage uniform inventory preparation using the most up-to-date emission and load factors for both propulsion and auxiliary engines. It also provides information for port authorities and government agencies to understand the inventories prepared by others.

State Implementation Plans (SIPs)[5] evaluate the emissions within and contributing to a non-attainment area. Because that geographic boundary is typically larger than a port, SIPs do not necessarily call out the geographic boundary of a port and tend to calculate impacts from engines (e.g., trucks or even non-road equipment) in a manner that may not make explicit the port's contribution. The purpose of this report is to lay out a method for doing so, because it is important for the entities that make up a port to be able to understand the current and future emissions associated with their sources. Thus, it is important to capture all of the sources of emissions within the geographic boundary selected for the analysis, including all marine, non-road, on-highway and stationary sources. This report presents a method for estimating emissions from marine, non-road, and on-highway sources. Detailed information on calculating emissions from stationary sources can be found at the EPA Office of Air Quality Planning and Standards website http://www.epa.gov/ttn/chief/.

1.2. Purpose of Port Emission Inventories

The purpose of a port emission inventory determines what should be included in the inventory and also may influence the development strategy used.

- For the development of a well-informed emission reduction strategy, all port emissions should be calculated. This will provide a baseline from which performance can be measured over time.
- In developing SIPs, land-based port emission sources are usually combined with other land-based non-road sources of similar type throughout the region. Therefore land-side emissions of non-road equipment at ports are accounted for by running EPA's NONROAD model for the region (California uses its Air Resources Board's (ARB's) OFFROAD model). Similarly, land-side emissions of on-road vehicles at ports are generally calculated using EPA's MOBILE model for the region (California uses ARB's EMFAC model). In a future release of EPA's new emission factor model, **MO**tor **V**ehicle **E**mission **S**imulator (MOVES), ports will be able to estimate all land-side emissions within port boundaries.

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[5] A SIP is the federally approved and enforceable plan by which each state identifies how it will attain and/or maintain the National Ambient Air Quality Standards (NAAQS) described in Section 109 of the Clean Air Act and 40 Code of Federal Regulations (CFR) 50.4 through 50.12.

- For NEPA[6] (or CEQA[7] in California) or general conformity[8] purposes, land-side emissions, in addition to those from OGVs, need to be estimated. Ports and government agencies also may estimate land-side emissions in order to more effectively develop control strategies for these sources.

There is no right answer to which approach should be followed for each type of port, because each port authority, terminal operator, shipping company, or state or local air quality agency must weight its individual needs and available resources. The factors that should be considered in determining which approach to adopt include the following:

- Purpose of the inventory
- Clean Air Act (CAA) status of the port region (e.g., attainment or non-attainment)
- Location of the port
- Geographic size of port
- Financial size of port (and fiscal resources available to conduct the inventory)
- Current and projected increases in the number of vessel calls, and in cargo volume
- Complexity of port owner/operator relationships
- Social, economic, and political issues surrounding the local and regional communities in which the port is located.

1.3. Pollutants of Concern

Pollutants of concern from the engines operating at ports include criteria and toxic air pollutants, as well as emissions which can cause global climate change.

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[6] The National Environmental Policy Act (NEPA) requires federal agencies to integrate environmental values into their decision making processes by considering the environmental impacts of their proposed actions and reasonable alternatives to those actions. To meet this requirement, federal agencies initially prepare an environmental assessment (EA) to determine the extent of environmental impact that may result from a federal action. If the impact is considered to be significant, a more detailed environmental impact statement (EIS) is prepared to fully calculate the environmental effects resulting from a federal action and its alternatives and to offer mitigation strategies, where available. Both documents are subject to public review and comment.

[7] The California Environmental Quality Act (CEQA) is California's equivalent to NEPA and applies to projects proposed to be undertaken or requiring approval by state and local government agencies. An environmental impact report (EIR) provides details on potential environmental impacts from a state or local action and its alternatives. Mitigation strategies also are considered.

[8] General conformity refers to a federal rule established by EPA and the U.S. Department of Transportation (DOT) that requires agency coordination to ensure that the economic, environmental, and social aspects of transportation and air quality planning are considered. All federal plans, programs, and projects must be shown to meet the requirements of the Clean Air Act and any applicable SIPs.

1.3.1. Criteria Pollutants

Criteria pollutants are those for which either the Federal government and/or the California State government have established ambient air quality standards based on short- and/or long-term human health effects associated with exposure to these pollutants. The Federal government, via the U.S. Environmental Protection Agency (EPA) has established ambient air quality thresholds for the following six pollutants:

- Ground-level ozone (O_3)
- Carbon monoxide (CO)
- Particulate matter less than 10 (PM_{10}) and 2.5 microns ($PM_{2.5}$)
- Nitrogen dioxide (NO_2)
- Sulfur dioxide (SO_2), and
- Lead (Pb).

While not a criteria pollutant, reactive organic species[9] are often considered along with criteria pollutants as they are chemical precursors for ground level ozone. Also, typically PM is expressed as primary PM. That is, the amount emitted directly. Ammonia and other species also contribute to secondary PM formation and may also be considered.

Other than lead, diesel (and other) fuel combustion at ports is an emission source for all criteria pollutants.

1.3.2. Greenhouse Gases, including Elemental Carbon

Transportation is one of the most significant and fastest growing sources of greenhouse gas emissions in the US, accounting for 29 percent of total U.S. greenhouse gas (GHG) emissions in 2006 and 47 percent of the net increase in total U.S. emissions since 1990.[10]

Carbon dioxide (CO_2), the primary greenhouse gas associated with combustion of diesel (and other fossil fuels), accounted for about 96 percent of the transportation sector's global warming potential-weighted GHG emissions for 2003. Methane (CH_4) and nitrous oxide (N_2O) together account for about 2 percent of the transportation total GHG emissions in 2003. Both of these gases are released during diesel fuel consumption (although in much smaller quantities than CO_2) and are also affected by vehicle emissions control technologies.[11]

In addition to the GHGs, another climate forcing pollutant of concern is elemental carbon[12]. The IPCC Third Assessment Report (TAR) identified aerosols as potentially significant contributors to climate change with radiative forcing roughly similar in magnitude as methane, nitrous oxide, or halocarbons, but with significant uncertainty due to their composition and various

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[9] Reactive organic species are also are referred to as hydrocarbons, volatile organic compounds, reactive organic gases, total organic gases and various other names. Each has a specific definition, but in general all react with NOx to form ozone.

[10] http://www.grida.no/publications/other/ipcc_tar/?src=/CLIMATE/IPCC_TAR/WG1/index.htm

[11] Greenhouse Gas Emissions from the U.S. Transportation Sector, 1990-2003, US EPA, March 2006. Available at: http://www.epa.gov/otaq/climate/420r06003.pdf

[12] Also referred to as black carbon.

atmospheric properties.[13] Of particular concern for ports is the fraction of the exhaust aerosol from combustion of diesel or other fossil fuels that is black or elemental carbon (soot). This species can absorb sunlight and directly warm the atmosphere.

1.3.3. Air Toxics

Air toxics, also known as hazardous air pollutants (HAPs), toxic air contaminants (TACs), or non-criteria air pollutants, are contaminants found in the ambient air that are known or suspected to cause cancer, reproductive or birth defects, other health effects, or adverse environmental effects, but do not have established ambient air quality standards. HAPs may have short-term and/or long-term exposure effects.

EPA currently has implemented programs to reduce emissions of 188 HAPs[14], however 1,033 total HAPs are listed by EPA as related to mobile source emissions[15] and, of these, 644 are components of diesel exhaust, including benzene, cadmium, formaldehyde, and 1,3-butadiene. In California, diesel particulate matter is typically the toxic air contaminant of primary concern; however, there are no specific annual limits on its emissions.

Unlike criteria and climate forcing pollutants, emission factors for TACs are less readily available for many engines, thus estimating these emissions in a port-related emission inventory is more difficult. TAC emission factors for on-road vehicles may be obtained directly from the MOBILE6.2 model. In other cases, TAC emission factors may be scaled from organic carbon and particulate matter emissions, using EPA[16] or ARB[17] methodologies. The reader is directed to these sources rather than repeat all factors and methods here. However, in many cases, diesel particulate matter (DPM) is the TAC of primary concern, and can be directly derived from these emission factor models as exhaust PM for diesel-fueled engines.

1.4. Overview of Port Emission Inventory Methodologies

There are many different approaches to developing a port emission inventory, and they can vary greatly in terms of the time and resources required. To account for resource disparities, throughout this report two different approaches are presented:

- *Detailed Inventory*—Highly detailed inventories are typically prepared by the “larger” deep-sea ports in air quality non-attainment areas.[18] This type of inventory requires detailed data on vessels and land-based equipment characteristics and activities, as well as detailed

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[13] http://www.ipcc.ch/meetings/ar4-workshops-express-meetings/geneva-may-2005.pdf

[14] http://www.epa.gov/ttn/atw/188polls.html

[15] The full list is available at: http://www.epa.gov/otaq/regs/toxics/420b06002.xls

[16] http://www.epa.gov/ttn/atw/nata/mobile.html

[17] http://www.arb.ca.gov/ei/speciate/speciate.htm

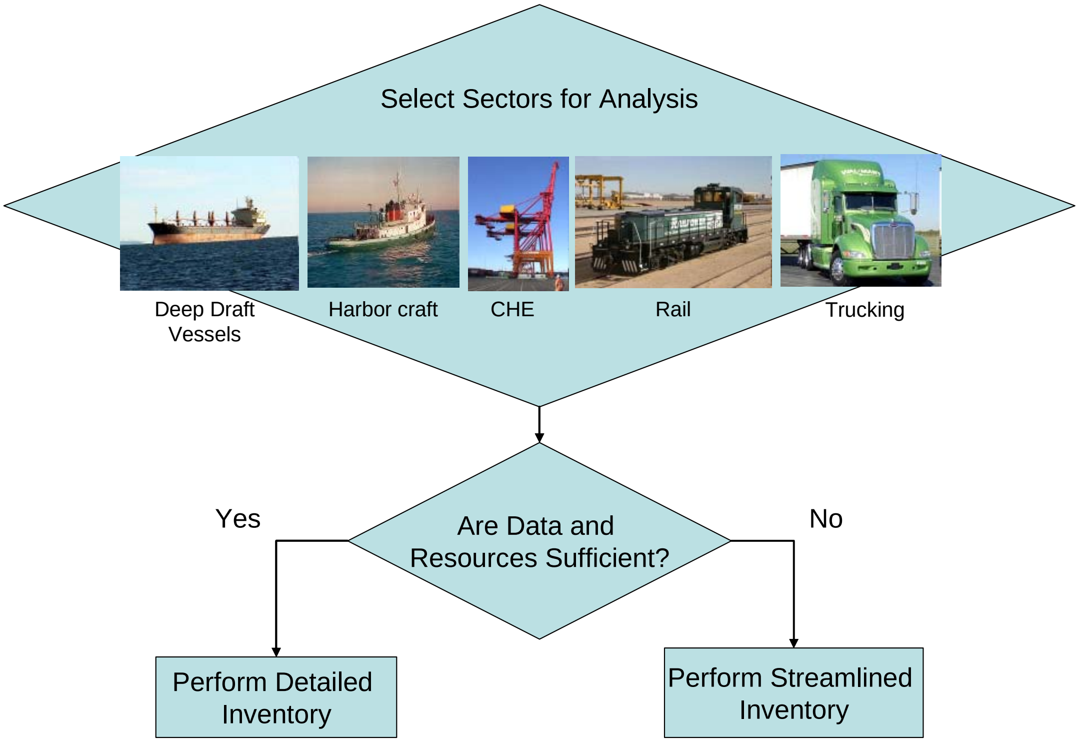
[18] The Clean Air Act regulates certain air pollutants, called criteria pollutants, which are harmful to human health. EPA sets limits on the amount of these pollutants that can be present in the air before human health may be impaired. If a pollutant limit is consistently exceeded within a certain area, generally defined around urban centers on the county level, or a certain area contributes to an exceedance of the limit in another downwind location, then that area (county or portion of a county) is designated a non-attainment area. For a list of non-attainment areas, visit EPA’s website at http://www.epa.gov/oar/oaqps/greenbk/index.html.

information on port geography and ship paths within the port. This is the best practice for all ports, but its application may be limited by available resources.

- *Streamlined Inventory*– A streamlined inventory approach is often used by “mid-size” and “smaller” seaports and ports that are either not in an ozone or PM non-attainment area or in a maintenance area.[19] Ports on the Great Lakes also might use this approach. Such an inventory requires some measure of port-specific activity data but applies “typical” port emission parameters by sector. The methodologies may be tailored to the amount of data available. In some cases, a highly streamlined inventory can be developed using extrapolations made from typical port data based on ship calls estimated by the U.S. Army Corps of Engineers (USACE).

As is discussed throughout this report, the quality and extent of input data and resources dictate which level of inventory that may be produced. This is generally outlined by Figure 1-2.

Figure 1-2: Decision Methodology for Port Inventory Type



1.5. Definition of Port Boundaries

In all cases, boundaries of the inventory must be included. Often these are not immediately clear since emitting activities do not necessarily follow political or property lines. It is therefore important to look at the purpose of the inventory to decide on the proper boundaries that it will encompass.

In most cases, the purpose of the inventory helps define useful port boundaries. In most cases, the land-side boundary should be selected to include at least the first intermodal point and thus includes

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[19] Maintenance areas are defined as those areas that were once in non-attainment of the NAAQS, but have cleaned their air to a level below the NAAQS. These areas must be careful to not slip back into non-attainment status.

trucks, rail, gates, etc. By doing so, improvements such as reducing wait times into and out of gates and distribution centers, reducing truck vehicle miles traveled (VMT) due to intermodal shifts, and other mitigation strategies can be evaluated. On the ocean side, it should include at least the first 25 nautical miles from where the pilot boards the ship for entry into the port, but this might be extended if wind direction is a factor.[20] For SIP purposes, the non-attainment area boundary(ies) might be used. EPA's marine inventory in the Category 3 engine rulemaking used 200 nautical miles from the coast as this represents the boundary of the exclusive economic zone (EEZ)[21] Using the 200 nautical mile boundary will include the effect of transiting ships which are typically considered inter-port emissions.

Another consideration is data resolution. In some cases, the inventory parameter boundaries might extend to the most resolved scope of the input data. For example, county boundaries might be used in cases where inputs are available only at the county level or greater.

Further, temporal boundaries must be considered. These, too, are likely to be dictated by data availability and purpose of the inventory. Typically, an inventory covers a single calendar year.

1.6. Estimated Growth Factors

While actual growth factors should be used if possible, average annual growth factors were estimated by Research Triangle Institute (RTI) for ocean going vessels based upon cargo movement data from Global Insights Inc.[22] Estimated growth rates by region are given in Table 1-2

Table 1-2: Annualized Growth Rates by Region

Region	Annual Growth Rate
South Pacific	5.00%
North Pacific	3.30%
Gulf Coast	2.90%
East Coast	4.50%
Great Lakes	1.70%

Regional definitions are as follows:

- *South Pacific*—Includes California and Hawaii
- *North Pacific*—Includes Oregon, Washington and Alaska[23]
- *Gulf Coast*—All Gulf Coast states including the west side of Florida
- *East Coast*—All East Coast states including the east side of Florida
- *Great Lakes*—All Great Lake states.

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[20] Many detailed port inventories do not include cruise in open ocean because it is outside the air basin boundaries in which the port is situated.

[21] EPA, Final Regulatory Support Document: Control of Emissions from New Marine Compression-Ignition Engines at or Above 30 Liters per Cylinder, EPA420-R-03-004, January 2003.

[22] RTI International, *Global Trade and Fuels Assessment—Future Trends and Effects of Designation Requiring Clean Fuels in the Marine Sector: Task Order No. 1, Draft Report*, EPA Report Number EPA420-R-07-012, December 2006.

[23] The RTI document divides North and South Pacific at the Oregon-Washington border; however, due to the fact that Oregon ports are on the Columbia River, it is more likely that growth will be smaller there than at California ports.

The dividing line between East Coast and Gulf Coast is a vertical line roughly through Key Largo (Longitude 80° 26' West). These growth factors should be applied to the number of known calls to determine future calls at a future date.

1.7. How this Document Differs from the Previous Best Practices Report

In 2006, ICF released *Current Methodologies and Best Practices in Preparing Port Emission Inventories*.[1] That document described current methodologies and best practices used for preparation of a port emission inventory, primarily focused on creation of detailed inventories for ocean going vessels.

The present report updates that document to reflect the current state of the science in emission inventories, but also provides additional details on a streamlined approach to inventory creation that should be useful to those either operating with more limited data and/or resources than those necessary to create a full, detailed emission inventory or those with more limited knowledge of emission inventories. It should be noted that "best practices" still dictate that a full detailed inventory be conducted, however, to address the needs of port authorities, those doing business at ports, state and local entities, or other interested parties to have a standard approach to inventory development, additional sections have been added here to address creation of streamlined inventories.

Further, this document addresses the issues of greenhouse gas and black carbon emissions. These species are of current concern for their climate forcing properties but were not included in the previous report.

Finally, due to the change in focus, this report is no longer referred to as "Best Practices," although it does address current best practices in inventory development. Rather, the title has been changed to "Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories."

1.8. How to Use this Document

This document is intended to guide both producers and consumers of information regarding emissions from port activities—including port authorities, those doing business at ports, state and local entities, and other interested parties—in a common methodology for analyzing port emissions.

This report is structured in such a way that it may be used as a reference for specific topics or read completely to inform the reader on the current methods of producing a port emission inventory. It is intended to provide a reference to both the experienced and novice dealing with port emissions, especially by enhancing the coverage of streamlined approaches to inventory development.

Each chapter is set out by source category, starting with ocean going vessels then followed by harbor craft, cargo handling equipment, rail, and trucks. In each chapter, a detailed approach is discussed along with methods to streamline calculations. Ports may decide to do a detailed approach in some sectors and a more streamlined approach in others.

1.9. Report Organization

The remainder of this report is organized into seven chapters. Chapters 2 through 5 describe how to prepare emission inventories for the various sectors active at ports (ocean going vessels, harbor craft, cargo handling equipment, rail, and trucking). Each of these chapters includes a discussion of best practice, detailed emission inventory development, as well as methods for creating streamlined inventory calculations. Chapter 6 describes several case studies of how port emission inventories have been used in the development and implementation of emission reduction strategies at ports. Finally, Chapter 7 provides recommendations for further study to improve port emission inventories. A list of the references reviewed to prepare this document is attached at the end of the report. A list of acronyms is at the beginning of this report.

2. Ocean Going Vessels

This section describes the necessary steps to prepare a detailed ocean going vessel (OGV) port emissions inventory. It includes (1) emissions determination, (2) data sources, (3) vessel characteristics, (4) activity determinations, (5) load factors, and (6) emissions factors. It then describes how to prepare more streamlined approximations.

2.1. Emissions Determination

The current practice to calculate emissions from OGVs is to use energy-based emission factors together with activity profiles for each vessel. The bulk of the work involves determining representative engine power ratings for each vessel and the development of activity profiles for each ship call. Using this information, emissions per ship call and mode can be determined using the equation below.

$$\mathbf{E = P \times LF \times A \times EF}$$

Where **E** = Emissions (grams [g])
P = Maximum Continuous Rating Power (kilowatts [kW])
LF = Load Factor (percent of vessel's total power)
A = Activity (hours [h])
EF = Emission Factor (grams per kilowatt-hour [g/kWh])

The emission factor is in terms of emissions per unit of energy from the engine. It is multiplied by the power needed to move the ship in a particular activity.

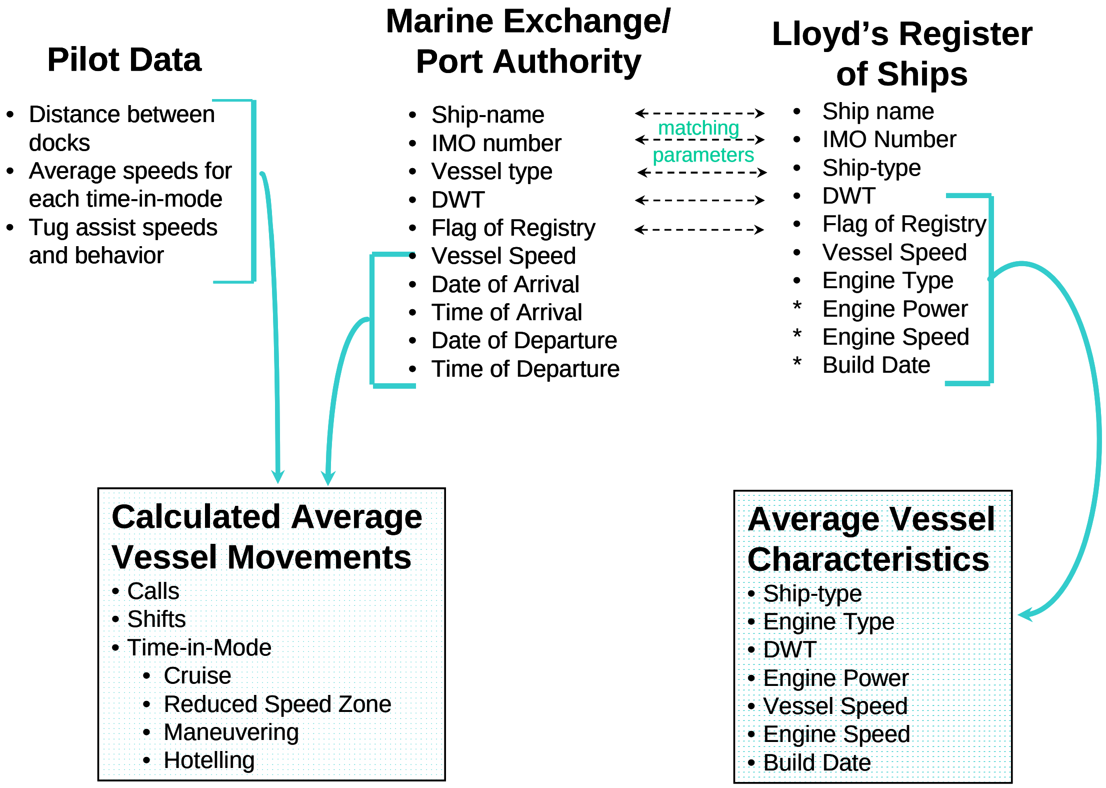
The next several sections describe data sources to use and how to determine (1) ship characteristics, (2) activity profiles, (3) load factors, and (4) emissions factors for ocean going vessels. In each subsection, the detailed approach will be described followed by methods to streamline the calculations if less accuracy is acceptable.

In a detailed inventory, emissions for each mode (cruise, reduced speed zone, maneuvering, and hotelling with and without cold ironing) during a call should be calculated using ship type, actual speed, engine power, load factor, time in that mode and emission factors for propulsion and auxiliary engines and boilers. It should first be summed by call, then summed by DWT ranges and then by ship type for an entire year of calls. These data can be used by others when developing port emission inventories. For the highest level of detailed inventory, parameters used in the calculation should be weighted by activity. In a simpler methodology, parameters such as load factor, time in mode, and average power can be weighted by call.

2.2. Data Sources

Various data sources are available to those preparing port emission inventories. These include Marine Exchange/Port Authority (MEPA) data, U.S. Army Corps of Engineers (USACE) entrances and clearances data, Lloyd's Register of Ships (Lloyd's Data), and Pilot data. The importance and use of each are discussed below and shown in Figure 2-1. The Coast Guard Vessel Traffic System (VTS) and the Automatic Identification System (AIS) also can be used to determine vessel movements. Other data sources that can be found useful are listed in the reference section at the end of this report.

Figure 2-1: Data Sources and their Uses



2.2.1. Marine Exchange/Port Authority Data

The best source of data on vessel operations can be obtained from the local port authority, marine exchange, board of trade, or other local organization with reliable information on vessel movements. In most cases, data are in electronic format. Almost all MEPAs record vessel name, date and time of arrival, and date and time of departure. Larger MEPAs also record Lloyd's register numbers, flag of registry, ship type, pier/wharf/dock (PWD) names, dates, and times of arrival and departure from various PWDs, anchorages, next ports, cargo type, cargo tonnage, activity description, draft, vessel dimensions, and other information. Generally, one record of data corresponds to one call within the MEPA but may include shifts between berths located in the MEPA. MEPAs also can contain more than one port, such as for the Ports of Los Angeles and Long Beach. Because those ports are in close proximity, one MEPA records ship movements into and out of both ports.

The electronic data received from the MEPAs provide a way to characterize a typical vessel call in each port, using the following elements:

- Total time the vessel was in port
- Port(s) of call within the MEPA
- Vessel characteristics (using Lloyd's vessel characteristic data).

2.2.2. U.S. Army Corps of Engineers Entrances and Clearances

As a substitute for MEPA data, the USACE entrances and clearances data can be used to determine ship calls. The Maritime Administration (MARAD) maintains the Foreign Traffic Vessel Entrances and Clearances database, which contains statistics on U.S. foreign maritime trade. Data are compiled during the regular processing of statistics on foreign imports and exports. The database contains information on the type of vessel, commodities, weight, customs districts and ports, and origins and destinations of goods.

There are several drawbacks to using USACE entrances and clearances data. First, it does not contain any call time-in-mode information. Average time in mode and speeds need to be used with the USACE data to perform a mid-tier analysis. Second, it only represents foreign cargo movements. Thus domestic traffic, U.S. ships delivering cargo from one U.S. port to another U.S. port covered under the Jones Act[24], is not accounted for in the database. However, U.S. flagged ships carrying cargo from a foreign port to a U.S. port or from a U.S. port to a foreign port are accounted for in the USACE entrances and clearances database as these are considered foreign cargo movements. While at most ports, domestic commerce is carried out by Category 2 ships, there are a few exceptions, particularly on the West Coast. Unfortunately, there is little or no readily available information on domestic trips, so determining this without direct port input is difficult. Third, the entrances and clearances data does not always match MEPA data because it does not differentiate between public and private terminals at a port. This is important because a Port Authority may not have jurisdiction over private terminals. A recent ICF study found that the USACE entrances and clearances data accounted for over 90 percent of the emissions from Category 3 ships calling on US ports.[25]

2.2.3. Lloyd's Register of Ships

Lloyd's Data is produced by Lloyd's Register-Fairplay Ltd., headquartered in Surrey, England.[26] They offer the largest database of commercially available maritime data in the world in several formats. The newest version (2008) of Lloyd's Register of Ships has details on 170,000 vessels and 200,000 companies that own, operate, and manage them. Two versions worth noting are the Sea-Web (ships over 100 GT) at $2,950 for a single user and the Internet Ships Register (ships over 299 GT) at $1,450 for a single user.

Lloyd's Data contains information on ship characteristics that are important for preparing detailed marine vessel inventories including the following:

- Name
- Ship Type
- Build Date
- Flag
- Dead weight tonnage (DWT)
- Vessel service speed
- Engine power plant configuration and power.

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[24] Merchant Seaman Protection and Relief 46 USCS Appx § 688 (2002) Title 46. Appendix. Shipping Chapter 18.

[25] ICF International, *Inventory Contribution of U.S. Flagged Vessels,* June 2008.

[26] http://www.lrfairplay.com/Maritime_data/ships.html

All data are referenced to both ship name and Lloyd's number (IMO Number). Only Lloyd's number is a unique identifier for each ship. Lloyd's insures many of the OGVs on an international basis, and for these vessels, the data are quite complete. For other ships using a different insurance certification authority, the data are less robust.

2.2.4. Pilot Data

Information from pilot associations and tide books can be invaluable to the calculation of time-in-modes.[27] A harbor pilot will often board an OGV near the breakwater. This transfer takes place while the pilot's vessel and the vessel calling on the MEPA are traveling at a reduced speed of 5 to 7 knots. The harbor pilot takes over from the main pilot and coordinates with any tugs that are going to assist the vessel in docking. Many times, it is this boarding by the harbor pilot and the subsequent record keeping that allow the MEPAs to have such detailed records of vessel activity.

Pilots at all of the MEPA waterways should be contacted and asked about typical operations, including speeds by vessel type. Information on reduced speeds in a typical waterway can be obtained through conversations with knowledgeable personnel at the MEPA and, when possible, directly with the pilots responsible for actually handling the vessels in the waterway. Vessel movements then can be calculated from the MEPA data, and any inconsistencies or lack of data can be resolved by discussions with the pilots. The data provided by pilots can be used to supplement the data received from the MEPA and to form a more complete record of each time-in-mode.

2.2.5. Coast Guard Vessel Tracking System (VTS)

The Coast Guard maintains a vessel tracking system to improve maritime safety as well as national security, and also could enhance port operations. The tracking system provides static information about vessels, including identity, vessel type, and size, as well as dynamic information, including its current cargo, destination, course, speed, and estimated arrival time. This information can be used to verify and improve upon MEPA data as well as provide statistics of compliance rates for reduced speed zones. It can also be used to determine average speeds by vessel types in the various waterways of a port.

2.2.6. Automatic Identification System (AIS)

An Automatic Identification System (AIS) is used for identifying and monitoring maritime traffic.[28] The AIS sends and receives vessel identification information which can be displayed on a laptop computer or chart plotter. Information such as vessel name, radio call sign, navigational status (e.g., at anchor or under way using engine), speed, heading, type of ship/cargo, destination, and estimated time of arrival are all examples of information that can be displayed. A schematic of the AIS system is shown in Figure 2-2. The main problem with AIS is that because it is transmitted from the ship, the receiver needs to be within a reasonable distance of the ship to pick up the signal. Generally the ship needs to be no more than 60 nautical miles from the receiver, less for receiving stations that are at lower elevations.

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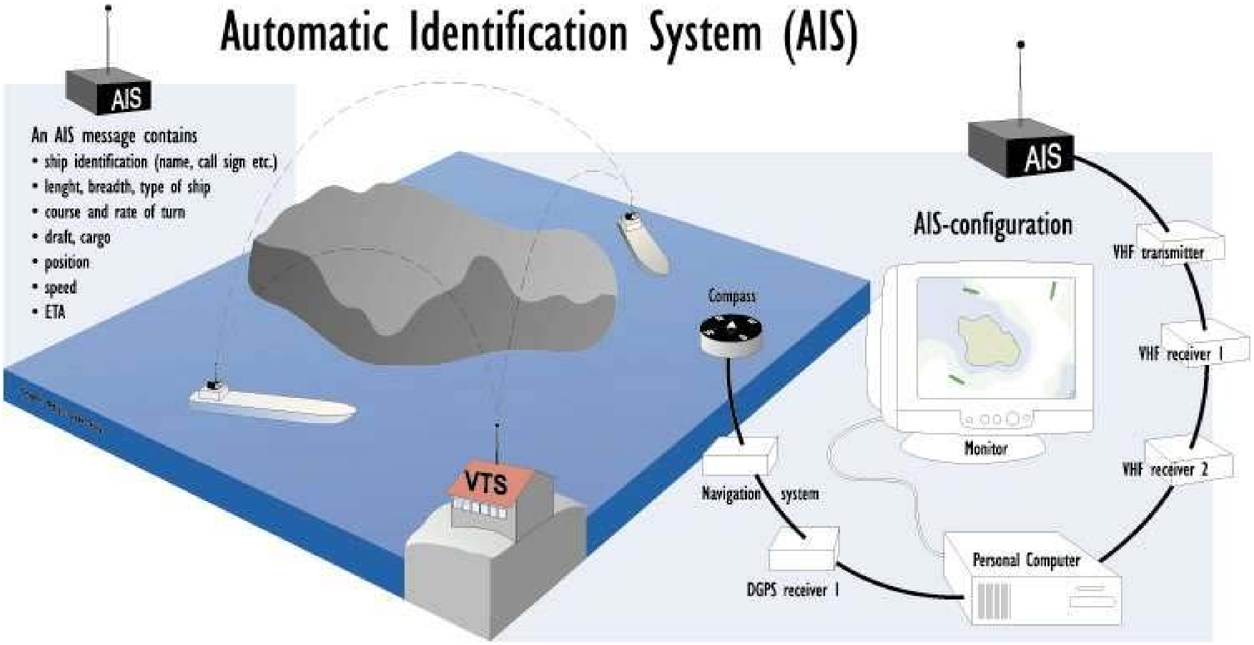
[27] Different modes of concern in determining emissions (based on the amount of time spent in each mode) per a vessel call include cruise, reduced speed zone, maneuvering, and hotelling.

[28] http://www.shinemicro.com/AISOverview.asp

Figure 2-2: How AIS Works



Lloyds Fairplay offers an integrated network of AIS receivers in their AIS Live product.[29] AIS Live was the first global AIS network and continues to provide an online application with access to real time ship movements. Lloyd's network coverage extends from Europe to North America, the Caribbean, Mediterranean, and Far East. The AIS Live network provides real time information in over 100+ countries and over 2,000 ports and terminals around the world. It currently shows the live positions of circa 27,000 vessels a day. The position of each vessel within the areas of coverage is displayed on a chart and is updated every 3 minutes, 24 hours a day. Simply by clicking on a vessel, additional details are available such as IMO number, MMSID, latitude, longitude, course, speed, and next port.

2.3. Vessel Characteristics

OGVs vary greatly in speed and engine sizes based on ship type. Various studies break out vessel types differently, but it makes most sense to break vessel types out by the cargo they carry. Table 2-1 lists various OGV types that should be described in any detailed inventory.

Other characteristics that should be determined from Lloyd's Data are the propulsion engine power and engine speed, maximum vessel speed, and engine speed. EPA defines marine vessel engines (propulsion and auxiliary) in terms of categories as shown in

Table 2-2. These categories relate to land-based engine equivalents. Engine speed designations are shown in Table 2-3. Most ships have diesel engines, although some older ships are steamships.

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[29] http://www.lrfairplay.com/Maritime_data/AISlive/AISlive.html

Table 2-1: Oceangoing Vessel Ship Types

Ship Type	Description
Auto Carrier	Self-propelled dry-cargo vessels that carry containerized automobiles.
Barge Carrier	Self-propelled vessel that tows lashed barges.
Bulk Carrier	Self-propelled dry-cargo ship that carries loose cargo.
Container Ship	Self-propelled dry-cargo vessel that carries containerized cargo.
Cruise Ship	Self-propelled cruise ships.
General Cargo	Self-propelled cargo vessel that carries a variety of dry cargo.
Miscellaneous	Category for those vessels that do not fit into one of the other categories or are unidentified.
Oceangoing Tugs/Tows	Self-propelled tugboats and towboats that tow/push cargo or barges in the open ocean.
Reefer	Self-propelled dry-cargo vessels that often carry perishable items.
Roll-on/Roll-off (RORO)	Self-propelled vessel that handles cargo that is rolled on and off the ship, including ferries.
Tanker	Self-propelled liquid-cargo vessels including chemical tankers, petroleum product tankers, liquid food product tankers, etc.

Table 2-2: EPA Marine Compression Ignition Engine Categories

Category	Specification	Use	Approximate Power Ratings
1	Gross Engine Power ≥ 37 kW[a] Displacement < 5 liters per cylinder	Small harbor craft and recreational propulsion	< 1,000 kW
2	Displacement ≥ 5 and < 30 liters per cylinder	OGV auxiliary engines, harbor craft, and smaller OGV propulsion	1,000 – 3,000 kW
3	Displacement ≥ 30 liters per cylinder	OGV propulsion	> 3,000 kW

[a] EPA assumes that all engines with a gross power below 37 kW are used for recreational applications and are treated separately from the commercial marine category.

Table 2-3: Marine Engine Speed Designations

Speed Category	Engine RPM[a]	Engine Stroke Type
Slow	< 130 RPM	2
Medium	130 – 1,400 RPM	4
High	> 1,400 RPM	4

[a] RPM = revolutions per minute

In the 2001 emission inventory for the Port of Los Angeles (PoLA), Starcrest shows that Lloyd's Data fairly accurately records both ship power and vessel service speed.[30]

Auxiliary engine power also can be determined from Lloyd's Data, but many records are missing this information. Prior practice has been to use a fixed power rating for auxiliaries based on ship type and activity mode or to assume auxiliary power is equivalent to 10 percent of propulsion power.[31] In the PoLA inventory, Starcrest collected information from Lloyd's Data and Starcrest's vessel boarding program. California Air Resources Board (ARB) conducted an Oceangoing Ship Survey of 327 ships in January 2005.[32] Table 2-4 shows average auxiliary engine power compared to propulsion power obtained from the ARB survey. While it is important to determine proper ratios for each port because of differences in the types of ships calling on that port, these ratios and engine speeds can be used in mid-tier inventory development as a surrogate for auxiliary power if no other data are available.

Table 2-4: Auxiliary Engine Power Ratios (ARB Survey)

Ship Type	Average Propulsion Engine (kW)	Average Auxiliary Engines				Auxiliary to Propulsion Ratio
		Number	Power Each (kW)	Total Power (kW)	Engine Speed	
Auto Carrier	10,700	2.9	983	2,850	Medium	0.266
Bulk Carrier	8,000	2.9	612	1,776	Medium	0.222
Container Ship	30,900	3.6	1,889	6,800	Medium	0.220
Cruise Ship[a]	39,600	4.7	2,340	11,000	Medium	0.278
General Cargo	9,300	2.9	612	1,776	Medium	0.191
RORO	11,000	2.9	983	2,850	Medium	0.259
Reefer	9,600	4.0	975	3,900	Medium	0.406
Tanker	9,400	2.7	735	1,985	Medium	0.211

[a] Cruise ships typically use a different engine configuration known as diesel-electric. These vessels use large generator sets for both propulsion and ship-board electricity. The figures for cruise ships above are estimates taken from the Starcrest Vessel Boarding Program.

Fuel type also is instrumental in determining emission factors and should be determined for each port. Practically all OGVs operate their main propulsion engines on residual oil (RO). However, most ships have at least two tanks and reserve one for either marine diesel oil (MDO) or marine gas oil (MGO). The later two fuels are refined and used mostly for auxiliary engines and for cleaning and cold start-up of propulsion engines.

Data collected during the ARB survey in January 2005 indicated that approximately 29 percent of auxiliary engines used MGO instead of RO. For cruise vessels, only 8 percent used MGO

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[30] Starcrest Consulting Group LLC, *Port of Los Angeles Baseline Ai Emissions Inventory -2001,* prepared for the Port of Los Angeles, July 2005.

[31] ENVIRON International Corporation, *Commercial Marine Emission Inventory Development*, prepared for the U.S. Environmental Protection Agency, April 2002.

[32] California Air Resources Board, *2005 Oceangoing Ship Survey, Summary of Results,* September 2005.

instead of RO. Generally older ships require MDO in their auxiliary engines while newer ships can tolerate RO. As the price of fuel increases, many ship operators will opt to use RO in their auxiliary engines due to its lower cost. While it is better to determine actual percentages of ships that use MGO instead of RO for their auxiliary engines for a given port, the percentages listed above can be used as a surrogate.

Generally, one should calculate auxiliary power from the total propulsion power (listed in the Lloyds data) using the ratios in Table 2-4. Auxiliary power is considered in addition to the propulsion power on a ship. However, many passenger ships and tankers have either diesel-electric or gas turbine-electric engines that are used for both propulsion and auxiliary purposes. Lloyds clearly calls out these types of engines in their database and that information can be used to distinguish them from direct and geared drive systems. Generally the power Lloyds lists for electric drive ships is the total power, which includes power for both propulsion and auxiliary uses. To separate out propulsion from auxiliary power for purposes of calculating emissions for electric drive ships, the total power listed in the Lloyds data should be divided by 1 plus the ratio of auxiliary to propulsion power to give the propulsion power portion and the remaining portion should be considered auxiliary engine power.

Great Lake deep draft vessels are unique from OGVs in several ways. First, much of the fleet remains within the Great Lakes and never transits to the open ocean. These ships are called “Lakers.” Lakers are generally self unloading bulk carriers and most have Category 2 propulsion engines. Ships that enter the Great Lakes from the open ocean through the St. Lawrence River are known as “Salties.” While there is considerable transit of Salties down the St. Lawrence River and cruise in the open ocean, most of the transit and cruise modes occur in Canada and thus are ignored in the U.S. inventory.

Some ship types are also unique to the Great Lakes. These include self-unloaders, shuttles, and ITBs. Self-unloaders are bulk carriers with self-unloading equipment. Shuttles are self-unloaders that shuttle cargo from one dock to another within a port and are unique to Cleveland, OH. ITBs are integrated tug-barges and include ATBs or articulated tug-barges. These are unique from pushboats/towboats and barges because the barge is always attached.

2.4. Activity Determination

The description of a vessel’s movements during a typical call is best accomplished by breaking down the call into sections that have similar speed characteristics. Vessel movements for each call are described by using four distinct time-in-mode calculations. A call combines all four modes, while a shift normally occurs as maneuvering. Each time-in-mode is associated with a speed and, therefore, an engine load that has unique emission characteristics. While there will be variability in each vessel’s movements within a call, these time-in-modes allow an average description of vessel movements at each port. Time-in-modes should be calculated for each vessel call occurring in the analysis year over the waterway area covered by the corresponding MEPA. The time-in-modes are described in Table 2-5.

Table 2-5: Vessel Movements and Time-In-Mode Descriptions within the MEPA Areas

Summary Table Field	Description
Call	A call is one entrance and one clearance from the MEPA area.
Shift	A shift is a vessel movement within the MEPA area. Shifts are contained in calls. While many vessels shift at least once, greater than 95 percent of vessels shift three times or less within most MEPA areas. Not all MEPAs record shifts.
Cruise (hr/call)	Time at service speed (also called sea speed or normal cruising speed) usually considered to be 94 percent of maximum speed and 83 percent of MCR. Calculated for each MEPA area from the port boundary to the breakwater or reduced speed zone. The breakwater is the geographic marker for the change from open ocean to inland waterway (usually a bay or river).
Reduced Speed Zone[a] (RSZ) (hr/call)	Time in the MEPA area at a speed less than cruise and greater than maneuvering. This is the maximum safe speed the vessel uses to traverse distances within a waterway leading to a port. Reduced speeds can be as high as 15 knots in the open water of the Chesapeake Bay, but tend to be more in the order of 9 to 12 knots in most other areas. Some ports are instituting RSZs to reduce emissions from OGVs as they enter their port.
Maneuver (hr/call)	Time in the MEPA area between the breakwater and the PWD. Maneuvering within a port generally occurs at 5 to 8 knots on average, with slower speeds maintained as the ship reaches its pier/wharf/dock (PWD) or anchorage. Even with tug assist, the propulsion engines are still in operation.
Hotelling (hr/call)	Hotelling is the time at PWD or anchorage when the vessel is operating auxiliary engines only or is cold ironing. Auxiliary engines are operating at some load conditions the entire time the vessel is manned, but peak loads will occur after the propulsion engines are shut down. The auxiliary engines are then responsible for all onboard power or are used to power off-loading equipment, or both. Cold ironing uses shore power to provide electricity to the ship instead of using the auxiliary engines. Hotelling needs to be divided into cold ironing and active to accurately account for reduced emissions from cold ironing.

[a] Referred to as the Transit zone in many inventory documents.

Cruise speed (also called service speed) is listed in Lloyd’s data and is generally taken as 94 percent of the maximum service speed. Distances from the maximum port boundary to either the RSZ or the breakwater[33] are used with the cruise speed to determine cruise times into and out of the port. Some MEPAs record which route was used to enter and leave the port and this information can be used to determine the actual distances the ships travel. Average cruise speeds by ship type from the Category 3 inventory[34] are given in Table 2-6. While actual cruise speeds should be calculated in a detailed inventory, these can be used as surrogates for more streamlined analyses.

RSZ time-in-mode also is an estimation based on average ship speed and distance. Starcrest refers to this time-in-mode as “Transit” in their inventory documents. Pilots generally can report average ship speeds for a precautionary or reduced speed zone. As was found in the PoLA study, ships tend to move at less than the maximum RSZ speed. For instance, in the PoLA, the precautionary zone speed is 12 knots or less. Starcrest found, through conversations with pilots and its vessel boarding program, that auto carriers, container ships, and cruise ships average 11 knots in the RSZ while other ship types average 9 knots in the RSZ. In addition, compliance with RSZ speeds should be determined. Generally the RSZ starts when a ship enters the US

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[33] Not all ports have a physical breakwater. Thus for these ports, an imaginary breakwater needs to be defined.

[34] ICF International, *Commercial Marine Port Inventory Development—2002 and 2005 Inventories*, September 2007.

coastline such as a shipping channel, river or bay where speeds need to be reduced for navigational purposes. The RSZ ends at the port entrance.

Maneuvering time-in-mode is estimated based on the distance a ship travels from the breakwater to the pier/wharf/dock (PWD). Average maneuvering speeds vary from 3 to 8 knots depending on direction and ship type. Generally, outbound speeds are greater because the ship does not need to dock. Ships go from half speed to dead slow to stop during maneuvering. Time-in-mode varies depending on the location of and the approach to the destination terminal and turning requirements of the vessel. Maneuvering speeds should be determined through conversations with the pilots. In the PoLA inventory, inbound auto carriers, container ships, and cruise ships averaged 7 knots during maneuvering, while all other ship types averaged 5 knots. On the outbound route, all vessels averaged 8 knots.

Table 2-6: Average Cruise Speeds by Ship Type

Ship Type	Cruise Speed (knots)
Auto Carrier	18.7
Bulk	14.5
Container Ship	21.6
Cruise Ship	20.9
General Cargo	15.2
Miscellaneous	13.0
OG Tug	14.5
RORO	16.8
Reefer	19.5
Tanker	14.8

One Knot,
or one nautical mile per hour,
is equivalent to
1.15 miles per hour.

Hotelling can be calculated by subtracting time spent maneuvering into and out of a PWD from the departure time minus the arrival time into a port. If possible, anchorage time (time at anchorage within the port but not at a PWD) should be broken out from time at a PWD. Some MEPAs record shifts as well and this will allow for further refinements in maneuvering time. Other methods to determine hotelling include conversations with pilots. During hotelling, the main propulsion engines are off, and only the auxiliary engines are operating, unless the ship is cold ironing. Hotelling times can also be determined from pilot records of vessel arrival and departure times when other data is not available. Actual hotelling times should be calculated for each individual port, because hotelling is generally a large portion of the emissions at a port. Hotelling times should be separated for those ships that use cold ironing at a port and those that do not. It is important to also look for outliers (ships with extremely long hotelling times) to eliminate those in the average since they may represent ships at a PWD but not with auxiliary engines on.

Many variables affect one or more time-in-mode calculations. These variables cannot be accurately predicted for a ship-type category over an entire year of calls. Traffic conditions, weather, vessel schedule, and current are some of the more important variables that dictate how much time is required at each time-in-mode, especially maneuvering as described below.

- Traffic conditions may make travel in the waterway slower because a wake is more damaging in a congested waterway, forcing vessels to be more careful and travel at slower speeds.
- Bad weather in the form of high winds causes vessels to be more difficult and less predictable to maneuver. Rain and fog obscure visibility and can make a vessel's maximum speed in the waterway one-third of what it would be on a clear day. Docking at a PWD takes much longer in bad weather and on busy days, resulting in more time spent at maneuvering speeds.
- River or Strait currents should also be taken into account. In some locations, travel up river is much slower than down river and can affect transit times and loads.
- Vessel schedule also affects time-in-mode. The waterway pilot is at least partially responsible for keeping the vessel on schedule to meet the tug assist for docking, the loading or unloading crews, and/or the bunkering vessel. If a vessel is ahead of schedule, the pilot may use slower speeds in the waterway to conserve fuel and arrive closer to schedule. If the vessel is behind schedule, the pilot may push speeds to the maximum safe limit in an attempt to get back on schedule.

In a detailed inventory where actual speeds are used, these factors will be accounted for. In a mid-tier inventory, these issues cannot be accounted for directly, thus averaging time-in-modes over a year will smooth out some of these issues.

Since much of the Great Lake fleet operates within the lakes, cruise mode is defined to start 10 nautical miles from the port within the lake and end at 3 nautical miles from the port when the ship begins to slow to maneuvering speed. RSZ mode begins 3 nautical miles from the port and is estimated at halfway between cruise or service speed and maneuvering speed. Maneuvering and hotelling are defined similar to OGVs.

Two unique factors need to be taken into account for Great Lake vessels as well. First, much of the fleet is older Category 2 vessels and they tend to operate on distillate fuels. Second, a considerable amount of cargo movements are by Jones Act ships (ships which transfer cargo from one U.S. port to another) and thus not accounted for in USACE entrances and clearances data. Furthermore, Lakers tend to have many unloaded trips which are also not counted in the USACE data.

2.5. Load Factors

Load factors are expressed as a percent of the vessel's total propulsion or auxiliary power. At service or cruise speed, the propulsion load factor is 83 percent. At lower speeds, the Propeller Law should be used to estimate ship propulsion loads, based on the theory that propulsion power varies by the cube of speed as shown in the equation below.[35]

$$\mathbf{LF = (AS/MS)^3}$$

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[35] When ships move against significant river currents, the actual speed in the above equation should be calculated based upon the following: for vessels traveling with the river current, the actual speed should be the vessel speed minus the river speed; for vessels traveling against the river current, the actual speed should be the vessel speed plus the river speed.

Where **LF** = Load Factor (percent)
AS = Actual Speed (knots)
MS = Maximum Speed (knots)

Earlier work by Starcrest and others assumed that this law had a lower limit of approximately 10 percent, representing an assumed stall speed for diesel engines.[36] This assumption was consistent with that used by ENVIRON in their calculations of load factors for ships.[31] In Starcrest's more recent inventories, they found that load factors as low as 2 percent were possible.[30,37] These lower factors are possible, because ships often cycle their propulsion engine on and off during maneuvering to reduce speeds below the dead slow setting of approximately 5.8 knots. In fact, during its vessel boarding program at the PoLA, Starcrest found container ships had engines stopped 25 to 50 percent of their time during maneuvering. While load factors should be calculated using the above propeller law for each call, load factors below 2 percent should be set to 2 percent as a minimum.

Load factors for auxiliary engines vary by ship type and time-in-mode. It was previously thought that power generation was provided by propulsion engines in all modes but hotelling. Several studies have shown that auxiliary engines are on all of the time, with the largest loads during hotelling (except when cold ironing[38]). Starcrest determined estimates in their 2005 inventory for Port of Los Angeles[39] for auxiliary engine load factors through interviews conducted with ship captains, chief engineers, and pilots during its vessel boarding programs. The auxiliary engine load factors shown in Table 2-7 are based upon those estimates. Auxiliary load factors should be used in conjunction with total auxiliary power. For detailed inventories, auxiliary load factors should be determined for the individual port, while mid-tier inventory development could use the values in Table 2-7 together with the total auxiliary engine power from Table 2-4.

Table 2-7: Auxiliary Engine Load Factor Assumptions

Ship-Type	Cruise	RSZ	Maneuver	Hotel
Auto Carrier	0.15	0.30	0.45	0.26
Bulk Carrier	0.17	0.27	0.45	0.10
Container Ship	0.13	0.25	0.48	0.19
Cruise Ship	0.80	0.80	0.80	0.64
General Cargo	0.17	0.27	0.45	0.22
Miscellaneous	0.17	0.27	0.45	0.22
OG Tug	0.17	0.27	0.45	0.22
RORO	0.15	0.30	0.45	0.26
Reefer	0.20	0.34	0.67	0.32
Tanker	0.24	0.28	0.33	0.26

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[36] SENES Consultants Limited, *Review of Methods Used in Calculating Marine Vessel Emission Inventories*, prepared for Environment Canada, September 2004.

[37] Starcrest Consulting Group LLC, *Update to the Commercial Marine Inventory for Texas to Review Emission Factors, Consider a Ton-Mile EI Method, and Revised Emissions for the Beaumont-Port Arthur Non-Attainment Area*, prepared for the Houston Advanced Research Center, January 2004.

[38] Cold ironing is a process where shore power is provided to a vessel, allowing it to shut down its auxiliary generators.

[39] Starcrest Consulting Group, *Port of Los Angeles Air Emissions Inventory for Calendar Year 2005*, September 2007

Starcrest provides more detailed load factors for containerships based upon ship size in TEUs[40]. The container factors in Table 2-7 are combined based upon the 2002 U.S. inventory.[34]

Auxiliary engine load factors for Great Lake vessels are given in Table 2-8.

Table 2-8: Auxiliary Engine Load Factors for Great Lake Vessels

Ship-Type	Cruise	Transit	Maneuver	Hotel
Self-Unloader[a]	0.17	0.27	0.45	0.30
Bulk Carrier	0.17	0.27	0.45	0.22
Passenger Ship	0.80	0.80	0.80	0.64
General Cargo	0.17	0.27	0.45	0.22
ITB	0.17	0.27	0.45	0.22
Shuttle	0.17	0.27	0.45	0.30
Tanker	0.13	0.27	0.45	0.67

[a] Self-unloaders were assigned a higher hotelling load factor than bulk carriers due to the fact that auxiliary engines are used during unloading.

2.6. Emission Factors

The weakest link in deep sea vessel emission inventories is the emission factors for Category 3 ship engines. Emission factors continue to be derived from limited data. Emission testing of OGVs is an expensive and difficult undertaking; and thus, emissions data are relatively rare. In most cases, the power generated is only estimated, leading to inaccuracies in the overall emission factors.

One of the more recent analyses of emission data was published in 2002 by Entec[41]. The factors from this study are generally accepted as the most current set available. The Entec analysis included emissions data from 142 propulsion engines and 2 of the most recent research programs: Lloyd's Register Engineering Services in 1995 and IVL Swedish Environmental Research Institute in 2002. The resulting Entec emission factors include individual factors for three speeds of diesel engines (slow-speed diesel (SSD), medium-speed diesel (MSD), and high-speed diesel (HSD)), steam turbines (ST), gas turbines (GT), and three types of fuel (RO, MDO and MGO). Table 2-9 lists the propulsion engine emission factors based on the Entec study and other data sources (discussed below) for the various fuels.

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[40] Twenty-foot equivalent unit representing a standard shipping container 20 feet long and 8 feet wide

[41] Entec UK Limited, *Quantification of Emissions from Ships Associated with Ship Movements between Ports in the European Community*, prepared for the European Commission, July 2002.

Table 2-9: Emission Factors for OGV Main Engines, g/kWh

Engine Type	Fuel Type	Sulfur	Emission Factors (g/kWh)							
			NOx	PM_{10}	$PM_{2.5}$	HC	CO	SOx	CO_2	BSFC
SSD	RO	2.70%	18.10	1.42	1.31	0.60	1.40	10.29	620.62	195
	MDO	1.00%	17.00	0.45	0.42	0.60	1.40	3.62	588.79	185
	MGO	0.50%	17.00	0.31	0.28	0.60	1.40	1.81	588.79	185
	MGO	0.10%	17.00	0.19	0.17	0.60	1.40	0.36	588.79	185
MSD	RO	2.70%	14.00	1.43	1.32	0.50	1.10	11.24	677.91	213
	MDO	1.00%	13.20	0.47	0.43	0.50	1.10	3.97	646.08	203
	MGO	0.50%	13.20	0.31	0.29	0.50	1.10	1.98	646.08	203
	MGO	0.10%	13.20	0.19	0.17	0.50	1.10	0.40	646.08	203
GT	RO	2.70%	6.10	1.47	1.35	0.10	0.20	16.10	970.71	305
	MDO	1.00%	5.70	0.58	0.53	0.10	0.20	5.67	922.97	290
	MGO	0.50%	5.70	0.35	0.32	0.10	0.20	2.83	922.97	290
	MGO	0.10%	5.70	0.17	0.15	0.10	0.20	0.57	922.97	290
ST	RO	2.70%	2.10	1.47	1.35	0.10	0.20	16.10	970.71	305
	MDO	1.00%	2.00	0.58	0.53	0.10	0.20	5.67	922.97	290
	MGO	0.50%	2.00	0.35	0.32	0.10	0.20	2.83	922.97	290
	MGO	0.10%	2.00	0.17	0.15	0.10	0.20	0.57	922.97	290

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 IVL Swedish Environmental Research Institute Ltd. Since then, IVL has published lower CO rates for SSDs as well as non-methane VOC rates for SSDs and MSDs which are much lower.[42] Entec also does not list PM factors for either PM_{10} or $PM_{2.5}$. The PM_{10} to $PM_{2.5}$ conversion factor used here is 0.92. While the NONROAD model uses 0.97 for such conversion based upon low sulfur fuels, a higher value of 0.80 was suggested in a report from the *Journal of Aerosol Science*[43].

PM_{10} values were determined by EPA based on existing engine test data in consultation with ARB.[44] The values were curve fit based upon fuel type and produced the following equations:

$$\textbf{For RO } PM_{10}\ EF = 1.35 + BSFC \times 7 \times 0.02247 \times (\text{Fuel Sulfur Fraction} - 0.0246)$$

$$\textbf{For MDO \& MGO } PM_{10}\ EF = 0.23 + BSFC \times 7 \times 0.02247 \times (\text{Fuel Sulfur Fraction} - 0.0024)$$

The above equations are based upon the fact that the sulfate component in PM_{10} has a molecular weight 7 times that of sulfur and that 2.247% of the fuel sulfur is converted to PM_{10} sulfate. SO_2 emission factors were based upon a fuel sulfur to SO_2 conversion factor from ENVIRON.[45] Emission factors for SO_2 emissions were calculated using the below formula

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[42] D. Cooper and T. Gustafsson, *Methodology for calculating emissions from ships: 1. Update of Emission Factors*, Swedish Methodology for Environmental Data, February 2004.

[43] Lyyränen, J., Jokiniemi, J., Kauppinen, E. and Joutsensaari, J., *Aerosol characterisation in medium-speed diesel engines operating with heavy fuel oils,* published in the *Journal of Aerosol Science,* Vol. 30, No. 6. pp. 771-784, 1999.

[44] Draft Memo from Michael Samulski entitled "Estimation of Particulate Matter Emission Factors for Diesel Engines on Ocean-Going Vessels," September 12, 2007.

[45] Memo from Chris Lindhjem of ENVIRON, *PM Emission Factors,* December 15, 2005.

assuming that 97.753% of the fuel sulfur was converted to SO_2 and taking into account the molecular weight difference between SO_2 and sulfur (molecular weight 2 times sulfur).

$$\mathbf{SO_2\ EF = BSFC \times 2 \times 0.97753 \times Fuel\ Sulfur\ Fraction}$$

CO_2 emission factors were calculated from the BSFC assuming a fuel carbon content of 86.8 percent by weight[41] and a ratio of molecular weights of CO_2 and C at 3.667.

$$\mathbf{CO_2\ EF = BSFC \times 0.868 \times 3.667}$$

The International Maritime Organization (IMO) adopted NOx limits in Annex VI to the International Convention for Prevention of Pollution from Ships in 1997. These NOx limits apply for all marine engines over 130 kilowatts (kW) for engines built on or after January 1, 2000, including those that underwent a major rebuild after January 1, 2000. The required number of countries ratified Annex VI in May 2004 and it went into force for those countries in May 2005. The Annex has been ratified by the United States on October 8, 2008. Most ship engine manufacturers have been building engines compliant with Annex VI since 2000. Annex VI emission standards are given in Table 2-10.

Table 2-10: Annex VI NOx Emission Standards (g/kWh)

Engine Speed (n)		
n ≥ 2000 rpm	**2000 > n ≥ 130 rpm**	***n < 130 rpm***
9.8	$45.0 \times n^{-0.2}$	*17.0*

Most manufacturers build engines to emit well below the standard. EPA determined the effect of the IMO standard to be a reduction in NOx emissions of 11 percent below engines built before 2000.[46] Therefore for engines built in 2000 and later, a NOx factor of 0.89 should be applied to the calculation of NOx emissions for both propulsion and auxiliary engines. Since this standard only applies to diesel engines, the factor is not applied to either steam turbines or gas turbines.

New Emission Control Area (ECA) standards were adopted by IMO in October 2008. These new proposed standards are listed in Table 2-11. The U.S. has applied to become an ECA area but most likely won't be in force until August 2012.[47]

In addition, as part of the new IMO standards, marine diesel engines built between 1990 and 1999 that are 90 liters per cylinder or more need to be retrofit to meet Tier 1 emission standards. Generally all SSDs are 90 liters per cylinder or more, but only 35% of MSD propulsion engines are greater than 90 liters per cylinder.

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[46] Conversation with Michael Samulski of EPA, May 2007.

[47] EPA, *Frequently Asked Questions about the Emission Control Area Application Process*, http://epa.gov/OMS/oceanvessels.htm#controlprocess

Table 2-11: International Ship Engine and Fuel Standards (MARPOL Annex VI)

Area	Year	Fuel Sulfur	NOx
Emission Control Area	Today to Jul 2010	15,000 ppm	
	2010	10,000 ppm	
	2015	1,000 ppm	
	2016		Tier 3 Aftertreatment*
Global	Today to Jan 2012	45,000 ppm	
	2012	35,000 ppm	
	2020	5,000 ppm	
	2011		Tier 2 Engine Controls*

* Today's Tier 1 NOx standards range from approximately 10 to 17 g/kW-h, depending on engine speed. The Tier 2 standards represent a 20% NOx reduction below Tier 1, and the Tier 3 standards represent an 80% NOx reduction below Tier 1.

Based upon the national inventory of ships stopping at US ports in 2005, the adjustment factors listed in Table 2-12 can be applied to the NOx emission factors listed in Table 2-8 for RO by analysis year to account for Tier 1, Tier 2, and Tier 3 IMO standards. Best practice is to determine adjustment factors based upon the age profiles of ships calling on a specific port.

Table 2-12: ECA and Global Control NOx Adjustment Factors

Analysis Year	Global		ECA	
	Main	Auxiliary	Main	Auxiliary
2005	0.9024	0.9060	0.9024	0.9060
2010	0.8750	0.8767	0.8750	0.8767
2015	0.8020	0.8059	0.8020	0.8059
2020	0.7565	0.7478	0.5958	0.5842
2025	0.7319	0.7173	0.4278	0.4108
2030	0.7149	0.6955	0.3184	0.2989

While the majority of greenhouse gas emissions from ships are CO_2, additional GHG emissions include methane (CH_4) and nitrous oxide (N_2O). Emission factors for various engine types listed in Table 2-13 are taken from the IVL 2004 update.[42] To estimate CO_2 equivalents, CH_4 emissions should be multiplied by 21 and N_2O emissions should be multiplied by 310.

Table 2-13: Greenhouse Gas Emission Factors, g/kWh

Engine Type	RO		MDO or MGO	
	CH_4	N_2O	CH_4	N_2O
SSD Propulsion	0.006	0.031	0.006	0.031
MSD Propulsion	0.004	0.031	0.004	0.031
ST Propulsion	0.002	0.080	0.002	0.080
GT Propulsion	0.002	0.080	0.002	0.080
Auxiliary	0.004	0.031	0.004	0.031

In addition, black carbon is another source of greenhouse gas emissions. Black carbon emissions from marine diesel engines burning residual oil and marine gas oil have been recently studied by University of California Riverside[48], MAN diesel[49], and Germanischer Lloyd[50]. University of California Riverside found that black carbon was less than 1 percent of particulate emissions for slow speed engines running on residual fuel with sulfur levels over 2 percent of the fuel by weight. MAN diesel found black carbon emissions were from 2 to 7 percent of particulate emissions depending on load for medium speed engines when operating on residual oil with a sulfur content of 2.2 percent and 10 to 38 percent of particulate emission depending on load when operating on marine gas oil with a sulfur content of less than 0.01 percent. Germanischer Lloyd found that black carbon emissions varied from 4 to 10 percent of particulate emissions in a slow speed diesel engine with sulfur level varying from 2.9 to 0.1 percent of fuel respectively. Further work needs to be done to determine emission factors for methane, nitrous oxide, and black carbon for ocean going vessels.

Global warming potential for black carbon is highly variable because it is an aerosol. Recent findings place the 100 year global warming potential at 840 to 1280 times that of carbon dioxide.[51]

Emission factors are considered to be constant down to about 20 percent load. Below that threshold, emission factors tend to increase as the load decreases. This trend results because diesel engines are less efficient at low loads and the BSFC tends to increase. Thus, while mass emissions (grams per hour) decrease with low loads, the engine power tends to decrease more quickly, thereby increasing the emission factor (grams per engine power) as load decreases. Energy and Environmental Analysis Inc. (EEA) demonstrated this effect in a study prepared for EPA in 2000.[52] In the EEA report, various equations have been developed for the various emissions. The low-load emission factor adjustment factors were developed based upon the concept that the BSFC increases as load decreases below about 20 percent load. For fuel consumption, EEA developed the following equation:

$$\textbf{Fuel Consumption (g/kWh)} = \textbf{14.1205 (1/Fractional Load) + 205.7169} \tag{4}$$

In addition, based upon test data, they developed algorithms to calculate emission factors at reduced load. These equations are noted below:

$$\textbf{Emission Rate (g/kWh)} = \textbf{a (Fractional Load)}^{-x} + \textbf{b} \tag{5}$$

For SO_2 emissions, however, EEA developed a slightly different equation:

$$\textbf{Emission Rate (g/kWh)} = \textbf{a (Fuel Consumption x Fuel Sulfur Fraction) + b} \tag{6}$$

The coefficients for the above equations are given in Table 2-14 below.

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[48] University of California Riverside, *Measurements of Emissions from Engines on Ocean Going Vessels*, presented at the ARB Ocean-Going Ship Main Engine Workshop, August 2007.

[49] MAN, *Medium-speed 4-stroke engine*, 10/01/2007

[50] Germanischer Lloyd, *Emission of particulate matter from marine diesel engines*, 10/30/2007 BLG Meeting

[51] Institute for Governance & Sustainable Development, *Reducing Black Carbon May Be the Fastest Strategy for Slowing Climate Change,* IGSD/INECE Climate Briefing Note, December 2008. Available online at http://regserver.unfccc.int/seors/attachments/file_storage/gfiq5a100v6241g.pdf

[52] Energy and Environmental Analysis Inc., *Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data*, EPA420-R-00-002, February 2000.

Table 2-14: Emission Factor Algorithm Coefficients for OGV Main Engines

Coefficient	NOx	HC	CO	PM	SO_2	CO_2
a	0.1255	0.0667	0.8378	0.0059	2.3735	44.1
x	1.5	1.5	1.0	1.5	n/a	1.0
b	10.4496	0.3859	0.1548	0.2551	-0.4792	648.6

Using these algorithms, fuel consumption and emission factors versus load were calculated. By normalizing these emission factors to 20% load, the low-load multiplicative adjustment factors presented in Table 2-15 were calculated. SO_2 adjustment factors were calculated using 2.7% sulfur. As these adjustment factors were derived for diesel engines, Starcrest only applies them to MSD and SSD propulsion engines. It should be noted, however, that both GTs and STs are also less efficient at lower loads and therefore the low load adjustment factors could be applied to those engines as well.

Table 2-15: Calculated Low Load Multiplicative Adjustment Factors

Load	NOx	HC	CO	PM	SO_2	CO_2
1%	11.47	59.28	19.32	19.17	5.99	5.82
2%	4.63	21.18	9.68	7.29	3.36	3.28
3%	2.92	11.68	6.46	4.33	2.49	2.44
4%	2.21	7.71	4.86	3.09	2.05	2.01
5%	1.83	5.61	3.89	2.44	1.79	1.76
6%	1.60	4.35	3.25	2.04	1.61	1.59
7%	1.45	3.52	2.79	1.79	1.49	1.47
8%	1.35	2.95	2.45	1.61	1.39	1.38
9%	1.27	2.52	2.18	1.48	1.32	1.31
10%	1.22	2.20	1.96	1.38	1.26	1.25
11%	1.17	1.96	1.79	1.30	1.21	1.21
12%	1.14	1.76	1.64	1.24	1.18	1.17
13%	1.11	1.60	1.52	1.19	1.14	1.14
14%	1.08	1.47	1.41	1.15	1.11	1.11
15%	1.06	1.36	1.32	1.11	1.09	1.08
16%	1.05	1.26	1.24	1.08	1.07	1.06
17%	1.03	1.18	1.17	1.06	1.05	1.04
18%	1.02	1.11	1.11	1.04	1.03	1.03
19%	1.01	1.05	1.05	1.02	1.01	1.01
20%	1.00	1.00	1.00	1.00	1.00	1.00

No low load adjustment factor should be applied to diesel electric or gas turbine electric engines for loads below 20% MCR because several engines are used to generate power, and some can be shut down to allow others to operate at a more efficient setting.

In Starcrest's new Port of Long Beach and Los Angeles inventories for 2007,[53,54] CH_4 propulsion emission factors are multiplied by HC low load adjustment factors for load factors below 20 percent

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[53] Starcrest Consulting Group LLC, Port of Los Angeles Inventory of Air Emissions—2007, December 2008

[54] Starcrest Consulting Group LLC, Port of Long Beach Air Emissions Inventory—2007, January 2009

based upon the premise that CH_4 emissions are tied to HC emissions. N_2O propulsion emission factors are multiplied by NOx low load adjustment factors on the premise that N_2O is linked to NOx.

As with propulsion engines, the most current set of auxiliary engine emission factors comes from Entec except as noted above. Table 2-16 provides these auxiliary engine emission factors. There is no need for a low load adjustment factor for auxiliary engines, because they are generally operated in banks. When only low loads are needed, one or more engines are shut off, allowing the remaining engines to operate at a more efficient level.

Table 2-16: Auxiliary Engine Emission Factors, g/kWh

Fuel Type	Sulfur	Emission Factors (g/kWh)							
		NOx	PM_{10}	$PM_{2.5}$	HC	CO	SOx	CO_2	BSFC
RO	2.70%	14.7	1.44	1.32	0.40	1.10	11.98	722.54	227
MDO	1.00%	13.9	0.49	0.45	0.40	1.10	4.24	690.71	217
MGO	0.50%	13.9	0.32	0.29	0.40	1.10	2.12	690.71	217
MGO	0.10%	13.9	0.18	0.17	0.40	1.10	0.42	690.71	217

In addition to the auxiliary engines that are used to generate electricity onboard ships, most OGVs also have boilers used to heat RO to make it fluid enough to use in diesel engines and to produce hot water. These boilers are not typically used during cruise or reduced speed zone modes because most vessels are equipped with exhaust heat recovery systems ("economizers") that use heat from the main engine's exhaust for their hot water needs. The fuel-fired boilers are used when the main engine exhaust flow and/or temperature fall below what is needed for the economizer to provide adequate heat, such as during maneuvering and when the main engines are shut down at berth. In Starcrest's newest inventory for Port of Los Angeles[39], boiler loads were calculated from boiler fuel use determined during Starcrest's vessel boarding program. These loads are presented in Table 2-17.

Table 2-17: Auxiliary Boiler Energy Defaults, kW

Ship-Type	Cruise	RSZ	Maneuver	Hotel
Auto Carrier	0	0	371	371
Bulk Carrier	0	0	109	109
Container Ship	0	0	506	506
Cruise Ship	0	0	1,000	1,000
General Cargo	0	0	106	106
Miscellaneous	0	0	371	371
OG Tug	0	0	0	0
RORO	0	0	109	109
Reefer	0	0	464	464
Tanker	0	0	371	3,000
Tanker – ED	0	0	346	346

Steam turbine propulsion emission factors should be used for calculating boiler emissions in the various modes. Emissions from boilers should be calculated as follows.

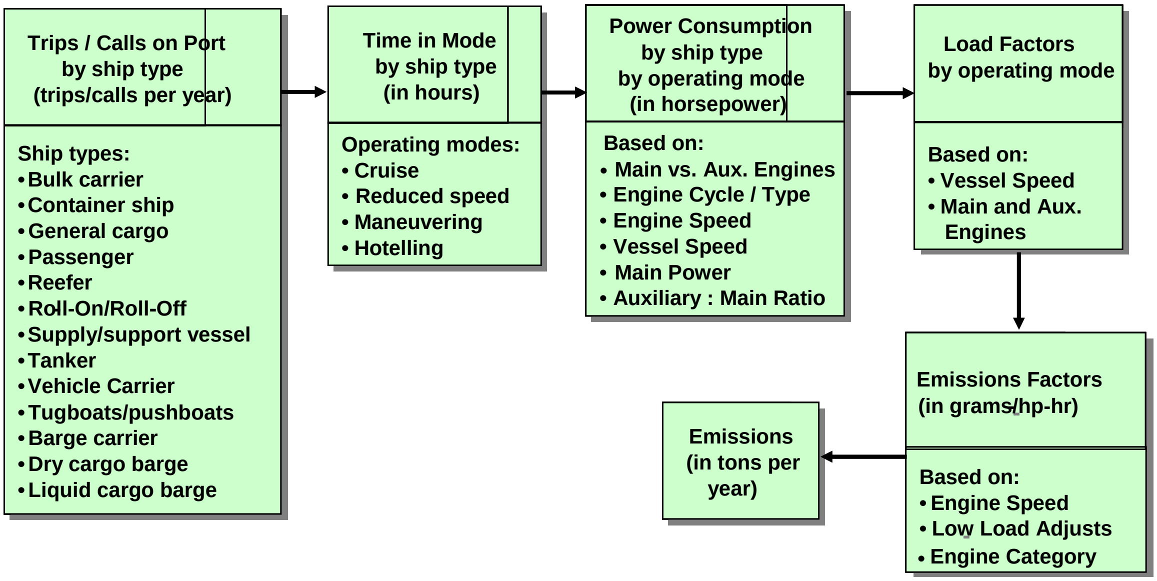
Boiler emissions (g/mode) = Boiler Energy (kW) x ST EFs (g/kWh) x time in mode (hrs)

Cruise ships and tankers (except for electric drive tankers) have much higher auxiliary boiler usage rates than the other vessel types. Cruise ships have higher boiler usage due to the number of passengers and need for hot water. Tankers provide steam for steam-powered liquid pumps, inert gas in fuel tanks, and to heat fuel for pumping.

2.7. Mid-Tier Inventory Preparation

Some mid-size ports, or those preparing emission inventories with mid-sized resources, could prepare a simplified version of the detailed inventory by averaging vessel characteristics and operational data by ship type. Even better resolution can be gained if the average information also includes a DWT range. Load factors and emission factors then can be applied to average vessel characteristics for a given ship type and DWT range and multiplied by the number of calls that all vessels of a given type of vessel and DWT range made in a year at the port. Each call should be divided into the various modes of operation and each mode also averaged for the vessel type and DWT range. Detailed guidance for typical ports is provided in the two EPA documents for deep sea ports[55] and Great Lake and inland river ports.[56] ENVIRON offers additional guidance in its report.[31] Further guidance can be found in the 2002 & 2005 US Port baseline emissions inventory report.[34] A flow chart for preparation of marine vessel inventories using the mid-tier approach is shown in Figure 2-3.

Figure 2-3: Flow Chart for Mid-Tier Inventory Preparation



By combining vessels in ship type and DWT categories and summing the calls, an averaged approach can be used to determine time-in-mode and load factors for a set of vessel calls instead of each individual call. This pared down method should reduce the amount of time and information needed to prepare an inventory.

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[55] ARCADIS, Commercial Marine Activity for Deep Sea Ports in the United States, EPA420-R-99-020, September 1999.

[56] ARCADIS, Commercial Marine Activity for Great Lake and Inland River Ports in the United States, EPA Report EPA420-R-99-019, September 1999.

The mid-tier approach is detailed in the EPA Commercial Marine Port Inventory Development report.[34] In this report, USACE entrances and clearances data[57] married with Lloyd's data[26]. In that approach, emissions for the modeled port were determined by mode, ship type, engine type, and DWT range from similar categories at the typical like port at which a detailed inventory was done. A discussion of the port matching process and each time in mode calculation is discussed below.

2.7.1. Port Matching Process

In the 2002 Environ report[31], two criteria were used for port matching: regional differences[58] and maximum vessel draft. A third consideration that was taken into account is the ship types that call on a specific port. One container port, for instance, may have much smaller bulk cargo and reefer ships call on that port than another. Using these three criteria and the new port inventories that have been recently prepared and are suitable for port matching, deep sea ports and Great Lake ports have been matched to the typical and new ports which a detailed emission inventory were prepared. All emissions can then be calculated using this information and the emission and load factors discussed in the previous subsections. Table 2-18 lists the major ports and their suggested match ports as well the regions the ports are assigned to and the one way transit distances in nautical miles. Additional ports can be found in the EPA 2002 & 2005 National Inventory report.[34]

In cases where port information is used directly from a recent port inventory, maneuvering times and hotelling times can be taken directly from that inventory. Otherwise they should be assumed to be the same as the typical port they are matched to. For all ports, calls from the USACE entrances and clearances data can be used to calculate emissions. Local port RSZ distances and speeds should be used to calculate RSZ emission.

Table 2-18: Matched Ports and Regions

Port	Matched Port	Region	RSZ Distance
Anacortes, WA	Anacortes	North Pacific	108.3
Anchorage, AK	Coos Bay	North Pacific	143.6
Ashtabula, OH	Duluth	Great Lakes	3.0
Baltimore, MD	Baltimore	East Coast	157.1
Baton Rouge, LA	Lower Mississippi	Gulf Coast	219.8
Beaumont, TX	Houston	Gulf Coast	53.5
Boston, MA	Delaware River	East Coast	14.3
Bridgeport, CT	Delaware River	East Coast	2.0
Brownsville, TX	Tampa	Gulf Coast	18.7
Brunswick, GA	Delaware River	East Coast	38.8
Camden, NJ	Delaware River	East Coast	94.0
Canaveral, FL	Delaware River	East Coast	4.4
Charleston, SC	Delaware River	East Coast	17.3

continued

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[57] U.S. Army Corps of Engineers, *Waterborne Commerce of the United States*, http://www.iwr.usace.army.mil/ndc/data/dataclen.htm

[58] The geographical area of the port was used to group top ports as it was considered a primary influence on the characteristics (size and installed power) of the vessels calling at those ports.

Table 2-18. Matched Ports and Regions *(continued)*

Port	Matched Port	Region	RSZ Distance
Chester, PA	Delaware River	East Coast	78.2
Chicago, IL	Duluth	Great Lakes	3.0
Cleveland, OH	Cleveland	Great Lakes	3.0
Conneaut, OH	Duluth	Great Lakes	3.0
Detroit, MI	Duluth	Great Lakes	3.0
Duluth-Superior, MN&WI	Duluth	Great Lakes	3.0
Everglades, FL	Lower Mississippi	Gulf Coast	2.1
Freeport, TX	Houston	Gulf Coast	2.6
Galveston, TX	Houston	Gulf Coast	9.3
Georgetown, SC	Delaware River	East Coast	17.6
Gulfport, MS	Tampa	Gulf Coast	17.4
Hilo, HI	Coos Bay	South Pacific	7.1
Honolulu, HI	Puget Sound	South Pacific	10.0
Houston, TX	Houston	Gulf Coast	49.6
Hueneme, CA	ARB	South Pacific	2.8
Jacksonville, FL	Delaware River	East Coast	18.6
Kahului, HI	Coos Bay	South Pacific	7.5
Kalama, WA	Portland	North Pacific	68.2
Lake Charles, LA	Lower Mississippi	Gulf Coast	38.0
Long Beach, CA	Long Beach	South Pacific	18.1
Longview, WA	Portland	North Pacific	67.3
Los Angeles, CA	Los Angeles	South Pacific	20.6
Marcus Hook, PA	Delaware River	East Coast	94.7
Matagorda Ship	Tampa	Gulf Coast	24.0
Miami, FL	Delaware River	East Coast	3.8
Milwaukee, WI	Cleveland	Great Lakes	3.0
Mobile, AL	Lower Mississippi	Gulf Coast	36.1
Morehead City, NC	Delaware River	East Coast	2.2
Nawiliwili, HI	Coos Bay	South Pacific	7.3
New Castle, DE	Delaware River	East Coast	60.5
New Haven, CT	Delaware River	East Coast	2.1
New Orleans, LA	Lower Mississippi	Gulf Coast	104.2
New York/New Jersey	New York/New Jersey	East Coast	15.7
Newport News, VA	Baltimore	East Coast	24.3
Nikishka, AK	Coos Bay	North Pacific	90.7
Oakland, CA	Oakland	South Pacific	17.1
Palm Beach, FL	Delaware River	East Coast	3.1
Panama City, FL	Tampa	Gulf Coast	10.0
Pascagoula, MS	Tampa	Gulf Coast	17.5
Paulsboro, NJ	Delaware River	East Coast	83.5
Penn Manor, PA	Delaware River	East Coast	114.5
Philadelphia, PA	Delaware River	East Coast	88.1
Plaquemines, LA	Lower Mississippi	Gulf Coast	52.4

continued

Table 2-18. Matched Ports and Regions *(continued)*

Port	Matched Port	Region	RSZ Distance
Port Angeles, WA	Port Angeles	North Pacific	65.0
Port Arthur, TX	Houston	Gulf Coast	21.0
Portland, ME	New York/New Jersey	East Coast	11.4
Portland, OR	Portland	North Pacific	105.1
Providence, RI	Delaware River	East Coast	24.9
Richmond, CA	ARB	South Pacific	22.6
Richmond, VA	Delaware River	East Coast	106.4
San Diego, CA	ARB	South Pacific	11.7
San Francisco, CA	ARB	South Pacific	14.4
Savannah, GA	Baltimore	East Coast	45.5
Searsport, ME	Delaware River	East Coast	22.2
Seattle, WA	Seattle	North Pacific	133.3
South Louisiana, LA	Lower Mississippi	Gulf Coast	142.8
St Clair, MI	Cleveland	Great Lakes	3.0
Stockton, CA	ARB	South Pacific	86.9
Tacoma, WA	Tacoma	North Pacific	150.5
Tampa, FL	Tampa	Gulf Coast	30.0
Texas City, TX	Houston	Gulf Coast	15.1
Toledo, OH	Duluth	Great Lakes	3.0
Valdez, AK	Puget Sound	North Pacific	27.2
Vancouver, WA	Portland	North Pacific	95.7
Wilmington, DE	Delaware River	East Coast	65.3
Wilmington, NC	Delaware River	East Coast	27.6

2.7.2. Cruise Mode

Average time in mode for the modeled port (mp) should be determined using the average service speed assuming a 25 nautical mile distance into and out of the port for deep sea ports and 7 nautical miles into and out of the port for Great Lake ports. Emissions for propulsion (main) engines at the typical like port (tp) should be multiplied by the ratio of calls, propulsion power, and time in mode differences between the two ports. Auxiliary engine emissions should be determined from the typical like port auxiliary engine emissions based upon the ratio of auxiliary power, number of calls and time in mode between the two ports.

$$\textbf{Time}_{mp}\ \textbf{[hrs/call] = Cruise Distance [miles]/Cruise Speed}_{mp}\ \textbf{[knots] x 2 trips/call}$$

$$\textbf{Emissions [main engine]}_{mp} = \textbf{Emissions [main engine]}_{tp} \textbf{ x (calls}_{mp}\textbf{/calls}_{tp}\textbf{) x (Main Power}_{mp}\textbf{/Main Power}_{tp}\textbf{) x (time}_{mp}\textbf{/time}_{tp}\textbf{)}$$

$$\textbf{Emissions [aux engine]}_{mp} = \textbf{Emissions [aux engine]}_{mp} \textbf{ x (calls}_{mp}\textbf{/calls}_{tp}\textbf{) x (Aux Power}_{mp}\textbf{/Aux Power}_{tp}\textbf{) x (time}_{mp}\textbf{/time}_{tp}\textbf{)}$$

2.7.3. Reduced Speed Zone Mode

Average time in mode for the modeled port should be determined using the reduced speed zone speed and distance for the modeled port. Load factors should also be calculated based upon the reduced speed zone speed at the modeled port and the average maximum speed at the modeled port for the given ship type, engine type, and DWT range bin. The cruise speed listed in Lloyds data is considered to be 94 percent of the maximum speed. Once load factors are calculated for the modeled port, if either of the modeled port or typical like port load factors are below 20 percent, low-load multiplicative adjustment factors should also be calculated. The main engine emissions for the modeled port should then be estimated from the typical like port emissions times the ratio of calls, main propulsion power, the load factors, the time in mode and the low-load multiplicative adjustment factors between the two ports. If the load factor at either port is 20 percent or greater, the low load adjustment factor is set to 1.00. Auxiliary engine emissions should be determined from the typical like port based upon the ratio of auxiliary power, number of calls and time in mode between the two ports.

$$\textbf{Time}_{\textbf{mp}}\ \textbf{[hrs/call] = RSZ distance}_{\textbf{mp}}\ \textbf{(nm)/RSZ Speed}_{\textbf{mp}}\ \textbf{[knots] x 2 trips/call}$$

$$\textbf{Maximum Speed}_{\textbf{mp}}\ \textbf{[knots] = Cruise Speed}_{\textbf{mp}}\ \textbf{[knots]/0.94}$$

$$\textbf{Load Factor}_{\textbf{mp}} = \textbf{(RSZ Speed}_{\textbf{mp}}\textbf{/Maximum Speed}_{\textbf{mp}}\textbf{)}^{3}$$

$$\begin{aligned}\textbf{Emissions [main engine]}_{\textbf{tp}}\ \text{and}\ &\textbf{Emissions [main engine]}_{\textbf{mp}} = \textbf{Emissions [main engine]}_{\textbf{tp}}\ \textbf{x (calls}_{\textbf{mp}}\textbf{/calls}_{\textbf{tp}}\textbf{)}\\ &\textbf{x (Main Power}_{\textbf{mp}}\textbf{/Main Power}_{\textbf{tp}}\textbf{) x (time}_{\textbf{mp}}\textbf{/time}_{\textbf{tp}}\textbf{)}\\ &\textbf{x (Load Factor}_{\textbf{mp}}\textbf{/Load Factor}_{\textbf{tp}}\textbf{)}\\ &\textbf{x (Low Load Adjustment Factor}_{\textbf{mp}}\textbf{/ Low Load Adjustment Factor}_{\textbf{tp}}\textbf{)}\end{aligned}$$

$$\begin{aligned}\textbf{Emissions [aux engine]}_{\textbf{mp}} = \textbf{Emissions [aux engine]}_{\textbf{mp}}\ &\textbf{x (calls}_{\textbf{mp}}\textbf{/calls}_{\textbf{tp}}\textbf{)}\\ &\textbf{x (Aux Power}_{\textbf{mp}}\textbf{/Aux Power}_{\textbf{tp}}\textbf{) x (time}_{\textbf{mp}}\textbf{/time}_{\textbf{tp}}\textbf{)}\end{aligned}$$

2.7.4. Maneuvering Mode

In determining emissions for the modeled port, the maneuvering times and load factors at the modeled port should be like the time in mode and load factor for the typical like port for the given ship type, engine type, and DWT range. This also assumes that the number of shifts per call at the modeled port were the same as at the typical like port. While it would be more accurate to calculate actual maneuvering times at the modeled port, the USACE entrances and clearances data provide no detail on either the number of shifts or the final PWD at which the vessel berthed. Therefore emissions at the modeled port need to be determined directly from the emissions at the typical like port using the ratio of the number of calls and main or auxiliary power.

$$\begin{aligned}\textbf{Emissions [main engine]}_{\textbf{mp}} = \textbf{Emissions [main engine]}_{\textbf{tp}}\ &\textbf{x (calls}_{\textbf{mp}}\textbf{/calls}_{\textbf{tp}}\textbf{)}\\ &\textbf{x (Main Power}_{\textbf{mp}}\textbf{/Main Power}_{\textbf{tp}}\textbf{)}\end{aligned}$$

$$\begin{aligned}\textbf{Emissions [aux engine]}_{\textbf{mp}} = \textbf{Emissions [aux engine]}_{\textbf{mp}}\ &\textbf{x (calls}_{\textbf{mp}}\textbf{/calls}_{\textbf{tp}}\textbf{)}\\ &\textbf{x (Aux Power}_{\textbf{mp}}\textbf{/Aux Power}_{\textbf{tp}}\textbf{)}\end{aligned}$$

2.7.5. Hotelling Mode

Again due to lack of information as to actual hotelling times at the various modeled ports, hotelling time at the modeled port can be assumed to be the same as the hotelling time at the typical like port for the same ship type, engine type, and DWT range. Thus emissions at the modeled port can be determined directly from the emissions at the typical like port using the ratio of the number of calls and auxiliary power.

$$\text{Emissions [aux engine]}_{mp} = \text{Emissions [aux engine]}_{mp} \times (\text{calls}_{mp}/\text{calls}_{tp}) \times (\text{Aux Power}_{mp}/\text{Aux Power}_{tp})$$

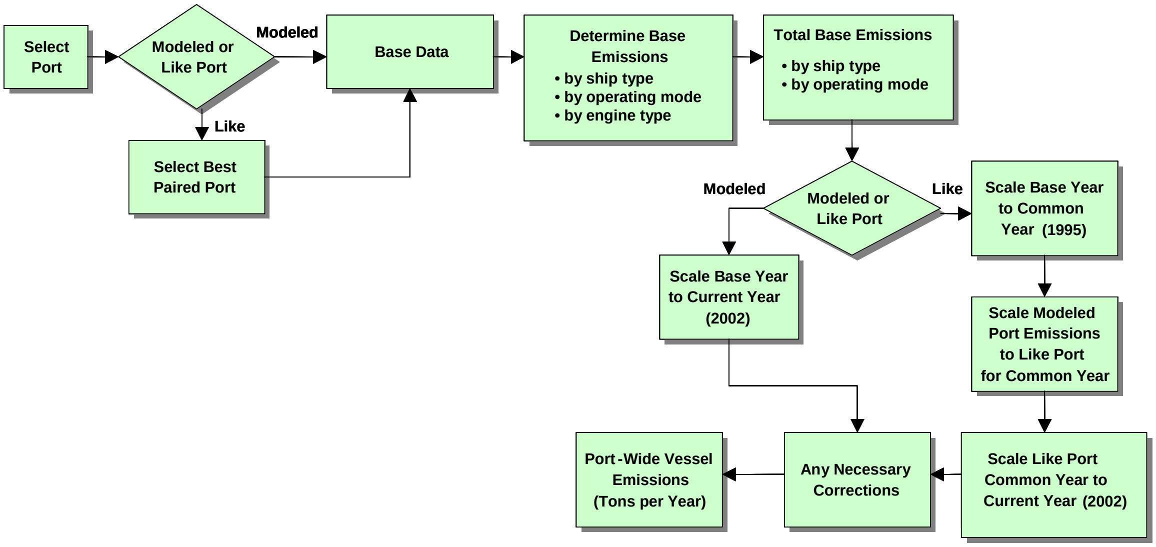
2.7.6. Bin Mismatches

In some cases, the specific DWT range bin at the modeled port is not in the typical like port data. In those cases, the next nearest DWT range bin should be used for the calculations. If the engine type for a given ship type is not in the typical like port data, then the closest engine type at the typical like port should be used along with ratios of emission factors used in calculation of emissions for the specific engine type at the modeled port. If a specific ship type in the modeled port data is not in the typical like port data, then the nearest like ship type at the typical port should be chosen to calculate emissions at the modeled port.

2.8. Streamlined Approach

A streamlined approach can be applied if those preparing port inventories do not have sufficient resources to follow the mid-tier approach outlined above. In this approach, those preparing port inventories should use an existing emission inventory from another similar port, scaling the emissions up or down based on the ratio of vessel operation data between the two ports. The two EPA activity guidance documents provide details on estimating emission inventories from other ports.[55,56] The documents use USACE data to scale emissions based on the ratio of ship trips from a “like” port that has an existing inventory compared to the port in question.[57] ENVIRON used this method to prepare a national inventory for an EPA rulemaking.[31] While there are significant issues with this sort of approach, it does provide a first cut inventory for ports to use in SIPs and for other purposes. A flow chart of this method is shown in Figure 2-4.

Figure 2-4: Flow Chart for Streamlined Inventory Preparation

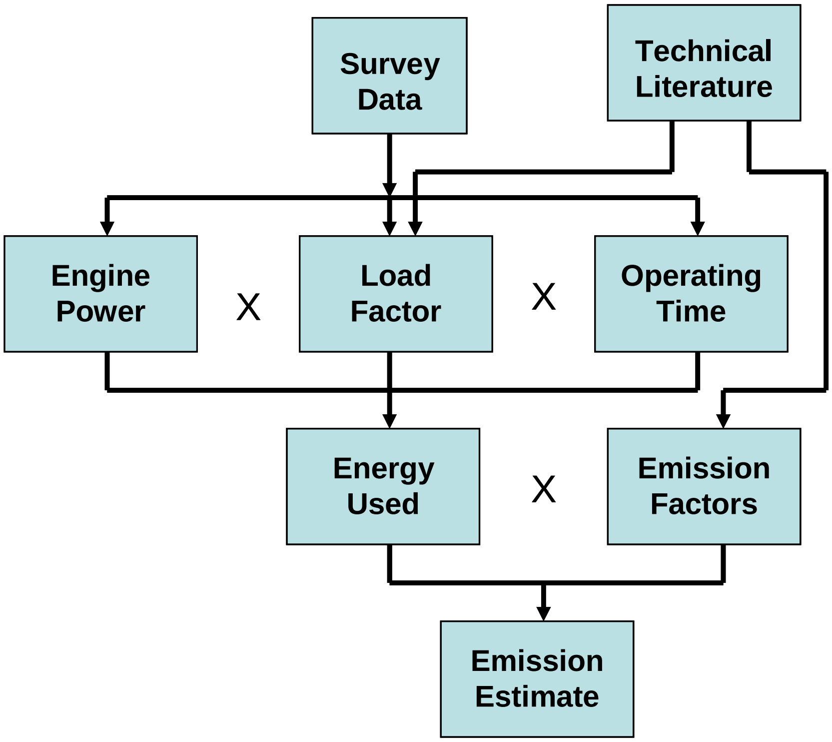


3. Harbor Craft

Harbor craft are commercial and recreational vessels that spend the majority of their time within or near a port or harbor. Almost all harbor craft use Category 1 or Category 2 engines.

Best practice for calculating harbor craft emissions dictates that the count of vessels and determination of associated parameters be made from a survey of each of the vessel types operating in the port area in question and that this information be merged with emission factor and load factor data from the technical literature to complete an inventory of harbor craft emissions. In cases where all needed information is not available, an alternative or streamlined approach may be followed to substitute for missing data. These processes are summarized by the flow chart of Figure 3-1.

Figure 3-1: Harbor Craft Emission Estimation Flow Chart



Generally, total annual harbor craft emissions within the region of study should be computed by considering the annual emissions from each of the individual engines (main and auxiliary), and summed over the full set. Emissions from each engine type are calculated considering the load factor (LF), emission factor (EF), the average annual activity, the rated horsepower (HP), and fuel or other correction factors (CF). That is:

$$\text{Emissions}_{\text{Pollutant}} = \sum_{\text{Main+Auxiliary}} \text{EF}_{\text{Pollutant}}(\text{Tier}) \cdot \text{LF} \cdot \text{Activity} \cdot \text{HP} \cdot \text{CF}$$

Should transient adjustment or deterioration factors be considered, they should be explicitly applied to the emission factors determined for the various engines. Each of these is discussed throughout the rest of this section.

3.1. Fleet Characteristics

Table 3-1 lists port harbor vessels types. A detailed inventory should include each of these.

Table 3-1: Harbor Craft Vessel Types

Vessel	Description
Assist tugboats	Help OGVs maneuver in the harbor during arrival and departure and shifts from berth. Also provide “tugboat escort” for tankers. Vessels with a DWT of 20,000 tons or less use one tugboat, greater than 20,000 tons use two tugboats.
Towboats/pushboats/tugboats	Self-propelled vessels that tow or push barges within and outside of the port.
Ferries and excursion vessels	Ferries transport people and property. Excursion boats provide harbor cruises and whale watching.
Crew boats	Carry personnel and supplies to and from off-shore and in-harbor locations.
Work boats	Include utility, inspection, survey, spill/response, research, mining, training, and construction.
Government vessels	Belong to U.S. Coast Guard; U.S. Navy, Fish and Game; and fire, police, and harbor departments. Generally states cannot require emission reductions from federal vessels.
Dredges and dredging support vessels	Perform or assist in performing dredging activities in the harbor.
Commercial fishing vessels	Used for commercial fishing.
Recreational vessels	Privately owned boats, including powerboats and sailboats.

3.2. Activity Determination

3.2.1. Best Practices

To calculate emissions from harbor vessels, the following information needs to be collected from vessel owners and operators for each type of harbor craft operating in the port area:

- Hours of operation (annual and average daily, plus schedules if relevant and available).
- Percentage of time in operational modes (e.g., idling, half power, full power).
- Vessel characteristics.
- Number, type, age, and horsepower (or kilowatts) of main engine(s).
- Number, type, age, and horsepower (or kilowatts) of auxiliary engine(s).
- Other operational parameters such as fuel consumption rates, fuel type, and dredging volumes.
- Qualitative information regarding how the vessels are used in service.
- Any information on emissions-modifying methods applied to the vessels, such as exhaust after-treatment equipment installed or internal engine modifications.

Most harbor craft have Category 1 marine diesel engines for main and/or auxiliary power. Some of the larger assist tugs and most oceangoing towboats have Category 2 marine diesel main engines.[59]

For detailed inventory preparation, best practice dictates that average values of annual operating hours, number of main and auxiliary engines, engine power, and engine age should be determined from the information collected from the vessels operating at the specific port. For a more streamlined approach, average propulsion and auxiliary engine sizes and hours of annual operation by harbor craft type are presented in Section 3.6.2.

3.2.2. Streamlined/Alternative Approach

The amount of resources required to conduct a detailed inventory of harbor craft emissions is large. Thus, many studies are likely to reduce this scope, either by focusing on a subset of vessel types or by substituting from other sources for the data discussed in Section 3.2.1. A reasonable, more streamlined approach to estimating harbor craft emissions is discussed in this section.

Vessel Inventory

In some cases, it may be possible to forego a detailed survey of harbor craft, as dictated by best practices, and estimate a harbor craft vessel inventory from other datasets. This is extremely advantageous from a resource perspective but is likely to have inferior data quality.

In the ARB harbor craft inventory[60], for example, vessel counts by vessel type are drawn from the USCG’s Merchant Vessels of the United States database. This database includes commercial and recreational vessels documented by the USCG. It is based on the USCG's Marine Information for Safety and Law Enforcement (MISLE) and Vessel Documentation System (VDS) databases. These databases consist of information on vessel characteristics and owner information for vessels with a valid Certificate of Documentation. However, there are several concerns with use of this database. First, no foreign vessels are included. Second, older versions of the database may not be available. Third, key fields of the database are often unpopulated. Finally, the information in the database on activity region—the vessels hailing port—may not be the best determinate of the vessels area of operation. ARB was able to avoid some of these resolution issues by calculating emissions at an air basin or county level, but this may not be practical when attempting to reproduce calculations for individual ports.

Other databases may provide similar data. For example, the US Army Corps of Engineers maintains a comprehensive and current inventory for tug and towboats in the US.[57] This database lists approximately 5,000 towboats, corresponding vessel horsepower, and is reported by the towboat operator and state of operations base. This could be used to approximate tug and tow activity at a port under a streamlined calculation. However, the same caveats on operating domain may apply.

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[59] For the purpose of emission regulations, EPA divides marine engines into three categories, where each category represents a different engine technology, based on displacement (swept volume) per cylinder. Category 1 and 2 marine diesel engines range in size from about 700 to 11,000 hp (500 to 8,000 kW). These engines are used to provide propulsion power on many oceangoing vessels and harbor craft or as stand-alone auxiliary engines.

[60] California Air Resources Board, *Emissions Estimation Methodology for Commercial Harbor Craft Operating in California*, September 2007.

One of the hardest categories to get consistent information on is recreational vessels. Most harbors only have data on number of slips, percentage of sailboats versus powerboats, and whether the marinas are at full capacity. Coincidentally, most harbor craft inventories ignore the non-commercial sector. If the data required for a detailed inventory—where best practice dictates that a count of the number of vessels should be paired with emission factors and other appropriate details—is not available, it may be estimated for a mid-tier approach. Starcrest used data from ARB's Pleasure Craft Exhaust Emissions Inventory and the OFFROAD model to determine emissions from recreational vessels. This practice may be used for California ports. Various other states have also done recreational boating surveys, which could be used together with EPA's NONROAD model for other non-California ports in absence of local vessel inventories. However, in both cases, the inventories will need to be tailored to the specific port in question. Note also that many recreational vessels may be driven by spark ignition engines, thus a different fuel and exhaust emission factors may need to be considered.

In any case, it is likely that a vessel inventory may need to be estimated from a variety of databases or other sources to verify and achieve best results in a streamlined approach.

Vessel Types

Another issue with using external databases is matching vessel types. The USCG vessel database includes the following vessel types: Commercial Fishing, Fish Processing Vessel, Freight Barge, Freight Ship, Industrial Vessel (e.g., Cable Layer, Dredge, Crane Barge), Mobile Offshore Drilling Unit, Offshore Supply Vessel, Oil Recovery (vessels designated to recover spilled oil), Passenger (More Than 6), Passenger Barge, Public Freight, Public Tank Ship/Barge, Public Vessel (Unclassified), Recreational, Research Vessel, School Ship, Tank Barge, Tank Ship, Towing Vessel, Unclassified, and Unknown. Should these vessel types not agree with those of the inventory underway, mapping must be done between vessel types.

For example, it might be reasonable to determine vessel types as was done in the ARB analysis but without distinction being made between commercial fishing boats and commercial charter fishing. The vessel types may then include: Commercial Fishing, Crew and Supply, Ferry-Excursion, Pilot, Work Boat, Assist Tug, Tug-Tow-Push Boat, and Other. In this case, the mapping between the USCG database and the ARB vessel types is shown in Table 3-2.

Once each type of harbor craft operating in each port of interest is determined from the USCG database, the vessels may be grouped into the types of vessels included in the study. Two potential issues involving types of engines to include may arise. In some cases, only vessels listed in the database as self propelled may need to be included. In other cases, attempts may need to be made to distinguish harbor craft with Category 1 versus Category 2 engines for tug, tow, and push boats. In the latter case, it might be worth noting that in its 2008 rulemaking, EPA utilized a factor of 25% for the fraction of tugboat propulsion engines that are Category 2. [61]

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[61] EPA, Final Regulatory Impact Analysis: Control of Emissions of Air Pollution from Locomotives and Marine Compression-Ignition Engines Less Than 30 Liters per Cylinder , EPA420-R-08-001a, May 2008.

Table 3-2: Example Vessel Types Matching between the USCG database and Other Analyses

Example Inventory Methodology Category	USCG Database Categories
Commercial Fishing	Commercial Fishing Vessel
Commercial Fishing	Fish Processing Vessel
Crew and Supply	Freight Barge
N/A[a]	Freight Ship
Work Boat	Industrial Vessel
Work Boat	Mobile Offshore Drilling Unit
Crew and Supply	Offshore Supply Vessel
Work Boat	Oil Recovery
Ferry-Excursion	Passenger (Inspected)
Ferry-Excursion	Passenger (Uninspected)
Ferry-Excursion	Passenger Barge (Inspected)
Ferry-Excursion	Passenger Barge (Uninspected)
Crew and Supply	Public Freight
Crew and Supply	Public Tankship/Barge
Other	Public Vessel, Unclassified
Recreation	Recreational
Work Boat	Research Vessel
Work Boat	School Ship
Crew and Supply	Tank Barge
N/A[a]	Tank Ship
Tug-Tow-Push Boat	Towing Vessel
Other	Unclassified
Other	Unknown
Other	UNSPECIFIED

[a] Considered ocean going vessels

Age Distributions

If vessel inventories are not available in sufficient detail to perform a detailed inventory, it is unlikely that engine details will be either. In this case, a mid-tier approach may be conducted following NONROAD guidance for age distributions. A continuous age distribution may be determined for both main and auxiliary engines for each harbor craft type.[62] (This approach parallels that for Cargo Handling Equipment; see the full discussion in Section 4.5.2).

It is reasonable to assume that the set of governing parameters are fairly consistent for harbor craft at all ports. Thus, only a single age distribution may be required for each vessel and engine type. This age distribution may be estimated to cover 50 years regressively from the baseline year in question (age 0). Survival should be determined as a function of the ratio of actual to median age.

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[62] Calculation of Age Distribution in the NONROAD Model: Growth and Scrappage, EPA420-P-04-007, NR-007b, April 2004 (Rev.).

Annual, linear growth in the population of harbor craft at the port should also be included to create a reasonable age distribution. If this is not known, it may be estimated from surrogate data, such as regional economic growth. Otherwise, a default value for the annual population growth rate of 1.009, as used in the 2008 rulemaking[61] for each engine type may be reasonable. This value is folded into the growth and scrappage curves to estimate the age distribution of engines.

In the NONROAD formulation, the median lifetime is the principal governing parameter for the age distribution. In the 2008 rulemaking, EPA used a median lifetime for Category 1 propulsion engines of 13 years, 17 years for Category 1 auxiliary engines, and 23 years for Category 2 propulsion engines. These are likely to be better estimates than those derived following NONROAD guidance,[63] since, that methodology sometimes can produces unrealistic values for engine lifetime in marine applications. Whichever method is used, however, in cases where the resulting estimates for median lifetime for each harbor craft engine type do not produce age distributions whose average model year agrees with that determined from the average values described above, the estimated equipment median lifetime value should be adjusted until the average model year determined from the harbor craft fleet age distribution agrees with that predicted by the scaling methodology.

3.3. Load Factors

3.3.1. Best Practices

True best practices for load factors would be to collect information for the vessels operating at a specific port. However, this is not likely to be reasonable for most applications. Rather, in its 2008 rulemaking, EPA presents harbor craft load factors. These are summarized in Table 3-3. Pending better evidence to the contrary, best practices are to follow this guidance, although the values are significantly higher than other values measured and documented elsewhere (see Section 3.3.2).

Table 3-3: EPA Load Factors for Harbor Craft

Engine Category	Engine Size	Likely Annual Transit Days	Average Annual Activity	Load Factor
Category 2		219		0.85
Category 1 Main	<805 HP		943	0.45
	>805 HP		4503	0.79
Category 1 Aux	<805 HP		798	0.56
	>805 HP		2500	0.65

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[63] Median Life, Annual Activity, and Load Factor Values for Nonroad Engine Emissions Modeling, EPA420-P-02-014, NR-005b, December 2002.

3.3.2. Streamlined/Alternative Approach

Load factors used in the PoLA[53] and PoLB[54] inventories are shown in Table 3-4. The 43 percent value for other auxiliary vessels comes from EPA's NONROAD model. Starcrest determined the 31 percent for assist tugs from actual vessel load readings and obtained the remaining load factors from other studies, as documented in Starcrest's PoLA inventory report.[30] in cases where collecting information for the vessels operating at a specific port is not practical and it is reasonable to believe that the values discussed in Section 3.3.1 are inappropriate, these load factors are likely to be reasonable alternatives.

Table 3-4: Load Factors for Harbor Craft (Port of Los Angeles and Long Beach)

Vessel Category	Load Factor	Source
Assist Tugboat	31%	PoLA
Dredge Tenders	69%	PoLA
Recreational	21%	PoLA
Recreational, Auxiliary	32%	PoLA
Crew Boat	45%	PoLB
Excursion	42%	PoLB
Ferry	42%	PoLB
Government	51%	PoLB
Ocean Tug	68%	PoLB
Tugboat	31%	PoLB
Work Boat	43%	PoLB
Other Categories	43%	PoLA
Other Auxiliaries	43%	PoLA

3.4. Emission Factors

Marine engines are assigned an emission tier structure similar to other nonroad engines; however the range of tiers is much smaller. Engines built prior to 2009 are Tier 0 (baseline), Tier 1, or Tier 2, where the baseline technology applies to all pre-control engines, Tier 1 technologies include the first round of standards (for NOx only) beginning in 2000, and Tier 2 includes the second round of standards for HC+NOx and PM beginning between 2004 and 2007, depending on engine displacement.

In 2008, EPA adopted new emission standards for harbor craft engines that established new Tier 3 and 4 standards for new Category 1 and 2 diesel propulsion engines (over 50 hp) for most harbor craft. [61] The new Tier 3 engine standards phase in beginning in 2009. New Tier 4 standards begin applying in 2014, but only to commercial marine diesel engines greater than 800 hp. (Tier 4 standards are based on catalytic exhaust after-treatment technologies.) These standards must be considered for inventories and emission projections for years 2009 and later.

3.4.1. Best Practices

If detailed data on engine age and displacement category is available, criteria pollutant emission factors published in the 2008 Regulatory Impact Analysis document may be applied. These are shown by Table 3-5.

Table 3-5: Harbor Craft Emission Factors

Engine Type	Disp Category (Max L/Cyl)	Engine EFs (g/kW hr)											
		PM_{10}			NOx			HC			CO		
		Tier 0	Tier1	Tier2	Tier 0	Tier1	Tier2	Tier 0	Tier1	Tier2	Tier 0	Tier1	Tier2
Cat 1 Main	<0.9	0.54	0.54	0.23	10.0	9.8	5.7	0.41	0.41	0.41	1.6	1.6	1.6
	<1.2	0.47	0.47	0.12	10.0	9.8	6.1	0.32	0.32	0.32	1.6	1.6	0.9
	<2.5	0.34	0.34	0.13	10.0	9.8	6.0	0.27	0.27	0.19	1.6	1.6	1.1
	<3.5	0.30	0.30	0.13	10.0	9.1	6.0	0.27	0.27	0.19	1.6	1.6	1.1
	<5	0.30	0.30	0.13	11.0	9.2	6.0	0.27	0.27	0.19	1.8	1.8	1.1
Cat 1 Auxiliary	<0.9	0.84	0.84	0.23	11.0	9.8	5.7	0.41	0.41	0.41	2.0	2.0	1.6
	<1.2	0.53	0.53	0.21	10.0	9.8	5.4	0.32	0.32	0.32	1.7	1.7	0.8
	<2.5	0.34	0.34	0.15	10.0	9.8	6.1	0.27	0.27	0.21	1.5	1.5	0.9
	<3.5	0.32	0.32	0.15	10.0	9.1	6.1	0.27	0.27	0.21	1.5	1.5	0.9
	<5	0.30	0.30	0.15	11.0	9.2	6.1	0.27	0.27	0.21	1.8	1.8	0.9
Cat2		0.32	0.32	0.32	13.36	10.55	8.33	0.134	0.134	0.134	2.48	2.48	2.00

$PM_{2.5}$ emission factors are estimated to be 97 percent of PM_{10} emissions for both Category 1 and Category 2 engines.

Fuel correction factors should be used to update base emission factors for different fuel usage. All harbor craft not fueled with offroad diesel fuel must have an appropriate fuel correction factor applied. Fuel correction factors for PM emissions from Tier 2 and older engines should follow the methodology developed in the EPA Regulatory Impact Analysis for the 2008 rulemaking to account for differences in fuel sulfur content between the certification fuel and the episodic (calendar year) fuel.[64] Tier 3 and greater engines are not corrected. The corrections are determined as:

$$SPM_{adj} = (FC) \times 7.1 \times 0.02247 \times (224 / 32) \times (sox_{dsl} - sox_{bas}) \times (1 / 2000)$$

where:

SPM_{adj} is the PM sulfate adjustment (tons),
FC is the fuel consumption (gallons),
7.1 is the fuel density (lb/gal),
0.02247 is the fraction of fuel sulfur converted to sulfate,
224/32 is the mass of PM sulfate (grams) per mass of PM sulfur (grams),
sox_{dsl} is the episodic fuel sulfur weight fraction for a given calendar year,
sox_{bas} is the certification fuel sulfur weight fraction, and
2000 converts from lbs to tons.

The certification fuel sulfur term is the fuel sulfur level associated with a base emission factor such that a lower episodic fuel sulfur level results in a decrease in PM emissions (negative adjustment factor) and vice-versa. EPA assumes values of sox_{bas} as follows:

sox_{bas} = 3,300 ppm (Tier 1 and below engines)
2,000 ppm (Tier 2 engines under 50 hp (37 kW))

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[64] EPA, Final Regulatory Impact Analysis: Control of Emissions of Air Pollution from Locomotives and Marine Compression-Ignition Engines Less Than 30 Liters per Cylinder , EPA420-R-08-001a, May 2008.

350 ppm (Tier 2 engines above 50 hp (37 kW))

In cases where the in-use fuel sulfur is not known, the PM correction factors can be determined using the calculation methodologies above with sox_{dsl} values as used by EPA in the 2008 rulemaking. These are shown by Table 3-6.

Table 3-6: In-Use Fuel Sulfur Content (ppm)

Calendar Year	Sulfur Content (ppm)
2000 and Earlier	2,640
2001	2,635
2002-2005	2,637
2006	2,588
2007	1,332
2008-2009	435
2010	319
2011	236
2012	124
2013	44
2014	52
2015-2017	56
2018-2040	55

3.4.2. Streamlined/Alternative Approach

In many cases, the engine power density is likely not to be known and/or other species will be needed. In those cases, emission factors can be determined from other published sources. One set of combined sources by tier structure is documented in Table 3-7. [65] Notably, these include greenhouse gas emission factors omitted in the 2008 RIA. Here, Category 1 emission factors for Tier 1 and 2 engines on harbor craft come from the 1999 EPA rulemaking for Category 1 and 2 engines; Category 2 emission factors come from Entec, IMO, and the 1999 EPA rulemaking.

Table 3-7: Sources for Harbor Craft Emission Factors

Tier	Category	Model Year	Emission Factor Source	
0	1	<= 1999	1999	EPA RIA
0	2	<= 1999	2002	Entec
1	1	2000-2003	1999	EPA RIA, IMO NOX
1	2	2000-2003	2002	Entec, IMO NOX
2	1	>= 2004	1999	EPA RIA
2	2	>= 2004	2002	Entec, 1999 EPA RIA

Table 3-8 presents the resulting emission factors from the literature sources shown in Table 3-7. $PM_{2.5}$ emission factors are estimated to be 97 percent of PM_{10} emissions for both Category 1 and Category 2 engines. SO_2 emissions are based on fuel sulfur content of 1.5 percent and should be scaled up or down based on actual fuel sulfur content used for harbor craft at the

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[65] EPA, Final Regulatory Impact Analysis: Control of Emissions from Marine Diesel Engines, EPA420-R-99-026, November 1999.

port. PM emissions are proportional to sulfate emissions which, in turn, are directly related to fuel sulfur level, as discussed above. As an alternative, to calculating fuel correction factors, simple adjustment factors for sulfate PM and other species may be taken from the Puget Sound Inventory,[66] as shown in Table 3-9.

Table 3-8: Harbor Craft Emission Factors (g/kWh)

Minimum Power (kW)	NOx (g/kWh)	VOC (g/kWh)	CO (g/kWh)	PM_{10} (g/kWh)	SO_2 (g/kWh)	CO_2 (g/kWh)	N_2O (g/kWh)	CH_4 (g/kWh)
Tier 0 Engines								
37	11	0.27	2	0.9	1.3	690	0.02	0.09
75	10	0.27	1.7	0.4	1.3	690	0.02	0.09
130	10	0.27	1.5	0.4	1.3	690	0.02	0.09
225	10	0.27	1.5	0.3	1.3	690	0.02	0.09
450	10	0.27	1.5	0.3	1.3	690	0.02	0.09
560	10	0.27	1.5	0.3	1.3	690	0.02	0.09
1,000	13	0.27	2.5	0.3	1.3	690	0.02	0.09
Cat 2	13.2	0.5	1.1	0.72	1.3	690	0.02	0.09
Tier 1 Engines								
37	9.8	0.27	2	0.9	1.3	690	0.02	0.09
75	9.8	0.27	1.7	0.4	1.3	690	0.02	0.09
130	9.8	0.27	1.5	0.4	1.3	690	0.02	0.09
225	9.8	0.27	1.5	0.3	1.3	690	0.02	0.09
450	9.8	0.27	1.5	0.3	1.3	690	0.02	0.09
560	9.8	0.27	1.5	0.3	1.3	690	0.02	0.09
1,000	9.8	0.27	2.5	0.3	1.3	690	0.02	0.09
Cat 2	9.8	0.5	1.1	0.72	1.3	690	0.02	0.09
Tier 2 Engines								
37	6.8	0.27	5	0.4	1.3	690	0.02	0.09
75	6.8	0.27	5	0.3	1.3	690	0.02	0.09
130	6.8	0.27	5	0.3	1.3	690	0.02	0.09
225	6.8	0.27	5	0.3	1.3	690	0.02	0.09
450	6.8	0.27	5	0.3	1.3	690	0.02	0.09
560	6.8	0.27	5	0.3	1.3	690	0.02	0.09
1,000	6.8	0.27	5	0.3	1.3	690	0.02	0.09
Cat 2	9.8	0.5	5	0.72	1.3	690	0.02	0.09

Table 3-9: Harbor Craft Fuel Correction Factors from Offroad Diesel Fuel

Fuel	NOx	VOC	CO	SO_2	PM	CO_2
Diesel, offroad	1	1	1	1	1	1
Diesel, onroad	1	1	1	0.1	0.87	1
Diesel, ultra low sulfur	1	1	1	0.005	0.86	1
Biodiesel (B99)	1.17	0.5	0.65	0	0.68	0.96

If information on the distribution of Category 1and 2 engines is not available, it may be assumed from other sources. Information from the Puget Sound inventory indicates that about 90% of all tug, tow,

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[66] Starcrest Consulting Group, Puget Sound Maritime Air Forum Maritime Air Emissions Inventory, April 2007.

push, and assist tugs are Category 1 and 10% are Category 2. In the 2008 RIA, EPA used a 25% fraction of Category 2 towboat propulsion engines. EPA's higher number might be a result of including tugs and tows on inland rivers which would have a higher percentage of Category 2 vessels.

In addition to the greenhouse gas emission factors discussed above, it is possible to estimate elemental carbon emission factors from the EPA's SPECIATE4 model for emissions of $PM_{2.5}$.[67] For diesel harbor craft, the diesel commercial marine vessel (SCC 2280002000) sector is appropriate. That sector is assigned an emission fraction of 77.12% elemental carbon. That is:

$$\boldsymbol{EF_{EC} = 77.12\% \times 97\% \times EF_{PM10}}$$

after adjusting the PM_{10} emission factor for fuel sulfur.

3.5. Other Factors

Control factors should be applied to account for any reduction in emissions due to exhaust or engine controls that reduce emissions from harbor craft. However, these must apply only to the vessels on which they are installed and the reduction levels should be approved by ARB or EPA. In particular, for any emission inventory projecting emissions beyond the 2014 baseline year when EPA's Tier 4 standards begin to phase in, or any inventory where early reduction measures are considered, control factors must be considered. Further, control factors must only apply to the appropriate activity. For example, if harbor craft cold ironing is offered, those reductions should only apply to the engines that would normally be operating otherwise.

Most detailed inventories do not explicitly apply transient adjustment factors or deterioration factors to the zero hour emission factors for marine vessels, although the most recent (2007 inventory year) PoLB report does use values from ARB. The 2008 EPA rulemaking documents also apply deterioration to PM emissions. more information is available in Section 3.1 of *Regulatory Impact Analysis: Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression Ignition Engines Less than 30 Liters Per Cylinder*.[64]

3.6. Estimating Other Parameters

Once a vessel inventory is estimated, the best practice is to use a NONROAD-based methodology described above to estimate emissions. Other parameters necessary to estimate emissions for harbor craft at each of the harbor areas of interest include the number and rated power of main and auxiliary engines on each vessel, annual activity, and engine model year.

3.6.1. Best Practices

Some of these parameters have been discussed above. In particular, the best practice for determining annual activity and engine power is to conduct surveys and use the resulting values, or appropriate surrogates from the EPA rulemaking.

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[67] SPECIATE Version 4.0, January 18, 2007. Available at http://www.epa.gov/ttn/chief/software/speciate/index.html

3.6.2. *Streamlined/Alternative Approach*

In many cases, however, much of the activity and engine power data may be missing or unavailable. In those cases, this data may be estimated either from other inventories, should these be determined more appropriate than using the 2008 rulemaking values.

As noted above, detailed, current harbor craft information is readily available for the Ports of Los Angeles, Long Beach, and the Puget Sound. Houston also has information that may be useful. However, because extrapolation between ports is difficult for harbor craft, it is reasonable to instead use average values of number of main and auxiliary engines for a given vessel type, engine model year and rated power, and annual activity from other detailed inventories. Table 3-10 shows average propulsion and auxiliary engine sizes and hours of annual operation by harbor craft type for the combined Ports of Los Angeles[53], Long Beach[54], and Puget Sound[66], after mapping to the harbor craft types suggested in this report. Note that Houston is not included in these average values since the number of engines is not included in the summary tables.

Table 3-10: Average Engine Horsepower and Annual Hours of Operation (Average values from the Ports of Los Angeles, Long Beach, and Puget Sound)

Vessel Category	Main Engines				Auxiliary Engines			
	Number of Engines (per Vessel)	Engine Power (kW)	Annual Operating Hours	Model Year	Number of Engines (per Vessel)	Engine Power (kW)	Annual Operating Hours	Average Model Year
Commercial Fishing	1.9	368.7	114	1984	1.0	55.2	52	1984
Crew and Supply	2.2	301.6	725	1987	1.1	76.1	628	1987
Ferry-Excursion	1.9	857.5	1693	1997	1.2	81.9	1467	1994
Pilot	2.0	820.3	2675	2000	2.0	35.0	1000	2000
Work Boat	1.8	275.9	329	1989	0.6	55.7	386	1986
Assist Tug	2.0	1540.1	1861	1994	1.9	100.2	2184	1994
Harbor Tug	1.9	711.4	1130	1990	1.5	55.7	982	1990
Ocean Tug	2.0	1399.4	350	1986	2.0	95.2	350	1987

3.7. Emissions Determination

Once the age distributions, average operating parameters, engine counts, fuels, and other parameters have been estimated, annual harbor craft emissions at the port in question may be estimated. This is done as the product of the number of vessels of a given type operating in the harbor area, the average number of engines of each type per vessel, the load factor, the average annual activity, and the average rated horsepower. That is:

$$\textbf{Emissions}_{\text{pollutant,H/C}} = \textbf{N}_{\text{H/C}} \times \{(<\textbf{EF}_{\text{pollutant,H/C,main}}> \times \textbf{N Eng}_{\text{H/C,main}} \times \textbf{LF}_{\text{H/C.main}} \times \textbf{Activity}_{\text{HC,main}} \times \textbf{HP}_{\text{H/C,main}}) + (<\textbf{EF}_{\text{pollutant,H/C,aux}}> \times \textbf{N Eng}_{\text{H/C,aux}} \times \textbf{LF}_{\text{H/C,aux}} \times \textbf{Activity}_{\text{H/C,aux}} \times \textbf{HP}_{\text{H/C,aux}})\}$$

Should transient adjustment factors and/or deterioration factors be explicitly applied, they should be included in emission factors determined for each engine.

4. Cargo Handling Equipment

A wide range of cargo handling equipment (CHE) exists at ports due to the diversity of cargo. Container terminals use CHE most extensively. Truck to rail equipment and dry bulk terminals also have high use of CHE. Liquid bulk and auto terminals use CHE the least. Starcrest found that much of CHE is used to load and unload containers.[68] In fact for the PoLA, 99 percent of CHE was associated with container terminals, while the 2007 PoLB inventory found 81% of the port-wide CHE was employed by its container terminals. While only 42 percent of the CHE in the Port of Houston was engaged in container terminal activity, approximately 70 percent of the port-wide NOx emissions came from this equipment. Thus, determining emissions from container terminal CHE is important in any land-side emission inventory.

Although critical for all sectors, appropriate designation of geographic boundaries for the inventory being prepared is especially important for CHE. For example, the boundary may be set to only include terminals under jurisdiction of the local port authority and exclude activity at privately-owned piers. Alternatively, boundaries may be chosen to characterize all marine-related emissions in an air basin, and would thus include activity at all private and publicly owned land. Regardless of whether a Best-Practice or Streamlined approach is employed, the scope of the inventory should be declared in advance of any calculations and in accordance with the projects' objective.

4.1. Emission Inventory Methodology

4.1.1. Best Practices

Best practices in developing an emissions inventory from CHE activity dictate that one should gather detailed information on all CHE present at the port in question (within the study boundaries) and make simulations using the NONROAD (OFFROAD in California) model. To do so, the following information for each piece of CHE used at the port must be collected:

- Equipment type
- Rated horsepower
- Model year
- Type of fuel used
- Annual hours of operation
- Equipment load data
- Retrofit devices or other emission mitigation measures employed.

In preparing inputs, diesel sulfur content in parts per million (ppm) should be determined for the fuels used for CHE at the port. National diesel fuel sulfur levels are currently set following EPA's Nonroad Diesel Rule. Since 2007 all nonroad diesel fuel sulfur levels have been limited to a maximum of 500 ppm and will be reduced to 15 ppm sulfur or less by 2010 (2006 in California). This is to be compared to a national average non-road fuel sulfur level of 3,400 ppm before

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[68] Starcrest Consulting Group LLC, The Port of New York and New Jersey Emission Inventory for Container Terminal Cargo Handling Equipment, Automarine Terminal Vehicles, and Associated Locomotives, prepared for the Port of New York and New Jersey, June 2003.

enactment of the Rule. Because ambient temperatures do not affect diesel exhaust emissions in NONROAD, an input of 75^{o} F can be used.

Using the data collected on equipment numbers, types, horsepower, model year, hours of operation and load data, inputs can be generated for the various NONROAD equipment types to determine emissions for CHE at the port. It should be noted that the NONROAD model uses 1996 and 1998 baseline populations and then assigns an average growth rate to estimate emissions in subsequent years. As such, growth should be set to zero so that the emissions will not increase over time and the results will be accurate for a given analysis year. For future forecasts, an updated population and activity file will be required.

For alternative fuels such as natural gas or liquefied petroleum gas (LPG), the NONROAD model can estimate emissions by specifying “ALL FUELS” during a run. For retrofit devices such as diesel oxidation catalysts, diesel particulate filters, and PuriNOx, reductions shown on EPA’s Verified Retrofit Technology website[69] or that specified by EPA’s Diesel Emission Quantifier[70] should be used. In these cases, emission factors should be determined using NONROAD for diesel equipment and then the emission reduction percentages applied.

A discussion of each of these parameters is presented below.

4.1.2. Streamlined/Alternative Approach

In cases where all necessary information is not available, resulting emissions from CHE activity may be approximated using a more streamlined approach.

Until recently, few preparers of port inventories had developed estimates of CHE emissions. Because the information was most commonly needed for SIP development and calculated using EPA’s NONROAD model (California uses ARB’s OFFROAD model), CHE was considered together with other non-road sources and emissions were generally assigned only to the counties or air districts in which these emissions occur, rather than to a port. This is still common practice. However, several mid-sized to larger ports recently have developed their own bottom-up inventories that cover the CHE sector, including Puget Sound, Charleston, SC, Portland, OR, San Diego, CA, Oakland, CA, and Philadelphia, PA. This is in addition to a number of the nation’s largest ports that have developed and/or recently updated their estimates of CHE emissions, including the Ports of Los Angeles, Long Beach, Houston, and New York/New Jersey. Thus, the amount of information available has grown significantly.

Unlike vessel emissions, there is no EPA guidance or other standardized methodology for developing estimates of port CHE emissions. Developing a detailed CHE inventory requires extensive time and resources in order to survey all port tenants regarding their equipment (within the study boundaries). Although best practices are to perform such calculations as described above, including use of the NONROAD (OFFROAD in CA) model, this level of effort is not always feasible. As an alternative, CHE emissions can be estimated using inputs developed for CHE inventories prepared by other ports. There are no fixed methods for doing so. Rather, the following discussion presents possible methodologies to develop emission

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[69] http://www.epa.gov/otaq/retrofit/verif-list.htm

[70] http://cfpub.epa.gov/quantifier/view/index.cfm

inventories from limited amounts of information. These methodologies may be followed to develop streamlined inventories depending on the amount of data available.

The essence of a streamlined CHE evaluation is to estimate any missing number inventory and/or equipment parameters from other published studies. Of the ports that have developed CHE inventories, the Ports of Long Beach and Los Angeles, New York/New Jersey (2008), Houston (2009), and the Puget Sound Ports all have emissions estimates from land-side activity provided with sufficient detail to allow application of ratios to other ports. Data from other inventories, such as Oakland and San Diego, CA, Portland, OR, and Charleston, SC, can also be used to guide calculations. To perform a streamlined estimate of CHE emissions from other port inventories, one must first determine the number and parameters (power, age, etc.) of each type of equipment and then calculate emissions as described below.

The discussion of each of these is presented below, in the appropriate subsection.

4.2. Fleet Characteristics

The majority of CHE can be classified into the equipment types shown in Table 4-1. The table provides EPA’s NONROAD model equipment type used to estimate emissions and the corresponding source classification codes (SCC) used in NONROAD. Similar categories are used with California ARB’s OFFROAD model.

Table 4-1: Cargo Handling Equipment Types

Aggregated CHE Type	Estimated SCC	SCC Type
Compressor	2270006015	Commercial
Crane	2270002045	Construction
Forklift	2270003020	Industrial
Manlift	2270003010	Industrial
Sweeper	2270003030	Industrial
Car loader	2270003050	Industrial
Chassis rotator	2270003040	Industrial
Empty container handler	2270003040	Industrial
Generator	2270006005	Commercial
Light tower	2270002027	Construction
Specialized Bulk Handler	2270003050	Industrial
Nonroad vehicle	2270002051	Construction
Gantry Crane	2270003050	Industrial
Rail pusher	2270003040	Industrial
Reach Stacker	2270003050	Industrial
Roller	2270002015	Construction
Side Handler	2270003050	Industrial
Skid Steer Loader	2270002072	Construction
Top Handler	2270003040	Industrial
Tractor	2270002060	Construction
Excavator	2270002036	Construction
Welder	2270006025	Commercial
Yard Tractor	2270003070	Industrial

4.2.1. Best Practices

To develop inputs for EPA's NONROAD model, the user must define the populations of the various categories of equipment shown in Table 4-1. Population is the number of similar engines of a specific equipment type with a similar horsepower rating. EPA's NONROAD model uses a "bin" approach for horsepower as follows:

25-40 hp	600-750 hp
40-50 hp	750-1,000 hp
50-75 hp	1,000-1,200 hp
75-100 hp	1,200-1500 hp
100-175 hp	1,500-2,000 hp
175-300 hp	2,000-3,000 hp
300-600 hp	3,000+ hp

Thus, the fleet of CHE should be defined both by equipment type and power rating, based on surveys.

4.2.2. Streamlined/Alternative Approach

In the case that the number inventory of each type of equipment shown in Table 4-1 is not available, it can be approximated. We propose two possible methods to estimate this equipment inventory.

The first method involves translating equipment types directly from one of the above listed ports in which inventory calculations have been done. To do this, a correct surrogate (principal) port must be chosen. This may be done by comparing the share of cargo passing through the port in each of the four principal conveyance types (liquid bulk, dry bulk, container, and other—see details in the Cargo Tonnage Data section, below) handled at the complex and assigning each equipment type to one of the four cargo categories typically associated with it. This method relies on the assumption that if the two ports are similar enough, the number of pieces of equipment of a given CHE type at the typical port can be reasonably assumed to be related to those at the port in question by the ratio of cargo tonnage in each category. For example, the number of cranes at a port in this methodology could be determined by the ratio of the amount of containerized tonnage between the two ports. This method is uncertain, but is expected to perform better for larger ports where most of the various types of CHE are in use, but not well for smaller ports, or ports where specialized equipment is more prevalent.

A more technical method could involve assembling all tonnage data, both by each of the four individual conveyance methods, the port total tonnage, and the equipment counts and parameters for all principal ports that have prepared detailed inventories and performing multilinear regressions to estimate the number of pieces of equipment needed at a typical port based on the amount and type of cargo handled. This method essentially attempts to predict the number of a given type of CHE that is necessary to move a given amount of cargo, without tying the results to any individual principal port. However, the regressions may not show low correlations or may predict unrealistic numbers of CHE. Also, because detailed ports are typically the largest, wealthiest, and most able to afford newer, cleaner equipment, the results may be biased if applied to dissimilar ports. Thus, professional judgment should be used to evaluate the performance of this method.

Note that, regardless of method chosen, determination of CHE populations based on the U.S. Army Corps of Engineers (USACE) cargo tonnage data[57], as utilized here, inherently introduces uncertainties into the determination of populations. For example, using USACE data implicitly relies on the Corp's allocation of activity to given harbor areas. Care must be taken to attempt to clarify with USACE exactly how these allocations are made, and how well the tonnage moved through the physical boundaries of a port authority or similar entity agree with the allocation of tonnage assigned to a harbor area by USACE. This will introduce uncertainties because principal port's detailed inventories may not share the same footprint as implied in the USACE data, which will create errors when used to extrapolate between principal and typical ports. For example, at the Port of Portland, OR, significant activity occurs beyond the port authority boundaries; however detailed activity data are only available within the port authority's boundaries. Hence, scaling of USACE data to the activity only within the port authority boundaries may exaggerate the amount of work done by a given unit of CHE or misrepresent the types of CHE associated with a given cargo tonnage category when extrapolated to a typical port.

Cargo Tonnage Data

Cargo tonnage data may be obtained from the USACE for most current years. USACE data is disaggregated into six categories: Tonnage by Self-Propelled, Dry Cargo Vessels; Self-Propelled Tanker Vessels; Non-Self-Propelled, Dry Cargo Barges; Non-Self-Propelled, Tanker Barges; Containerized Cargo; and Non-Containerized Cargo. Tonnage by four conveyance methods (dry bulk, liquid bulk, container, and other (principally Ro-Ro and automobile)) may be determined as follows.

Liquid bulk and container traffic at each harbor area may be taken directly from the USACE conveyance data. The amount of cargo in the "other" category may be determined from the detailed USACE individual commodity data (See Section 5.4.3, Commodity Analysis, for more information) for cargo types likely to fit into this (typically small) category. All remaining cargo may be assumed to be bulk.

4.3. Activity Determination

Activity is the number of hours an engine operates during a given analysis year. Once the number of units of a given CHE type and power rating bin at the port of interest is known, the equipment profiles—power, load factor, activity, age, and fuel type—must be determined. This section focuses on activity.

4.3.1. Best Practices

Activity should be determined from interviews with terminal operators. In general, container terminals use their cargo handling equipment much more intensively than other terminals and thus should have either much higher activity values or higher populations with similar activities.

4.3.2. Streamlined/Alternative Approach

For a mid-tier inventory, a reasonable approach is to determine the port(s) with a detailed CHE inventory that is (are) most like the port in question and adopt those values.

As discussed above, the primary method of scaling between similar published port inventories and the port under consideration is the equipment inventory—the number of units of a given CHE type at the typical port—determined based on cargo throughput. However, the equipment profiles have a linear relationship with the emissions from CHE at a given port. For example, if the number of cranes of equivalent load factors, age, fuel, and rated power at one port is twice that at another port, but the annual usage of each is half, the emissions are equivalent. Thus, the estimated emissions may be just as sensitive to these parameters as the equipment inventory.

For a streamlined analysis, the necessary equipment profiles may be obtained by translating directly from an appropriately matched port with an available detailed inventory. For example, if the port under consideration is taken to be most similar to the Port of Seattle, WA, based on cargo type throughput, the rated power, annual activity, and average age of the CHE may be taken from that inventory, whose values are shown in Table 4-2 along with USACE cargo type information in Table 4-3. Detailed values for other ports are available in their individual inventories.

In the case where appropriate operating parameters are not available at the best matched principal port, an alternative match may be determined and parameters for one or more additional CHE types taken from there. An alternative with more degraded resolution could be to use the CHE profiles and average parameters from all principal ports with sufficiently detailed CHE inventories. Because the inventories cover different baseline years and equipment in use at each will evolve, this method is not as valid as a detailed inventory, but may suffice for a highly streamlined application. Table 4-4 shows the average parameters from the latest inventories by the Ports of Houston, New York/New Jersey, Long Beach, Los Angles, and each of the Puget Sound Ports, compiled together.

Table 4-2: CHE Average Parameters at the Port of Seattle, WA, 2005

CHE Types	Count	Average HP	Average Model Year	Average Hours
Car loader	8	150	1985	500
Crane	26	300	1995	300
Forklift	173	130	1993	1212
Generator	33	130	1990	873
Manlift	1	60	1986	113
RTG Crane	4	900	2005	550
Side Handler	11	195	2001	771
Sweeper	2	50	1997	441
Top Handler	68	282	1998	2095
Yard Tractor	188	188	1999	1956

Table 4-3: Port of Seattle Cargo Type Data from USACE for 2005

Cargo Type	Liquid	Bulk	Container	Other
Cargo Tonnage	2,810,150	13,807,844	11,028,239	434,904
Cargo Type Fraction	10%	49%	39%	2%

Table 4-4: CHE Average Parameters from all Detailed Ports, Various Years

CHE Type	Average HP	Average Age (Years)	Average Operating Hours
Car loader	150	20	500
Chassis rotator	156	21	1,102
Compressor	26	11	607
Crane	274	9	534
Empty container handler	247	7	1,864
Excavator	312	12	1,909
Forklift	127	10	1,029
Gantry Crane	453	5	2,641
Generator	141	13	692
Light tower	4	1	57
Manlift	68	7	273
Nonroad vehicle	210	12	659
Rail pusher	214	8	962
Reach Stacker	274	5	2,810
Roller	103	13	297
Side Handler	184	6	1,228
Skid Steer Loader	85	8	679
Specialized Bulk Handler	245	11	1,001
Sweeper	109	7	644
Top Handler	282	7	1,955
Tractor	131	11	553
Welder	52	15	155
Yard Tractor	206	5	1,861

4.4. Load Factors

Load factors describe the fraction of full engine power used, on average, over a period of time. Once the number of units of a given CHE type at the port of interest is known, the equipment profiles—power, load factor, activity, age, and fuel type—must be determined. The following discusses load factors.

4.4.1. Best Practices

Load factors should be determined from interviews with terminal operators. In general, container terminals use their cargo handling equipment much more intensively than other terminals. Load factors should be calculated by examining the power requirement versus time over the normal operation of the equipment.

4.4.2. Streamlined/Alternative Approach

In addition to the equipment average parameters shown above, another parameter that determines equipment emissions is equipment load factor. Equipment load factors may be taken from other published inventories, such as the Port of Los Angeles, after extrapolating to the 23 CHE types listed in Table 4-1. Table 4-5 shows these, along with corresponding median useful life values, also extrapolated from PoLA values.

Table 4-5: CHE Useful Life and Load Factors, Extrapolated from the Port of Los Angeles Inventory

Equipment Type	Useful Life	Load Factor
Car loader	16	0.51
Chassis rotator	16	0.51
Compressor	16	0.51
Crane	24	0.43
Empty container handler	16	0.59
Excavator	16	0.57
Forklift	16	0.30
Generator	16	0.59
Light tower	16	0.51
Manlift	16	0.30
Nonroad vehicle	12	0.65
Rail pusher	16	0.51
Reach Stacker	16	0.30
Roller	16	0.51
RTG Crane	24	0.43
Side Handler	16	0.59
Skid Steer Loader	16	0.55
Specialized Bulk Handler	16	0.59
Sweeper	16	0.68
Top Handler	16	0.59
Tractor	16	0.57
Welder	16	0.51
Yard Tractor	12	0.65

4.5. Age Distribution and Emission Tier

CHE is assigned an emission tier value based on the model year of the engine. To accurately estimate emissions factors for the fleet of CHE, the distribution of age and corresponding emission tier must be known. Table 4-6[71] shows the current relationship between engine tier and engine age for CHE.

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[71] *Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling—Compression-Ignition*, EPA420-P-04-009, April 2004.

Table 4-6: Tier Structure of Nonroad Engines

Engine Power (hp)	Model Year	Fraction of Population in Each Technology Type									
		Base	Tier 0	Tier 1	Tier 2	Tier 3	Tier 3B	Tier 4A	Tier 4B	Tier 4	Tier 4N
≤25 hp	Pre-1988	1									
	1988-1999		1								
	2000-2001		0.2	0.8							
	2002-2004		0.1	0.9							
	2005		0.1		0.9						
	2006-2007				1						
	2008-2012							1			
	2013+								1		
>25 to 50	Pre-1988	1									
	1988-1998		1								
	1999-2000		0.2	0.8							
	2001-2003		0.1	0.9							
	2004		0.1		0.9						
	2005-2007				1						
	2008-2012							1			
	2013+									1	
>50 to 75	Pre-1988	1									
	1988-1997		1								
	1998-2003			1							
	2004-2005			0.2	0.8						
	2006-2007			0.1	0.9						
	2008-2009			0.1				0.9			
	2010-2012							1			
	2013+									1	
>75 to 100	Pre-1988	1									
	1988-1997		1								
	1998-2003			1							
	2004-2005			0.2	0.8						
	2006-2007			0.1	0.9						
	2008-2009			0.1			0.9				
	2010-2011						1				
	2012-2013									0.5	0.5
	2014+										1
>100 to 175	Pre-1988	1									
	1988-1996		1								
	1997-2002			1							
	2003-2004			0.2	0.8						
	2005-2006			0.1	0.9						
	2007-2008			0.1		0.9					
	2009-2011					1					
	2012-2013									0.5	0.5
	2014+										1

Continued

Table 4-6: Tier Structure of Nonroad Engines *(continued)*

Engine Power (hp)	Model Year	Fraction of Population in Each Technology Type									
		Base	Tier 0	Tier 1	Tier 2	Tier 3	Tier 3B	Tier 4A	Tier 4B	Tier 4	Tier 4N
>175 to 300	Pre-1988	1									
	1988-1995		1								
	1996-2002			1							
	2003-2004			0.2	0.8						
	2005			0.1	0.9						
	2006-2008			0.1		0.9					
	2009-2010					1					
	2011-2013									0.5	0.5
	2014+										1
>300 to 600	Pre-1988	1									
	1988-1995		1								
	1996-2000			1							
	2001-2002			0.2	0.8						
	2003-2005			0.1	0.9						
	2006			0.1		0.9					
	2007-2010					1					
	2011-2013									0.5	0.5
	2014+										1
>600 to 750	Pre-1988	1									
	1988-1995		1								
	1996-2001			1							
	2002-2003			0.2	0.8						
	2004-2005			0.1	0.9						
	2006-2007			0.1		0.9					
	2008-2010					1					
	2011-2013									0.5	0.5
	2014+										1
>750	Pre-1988	1									
	1988-1999		1								
	2000-2005			1							
	2006-2007			0.3	0.7						
	2008			0.2	0.8						
	2009-2010				1						
	2011-2014									1	
	2015+										1

4.5.1. Best Practices

Best practices for determining engine tier distribution is to allow the NONROAD model to determine the overall tier structure based on the age of each piece of equipment, as noted through surveys and interviews with terminal operators.

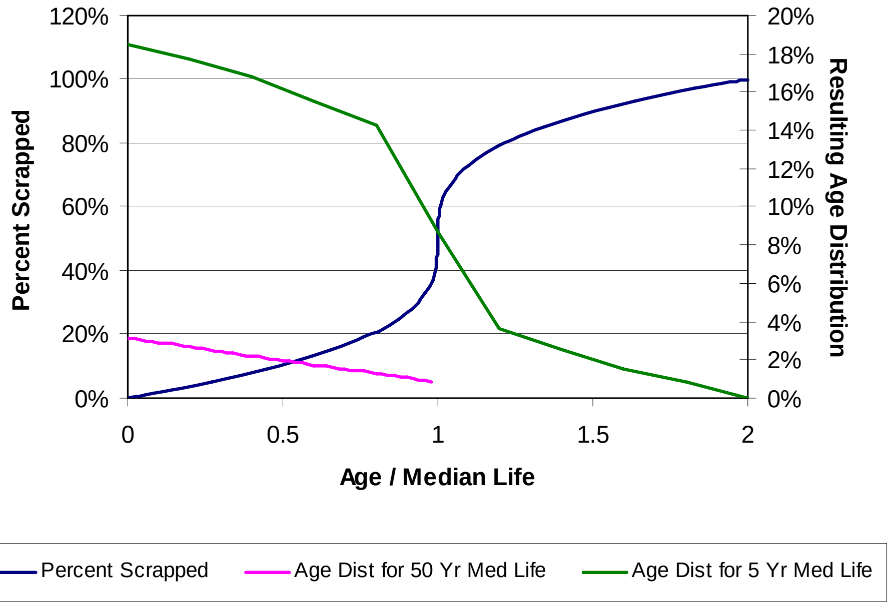
4.5.2. Streamlined/Alternative Approach

In a streamlined approach, a continuous age distribution is used to determine average emissions factors based on the Emission Tier structure of the engines.

Average equipment age for streamlined approaches was discussed above in Sections 4.2.2 and 4.3.2. One method for estimating emissions could be to assign all CHE the average age and use the average CHE parameters discussed above, However, a better approach is to determine an age distribution for each type of CHE at each typical port following NONROAD guidance.[72]

An age distribution should cover 50 years regressively from the baseline year of study (age 0), with survival determined as a function of the ratio of actual to median age. An appropriate annual, linear population growth of each type of CHE should be determined based on local data. However, if no better data is available, a generic 3% annual growth factor may be assumed, based on ARB's CHE inventory.[73] Scrappage—i.e., percent survival—as a function of equipment age to median useful life may be taken from NONROAD guidance. Figure 4-1 shows the NONROAD scrappage curve to be applied. The age distribution is then determined by calculating the age for each of the 50 model years, applying the annual growth rate from the lowest year in the curve, applying the scrappage rate from the NONROAD model, and renormalizing the overall distribution. Figure 4-1 also shows resulting age distributions for 5 and 50 years median life. (Both are normalized to unity. Note that a 50 year age distribution for a 50 year median life only covers values of age / median age of zero to one).

Figure 4-1: NONROAD Scrappage Curve for Use in Determining the CHE Age Distribution, and Corresponding Age Distributions for 5- and 50-Year Median Lifetimes



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[72] *Calculation of Age Distribution in the NONROAD Model: Growth and Scrappage*, EPA420-P-04-007, NR-007b, April 2004 (Rev.).

[73] *Appendix B: Emissions Inventory Methodology: Emission Estimation Methodology for Cargo Handling Equipment Operating at Ports and Intermodal Rail Yards in California*, CARB.

The driving parameter in determining an age distribution for NONROAD equipment is the median lifetime of the equipment. However, it should be noted that using the default lifetime shown in Table 4-5 for a given CHE type does not necessarily produce an age distribution where an average model year agrees with that determined from the scaling methodology described above. One method to reconcile this discrepancy is to adjust the equipment median lifetime value until the average model year determined from the CHE age distribution agrees with that predicted by the scaling methodology. However, to ensure consistency between all parameters in all cases where this is done, the adjusted median lifetime of a given CHE type and the annual activity of that CHE should also be scaled down to agree with the new value of median life according to the formulation of the NONROAD model.[74]

4.6. Emission Factors

Emission factors for CHE are a function of the engine power rating and tier. The following discusses how to determine average emission factors for a distribution of CHE.

4.6.1. Best Practices

Best practices for estimating CHE emissions at ports are to use the NONROAD or OFFROAD models, which incorporate appropriate emission factors for the known equipment population, determined as above.

4.6.2. Streamlined/Alternative Approach

In the event that a streamlined approach is used, emission factors for the given age distribution can be calculated from the NONROAD model documentation.

The primary emissions factors by engine tier for nonroad engines are shown by Table 4-7. These are all as documented as “Basis for regulation” tables in EPA420-P-04-009 for all tiers.[71] Baseline (BL) values are from NEVES. Table 4-8 and Table 4-9 show calculated emission factors based also on the same EPA document. In calculating the values in Table 4-8 and Table 4-9, a fuel sulfur content of 500 ppm (and a default of 3300 ppm) is used.

Unless better information is available, fuel type should be assumed as off-road diesel (currently with a sulfur content of less than 500 ppm. Each emission factor should be adjusted to account for fuel sulfur corrections where appropriate. A simple set of adjustments can be taken from Table 3-9.

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[74] *Median Life, Annual Activity, and Load Factor Values for Nonroad Engine Emissions Modeling*, EPA420-P-02-014, December 2002.

Table 4-7: Listed Emission Factors for Nonroad Engines

HP	HC g/hp-hr						CO g/hp-hr						NOx g/hp-hr						PM_{10} g/hp-hr					
	BL	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	BL	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	BL	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	BL	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4
>0 to 11	1.57	1.50	0.76	0.55	na	0.55	6.1	5.0	4.1	4.1	na	4.1	14.0	10.0	5.2	4.3	na	4.3	1.60	1.00	0.45	0.50	na	0.28
>11 to 16	1.57	1.70	0.44	0.44	na	0.44	6.1	5.0	2.2	2.2	na	2.2	14.0	8.5	4.4	4.4	na	4.4	1.60	0.90	0.27	0.27	na	0.28
>16 to 25	1.57	1.70	0.44	0.44	na	0.44	6.1	5.0	2.2	2.2	na	2.2	14.0	8.5	4.4	4.4	na	4.4	1.60	0.90	0.27	0.27	na	0.28
>25 to 50	1.57	1.80	0.28	0.28	na	0.13	6.1	5.0	1.5	1.5	na	0.2	14.0	6.9	4.7	4.7	na	3.0	1.60	0.80	0.34	0.34	na	0.02
>50 to 75	1.57	0.99	0.52	0.37	0.18	0.13	6.1	3.5	2.4	2.4	2.4	0.2	14.0	8.3	5.6	4.7	3.0	3.0	1.60	0.72	0.47	0.24	0.30	0.02
>75 to 100	1.57	0.99	0.52	0.37	0.18	0.13	6.1	3.5	2.4	2.4	2.4	0.2	14.0	8.3	5.6	4.7	3.0	0.3	1.60	0.72	0.47	0.24	0.30	0.01
>100 to 175	1.57	0.68	0.34	0.34	0.18	0.13	6.1	2.7	0.9	0.9	0.9	0.1	14.0	8.4	5.7	4.1	2.5	0.3	1.60	0.40	0.28	0.18	0.22	0.01
>175 to 300	1.57	0.68	0.31	0.31	0.18	0.13	6.1	2.7	0.7	0.7	0.7	0.1	14.0	8.4	5.6	4.0	2.5	0.3	1.60	0.40	0.25	0.13	0.15	0.01
>300 to 600	1.57	0.68	0.20	0.17	0.17	0.13	6.1	2.7	1.3	0.8	0.8	0.1	14.0	8.4	6.0	4.3	2.5	0.3	1.60	0.40	0.20	0.13	0.15	0.01
>600 to 750	1.57	0.68	0.15	0.17	0.17	0.13	6.1	2.7	1.3	1.3	1.3	0.1	14.0	8.4	5.8	4.1	2.5	0.3	1.60	0.40	0.22	0.13	0.15	0.01
>750 except gen sets	1.57	0.68	0.29	0.17	na	0.13	6.1	2.7	0.8	0.8	na	0.1	14.0	8.4	6.2	4.1	na	2.4	1.60	0.40	0.19	0.13	na	0.03
Gen sets >750 to 1200	1.57	0.68	0.29	0.17	na	0.13	6.1	2.7	0.8	0.8	na	0.1	14.0	8.4	6.2	4.1	na	0.5	1.60	0.40	0.19	0.13	na	0.02
Gen sets >1200	1.57	0.68	0.29	0.17	na	0.13	6.1	2.7	0.8	0.8	na	0.1	14.0	8.4	6.2	4.1	na	0.5	1.60	0.40	0.19	0.13	na	0.02

The above emission factors are zero-hour, steady-state EFs. NONROAD applies deterioration and transient adjustments, depending on the pollutant and equipment type.

Table 4-8: Calculated Emission Factors for Nonroad Engines

HP	$PM_{2.5}$ g/hp-hr						SO_2 g/hp-hr						Sulfur PM adj factor g/hp-hr						Crankcase HC g/hp-hr					
	BL	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	BL	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	BL	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	BL	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4
>0 to 11	1.55	0.97	0.43	0.49	0.29	0.27	0.18	0.18	0.18	0.18	0.18	0.18	0.08	0.08	0.08	0.08	0.08	0.08	0.03	0.03	0.02	0.01	0.00	0.01
>11 to 16	1.55	0.87	0.26	0.26	0.29	0.27	0.18	0.18	0.18	0.18	0.18	0.18	0.08	0.08	0.08	0.08	0.08	0.08	0.03	0.03	0.01	0.01	0.00	0.01
>16 to 25	1.55	0.87	0.26	0.26	0.29	0.27	0.18	0.18	0.18	0.18	0.18	0.18	0.08	0.08	0.08	0.08	0.08	0.08	0.03	0.03	0.01	0.01	0.00	0.01
>25 to 50	1.55	0.78	0.33	0.33	0.29	0.02	0.18	0.18	0.18	0.18	0.18	0.18	0.08	0.08	0.08	0.08	0.08	0.08	0.03	0.04	0.01	0.01	0.00	0.00
>50 to 75	1.55	0.70	0.46	0.23	0.29	0.02	0.18	0.18	0.18	0.18	0.18	0.18	0.08	0.08	0.08	0.08	0.08	0.08	0.03	0.02	0.01	0.01	0.00	0.00
>75 to 100	1.55	0.70	0.46	0.23	0.29	0.01	0.18	0.18	0.18	0.18	0.18	0.18	0.08	0.08	0.08	0.08	0.08	0.08	0.03	0.02	0.01	0.01	0.00	0.00
>100 to 175	1.55	0.39	0.27	0.17	0.21	0.01	0.16	0.16	0.16	0.16	0.16	0.16	0.07	0.07	0.07	0.07	0.07	0.07	0.03	0.01	0.01	0.01	0.00	0.00
>175 to 300	1.55	0.39	0.24	0.13	0.15	0.01	0.16	0.16	0.16	0.16	0.16	0.16	0.07	0.07	0.07	0.07	0.07	0.07	0.03	0.01	0.01	0.01	0.00	0.00
>300 to 600	1.55	0.39	0.19	0.13	0.15	0.01	0.16	0.16	0.16	0.16	0.16	0.16	0.07	0.07	0.07	0.07	0.07	0.07	0.03	0.01	0.00	0.00	0.00	0.00
>600 to 750	1.55	0.39	0.21	0.13	0.15	0.01	0.16	0.16	0.16	0.16	0.16	0.16	0.07	0.07	0.07	0.07	0.07	0.07	0.03	0.01	0.00	0.00	0.00	0.00
>750 except gen sets	1.55	0.39	0.19	0.13	0.15	0.03	0.16	0.16	0.16	0.16	0.16	0.16	0.07	0.07	0.07	0.07	0.07	0.07	0.03	0.01	0.01	0.00	0.00	0.00
Gen sets >750 to 1200	1.55	0.39	0.19	0.13	0.15	0.02	0.16	0.16	0.16	0.16	0.16	0.16	0.07	0.07	0.07	0.07	0.07	0.07	0.03	0.01	0.01	0.00	0.00	0.00
Gen sets >1200	1.55	0.39	0.19	0.13	0.15	0.02	0.16	0.16	0.16	0.16	0.16	0.16	0.07	0.07	0.07	0.07	0.07	0.07	0.03	0.01	0.01	0.00	0.00	0.00

The above emission factors are zero-hour, steady-state EFs. NONROAD applies deterioration and transient adjustments, depending on the pollutant and equipment type.

Table 4-9: Calculated Emission Factors for Nonroad Engines

HP	CO_2 g/hp-hr					
	BL	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4
>0 to 11	585.4	585.6	587.9	588.6	589.8	588.6
>11 to 16	585.4	584.9	589.0	589.0	589.8	589.0
>16 to 25	585.4	584.9	589.0	589.0	589.8	589.0
>25 to 50	585.4	584.6	589.5	589.5	589.8	590.0
>50 to 75	585.4	587.2	588.7	589.2	589.8	590.0
>75 to 100	585.4	587.2	588.7	589.2	589.8	590.0
>100 to 175	526.0	528.9	530.0	530.0	530.5	530.6
>175 to 300	526.0	528.9	530.1	530.1	530.5	530.6
>300 to 600	526.0	528.9	530.4	530.5	530.5	530.6
>600 to 750	526.0	528.9	530.6	530.5	530.5	530.6
>750 except gen sets	526.0	528.9	530.1	530.5	530.5	530.6
Gen sets >750 to 1200	526.0	528.9	530.1	530.5	530.5	530.6
Gen sets >1200	526.0	528.9	530.1	530.5	530.5	530.6

In addition to the greenhouse gas emission factors shown above, it is possible to estimate elemental carbon (black carbon) emission factors from the EPA's SPECIATE4 model from its emissions of $PM_{2.5}$.[75] For diesel cargo handling equipment, a reasonable estimate is for diesel commercial marine vessel (SCC 2280002000) which is assigned 77.12% elemental carbon. That is, the EC emission factor is 77.12% of the $PM_{2.5}$ emission factor, after adjusting for fuel sulfur.

Once an appropriate age distribution had been computed for each CHE type at the port of interest, each model year in the distribution (see Section 4.5.2) is assigned to the correct emission Tier according to the methodology of NONROAD model. In some cases, a given model year could correspond to two different Tier levels. In those cases, the population should be split according to the fractions shown by Table 4-6. Similarly, deterioration factors should be calculated for each model following the NONROAD methodology.[71]

The average emission factors for each CHE type at each typical port should then be determined as the age-distribution weighted product of the emission and deterioration factors. The in-use emission factor may then be determined as the product of the average emission factor and the pollutant-specific transient adjustment factor. That is:

$$< EF_{pollutant,CHE} > = TAF_{pollutant} \frac{\sum_{age=0}^{49} N_{CHE}(age) \cdot DF_{pollutant}(Tier(age)) \cdot EF_{pollutant}(Tier(age), HP)}{\sum_{age=0}^{49} N_{CHE}(age)}$$

In making the above calculation, transient adjustment factors for CO_2 and SO_2 can be taken as that for brake specific fuel consumption (BSFC). In cases where additional control factors are applied, the calculated emissions factor should also account for these reductions.

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[75] SPECIATE Version 4.0, January 18, 2007. Available at http://www.epa.gov/ttn/chief/software/speciate/index.html

4.7. Emissions Determination

4.7.1. Best Practices

As discussed above, best practices employ the use of the NONROAD model to calculate cargo handling emissions, after conducting appropriate surveys of activity and equipment.

4.7.2. Streamlined/Alternative Approach

Following the streamlined or alternative approach outlined above, annual CHE emissions at the port of interest should be determined as the product of the number of pieces of equipment of a given type, the load factor, the adjusted annual activity, and the average rated horsepower. That is:

$$Emissions_{Pollu\tan t,CHE} = < EF_{Pollu\tan t,CHE} > \cdot N_{CHE} \cdot LF_{CHE} \cdot Activity_{CHE} \cdot HP_{CHE}$$

Note that the fuel correction factor (FCF) and any control factors are included in the average emission factor determined above.

5. Rail and Heavy-duty Trucks

Movement of freight into and out of the port via rail and trucks should be included in a port emissions inventory if land-side emission estimates are sought. Railroad operations are usually described in terms of different types of operation, namely line haul and switching. Line haul rail operations refer to the movement of cargo over long distances and would include initiation or termination of a line haul trip in a port. Generally, the first intermodal point should be used in defining the train trips to and from the port. Switching rail operations refer to the assembling and dissembling of trains at various locations within a port. Besides emissions from locomotives, other sources of rail emissions include small gasoline and diesel engines that power refrigerated and heated rail cars. These engines operate independently of train motive power. These other sources of rail emissions are typically included in detailed inventories but not in streamlined inventories. Truck activity is measured both in terms of vehicle-miles traveled (VMT) and hours of idling.

There is typically a wide range of assumptions regarding land-side geographic boundaries in port emission inventories. For example, while some inventories have estimated the emissions from port-serving trucks throughout the region, other inventories considered only truck emissions that occurred at the port authority facilities. In order to ensure consistency across different port emission inventories, the land-side boundary should be up to the first intermodal point, or the geographical boundary of the metropolitan area for truck trips that either originated or terminated outside the region. As such, truck trips include drayage movements to off-dock rail facilities, short-haul truck movements to cross-docking facilities and local customers, as well as long-haul truck movements up to the region boundary.

By including the first intermodal point, improvements such as reducing wait times into and out of gates and distribution centers, reducing truck vehicle miles traveled (VMT) due to intermodal shifts, and other mitigation strategies could be evaluated in future analyses.

For ports near U.S. border areas, the effect of different emission standards for foreign trains and trucks entering the U.S. should be taken into account.

5.1. Definition of Land-side Boundaries

A region boundary must be determined to estimate the distance used in rail and long-haul truck trips. Boundaries for both modes should be consistent.

In order to ensure consistency across different port emission inventories, the land-side boundary should be up to the first intermodal point, or the geographical boundary of the metropolitan area for trips that either originated or terminated outside the region, whichever comes first. The geographical boundary of the metropolitan area is typically the air basin boundary, but it could be adapted depending on whether some regions are in non-attainment.

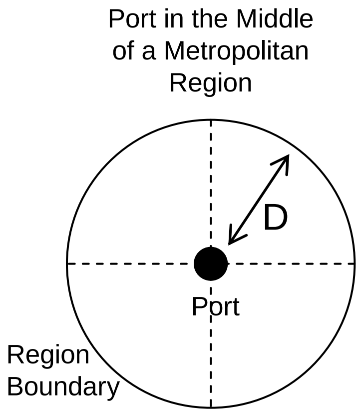
Because port inventories should not include rail operations beyond the first intermodal point, rail trips involving off-dock rail terminals (i.e., outside port facilities) should not be considered. Because only on-dock rail trips are considered, all rail trips are associated with origins or destinations outside the region boundary.

If resources are not available to implement surveying methods to determined land-side boundaries, data from the Census Bureau can be used as a surrogate.[76] More specifically, data on the size of metropolitan areas (in square miles) can be used to determine the average distance from the port to the region boundary.

As a simplification method, metropolitan regions can be assumed to be shaped as a circle. The average distance from the port to the region boundary is determined for two cases: (1) port is located on the edge of a metropolitan area, which is typically the case for deep-sea ports, and (2) port is located in the middle of a metropolitan area, which is generally the case for river ports.

Figure 5-1 and the associated equations include the detailed calculations to convert metropolitan area (A) into the average distance from the port to the region boundary (D).

Figure 5-1: Calculation of Average Distance from Port to Region Boundary

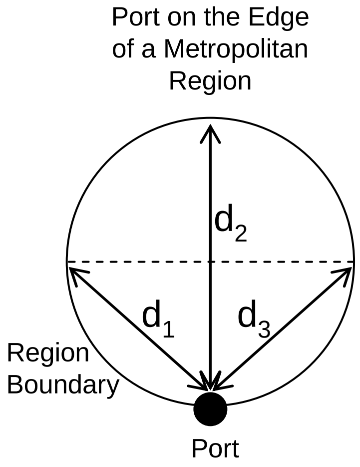


A = Area of metropolitan region (square miles)

R = Radius of metropolitan region—assumed circular (miles)

D = Average distance from port to region boundary (miles)

$$D = R = \sqrt{\frac{A}{\pi}}$$



$$D = \frac{d_1 + d_2 + d_3}{3}$$

$$d_1 = d_3$$

$$d_2 = 2R$$

$$d_2^2 = d_1^2 + d_3^2 \Rightarrow 4R^2 = 2d_1^2 \Rightarrow d_1 = \frac{2R}{\sqrt{2}}$$

$$D = \frac{4R + 2\sqrt{2}R}{3\sqrt{2}} = 1.61R = 1.61\sqrt{\frac{A}{\pi}}$$

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[76] U.S. Census Bureau (2000): Density Using Land Area for States, Counties, Metropolitan Areas and Places - Population, Housing Units, Area, and Density for Metropolitan Areas. Available online at http://www.census.gov/population/www/censusdata/density.html

5.2. Rail Emissions Inventory

5.2.1. Emissions Determination

The current practice to calculate emissions from locomotives serving ports is to use activity-based emission factors and activity profiles for each locomotive type.

$$\mathbf{E = A \times EF}$$

Where **E** = Emissions (grams [g])
A = Activity (hours [h], horsepower-hours [hp-hr], or gallons)
EF = Emission Factor (grams per horsepower-hour [g/hp-hr])

Rail operations can be classified in four types: (1) on-port switching operations, (2) off-port switching operations, (3) on-port line-haul operations, and (4) off-port line-haul operations.

EPA guidelines to estimate line-haul locomotive emissions suggest that line-haul locomotive activity be measured in terms of fuel consumption, which is then multiplied by emission factors in grams of pollutant per gallon of fuel to obtain locomotive emissions.[77] This approach should be taken for off-port line-haul locomotive emissions. However, an alternate approach should be considered for on-port line-haul emissions, since it better represents operations at rail yards within port terminals. This alternate approach consists of measuring on-port line-haul activity in terms of horsepower-hours.

Although EPA recommends that yard emissions be estimated by multiplying the number of switching locomotives by annual emissions per yard locomotive, an alternative approach should be taken to better reflect the operations associated with rail yards at port terminals. Switching activity should be measured in terms of hours of switching operations.

Locomotive emissions can be calculated based on the following equations:

$$\text{Switching Emissions (metric tons)} = \frac{\text{On-port Switching Activity (hours)} \times \text{Emission Factor (grams / hour)}}{10^{6}\ \text{grams / metric ton}}$$

$$\text{On-port Line-haul Emissions (metric tons)} = \frac{\text{On-port Line-haul Activity (horsepower-hours)} \times \text{Emission Factor (grams / horsepower-hour)}}{10^{6}\ \text{grams / metric ton}}$$

$$\text{Off-port Line-haul Emissions (metric tons)} = \frac{\text{Off-port Line-haul Activity (gallons)} \times \text{Emission Factor (grams / gallon)}}{10^{6}\ \text{grams / metric ton}}$$

The next several sections describe data sources to use and how to determine (1) rail characteristics, (2) activity profiles for rail movements, and (3) appropriate emission factors.

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[77] U.S. Environmental Protection Agency (1992): Procedures for Emission Inventory Preparation—Volume IV Mobile Sources. EPA420-R-92-009. Available online at http://www.epa.gov/otaq/invntory/r92009.pdf

5.2.2. Fleet Characteristics

All locomotives that serve ports are diesel-electric which use a diesel engine and a generator or an alternator to produce the electricity necessary to power their traction motors. Locomotives serving ports generally include both line-haul and switching locomotives. Line-haul locomotives have engines of 3,000 hp or more, while switching engines are smaller, typically 1,200 to 3,000 hp. Older line-haul locomotives tend to be converted to switch duty as newer and more powerful line-haul locomotives become available.

In a detailed inventory, information regarding the locomotive fleet should be gathered from the railroad companies that service a port, especially for switch locomotives. Because line-haul locomotives transport commodities over long-distances, there is generally no identifiable fleet of locomotives that calls on a specific port. As a result, a nationwide fleet of line-haul locomotives, which typically have engines of 3,000 hp or more, is generally considered in detailed inventories. If more specific information about such fleet is available from the serving railroads, it should replace the nationwide average fleet.

Switch locomotives should be characterized in terms of average horsepower, share of time spent at each throttle notch, fleet age distribution, and availability of alternative technologies for emissions reduction (e.g., hybrid technologies, or retrofits not required to comply with emissions standards). If the line-haul fleet varies significantly from the nationwide average due to local requirements, the same information should also be collected for line-haul locomotives.

Information from the railroad companies should be used in concert with EPA's guidance on locomotive emissions.[78, 79]

In a streamlined inventory, a detailed locomotive fleet age distribution is typically not available, and the EPA RSD documentation should be used to estimate the average fleet of line-haul and switch locomotives in service. Commodities can be categorized in four types (containerized, liquid bulk, dry bulk, and break bulk), which are assumed to be shipped in different types of rail equipment. Containerized commodities can be assumed to be transported in containers over double-stack trains, liquid bulk commodities in tank rail cars and trucks, dry bulk commodities in rail gondolas, and break bulk commodities on flat rail cars.

5.2.3. Activity Determination

Rail operations are typically categorized in switching and line-haul operations due to different activity patterns and vehicle profiles. Switching activities refer to the assembling and disassembling of trains in and around ports, sorting of rail cars, and delivery of empty rail cars to terminals. Switching operations involve short-distance movements, significant idling, and older equipment. Line-haul operations refer to the movement over long distances, as well as movements inside ports as the initiation or termination of a line-haul trip. Line-haul locomotives are generally "newer" than switching locomotives, and tend to idle less.

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[78] EPA, Technical Highlights—Emission Factors for Locomotives, EPA420-F-97-051, December 1997.

[79] EPA, Guidance for Quantifying and Using Long Duration Switch Yard Locomotive Idling Emission Reductions in State Implementation Plans, EPA420-B-04-002, January 2004.

Number of Trains and Rail Cars

In a detailed inventory, the number of trains and rail cars originating and terminating at a port should be obtained from the serving railroads, including both loaded and empty equipment.

In a streamlined inventory, the number of rail cars originating and terminating at a port can be derived from waterborne activity by port and by commodity. The U.S. Army Corps of Engineers (USACE) Waterborne Commerce Series reports import and export tonnage by port and by commodity.[57] Commodities are coded using nine major commodity classes and 140 detailed classes. USACE also provides data on containerized cargo in TEUs by port. From USACE data, containerized and non-containerized tonnage by commodity can be determined. Land-side mode split (rail and truck) can be estimated from the Federal Highway Administration's Freight Analysis Framework (FAF2) database. This enables to calculation of total tonnage (for non-containerized cargo) and TEUs by commodity moved by rail. Based on rail car configuration (e.g., volume capacity, payload), and commodity density, tonnage per rail car by commodity can be determined (for non-containerized cargo). Section 5.4 provides a detailed methodology on how the number of rail cars can be determined. Ideally, data from USACE and FHWA should be validated against local sources to confirm total waterborne cargo and mode split between rail and truck.

Switching Activity

EPA recommends that yard emissions be estimated by multiplying the number of switching locomotives by annual emissions per yard locomotive.[77] An alternative approach is recommended to better reflect the operations associated with rail yards at port terminals. Switching activity is calculated in numbers of switching locomotive hours within on-dock rail terminals.

If the number of switching locomotive hours is not available from the serving railroads, a nationwide average can be used as a surrogate method, based on the following equation:

$$\textbf{Number of switching locomotive hours} = \textbf{Number of rail cars} \times \frac{\textbf{Nationwide switching locomotive hours}}{\textbf{Nationwide switching events}} \times \textbf{Number of switching events per rail car}$$

A nationwide estimate of switching events and of switching locomotive switching hours is used to estimate a national rate for locomotive hours per switching event. This is then combined with an estimate of switching events per rail car. A switching event can be the pickup of a rail car from a shipper, the movement of a rail car from one train to another during classification operations at rail yards or in a block-swapping operation, and the delivery of a rail car to a recipient.

This methodology is based on a previous safety analysis of rail yard operations that covered the period between 1995 and 1999.[80] Table 5-1 presents the number of carloads by commodity type, with values normalized to represent annual averages during this time period. The empty carloads are based on the assumption that all bulk commodity cars return empty, 50% of

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[80] ICF International (2003): Analysis of Yard and Switching Accidents. Internal Report.

intermodal cars return empty[81], and for the rest of the traffic empty car miles are about 85% of loaded car-miles. The analysis also assumes that the number of switching events per car movement is 1.5 for a rail car in a unit train, and 5 for a rail car in a non-unit train, resulting in a total of 168.2 million per year over this period.

Table 5-1: Estimation of Switching Events

Commodity	Class I Carloads (1000s)	Multiplier on Class I	All Carloads (1000s)	Percent Unit Train	Unit Train Carloads (1000s)	Non-Unit Train Carloads (1000s)	Unit Train Empty Carloads (1000s)	Non-Unit Train Empty Carloads (1000s)
Coal	6,707	1.20	8,048	80%	6,439	1,610	6,439	1,610
Grain	1,324	1.20	1,589	70%	1,112	477	1,112	477
Intermodal	4,674	1.05	4,907	80%	3,926	981	1,963	491
All Other	11,854	1.25	14,817	10%	1,482	13,335	1,259	11,335
Total	**24,558**		**29,362**		**12,958**	**16,403**	**10,773**	**13,912**
Number of Associated Switching Events (1000s)					**19,438**	**82,016**	**16,160**	**69,561**

Switching locomotive hours were estimated based on 1998 data. The AAR Analysis of Class I railroads estimated 11.29 million hours in yard switching operations.[82] Switching hours were increased by a factor of 1.22 to account for miles on non-Class I railroads, yielding a total of 13.77 million hours for all railroads. The ratio was derived from railroad operations data in the 1998 FRA Railroad Safety Statistics, which reports yard switching train miles for both Class I and non-Class I railroads, and assumes that the ratio between switching hours and switching miles is constant. Since switching locomotives typically work singly or in pairs, depending on the weight of trains being handled, a factor of 1.5 locomotives per move is recommended. Therefore, 13.77 million hours were multiplied by 1.5, resulting in 20.66 million switching locomotive hours.

Dividing 20.66 million switching locomotive hours by 187.2 million switching events gives an average of 0.110 hour per event.

The estimates of switching events per rail car visit to a port area is simply derived from the definition of switching event adapted to typical operations with unit trains and single cars. By definition, a non unit train car will be subject to one switching event inbound and one outbound. For intermodal and bulk commodity trains, most cars are in unit trains which usually require much less switching, leading to an estimate of 1.2 events per car. Based on the values in Table 5-1, it was assumed that 45% of rail cars travel in unit trains, with the 55% remaining rail cars traveling in non-unit trains. Therefore, the weighted average switching events per rail car is 1.65, resulting in 0.182 switching hours per rail car.

On-port Line-haul Activity

Although EPA guidelines recommend that line-haul locomotive activity be measured in terms of fuel consumption[78], an alternative approach is taken in order to better reflect line-haul operations within port rail terminals. Since line-haul locomotives cover very short distances

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[81] The empty factor (share of loaded rail cars that return empty) was calculated based on the difference between inbound loaded and outbound loaded TEU volume at each port that handles containerized cargo.

[82] Federal Railroad Administration (1998): Railroad Safety Statistics—Annual Report.

within port terminals, rail activity should be measured in number of hours of operation. Because line-haul emission factors can be expressed in terms of horsepower-hour, rail activity should be measured in horsepower-hours, as follows.

On-port Line-Haul Rail Activity (horsepower-hours)	**=**	**Number of trains**	**x**	**Locomotives per train**	**x**	**Hours at port**	**x**	**Average Load Factor**	**x**	**Average Locomotive Horsepower**

In a detailed inventory, all inputs to this equation should be obtained from the participating railroads. In a streamlined inventory, inputs need to be estimated. The number of containerized trains can be calculated as follows:

$$\text{Number of Containerized Trains} = \frac{\text{Number of TEUs}}{\text{Train Capacity (TEUs)} \times \text{Utilization Rate}} \times (1 + \text{Empty Ratio})$$

If local estimates are not available, the number of containerized trains can be based on the assumption that each train consists of 25 double-stack rail cars for containerized cargo. Each double-stack rail car consists of five platforms that have each the capacity to hold four TEUs, which results in a total capacity of 500 TEUs per train. By assuming an 80% utilization rate, the estimated number of TEUs per train is 400. The empty factor (share of loaded rail cars that return empty) can be assumed to be 100% for all commodity types.

The number of non-containerized trains can be calculated as follows:

$$\text{Number of Non-Containerized Trains} = \frac{\text{Number of Rail Cars (Non Containers)}}{\text{Number of Rail Cars per Train}} \times (1 + \text{Empty Ratio})$$

If local estimates are not available, the number of non-containerized trains can be based on the assumption that each train consists of 75 rail-cars. The empty factor (share of loaded rail cars that return empty) can be assumed to be 100% for all commodity types.

Without more specific input data, it can be assumed that each train operates for 3.5 hours inside port terminals, accounting for both inbound and outbound trips, and that each train operates with three 4,000 hp locomotives.[39] The average line-haul locomotive load factor is taken from EPA's Regulatory Support Documentation for locomotives and marine rule.[84] The percentage of full power at each throttle notch setting is multiplied by the average percentage of line-haul operating time at that setting (Table 5-2).

Table 5-2: Average Line-haul Locomotive Load Factor

Notch	% of Full Power	% of Operating Time	% Full Power x % Time
DB	2.1%	12.5%	0.003
Idle	0.4%	38.0%	0.002
1	5.0%	6.5%	0.003
2	11.4%	6.5%	0.007
3	23.5%	5.2%	0.012
4	34.3%	4.4%	0.015
5	48.1%	3.8%	0.018
6	64.3%	3.9%	0.025
7	86.6%	3.0%	0.026
8	102.5%	16.2%	0.166
Average line-haul locomotive load factor:			**28%**

Off-port Line-haul Activity

This analysis follows EPA guidelines to estimate line-haul locomotive emissions, and measures off-port line-haul locomotive activity in gallons of fuel consumed.[77] Fuel consumption is estimated based on the following equation:

Fuel Consumption (gallons)	**=**	**Rail Traffic Density (revenue ton-miles)**	**x**	**Fuel Consumption Index (revenue ton-miles per gallon)**	**x**	**(1 + Empty Ratio)**

Traffic density is calculated as follows:

Rail Traffic Density (revenue ton-miles)	**=**	**Total Tonnage (tons)**	**x**	**Distance to Region Boundary (miles)**

Total tonnage (both containerized and non-containerized cargo) should be obtained based on vessel activity. Since only rail trips originating or terminating at on-dock rail terminals are considered (i.e., off-dock rail trips occur outside the port boundaries), all rail trips are assumed to cover the distance between the port and the geographical boundary of the metropolitan region. The ratio of trains that return empty should also be determined. If local estimates are not available, it can be assumed that 100% of loaded containerized and non-containerized trains return empty.

The fuel consumption index is based on a recent study sponsored by the Federal Railroad Administration, which examined rail fuel efficiency for different types of trains.[83] The average rail fuel efficiency is estimated at about 400 ton-miles/gallon. If more accurate estimates from serving railroads are available, they should be used instead of the national average.

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[83] ICF International (2009): Comparative Evaluation of Rail and Truck Fuel Efficiency on Competitive Corridors—Draft Version.

5.2.4. Emission Factors

Locomotive emission factors are determined based on EPA RIA documentation[84,85], an approach that is consistent with current detailed emissions inventories. The RIA documentation provides baseline emission rates for NOx, PM, HC, and CO in 2008.

Switch Emission Factors

Table 5-3 and Table 5-4 provide baseline emission standards and rates for switch locomotives by tier.[86] If information about the percentage of time at each notch setting is available from the participating railroads, ports are encouraged to refer to the sub-section "Accounting for Activity Profiles."

Table 5-3: Emission Standards for Switch Locomotives (grams/hp-hr)

Tier	Year in Effect	PM_{10}	NOx	HC
Remanufactured Tier 0	2008 as available, 2010 required	0.26	11.8	2.10
Remanufactured Tier 1	2008 as available, 2010 required	0.26	11.0	1.20
Remanufactured Tier 2	2008 as available, 2013 required	0.13	8.1	0.60
Tier 3	2011	0.10	5.0	0.60
Tier 4	2015	0.03	1.3	0.14

Table 5-4: Emission Rates for Switch Locomotives (grams/hp-hr)

Tier	Year in Effect	PM_{10}	NOx	HC
Remanufactured Tier 0	2008	0.23	10.62	0.57
Remanufactured Tier 1	2008	0.23	9.90	0.57
Remanufactured Tier 2	2013	0.11	7.30	0.26
Tier 3	2012	0.08	5.40	0.26
Tier 4	2015	0.015	1.00	0.08

The share of locomotive activity by locomotive tier should be obtained from the participating railroads to calculate a weighted average switch emission factor based on the emission rates in Table 5-4. Emission factors can be converted to grams per gallon by assuming a conversion factor of 0.048 gallons per horsepower-hour. Emission factors for greenhouse gases are taken from the EPA.[87] $PM_{2.5}$ emission factors can be calculated by assuming that they represent 97% of PM_{10} emissions. Black carbon emissions can be assumed to be 77.12% of $PM_{2.5}$ emissions.[88] PM_{10} emission factors reflect the emission rates expected from locomotives operating on fuel with sulfur levels at 3,000 ppm. EPA estimates that the PM_{10} emission rate for locomotives

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[84] U.S. Environmental Protection Agency (1998): Locomotive Emissions Standards, Regulatory Support Document, U.S. EPA, April 1998.

[85] U.S. Environmental Protection Agency (2004): Guidance for Quantifying and Using Long-Duration Switch Yard Locomotive Idling Emission Reductions in State Implementation Plans.EPA420-B-04-002, January 2004

[86] U.S. Environmental Protection Agency (2008): Regulatory Impact Analysis—Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression Ignition Engines Less than 30 Liters per Cylinder. EPA420-R-08-001a. May 2008.

[87] CO_2—Based on EPA (2004): Unit Conversions, Emissions Factors, and Other Reference Data, November 2004. CH4 and N_2O—Based on Table A 90, page A-112 in Annex 3 of the report (EPA #430-R-07-002, April 2007), entitled: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005.

[88] EPA (2006): Speciate 4.0—Speciation Database Development Documentation. Final Report. EPA/600/R-06/161.

operating on nominally 500 and 15 ppm sulfur fuel will be 0.05 and 0.06 g/bhp-hr lower than the PM_{10} emission rate for locomotives operating on 3,000 ppm sulfur fuel, respectively.[86]

Emission rates of SO_2 can be estimated based on a mass balance approach and a sulfur content of 3,000 ppm, assuming that 98% of fuel sulfur is converted to SO_2 and taking into account the molecular weight difference between SO_2 and sulfur.[89] If fuel with lower sulfur content is used by the serving railroads, the calculations should be updated accordingly. The calculation detailed below utilizes an average of 0.048 gallons per horsepower-hour, which is the value used by EPA to make similar conversions in the RSD, and a diesel fuel density of 0.85 kg/liter (or 3,218 grams per gallon).

$\frac{\text{3,000 g S}}{\text{1,000,000 g fuel}}$	**x**	**3,218 grams of fuel /gallon of fuel**	**x**	$\frac{\text{2 g } SO_2}{\text{1 g S}}$	**x**	**0.048 gallons / bhp-hr**	**x**	**0.98**	**=**	**Grams SO_2 / bhp-hr**

Since switch rail activity is estimated in horsepower-hours and gallons for on-port and off-port operations, respectively, the emissions calculation is a simple multiplication of rail activity by emission factors in either grams per horsepower-hour or grams per gallon.

Accounting for Activity Profiles

If information about the percentage of time at each notch setting is available from the participating railroads, the estimation of emission factors can be improved. This section provides guidelines to obtain switch emission factors that better reflect local activity profiles.

The average notch-specific horsepower values for an average switch locomotive are obtained by multiplying the horsepower value at each notch by the percentage of the total rated horsepower that is generated at that notch.[84] An example is given for notch setting 1, which means that an average switching locomotive utilizes 95 hp when in throttle setting 1. The process is repeated for each notch throttle setting (Table 5-5).

$$83 \text{ hp} / 1{,}750 \text{ hp} = 4.74\%$$

$$2{,}000 \text{ hp} \times 4.74\% = 95 \text{ hp}$$

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[89] One ton of sulfur generates two tons of SO2 because the atomic weight of sulfur and oxygen are 32 and 16, respectively. Therefore, each sulfur atom (weight of 32) combines with two oxygen atoms to form one molecule of SO2, with a weight of 64.

Table 5-5: Calculation of Average In-use Switch Locomotive Power

Notch	RSD Power in Notch, bhp	% of Avg Rated bhp	Avg In-use power, bhp
DB	67	3.83%	77
Idle	14	0.80%	16
1	83	4.74%	95
2	249	14.23%	285
3	487	27.83%	557
4	735	42.00%	840
5	1,002	57.26%	1,145
6	1,268	72.46%	1,449
7	1,570	89.71%	1,794
8	1,843	105.31%	2,106
Averages:	**1,750**		**2,000**

The EPA RSD provides baseline emission rates (in g/bhp-hr) for each notch throttle setting (Table 5-6). Baseline emission rates should be updated with emission rates for more recent locomotive tiers when such information becomes available.

By multiplying emission rates (in g/bhp-hr) by the average in-use power at each notch setting from Table 5-5, it is possible to obtain emission rates in grams per hour for each notch setting (Table 5-6). The EPA RSD also provides the percentage of operating time that an average switching locomotive spends in each notch throttle setting, so the average emission rate takes into account a weighted average based on these times. These calculations can be updated if more specific information on the percentage of operating time at each notch is available from the serving railroads.

Table 5-6: Switch Locomotive Emission Factors by Notch

Notch	Weighted Avg % in Mode	Emission Factors (g/bhp-hr)				Emission Factors (g/hr)			
		HC	CO	NOx	PM_{10}	HC	CO	NOx	PM_{10}
DB	0.00%	2.68	6.76	41.48	0.84	205	518	3,177	64
Idle	59.80%	7.44	15.47	74.47	2.30	119	247	1,191	37
1	12.40%	1.27	2.50	17.92	0.32	120	237	1,699	30
2	12.30%	0.48	1.28	12.47	0.33	135	363	3,547	93
3	5.80%	0.33	0.75	13.40	0.31	181	418	7,458	175
4	3.60%	0.30	0.54	14.45	0.24	248	454	12,134	202
5	3.60%	0.32	0.50	15.30	0.23	361	567	17,515	262
6	1.50%	0.33	0.62	16.05	0.28	479	898	23,251	407
7	0.20%	0.37	1.25	16.16	0.25	664	2,243	28,996	455
8	0.80%	0.40	2.74	15.76	0.28	843	5,761	33,185	599
					Weighted Average:	**202**	**509**	**4,719**	**92**

Line-haul Emission Factors

Table 5-7 and Table 5-8 provide estimated emission standards and rates for each locomotive tier, respectively.[86]

Table 5-7: Emission Standards for Line-haul Locomotives (grams/bhp-hr)

Tier	Year in Effect	PM_{10}	NO_x	HC	CO
Remanufactured Tier 0 and 1	2008 as available, 2010 required	0.22	7.4	0.55	1.28
Remanufactured Tier 2	2008 as available, 2013 required	0.10	5.5	0.30	1.28
Tier 3	2012	0.10	5.5	0.30	1.28
Tier 4	2015	0.03	1.3	0.14	1.28

Table 5-8: Emission Rates for Line-haul Locomotives (grams/bhp-hr)

Tier	Year in Effect	PM_{10}	NO_x	HC	CO
Remanufactured Tier 0 and 1	2008 as available, 2010 required	0.20	7.20/6.70	0.30/0.29	1.28
Remanufactured Tier 2	2008 as available, 2013 required	0.08	4.95	0.13	1.28
Tier 3	2012	0.08	4.95	0.13	1.28
Tier 4	2015	0.015	1.00	0.04	1.28

If the share of locomotive activity by locomotive tier is available from the participating railroads, it should be used to calculate a weighted average line-haul emission factor. Otherwise, estimated line-haul emission factors (in grams per horsepower-hour) for future years included in Table 5-9 can be used as a surrogate method.[90] Emission factors can be converted to grams per gallon by assuming a conversion factor of 0.048 gallons per horsepower-hour. Emission factors for greenhouse gases are taken from the EPA.[91] $PM_{2.5}$ emission factors can be calculated by assuming that they represent 97% of PM_{10} emissions. PM_{10} emission factors reflect the emission rates expected from locomotives operating on fuel with sulfur levels at 3,000 ppm. EPA estimates that the PM_{10} emission rate for locomotives operating on nominally 500 and 15 ppm sulfur fuel will be 0.05 and 0.06 g/bhp-hr lower than the PM_{10} emission rate for locomotives operating on 3,000 ppm sulfur fuel, respectively.[86] Emission factors for SO_2 can be calculated in the same way as described in the switch previous section.

Table 5-9: Line-haul Locomotive Emission Factors (g/bhp-hr)

Calendar Year	HC	CO	NO_x	PM_{10}	CO_2	N_2O	CH_4
2005	0.48	1.28	13.00	0.32	483	0.040	0.013
2006	0.47	1.28	12.79	0.32	483	0.040	0.013
2007	0.45	1.28	12.15	0.30	483	0.040	0.013
2008	0.42	1.28	11.14	0.28	483	0.040	0.013
2009	0.39	1.28	10.17	0.26	483	0.040	0.013
2010	0.36	1.28	9.15	0.24	483	0.040	0.013
2011	0.32	1.28	8.02	0.21	483	0.040	0.013
2012	0.28	1.28	7.19	0.19	483	0.040	0.013
2013	0.26	1.28	6.75	0.18	483	0.040	0.013
2014	0.25	1.28	6.54	0.17	483	0.040	0.013
2015	0.24	1.28	6.41	0.16	483	0.040	0.013

Continued

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[90] These calculations are based on similar penetration and usage rates for new locomotive tiers as used in the EPA RSD.

[91] CO_2—Based on EPA (2004): Unit Conversions, Emissions Factors, and Other Reference Data, November 2004. CH4 and N_2O—Based on Table A 90, page A-112 in Annex 3 of the report (EPA #430-R-07-002, April 2007), entitled: Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005.

Table 5-10: Line-haul Locomotive Emission Factors (g/bhp-hr)

Calendar Year	HC	CO	NO_x	PM_{10}	CO_2	N_2O	CH_4
2016	0.24	1.28	6.32	0.16	483	0.040	0.013
2017	0.23	1.28	6.28	0.15	483	0.040	0.013
2018	0.23	1.28	6.20	0.15	483	0.040	0.013
2019	0.22	1.28	6.13	0.15	483	0.040	0.013
2020	0.22	1.28	6.06	0.14	483	0.040	0.013
2021	0.21	1.28	5.77	0.13	483	0.040	0.013
2022	0.19	1.28	5.49	0.13	483	0.040	0.013
2023	0.18	1.28	5.23	0.12	483	0.040	0.013
2024	0.18	1.28	4.99	0.11	483	0.040	0.013
2025	0.17	1.28	4.76	0.11	483	0.040	0.013
2026	0.16	1.28	4.55	0.10	483	0.040	0.013
2027	0.15	1.28	4.35	0.10	483	0.040	0.013
2028	0.14	1.28	4.15	0.09	483	0.040	0.013
2029	0.14	1.28	3.97	0.08	483	0.040	0.013
2030	0.13	1.28	3.80	0.08	483	0.040	0.013

Since line-haul rail activity is estimated in horsepower-hours and gallons for on-port and off-port operations, respectively, the emissions calculation is a simple multiplication of rail activity by emission factors in either grams per horsepower-hour or grams per gallon.

5.3. Heavy-duty Trucks Emissions Inventory

Movement of freight into and out of the port by heavy-duty trucks should be included in a detailed inventory if land-side emission estimates are sought. Truck activity is measured both in terms of vehicle-miles traveled (VMT) and hours of idling. For ports near U.S. border areas, the effect of different emission standards for foreign trucks entering the U.S. should be taken into account.

5.3.1. Emissions Determination

The current practice to calculate emissions from vehicles serving ports is to use activity-based emission factors and activity profiles for each vehicle type.

$$\mathbf{E = A \times EF}$$

Where **E** = Emissions (grams [g])
A = Activity (hours [h], or miles)
EF = Emission Factor (grams/hour or grams/mile)

Vehicle emissions can be classified in two types: (1) running emissions, (2) idling emissions. The two types of vehicle emissions were calculated based on the following equations:

$$\begin{array}{c}\textbf{Idling Emissions}\\ \textbf{(metric tons)}\end{array} = \frac{\begin{array}{c}\textbf{Idling Activity}\\ \textbf{(hours)}\end{array} \times \begin{array}{c}\textbf{Emission Factor}\\ \textbf{(grams / hour)}\end{array}}{\mathbf{10^6}\ \textbf{grams / metric ton}}$$

$$\begin{array}{c}\textbf{Running Emissions}\\ \textbf{(metric tons)}\end{array} = \frac{\begin{array}{c}\textbf{Running Activity}\\ \textbf{(miles)}\end{array} \times \begin{array}{c}\textbf{Emission Factor}\\ \textbf{(grams / mile)}\end{array}}{\mathbf{10^6}\ \textbf{grams / metric ton}}$$

5.3.2. *Fleet Characteristics*

There are three types of on-road vehicles that service ports: on-road diesel trucks, diesel passenger buses, and other vehicles such as passenger cars used by port staff and maintenance trucks. EPA's MOBILE6.2 (California uses EMFAC2007) should be used for calculating emissions from these vehicles. Nearly all trucks serving ports are diesel-powered tractors, used to pull trailers or chassis. Therefore, all port trucks are assumed to be diesel Class 8b heavy-duty vehicles, as defined in EPA's MOBILE6.2.

On-Road Diesel Trucks

On-road diesel trucks are used extensively to move cargo into and out of ports. The first intermodal point should be considered when calculating truck emissions related to a port. In a detailed inventory, several issues should be examined in modeling truck traffic at ports, including the following:

- Fleet age
- Idling time
- Truck speeds within the port
- Truck speeds on arterials and freeways accessing the port
- Retrofit devices, repowers, and alternative fuels.

Because trucks manufactured before 1991 produce higher emissions, the truck fleet age profile is an important variable in preparing emission inventories. Most trucks serving ports are operated by independent owner-operators or as part of a short haul drayage fleet of a trucking company. These drayage trucks are typically older equipment (over 10 years old) moving over short distances with significant idling times. Port-serving trucks usually pick up containers and cargo at the port and drop them at a central facility outside of the port. From there, long haul trucks will pick up loads for other parts of the state and country and drop off loads. The port-serving fleet is typically much older than the long haul trucking fleet. According to the 1997 Vehicle Inventory and Use Survey (VIUS) data,[92] combination tractor-trailer Class 8B trucks that traveled less than 50 miles from the home base had an average age of 11.7 years, while long haul trucks that traveled over 200 miles from the home base had an average age of 4.7 years.

Alternative fuel trucks should be modeled as compressed natural gas (CNG) trucks as described in EPA MOBILE6 guidance.[93] For PuriNOx and retrofit devices such as diesel oxidation catalysts and diesel particulate filters, diesel emission factors should be discounted by the reduction percentages given for the devices on EPA's Verified Technology List website[69] or that specified by EPA's Diesel Emission Quantifier[94].

In a streamlined inventory, commodities can be divided in four groups (containerized, liquid bulk, dry bulk, and break bulk), which are assumed to be shipped in different types of truck equipment. Containerized commodities are transported on containers over chassis, liquid bulk

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[92] U.S. Census Bureau, *Vehicle Inventory and Use Survey, 1997*, CD-EC97-VIUS, January 2000.

[93] EPA, MOBILE6 Emission Factors for Natural Gas Vehicles, EPA420-R-01-033, April 2001.

[94] http://cfpub.epa.gov/quantifier/view/index.cfm

commodities are moved by tanker trucks, dry bulk commodities are shipped in “dump trucks,” and break bulk commodities are assumed to be transported in flat bed trailers.

All four types of truck equipment have different fleet age distributions, which also depend on whether the equipment is used for local/regional trips (short-haul trips) or for external trips (long-haul trips). Short-distance moves tend to be performed by older trucks, while long-distance moves rely on newer and more fuel-efficient equipment.

The 2002 Vehicle Inventory and Use Survey (VIUS) was used to estimate the age distribution of the truck fleets considered.[95] Each of the four truck types was considered, addressing short and long-distance fleets separately. Only Class 8 trucks were considered in the analysis. This originated eight different truck age distributions. Even though the VIUS database enables the evaluation of fleets by state, nationwide values were used in order to reduce the uncertainty associated with the small samples in each state. Table 5-11 includes the fleet age distribution associated with the eight truck groups.

Table 5-11: Truck Fleet Age Distribution

Trip	Local / Regional				External			
Equipment	Container	Flat Bed	Tank Truck	Dump Truck	Container	Flat Bed	Tank Truck	Dump Truck
16 and older	25%	25%	43%	31%	7%	8%	33%	33%
15 years old	4%	4%	5%	4%	2%	2%	4%	4%
14 years old	5%	5%	4%	6%	2%	2%	5%	5%
13 years old	5%	5%	4%	5%	3%	3%	5%	5%
12 years old	5%	5%	5%	5%	2%	2%	3%	3%
11 years old	4%	4%	2%	3%	2%	2%	3%	3%
10 years old	4%	4%	3%	3%	3%	3%	2%	2%
9 years old	5%	5%	5%	4%	4%	4%	4%	4%
8 years old	6%	6%	5%	5%	5%	5%	5%	5%
7 years old	7%	7%	4%	6%	7%	7%	6%	6%
6 years old	6%	5%	2%	5%	7%	7%	5%	5%
5 years old	4%	4%	2%	4%	6%	6%	6%	6%
4 years old	4%	4%	3%	4%	8%	8%	2%	2%
3 years old	5%	5%	3%	4%	11%	11%	5%	5%
2 years old	6%	6%	3%	5%	14%	14%	5%	5%
1 year old	3%	4%	4%	3%	9%	9%	5%	5%
0 year old	2%	2%	3%	2%	8%	8%	3%	3%
Average Age[a]	**10.5**	**10.4**	**12.4**	**11.1**	**6.2**	**6.3**	**11.1**	**11.1**

[a] Assumes that trucks 16 years and older have an average age of 18 years.

Diesel Passenger Buses

Diesel passenger buses transport cruise passengers into and out of the port. Generally these buses would be considered intercity buses, but MOBILE6.2 does not provide emission factors for intercity buses. Therefore, transit buses should be used when modeling diesel buses into and out of a port. Best practice is to collect age distributions and mileage accumulation rates for these buses that service a specific port. However, if that information is not available,

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[95] U.S. Census Bureau (2002): Vehicle Inventory and Use Survey 2002. Available online at http://www.census.gov/svsd/www/vius/products.html

MOBILE6.2 defaults for transit buses can be used. Only detailed inventories typically consider emissions from diesel passenger buses.

Other Port Vehicles

Other port vehicles include passenger cars and light trucks used by port staff and maintenance trucks. General light-duty car and truck emission factors can be used for modeling staff cars and trucks, while maintenance trucks can be modeled as Class 3 or 4 heavy-duty trucks. Only detailed inventories typically consider emissions from other port vehicles.

5.3.3. Activity Determination

On-road vehicle operations are typically categorized in running operations, measured in VMT, and idling operations, measured in hours.

Number of Trucks, Buses, and other Vehicles

In a detailed inventory, the number of trucks originating and terminating at a port should be obtained from each port terminal, including both loaded and empty trips. The number of passenger buses and other vehicles should also be estimated.

In a streamlined inventory, the number of trucks that originate and terminate at a port can be derived from waterborne activity by port and by commodity. The U.S. Army Corps of Engineers (USACE) Waterborne Commerce Series reports import and export tonnage by port and by commodity.[57] Commodities are coded using nine major commodity classes and 140 detailed classes. ACE also provides data on containerized cargo in TEUs by port. From USACE data, containerized and non-containerized tonnage by commodity can be determined. Land-side mode split (rail and truck) can be estimated from the Federal Highway Administration's Freight Analysis Framework (FAF2) database. This enables to calculation of total tonnage (for non-containerized cargo) and TEUs by commodity moved by rail. Based on truck configuration (e.g., volume capacity, payload), and commodity density, tonnage per truck by commodity can be determined (for non-containerized cargo). Section 5.4 provides a detailed methodology on how the number of trucks can be determined. Ideally, data from USACE and FHWA should be validated against local sources to confirm total waterborne cargo and mode split between rail and truck.

Estimation of Truck VMT

Different activity patterns should be taken into consideration in order to estimate truck VMT. Truck movements can be divided in three types of trips:

- Local trips: originate or end at facilities within 5 miles of the port.
- Regional trips: originate or end at facilities within 20 miles of the port.
- External trips: originate or end at facilities outside the region's metropolitan area. In this case, only the portion of the movement that fell within the metropolitan region is accounted in the inventory.

Local or regional trips are generally associated with drayage shipments between terminal facilities and off-dock rail terminals, cross-docking facilities (where cargo is consolidated and deconsolidated for future delivery), and local customers. For each of these three trip types, trucking activity inside the port and outside the port is considered.

Different types of trips and location (i.e., on-port, off-port, gate) are associated with different activity patterns. For example, local and regional trips cover shorter distances and have driving cycles that account for more “stops and goes” and more idling. External trips, on the other hand, are generally along freeways. These types of truck movements also require different equipment, which can have significantly different emission rates. For example, drayage trucks tend to be older and less fuel-efficient than long-haul trucks.

Besides loaded truck trips (i.e., trips where the truck equipment carries a full load), the inventory should also account for bobtail trips, chassis trips, and empty trips. A bobtail trip is one where the tractor moves independently of the trailer. Chassis trips are only associated with containerized cargo, since intermodal containers sit on top of a chassis that connects to the tractor. Empty trips are the ones where the truck equipment (e.g., container, trailer, tank, flat car) is empty.

Table 5-12 provides a framework to calculate truck VMT for each trip type (local, regional, external) for containerized and non-containerized movements in a detailed inventory. Truck VMT involving gate activities (i.e., queuing, checking-in) are modeled separately because they have a driving cycle that is substantially different from either on-port or off-port trips. For simplification purposes, one can assume that all trucks queue for a quarter of a mile before reaching the gate, at an average speed of 1.8 mph.[96]

Table 5-12: Estimation of Distance Traveled

Trip Type	Bobtail Trips		Chassis Trips		Loaded Trips		Empty Trips		Total Distance (miles)
	Number	Distance (miles)	Number	Distance (miles)	Number	Distance (miles)	Number	Distance (miles)	
Truck Trips Off-port—Containerized Cargo									
Local									
Regional									
External									
Truck Trips On port—Containerized Cargo									
Local									
Regional									
External									
Truck Trips Off-port—Non-containerized Cargo									
Local									
Regional									
External									
Truck Trips On port—Non-containerized Cargo									
Local									
Regional									
External									

*This is the distance from the port to the region boundary.

In a streamlined inventory, trip profiles are developed for containerized and non-containerized imports and exports (Figure 5-2). In containerized imports, a tractor travels to the port, picks up a chassis, moves the chassis to pick up a container, leaves the port, and drops the container at the importer. The inventory should also account for the movement of the empty container from the importer back to the port, and the chassis movement from the empty container drop-off location to the port gate. Containerized exports also start with a bobtail move to the port in order to pick an empty container. While it would be more beneficial to move an empty container

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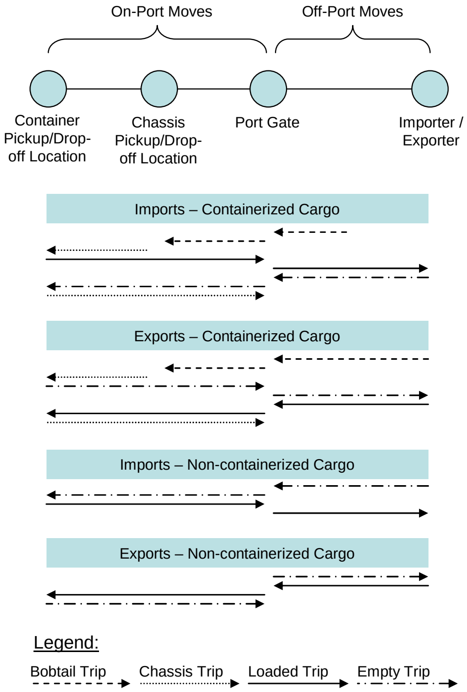
[96] Tioga (2007): Conversation with Daniel Smith from Tioga Group on December 13th, 2007.

directly from an importer to an exporter (i.e., street turn), a previous analysis indicated that the percentage of street turns is currently 2 percent.[97] After the bobtail enters the port, it picks up a chassis, moves to the empty container pickup location, picks up the empty container, leaves the port, and moves to the exporter. It then picks up the export load, and moves it back to the port. After it drops off the full container, the tractor drops the chassis and the bobtail leaves the port.

Figure 5-2: Truck Trip Profiles



Non-containerized trip profiles are modeled in a simpler way and do not account for bobtail trips or chassis trips. Non-containerized imports start with an empty trip to the port, where the truck equipment is loaded with cargo, leaves the port, and drops the load at the importer. Non-containerized exports start with an empty trip to the exporter, where the truck equipment is loaded, and moved to the port. After the truck equipment drops the cargo at the port, the empty equipment leaves the port.

Table 5-13 quantifies the total distance traveled for each trip type (local, regional, external) for containerized and non-containerized movements. Because imports and exports result in the same number of trips, it is not necessary to differentiate between import and export shipments. Truck VMT involving gate activities (i.e., queuing, checking-in) are modeled separately because they have a driving cycle that is substantially different from either on-port or off-port trips. For simplification purposes, it is assumed that all trucks queue for a quarter of a mile before reaching the gate, at an average speed of 1.8 mph.[96]

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[97] Tioga Group (2002): Empty Ocean Container Logistics Study, report prepared to Gateway Cities Council of Government, Port of Long Beach, and Southern California Association of Governments.

Table 5-13: Estimation of Distance Traveled

Trip Type	Bobtail Trips		Chassis Trips		Loaded Trips		Empty Trips		Total Distance (miles)
	Number	Distance (miles)	Number	Distance (miles)	Number	Distance (miles)	Number	Distance (miles)	
Truck Trips Off-port—Containerized Cargo									
Local	0.5	5	0	0	1	5	1	5	15
Regional	0.5	5	0	0	1	20	1	20	45
External	0.5	5	0	0	1	Varies*	1	Varies*	Varies
Truck Trips On port—Containerized Cargo									
Local	0.5	1	0.5	1	1	1	1	1	4
Regional	0.5	1	0.5	1	1	1	1	1	4
External	0.5	1	0.5	1	1	1	1	1	4
Truck Trips Off-port—Non-containerized Cargo									
Local	0	0	0	0	1	5	1	5	10
Regional	0	0	0	0	1	20	1	20	40
External	0	0	0	0	1	Varies*	1	Varies*	Varies
Truck Trips On port—Non-containerized Cargo									
Local	0	0	0	0	1	1	1	1	2
Regional	0	0	0	0	1	1	1	1	2
External	0	0	0	0	1	1	1	1	2

*This is the distance from the port to the region boundary.

In order to estimate the number of truck VMT at each port, it is assumed that 40% of the truck trips are local trips, 40% are regional trips, and 20% are external trips. In order to convert the number of TEUs to number of containerized truckloads, a 50/50 split can be assumed between 20 and 40-foot containers. Individual ports should rely on their own internal estimates to validate these assumptions.

Estimation of Truck Idling

Truck idling is considered separately for trips inside port facilities and at gates, since trip patterns are widely different from the average trip profile considered in MOBILE6.2. Individual ports should estimate the amount of time trucks idle at gates and inside terminals. Idling times for off-port trips are assumed to be reasonably accounted for within MOBILE6.2 emission factors, which consider an average driving cycle consistent with the operations of each vehicle category. For example, larger trucks tend to operate on highways and on relatively constant speed. Smaller trucks, on the other hand, tend to operate in urban areas and have more transient speeds.

In a streamlined inventory with limited data on truck idling times, it can be assumed that trucks idle for 7 and 23 minutes at the gates and inside terminals, respectively.[96] Individual ports should rely on their own internal estimates to validate these assumptions.

Estimation of Bus and Other Vehicles Activities

Because other vehicles (e.g., passenger buses, personal vehicles) generally represent a smaller share of total emissions when compared to those from heavy-duty trucks, their activity (i.e., VMT, idling hours) can be modeled at a more aggregate level. Typically only detailed inventories include emissions from buses and other vehicles.

There is no guidance for bus idle emission factors, so MOBILE6.2 should be run at 2.5 mph and the resulting emission factors in grams per mile should be multiplied by 2.5 miles per hour to get gram per hour emission rates at idle. Retrofits and alternative fuels should be handled similar to the methodology described above for on-road trucks. Foreign buses meeting different emissions standards should be accounted for near border areas.

5.3.4. Emission Factors

MOBILE6.2 should be used to estimate truck, bus, and passenger vehicles emission factors in grams per mile and grams per hour. MOBILE6.2 includes emission factors for HC, CO, NOx, CO_2, SO_2, Pb, PM_{10}, and $PM_{2.5}$, as well as some hazardous air pollutants. MOBILE6.2 also provides the elemental carbon portion of diesel exhaust particulates, so black carbon can be easily estimated.

Truck emission factors should be differentiated by equipment type, trip type (local, regional, external), and trip location (on-port, off-port, and gate). The estimation of truck emission factors should take into consideration the fleet age distribution discussed in the previous section. Since nearly all trucks serving ports are diesel-powered tractors used to pull trailers or chassis, all port trucks can be modeled as diesel Class 8b heavy-duty vehicles, as defined in MOBILE6.2. Emission factors for buses and passenger vehicles can be derived at a more aggregate level, assuming an average fleet and an average speed profile.

Because different levels of sulfur content are used nationwide, it is important to consider sulfur content when extracting emission factors from MOBILE6.2.

Because truck operations at the gates and inside port facilities have driving cycles that are very different from off-port trips, correction factors are developed for emission factors associated with gate and on-port trips. These correction factors are based on the DrayFLEET model. Alternatively, emissions from truck operations at the gates and inside port facilities can be evaluated directly with the DrayFLEET model.[98]

Truck movements can generally be divided in four operating modes: idling, creep, transient, and cruise. Drayage movements tend to spend a higher share of their time in idling, creep, and transient modes when compared to long-distance truck movements.

The emission factors from MOBILE6.2 reasonably account for the cruise operating mode, but conversion factors need to be applied to better reflect the operating conditions of idling, creep and transient modes. Trucks queuing at the gates are assumed to operate at creep mode, while trucks operating inside terminal facilities (i.e., on-port trips) were assumed to operate at 50% creep and 50% transient modes.

The following formulas are used to convert the emission factors from MOBILE6.2 (calculated at 20 mph) to each operating mode. The conversion factors were taken from E55/E59 data.[99]

$$\mathbf{EF_C = EF_{6.2} \text{ x Fuel Efficiency/2.29}}$$

$$\mathbf{EF_T = EF_{6.2} \text{ x Fuel Efficiency/3.85}}$$

Where, EF_C = Creep Emission Factor (grams/mile)

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[98] Tioga Group and Dowling Associates (2008): SmartWay DrayFLEET Truck Drayage Environment and Energy Model—Version 1.0 User's Guide—June 10, 2008. Prepared for the U.S. Environmental Protection Agency.

[99] Kear, T., Smith, D. (2007): Revised Description of Emissions Calculations per OTAQ Recommendations. Memorandum to Ken Adler at the U.S. Environmental Protection Agency. August 28th, 2007.

EF_T = Transient Emission Factor (grams/mile)

$EF_{6.2}$ = MOBILE6.2 Emission Factor (grams/mile)

Running emission factors for queuing trucks at the gates (i.e., gate trips) are equal to the creep emission factor, while the running emission factors for on-port trips are the average between the creep emission factor and the transient emission factor (because on-port trips are allocated 50% to each mode). As previously mentioned, emission factors associated with off-port trips are taken directly from MOBILE6.2.

In addition to running emission factors in grams per mile, idling emission factors (in grams per hour) should be developed to account for on-port and gate idling emissions. These factors can be derived by multiplying 20 mph emission factors in grams per mile (in MOBILE6.2) by 20 to obtain idling emission factors in grams per hour, and then multiplying it by the conversion factor included in the following formula.[99]

$$\mathbf{EF_I = EF_{6.2} \times Fuel\ Efficiency \times 0.45}$$

Where, EF_I = Idling Emission Factor (grams/hour)

$EF_{6.2}$ = $MOBILE_{6.2}$ Emission Factor (grams/hour)

For ports near border areas, the effect of foreign trucks meeting different emission standards and servicing the port should also be taken into account.

Other Sources of Emission Factors

Fleet specific emissions factors may also be estimated using the EPA SmartWay Transport Partnership Carrier FLEET modeling tool[100], or EPA's Diesel Emissions Quantifier (DEQ).[94]

The FLEET model was designed as business management tool to estimate the emissions performance of contract carrier and private truck fleets, based on assessment of technologies and strategies used to save fuel and reduce emissions. While not intended to be used as port activity or inventory tool, it may be useful as reference when studying fleet specific activity. EPA is developing a second-generation FLEET tool, for release in 2010, which will offer performance based emissions estimates.

The DEQ is an interactive tool to help state and local governments, fleet owners/operators, contractors, port authorities, and others to estimate emission reductions and cost effectiveness for clean diesel projects. Estimates are made using specific information about a fleet. EPA based the Quantifier on existing EPA tools and guidance. The DEQ may be useful as reference when studying project-specific activity such as evaluating control options or applying for grants. The Quantifier uses emission factors and other information from EPA's National Mobile Inventory Model (NMIM), which includes the MOBILE 6.2 and NONROAD2005 models.

5.4. Number of Truck and Rail Car Estimation

This section provides a detailed methodology on how the number of trucks and rail cars can be determined based on waterborne cargo activity. This method should only be used for

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[100] Available online at http://www.epa.gov/smartway/transport/partner-resources/resources-complete.htm#tools

inventories in which more accurate estimates of truck and rail trips cannot be obtained from participating organizations.

First, total tonnage of containerized and non-containerized cargo handled at each port is gathered, based on data from the Army Corps of Engineers. Containerized cargo is also measured in TEUs. This evaluation also considers the commodity mix at each port, deriving tonnage (for non-containerized cargo) and TEUs by port and by commodity. Second, mode split by commodity class is estimated based on data from the Federal Highway Administration's Freight Analysis Framework (FAF2) database. This enables to calculation of total tonnage (for non-containerized cargo) and TEUs by commodity moved by trucks and rail. Finally, tonnage per rail car and truck by commodity is determined based on rail car and truck configuration (e.g., volume capacity, payload), and commodity density.

5.4.1. Waterborne Cargo Activity

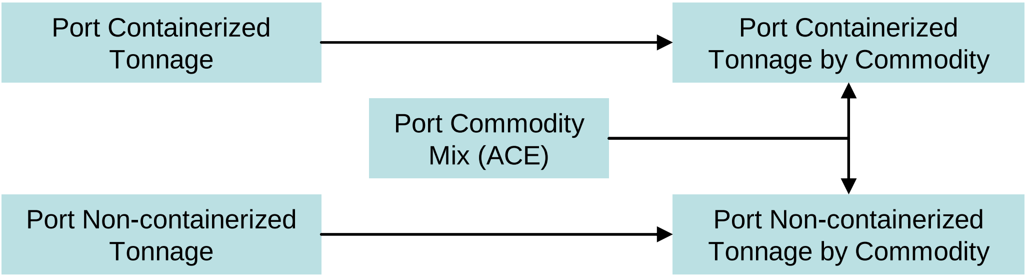
The number of rail cars originated and terminated at each port can be derived from waterborne activity by port and by commodity. Datasets from the U.S. Maritime Administration and U.S. Army Corps of Engineers were reviewed to evaluate the best source of waterborne cargo activity.

The MARAD database contains information on annual vessel calls by vessel type. Vessel calls are reported by metropolitan area, rather than by port.[101] Thus, in some cases, data for multiple ports (such as Los Angeles and Long Beach) are combined into one record. The MARAD database has two major shortcomings. It does not include inland waterway ports (e.g., rivers and the Great Lakes). And because vessels vary greatly in size, the number of vessel calls is probably not a good proxy for rail activity.

The U.S. Army Corps of Engineers (USACE) Waterborne Commerce Series reports import and export tonnage by port and by commodity.[57] Commodities are coded using nine major commodity classes and 140 detailed classes. USACE also provides data on containerized cargo in TEUs by port. USACE data were selected because it is important to understand the commodity mix at each port, since the mode share of the domestic leg of a foreign movement is generally correlated with the commodity carried. The same is true for domestic waterborne movements.

Total tonnage in the dataset is divided between containerized and non-containerized cargo. The commodity mix of each port is used to estimate containerized and non-containerized tonnage by commodity. Figure 5-3 summarizes this step.

Figure 5-3: Calculation of Port Tonnage by Commodity



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[101] U.S. Department of Transportation Maritime Administration (2005): U.S. Port Calls by Port and Vessel Type. Available online at http://www.marad.dot.gov/MARAD_statistics/index.html

5.4.2. Mode Split

An import waterborne shipment generally continues to its destination by truck, rail, air, pipeline, or a combination of these modes. The reverse movement is also true for export shipments.

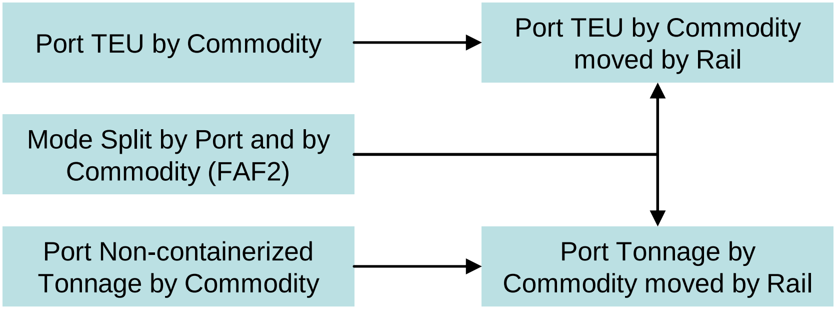
For ports without on-dock rail terminals, it can be assumed that all commodities will be shipped over-the-road (as previously indicated, rail shipments moved over near-dock or off-dock rail terminals should not be included in a port emissions inventory). For those ports with on-dock rail accessibility, it is necessary to understand how different shipments are distributed amongst the truck and rail. Aside from infrastructure availability (e.g., rail terminals), the best indicator of transportation mode is commodity.

Mode split data can be taken from the FAF2, a commodity flow database developed by the Federal Highway Administration in cooperation with the Bureau of Transportation Statistics.[102] It includes international and domestic shipments with information on origin, destination, port of entry (for international imports) or exit (for international exports), commodity, transportation mode used on the domestic leg, value, and weight. Modes included are truck, rail, water, air, truck-rail intermodal, other intermodal, and pipeline. Since geographic zones are based on the level of cargo activity, some zones include a great part of a state, while other zones are limited to a metropolitan zone. Mode split data are based on 2002 data, but future versions could possibly include more recent data. Although the FAF2 model contains significant amounts of data to support the estimation of mode shares based on commodity and port location, it presents a few drawbacks. The first is that there is considerable uncertainty in the domestic leg of the shipment. For example, whenever there is no specific data on mode share for a specific commodity or location, domestic freight movement patterns for the entire region were adopted. The second drawback concerns the fact that is not a direct correlation between all FAF2's geographic zones and ports. Therefore, ports are strongly encouraged to validate the mode split assumptions.

Because FAF2 and USACE rely on different commodity classifications, it is necessary to conciliate both classification systems.

Based on mode split by port and by commodity, it is possible to determine the number of TEUs moved by rail and truck, as well as the total tonnage (of non-containerized cargo) of each commodity type that is likely to be moved by rail and truck (Figure 5-4).

Figure 5-4: Calculation of Rail and Truck Cargo



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[102] Federal Highway Administration (2007): Freight Analysis Framework 2. Available online at http://ops.fhwa.dot.gov/freight/freight_analysis/faf/index.htm

5.4.3. Commodity Analysis

As it was previously mentioned, the commodity mix at ports can be determined based on USACE's Waterborne Commerce Series. This commodity mix can be applied to both containerized and non-containerized cargo, resulting in number of TEUs and tonnage by port and by commodity.

The 140 commodity classes are divided in four categories, depending on the transportation equipment that is most likely to be utilized to transport the commodity by rail: containerized, liquid bulk, dry bulk, and break bulk (Table 5-14). This division is necessary to estimate the number of rail cars and trucks generated by each commodity at each port. Table 5-15 provides a list of commodities and the transportation equipment utilized. Some commodities can fall in more than one category. These "borderline" commodities are more likely to be containerized in ports that handle substantial amounts of containerized cargo, or would be shipped in bulk in ports that predominantly handle bulk products. For example, food and agricultural products can sometimes be dry bulk or containerized. Chemicals can be either liquid bulk or containerized. Although this adds some degree of uncertainty to the calculation of rail loads associated with specific equipment types (i.e., intermodal cars, tank cars, flat cars), the total number of rail cars and trucks should not vary widely depending on the classification of specific commodities.

It is also necessary to investigate commodity densities to determine whether a commodity would weigh out or cube out. Very dense commodities tend to weigh out (i.e., reach tonnage capacity before it reaches the volume capacity of transportation equipment), while less dense commodities tend to cube out (i.e., reach volume capacity before it reaches tonnage capacity). Average densities for 18 commodity groups were obtained from U.S. DOT data[103], which were based on the Standard International Trade Classification Index Division (SITC). The 140 commodity classes included in this analysis were then matched with the 18 commodity groups for which densities were available (Table 5-14).

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[103] U.S. Department of Transportation (1982): A Shipper's Guide to Stowage of Cargo in Marine Containers

Table 5-14: Commodity Densities

SCTG Code	Product Name	SITC Code	Product Name	Density (LB/Cu.Ft)	Density (ton/m3)
4	Animal Feed and Prod of Animal	8	Feeding-Stuff for Animals	20	0.3204
7	Prepared Foodstuffs and Fats and Oils	9	Miscellaneous Food Preparations	38	0.6087
18	Fuel Oils	22	Oil-Seeds, Oil-Nuts and Oil Kernels / Essential Oils & Perfume Products	29	0.4645
25	Logs and Other Wood in the Rough	24	Wood, Lumber and Cork	25	0.4005
27	Pulp, Newsprint, Paper, and Paperboard	25	Pulp & Waste Paper	34	0.5446
22	Fertilizer	27	Crude Fertilizers & Crude Materials	64	1.0252
15	Coal	32	Coal, Coke & Briquettes	53	0.8490
19	Coal and Petroleum Products, n.e.c	33	Petroleum & Petroleum Products / Mineral Tar & Crude Petroleum Chemicals	51	0.8169
17	Gasoline and Aviation Turbine Fuel	34	Gas, Natural & Manufactured	26	0.4165
20	Basic Chemicals	51	Chemical Elements & Compounds	64	1.0252
20	Basic Chemicals	59	Chemical Materials & Products	36	0.5767
27	Pulp, Newsprint, Paper, and Paperboard	64	Paper, Paperboard & Manufactured Thereof	20	0.3204
12	Gravel and Crushed Stone	66	Concrete Brick / Block—Glazed Brick / Block	80	1.2815
31	Nonmetallic Mineral Products	66	Non-Metallic Mineral Manufactures	60	0.9611
32	Base Metal in Primary or Semi-finished Forms and in Finished Basic	67	Iron & Steel	139	2.2266
32	Base Metal in Primary or Semi-finished Forms and in Finished Basic	69	Manufactures of Metal	39	0.6247
26	Wood Products	82	Furniture	7	0.1121
43	Mixed Freight	89	Miscellaneous Manufactures Articles NEC	21	0.3364

Because of packaging issues, transportation equipment cannot be 100% utilized even for commodities that cube out. For example, some beverage products are bottled and packaged in boxes. The space between bottles and the packaging material account for a share of the total volume being shipped. Additionally, depending on the shape of the packaging material, it might not be possible to utilize the full volume capacity of the transportation equipment. Bulk materials, on the other hand, can utilize 100% of the rail car or truck capacity if they do not weigh out first. The commodity densities included in Table 5-14 were multiplied by rail car and truck utilization in order to obtain adjusted commodity densities. Table 5-15 presents the four commodity types together with their rail car and truck utilization.

Table 5-15: Commodity and Equipment Types

Commodity Type	Equipment Type	Equipment Utilization	Commodities
Containerized	Container on double-stack train Container on chassis	85%	alcoholic beverages, animals & prod Nec, bananas & plantains, chem Products nec, chemical additives, coffee, coloring mat Nec, cotton, dairy products, electrical machinery, explosives, fab Metal products, farm products nec, fish (not shellfish), fish prepared, flaxseed, food products nec, fruit & nuts nec, fruit juices, glass & glass prod, groceries, hay & fodder, inorg Elem oxides & halogen salts, inorganic chem nec, machinery (not elec), manufac Prod Nec, manufac Wood prod, meat fresh frozen, meat prepared, medicines, misc mineral prod, natural fibers nec, newsprint, nitrogen func Comp, nitrogenous fert, non-ferrous scrap, non-metal Min NEC, oats, ordnance & access, organic comp nec, organo - inorg Comp, paper & paperboard, paper products nec, perfumes & cleansers, petro Jelly & waxes, phosphatic fert, pigments & paints, plastics, radioactive material, rice, rubber & gums, rubber & plastic pr, shellfish, smelted prod Nec, sodium hydroxide, sorghum grains, soybeans, starches gluten glue, sugar, sulphuric acid, tallow animal oils, textile products, tobacco & products, Unknown or NEC, vegetable oils, vegetables & prod, Waste and Scrap NEC, wheat, wheat flour, wood & resin chem, wood chips
Liquid Bulk	Rail tank car Tanker	100%	acyclic hydrocarbons, alcohols, ammonia, asphalt tar & pitch, benzene & toluene, carboxylic acids, crude petroleum, distillate fuel oil, fert & mixes nec, gasoline, kerosene, liquid natural gas, lube oil & greases, naphtha & solvents, other hydrocarbons, pesticides, Petro Products NEC, potassic fert, residual fuel oil, sulphur (liquid)
Dry Bulk	Gondola Dump Truck	100%	aluminum ore, barley & rye, cement & concrete, Coal, Coal Coke, Cocoa Beans, copper ore, corn, iron & steel scrap, iron ore, limestone, manganese ore, marine shells, metallic salts, molasses, non-ferrous ores nec, peanuts, petroleum coke, sand & gravel, slag, soil & fill dirt, sulphur (dry), water & ice, waterway improv Mat
Break Bulk	Flat car Flat trailer	85%*	aircraft & parts, aluminum, animal feed prep, building stone, clay & refrac Mat, copper, ferro alloys, forest products nec, fuel wood, grain mill products, gypsum, i&s bars & shapes, i&s pipe & tube, i&S plates & sheets, i&S primary forms, lumber, oilseeds nec, phosphate rock, pig iron, primary i&s nec, primary wood prof, pulp & waste paper, ships & boats, vehicles & parts, wood in the rough

* Exceptions were made to the following commodities, which had a rail car utilization of 50%: aircraft and aircraft parts, electrical machinery, explosives, fabricated metal products, glass and glass products, non-electrical machinery, radioactive material, vehicles and vehicle parts.

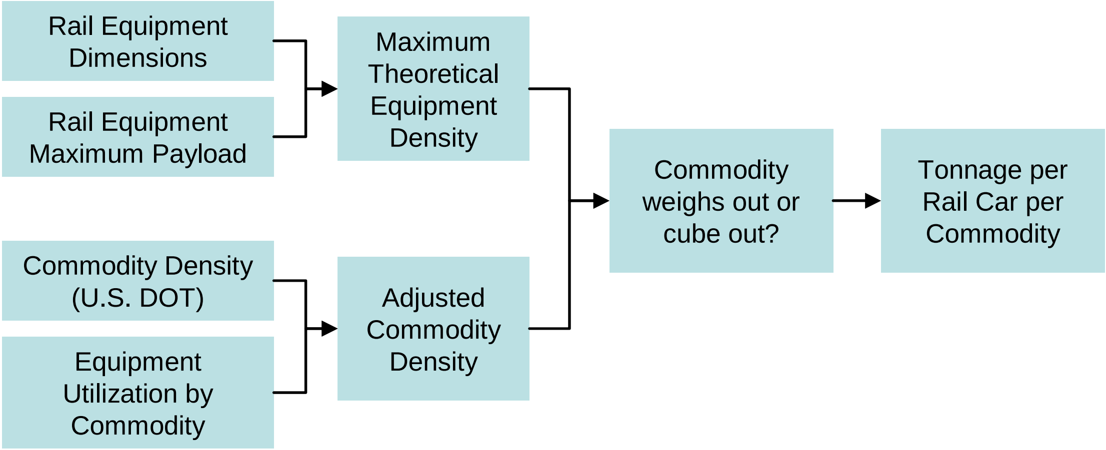
Table 5-16 presents rail and truck equipment together with their physical dimensions and payload capacities. A maximum theoretical equipment density is the ratio between payload capacity and volume. Commodities whose adjusted densities are lower than the maximum theoretical equipment density will cube out; commodities whose adjusted densities are higher than the maximum theoretical equipment density will weigh out.

Table 5-16: Equipment Dimensions

Equipment	Length (inches)	Width (inches)	Height (inches)	Volume (in^3)	Volume (m^3)	Maximum Payload (tons)	Maximum Theoretical Density (ton/m^3)
20' Container	233	92	95	2,036,420	33	22	0.65
40' Container	475	93	94	4,152,450	68	27	0.39
Flat Car	804	96	102	7,872,768	129	120	0.93
Gondola	660	108	84	5,987,520	98	120	1.22
Rail Tank	240	96	102	2,350,080	39	120	3.10
Flat Trailer	570	102	110	6,395,400	105	21	0.20
Dump Truck	570	102	110	6,395,400	105	40	0.48
Tanker Truck	570	102	110	6,395,400	105	27	0.25

Based on the adjusted commodity densities and whether commodities generally weigh out or cube out, the average tonnage per rail car could be determined for each commodity (Figure 5-5). This calculation applied to non-containerized commodities only, since the number of TEUs (for containerized cargo) was already available.

Figure 5-5: Calculation of Tonnage per Rail Car by Commodity



6. Case Studies

Three case studies are provided in this section to show how emission inventories have lead to focused emission reduction strategies at ports.

6.1. San Pedro Bay Ports

The San Pedro Bay ports of Port of Los Angeles and Port of Long Beach originally performed a detailed OGV inventory in 1996[104]. For calendar year 2001, Port of Los Angeles performed a full air emissions inventory of OGVs, harbor craft, CHE, trucks and rail which greatly improved port emission inventory modeling methodology[30]. The 2005 inventories for Ports of Los Angeles and Long Beach[53,54] lead to the development of a Clean Air Action Plan[105]. The plan included:

- The Ports undertake a 5-year, focused effort to replace or retrofit the entire fleet of over 16,000 trucks that regularly serve the Ports with trucks that at least meet the 2007 control standards and that are driven by people who at least earn the prevailing wage.
- The Ports establish within their respective districts a program that restricts the operation of trucks that do not meet the clean standards established in the Plan. Further, that the Ports impose a system of fees and transportation charges to raise the necessary funds to pay for the cleaner trucks. These fees would be imposed on “shippers,” and not on the drivers.
- The Ports will invite private enterprise trucking companies to hire the drivers on terms that offer the proper incentives and conditions to achieve the Clean Air Action Plan goals while resulting in adequately paid drivers.
- The Ports begin this program with an infusion of cash to the Gateway Cities Program that would fund a 500-truck program that will demonstrate the applicability of new retrofit technologies. This demonstration program will be activated in the 1st quarter of 2007, and the full 16,800-truck program will be rolled out shortly thereafter.
- The Ports develop requests for proposals that will encourage truck fleets of alternatively-fueled vehicles, for example, LNG.

Emission reduction measures also included vessel speed reduction, shore power and cleaner fuels for OGVs, replacing harbor craft engines with Tier 2 and 3 engines, and meeting Tier 4 standards with cargo handling equipment.

Since 2001, SOx emissions have decreased 40 percent while PM emissions have decreased by about 12 percent, even though cargo throughput has increased 61 percent.

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

[105] San Pedro Bay Ports Clean Air Action Plan. Available at http://polb.com/civica/filebank/blobdload.asp?BlobID=3452

6.2. Puget Sound Ports

Puget Sound Ports prepared an air emission inventory of OGVs, harbor craft, CHE, trucks and rail for calendar year 2005.[106] As a result of this inventory, the Ports of Seattle and Tacoma developed a Regional Clean Air Strategy[107] with Port of Vancouver B.C. The Strategy, initially released in May 2007, is the culmination of input from the three ports, major stakeholders, environmental groups and local citizens throughout the region. The overall goal of the Strategy is to reduce diesel and greenhouse gas emissions in the region by achieving early reductions in advance of, and complementary to, applicable regulations. It builds on emission reduction strategies already implemented, and establishes short- and long-term performance measures for reducing emissions from cargo-handling equipment, rail, harbor craft, ocean-going vessels, and trucks.

Each of the ports, along with their customers and tenants, continues to work collaboratively with air and environmental regulatory agencies to reduce emissions through such initiatives as:

- **Ships**: Using low-sulfur distillate fuels at berth. Adding “green design” environmental features to ships, including diesel-electric motors that save up to 30 percent in fuel and significantly reduce emissions.
- **Cargo-handling equipment**: Using ultra-low sulfur diesel, biodiesel, and other cleaner-burning fuels in cargo-handling equipment.
- **Trucks**: Setting targets to turn over older, less-efficient truck engines.
- **Rail**: Installing anti-idling devices on rail-switching engines, as well as partnering on other innovative technological advances..

6.3. Port of Charleston

Port of Charleston prepared an air emissions inventory of OGVs, harbor craft, CHE, trucks and rail for calendar year 2005.[108] “The new inventory, the first for any port in this region, will help us better understand both the sources and the scope of port-related air emissions,” said Bernard S. Groseclose Jr., the South Carolina State Ports Authority (SCSPA) president & CEO. “This is just the latest action as the Ports Authority works to do its part to improve regional air quality.” The new Baseline Air Emissions Inventory will:

- Allow the community to more accurately understand emissions sources related to port activities, including their relative contribution to overall regional emissions;
- Establish a baseline of emissions for the SCSPA and the community to track progress over time as new technology and efficiency improvements are implemented; and
- Help the Port, its customers and other transportation companies target future emissions reduction efforts.

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[106] Starcrest Consulting Group, Puget Sound Maritime Air Forum Maritime Air Emissions Inventory, April 2007.

[107] Regional Clean Air Strategy at http://www.portseattle.org/downloads/community/environment/NWCleanAirStrat_200712.pdf

[108] Moffatt & Nichol, *2005 Port of Charleston Baseline Air Emissions Inventory,* September 2008.

Port-related emissions today are already lower than the report's findings. Since 2005, the SCSPA has taken on numerous projects to reduce port-related air emissions, including:

- Replacing diesel-fueled cranes and equipment with electric cranes and cleaner fuels. Just this spring, four giant diesel container cranes left the port after being replaced by all-electric models, eliminating their diesel emissions.
- Along with nine other transportation firms, switching to ultra-low sulfur diesel with 15 parts per million (ppm) sulfur content, instead of fuel containing as much as 500 ppm. This voluntary move came more than two years ahead of a federal mandate for non-road diesel equipment.
- Reducing truck idling, decreasing truck trips on local roads and lessening construction impacts
- Being one of five U.S. ports selected for the national Environmental Management System project.

More details can be found at their Pledge for Growth website.[109]

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[109] http://www.pledgeforgrowth.com/documents/AIR.pdf

7. Recommendations for Further Study

There are a variety of opportunities to improve on the port emission inventory development procedures described in this document. Below are recommendations for future research and improvement.

- ***Recommendation 1***—There is a need for the development of updated and more accurate marine vessel emission factors and load factors. The current emission factors are still based on limited test data and only approximate emissions from newer vessels that meet the IMO Annex VI NOx standard. A test program by EPA to determine more accurate emission factors for all engine categories would greatly improve emission inventories. Utilizing international standards will resolve some of the current technical/legal problems and provide consistent requirements for OGVs as they participate in worldwide commerce. In addition, the PM emission factors for slow and medium speed ships needs further review. The recent difficulty in measuring PM emissions raises concerns with earlier measurements. Finally, there is a need to develop emission factors specific to $PM_{2.5}$. Currently, emission factors for $PM_{2.5}$ are an approximation based on PM_{10} emission factors. Further work needs to be done to develop algorithms to calculate PM and SOx emissions based upon fuel sulfur level.
- ***Recommendation 2***—There is little information on the number and size of auxiliary engines on Category 3 ships. Because hotelling emissions can be a substantial part of port emissions, better information on the size and number of auxiliary engines on ships calling on U.S. ports is needed. While ARB has surveyed over 300 ships to determine the number and power of auxiliary engines, more accurate information is needed to improve emission estimates, including information on load, type of operation, and fuel. It is recommended that emission factors for incinerators and boilers be improved.
- ***Recommendation 3***—With the increased interest in greenhouse gas emissions, more accurate methane and nitrous oxide emission factors need to be developed along with development of emission factors for black carbon emissions for all mobile sources.
- ***Recommendation 4***—Some emission inventories include assumptions regarding the amount of time that Category 2 vessels, such as tugs and pushboats, operate within a port's boundaries. In many cases these vessels travel from one port to another along the coastline, and this travel may not be properly accounted for in the inventory. Furthermore, some inventories assume that all Category 2 vessels operate within the 48-state U.S. airshed. This may be inaccurate in areas near U.S. borders where tugs and pushboats might push cargo into Alaska, Hawaii, Canada, Mexico or the Caribbean. Therefore, an improved methodology is needed to determine the amount of activity of Category 2 vessels in port areas and the U.S. airshed.
- ***Recommendation 5***—For NEPA (or CEQA) and general conformity purposes, the emission inventory process could be improved by the development of emission factors for on-dock equipment that better represent their in-use duty cycle. It is recommended that EPA spearhead the development of test cycles for dock equipment that realistically represent the operating patterns of this equipment.
- ***Recommendation 6***—For most sectors, EPA's diesel emission quantifier (DEQ) estimates the emission reductions available to users for various emission control strategies. Unfortunately, the current model does not include ocean going vessels. Since OGVs are a significant source of emissions, adding OGVs to the DEQ is advised.

- ***Recommendation 7***—Currently Jones Act ship movements are not recorded in an easily accessible database similar to foreign cargo movements. It is suggested that US Army Corps of Engineers also provide data on Jones Act ship movements within the United States.

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