Current Methodologies and Best Practices for Preparing Port Emission Inventories

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ABSTRACT

This paper describes current methodologies and best practices used for preparation of a port emission inventory. It 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.

Several detailed port emission inventories have been prepared in the last several years. However, because there has been little guidance on preparing port inventories, they tend to vary by who prepares them and the purpose of the inventory. In addition, emission factors and other operational data on marine vessels continually evolve; thus, the parameters often differ between studies.

Because the rationale and resources to prepare inventories vary between ports, this report provides a range of approaches to provide the appropriate level of detail to meet ports' needs. The three approaches presented in this report are (1) a detailed approach which details each ship trip into and out of a port as well as quantifies harbor craft and land-side emissions, (2) a mid-tier approach where ship trips are averaged by ship type and dead weight tonnage and then average trip characteristics are calculated, and (3) a streamlined approach in which marine, harbor craft, and land-side emissions are estimated from other detailed inventories.

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

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., cranes, yard trucks, locomotives, and marine vessels). Mobile source port 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. These land-based sources also are likely to have diesel engines. Diesel emissions of concern include nitrogen oxides (NOx), sulfur oxides (SOx), particulate matter (PM), and toxics. Stationary emission sources at ports also need to be counted in total port emissions, but are not discussed in this paper.

A more detailed description of port emission inventory preparation can be found in the full white paper.[1] The white paper 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 emission inventories.

Overview

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 were developed from very limited data sets. Ports can be a major contributor to regional NOx, SOx, toxics, and PM 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.

Estimating emissions generally involves applying emission factors to measures of port activity. 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.

Overview of Port 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, three different approaches are presented in this report:

- *Detailed Inventory* – Highly detailed inventories are typically prepared by the "larger" deep-sea ports in air quality non-attainment areas. This type of inventory requires detailed data on vessels and land-based equipment characteristics and activities, as well as detailed 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.
- *Mid-Tier Inventory* – A mid-tier 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. Ports on inland waterways or the Great Lakes also might use this approach. Such an inventory requires port-specific activity data but applies "typical" port emission rate averages by ship type.
- *Streamlined Inventory* – 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).

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.

- For National Environmental Policy Act (NEPA), California Environmental Quality Act (CEQA), or general conformity 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.

Recent Port Emission Inventories

A number of port authorities have done detailed inventories in the last several years. Other ports have used a streamlined method for preparing port emission inventories or prepared inventories for a specific terminal or industry. The detailed inventories listed in Table 1 represent recent bottom-up activity-driven inventories to the level recommended in this report. Several other ports are in the process of preparing detailed inventories, including Puget Sound, Port of Los Angeles, Port of Long Beach and Port of Oakland.

Many of the recent inventories have been done by Starcrest Consulting Group, LLC. As such, there has been some consistency in methodology for port emission inventories. However, there is no specific guidance on preparing such inventories; thus, methodologies vary. This paper 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.

DETAILED EMISSION INVENTORIES

This section describes the necessary steps to prepare a detailed port emissions inventory. It includes (1) the definition of port boundaries, (2) OGV emissions determinations, (3) harbor craft emissions determinations, (4) land-based emissions determinations, and (5) methodology for Great Lake and inland river ports.

Table 1. Summary of detailed port inventories

Port	Year Published	Data Year	Oceangoing Vessels	Harbor Craft	Land-Side Emissions	Pollutants[a]	Contractor[b]
Beaumont/Port Arthur	2004	2000	Yes	Yes	No	NOx, CO, HC, PM_{10}, SO_2	Starcrest
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
Los Angeles	2005	2001	Yes	Yes	Yes	NOx, TOG, CO, PM_{10}, $PM_{2.5}$, SO_2, DPM	Starcrest
Long Beach	2004	2002	No	No	Yes	NOx, TOG, CO, PM_{10}, $PM_{2.5}$, SO_2, DPM	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
Portland	2004	2000	Yes	Yes	Yes	NOx, HC, CO	Bridgewater

[a] NOx = oxides of nitrogen, TOG = total 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

[b] Starcrest = Starcrest Consulting Group LLC, ACES = Air Consulting and Engineering Solutions; Bridgewater = Bridgewater Consulting

c Truck and rail only

Definition of Port Boundaries

The purpose of the inventory will help define useful port boundaries. In most cases, the land-side boundary should include at least the first intermodal point so that it includes 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 miles from where the pilot boards the ship for entry into the port, but this might be extended if wind direction is a factor. For SIP purposes, the non-attainment area boundary(ies) might be used. For other purposes, county boundaries might be used. EPA’s marine inventory in the Category 3 engine rulemaking used 175 nautical miles (200 statute miles) from the coast as this represents the boundary of the exclusive economic zone (EEZ). Using the 175 nautical mile boundary will include the effect of transiting ships which are typically considered non-port emissions. It is therefore important to look at the purpose of the inventory to decide on the proper boundaries that it will encompass.

Oceangoing Vessel Emission Determinations

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.

Equation (1) $E = P \times LF \times A \times EF$

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 subsections describe data sources to use and how to determine (1) ship characteristics, (2) activity profiles for each ship call, (3) load factors for each activity during a call, (4) emissions from auxiliary engines and boilers, and (5) appropriate emission factors.

Data Sources

Various data sources are available to those preparing port emission inventories. These include Marine Exchange/Port Authority (MEPA) data, Lloyd's Register of Ships (Lloyd's Data), and Pilot data. The importance and use of each are discussed below. The Coast Guard Vessel Traffic System (VTS) also can be used to determine vessel movements.

The 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. Some 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: (1) total time the vessel was in port, (2) port(s) of call within the MEPA, and (3) vessel characteristics (using Lloyd's vessel characteristic data).

All data are referenced to both ship name and Lloyd's number (LMIS Number), 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.

Information from pilot associations and tide books can be invaluable to the calculation of time-in-modes. 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 by conversations with knowledgeable personnel at the MEPA and, when possible, directly from 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.

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.

Ship Characteristics

OGVs vary greatly in speed and generating capacity 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 lists various OGV types that should be described in any detailed inventory.

Table 2. 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, etc.

Other characteristics that should be determined from Lloyd's Data are the propulsion engine power and engine speed, maximum vessel speed, and auxiliary engine power and engine speed. EPA defines marine vessel engines (propulsion and auxiliary) in terms of categories as shown in Table 3. These categories relate to land-based engine equivalents. Engine speed designations are shown in Table 4. Most ships have diesel engines, although some older ships are steamships.

Table 3. 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 4. 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 latest emission inventory for the Port of Los Angeles (PoLA), Starcrest shows that Lloyd's Data fairly accurately records both ship power and maximum vessel speed.[2] Previous studies had established that Lloyd's ship power was only 92 percent of maximum continuous rating (MCR) and recommended that the Lloyd's power be divided by 0.92 to obtain MCR. Based on studies done by Starcrest during their vessel boarding program, it is now recommended that Lloyd's ship power be treated as MCR with no adjustment.

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 auxiliary engines based on ship type and activity mode or to assume auxiliary power is equivalent to 10 percent of propulsion power.[3] In the PoLA inventory, Starcrest collected information from Lloyd's Data and Starcrest's vessel boarding program. California Air Resources Board (ARB) recently conducted an Oceangoing Ship Survey of 327 ships in January 2005.[4] Table 5 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 port specific data.

Table 5. 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). Fuel switching while under power is rarely done and is discouraged by the U.S. Coast Guard.[5] However, many ships have 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 MDO instead of RO. For cruise vessels, only 8 percent used MDO 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 MDO instead of RO for their auxiliary engines for a given port, the percentages listed above can be used as a surrogate.

Activity Determinations

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 6.

Table 6. 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 (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 pier/wharf/dock (PWD). Maneuvering within a port generally occurs at 5 to 8 knots on average, with slower speeds maintained as the ship reaches its PWD or anchorage. Even with tug assist, the propulsion engines are still in operation.
Hotelling (hr/call)	Hotelling is the time at a 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.

Cruise speed listed in Lloyd's data is generally taken as 94 percent of the maximum service speed. Distances from the maximum port boundary (defined in Section 2.1 above) to either the RSZ or the breakwater 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.

RSZ time-in-mode also is an estimation based on average ship speed and distance. 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.

Maneuvering time-in-mode is estimated based on the distance a ship travels from the breakwater to the 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.

Hotelling should 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. 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 represents ships at a PWD but the auxiliary engines are not on the entire time.

Load Factors

Load factors are expressed as a percent of the vessel's total power. At service or cruise speed, the 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.

Equation (2) $LF = (AS/MS)^3$

where LF = load factor (percent)
AS = actual speed (knots)
MS = maximum speed (knots), usually 1.064 times Lloyd's service speed

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.[6] This assumption was consistent with that used by ENVIRON in their calculations of load factors for ships.[3] In Starcrest's two most recent inventories, they found that load factors as low as 2 percent were possible.[2,7] 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.

Auxiliary Loads

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 occurring during hotelling (except when cold ironing). Starcrest determined, through interviews conducted with ship captains, chief engineers, and pilots during its vessel boarding programs, the auxiliary engine load factors shown in Table 7. 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 7 together with the total auxiliary engine power from Table 5.

Table 7. Auxiliary engine load factor assumptions

Ship-Type	Cruise	RSZ	Maneuver	Hotel
Auto Carrier	0.13	0.30	0.67	0.24
Bulk Carrier	0.17	0.27	0.45	0.22
Container Ship	0.13	0.25	0.50	0.17
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	0.30
Reefer	0.20	0.34	0.67	0.34
Tanker	0.13	0.27	0.45	0.67

Propulsion Engine 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.

The most recent study of emission factors was done by Entec, and these factors are generally accepted as the most current set available.[8] Entec analyzed emissions data from 142 propulsion engines and included two of the most recent research programs, Lloyd's Register Engineering Services in 1995 and IVL Swedish Environmental Research Institute in 2002. Entec lists individual factors for three speeds of diesel engines (slow-speed diesel (SSD), medium-speed diesel (MSD), and high-speed diesel (HSD)), steam turbines (ST), and three types of fuel (RO, MDO, and MGO).

Currently recommended emission factors are shown in Table 8. It should be noted that Entec does not list PM factors for either PM_{10} or $PM_{2.5}$. PM emission factors are the most controversial as measurement of PM emissions on a ship is particularly difficult and there is much variation between sources. Generally the sulfur content of the fuel tends to overshadow other effects. PM_{10} and SO_2 emission factors listed in Table 8 were based upon recommendations from ENVIRON.[9]

Table 8. Emission factors for OGV main engines using residual oil, g/kWh

Engine	NOx	CO	HC	PM_{10}	$PM_{2.5}$	SO_2
SSD	18.1	1.40	0.60	1.05	0.96	10.3
MSD	14.0	1.10	0.50	1.11	1.02	11.1
ST	2.1	0.20	0.10	1.50	1.38	16.1

Another point of contention is how $PM_{2.5}$ is determined. EPA estimates that $PM_{2.5}$ is 97 percent of PM_{10} emissions for all nonroad sources,[10] but this is generally for lower sulfur diesel fuel in high speed engines. Starcrest estimated $PM_{2.5}$ at 80 percent of PM_{10} based upon a report from the *Journal of Aerosol Science*[11], but this relationship is still going through review by the scientific community. As medium and slow speed engines have lower pressure fuel injection systems and residual oil is not refined, it is likely that Category 2 and 3 engines may have a lower ratio of $PM_{2.5}$ emissions to PM_{10} emissions than high speed engines using low sulfur fuel, but 80 percent seems rather low. A more reasonable value of 0.92 is used in the Table 8 for marine diesel fuels in slow and medium speed engines. For higher speed engines using lower sulfur diesel fuel, such as harbor craft, cargo handling equipment, and on-highway diesel vehicles, the 97 percent ratio should be used.

In addition, because SO_2 and PM emission factors are directly proportional to the sulfur content of the fuel, SO_2 and PM emission factors should be adjusted if the sulfur content of RO in the ships calling on a port is different from the assumption of 2.7 percent used in Table 8.

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 fuel consumption tends to increase as load decreases. Energy and Environmental Analysis Inc. (EEA) demonstrated this effect in a study prepared for EPA in 2000.[12] Starcrest used the equations developed by EEA to determine emission factor adjustments based on load factor. The emission factor adjustments are given in Table 9. These factors should be multiplied by the emission factors given in Table 8 to determine emission factors at loads below 20 percent. For diesel-electric systems, low load adjustment factors should not be used because several engines are used to generate power and some can be shut down to allow others to operate at a more efficient setting.

Table 9. Emission factor adjustment factors at low loads

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

Auxiliary Engine Emission Factors

As with propulsion engines, the most current set of auxiliary engine emission factors comes from Entec. Starcrest used these emission factors for the PoLA inventory, and they are considered the most up to date. Auxiliary engine emission factors are given in Table 10. There is no need for a low load adjustment factor for auxiliary engines, because they are generally operated in banks. When low loads are needed, one or more engines are shut off, allowing the remaining engines to operate at a more efficient level.

It should be noted that Entec used a fuel sulfur content of 2.7 percent for RO, 1.5 percent for MDO, and 0.5 percent for MGO. Therefore, when calculating PM and SO_2 emission factors, they should be adjusted accordingly for areas where fuel sulfur content is different. Again PM and SO_2 emission factors were calculated based upon recommendations from ENVIRON.[9]

Table 10. Auxiliary engine emission factors, g/kWh

Engine	Fuel	NOx	CO	HC	PM_{10}	$PM_{2.5}$	SO_2
MSD	RO	14.70	1.10	0.40	1.11	1.02	11.1
	MDO	13.90	1.10	0.40	0.71	0.66	6.16
	MGO	13.90	1.10	0.40	0.37	0.34	2.05

Aggregation of Results

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 emissions 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 via the streamlined and mid-tier approaches.

Harbor Craft Emissions

Harbor craft are commercial and recreational vessels that spend the majority of their time within or near a port or harbor. Port harbor vessels types are listed in Table 11. To calculate emissions from harbor vessels, the following information needs to be collected from vessel owners and operators: (1) hours of operation, (2) percentage of time in operational modes, (3) vessel characteristics, (4) number, type, and horsepower (or kilowatts) of main engine(s), (5) number, type, and horsepower (or kilowatts) of auxiliary engine(s), (6) other operational parameters such as fuel consumption rates and dredging volumes, and (7) qualitative information regarding how the vessels are used in service.

Table 11. 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.

Average Engine Power and Operating Hours

Most harbor craft have Category 1 marine diesel engines; although, some of the larger assist tugs and most oceangoing towboats have Category 2 marine diesel engines. Table 12 gives average propulsion and auxiliary engine sizes and hours of annual operation by harbor craft type for the PoLA. For detailed inventory preparation, average values should be calculated from the information collected at the specific port. For mid-tier inventory preparation, the information presented in Table 12 can be used in developing a streamlined inventory of harbor craft emissions.

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. Starcrest used data from the California ARB's Pleasure Craft Exhaust Emissions Inventory and the OFFROAD model to determine emissions from recreational vessels. This practice should be used for California ports. Various other states have also done recreational boating surveys. This information could be use together with EPA's NONROAD model for non-California ports.

Table 12. Average engine horsepower and annual hours of operation (Port of Los Angeles)

	Propulsion Engine			Auxiliary Engine	
Vessel Category	Engine Power (kW)	Annual Operating Hours	Percent Category 2 Engines (%)	Engine Power (kW)	Annual Operating Hours
Assist Tug	1,532	1,043	44	82	1,207
Tugboat (Unit Tow)	903	654	25	56	859
Line Haul Towboats	3,357	654	80	82	859
Ferry	803	1,672	0	25	1,616
Excursion	250	1,971	0	41	2,199
Crew Boat	284	606	0	72	700
Work Boat	266	345	0	23	618
Government	237	413	0	176	156
Dredges	1,531	372	0	214	372
Dredge Tenders	450	158	0	19	136
Commercial Fishing	204	1,647	0	51	1,932

Load Factors

Load factors used in the PoLA inventory are shown in Table 13. 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.[2] While best practice is to collect information for a specific port, these load factors could be used for other port emission inventories if no other information is available.

Table 13. Load factors for harbor craft (Port of Los Angeles)

Vessel Category	Engine Power (hp)
Assist Tugboat	31%
Dredge Tenders	69%
Recreational	21%
Other Categories	43%
Recreational, Auxiliary	32%
Other Auxiliaries	43%

Emission Factors

Category 1 emission factors for harbor craft come from the 1999 EPA rulemaking for Category 1 and 2 engines and are listed in Table 14.[13] $PM_{2.5}$ emission factors are estimated to be 97 percent of PM_{10} emissions for Category 1 engines[10]; 92 percent should be used for 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 port. PM emissions also may change based upon sulfur level and also should be scaled.

Table 14. Category 1 harbor craft emission factors

Minimum Power		Emission Factors (g/kWh)				
kW	hp	NOx	CO	HC	PM_{10}	SO_2
37	50	11.0	2.0	0.27	0.9	0.63
75	100	10.0	1.7	0.27	0.4	0.63
130	175	10.0	1.5	0.27	0.4	0.63
225	300	10.0	1.5	0.27	0.3	0.63
450	600	10.0	1.5	0.27	0.3	0.63
560	750	10.0	1.5	0.27	0.3	0.63
1,000	1,341	13.0	2.5	0.27	0.3	0.63

Category 2 emission factors come from the 2002 Entec study and are listed in Table 15.[8] Again, the SO_2 and PM_{10} emission factors assume fuel sulfur content of 1.5 percent and, thus, should be scaled accordingly if sulfur levels are different.

Table 15. Category 2 harbor craft emission factors, g/kWh

NOx	CO	HC	PM_{10}	SO_2
13.2	1.10	0.50	0.72	0.63

Land-Side Emissions

As best practice, those preparing port inventories should estimate CHE emissions using EPA's NONROAD model (California uses ARB's OFFROAD model) and on-road trucks, buses and other vehicles using EPA's MOBILE6.2 model (California uses ARB's EMFAC2002 model). Rail emissions should be handled separately, as NONROAD does not contain rail emission factors. When the purpose of the inventory is to prepare a SIP, land-side emissions are usually calculated for the non-attainment region and, thus, should not be double counted by ports. However, calculating land-side emissions provides details for possible emission reductions when implementing an emissions mitigation program. NEPA, CEQA, and general conformity analyses also need land-side emissions estimated. There are three categories of land-side emissions that need to be examined: CHE, railroads, and on-road vehicles.

Cargo Handling Equipment

A wide range of 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.[14] In fact for the PoLA, 99 percent of CHE was associated with container terminals and 88.5 percent at the Port of Long Beach. 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.

The majority of CHE can be classified into the equipment types shown in Table 16. 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 16. Cargo handling equipment types

Equipment Type	NONROAD Model Equipment Type	SCC Code
Aerial Platform	Aerial Lift	2270003010
Bucket Loader	Rubber Tire Loader	2270002060
Chassis Rotator	Other Industrial Equipment	2270003040
Empty Container Handler	Other Industrial Equipment	2270003040
Forklift	Forklift	2270003020
Generator	Light commercial generator set	2270006005
Non-Road Vehicle	Off-highway Trucks	2270002051
Payloader	Skid-Steer Loader	2270002072
Portable Light Set	Signal Board/Light Plant	2270002027
Rubber Tire Gantry Crane	Other Material Handling Equipment	2270003050
Side Loaders	Other Industrial Equipment	2270003040
Straddle Carrier	Other Material Handling Equipment	2270003050
Sweeper	Sweepers/Scrubbers	2270003030
Terminal Tractor	Terminal Tractor	2270003070
Top Loader	Other Industrial Equipment	2270003040
Wharf Crane	Crane	2270002045

To develop a detailed emission inventory of CHE, those preparing port emission inventories should gather the following information for each piece of CHE used at the port: (1) equipment type, (2) rated horsepower, (3) engine model year, (4) type of fuel used, (5) annual hours of operation, (6) equipment load data, and (7) retrofit devices.

To develop inputs for EPA's NONROAD model, the user must define both activity and population of the various categories of equipment shown in Table 16. Activity is the number of hours an engine operates during a given analysis year and can be determined from interviews with terminal operators. In general, container terminals use their equipment much more intensively than other terminals. Population is the number of similar engines of a specific equipment type with a similar horsepower rating.

In preparing inputs, diesel sulfur content in parts per million (ppm) should be determined for the fuels used for CHE at the port. National average non-road fuel has approximately 3,400 ppm sulfur, while national average on-highway diesel fuel has 340 ppm sulfur. By 2010, most non-road diesel fuel will contain only 15 ppm sulfur or less (2006 in California) with a 500 ppm step starting in 2007. Because ambient temperatures do not affect diesel exhaust emissions in NONROAD, an input of 75^{o} F can be used.

Rail

Movement of freight into and out of the port via rail should be included in a detailed 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 refers 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 refers to the assembling and dissembling of trains at various locations within a port.

Line haul locomotives are typically large with engines of 2,200 kW or more, while switching locomotives have engines of 900 to 2,200 kW. Information on locomotives and their operation should be gathered from the railroad companies that service a port. Information from the railroad companies should be used in concert with EPA's guidance on locomotive emissions.[15,16]

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

On-Road Vehicles

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 EMFAC2002) should be used for calculating emissions from these vehicles.

On-road diesel trucks are used extensively to move cargo into and out of ports. Again, the first intermodal point should be considered when calculating truck emissions related to a port. On-road truck emissions should be modeled using MOBILE6.2 (California uses EMFAC2002). Several issues should be examined in modeling truck traffic at ports, including the following: (1) fleet age, (2) idling time, (3) truck speeds within the port, (4) truck speeds on arterials and freeways accessing the port, and (5) retrofit devices, repowers, and alternative fuels.

During delays at ports, trucks spend large amounts of time idling, which is not directly accounted for in MOBILE6.2. EPA cautions that curb idle rates calculated using MOBILE6.2 are too low to represent extended idling of commercial class 8B diesel trucks. For extended idle, EPA guidance suggests using average idle emission rates of 135 grams per hour for NOx and 3.68 grams per hour for PM.[17] These idle rates represent fleet average values at high idle speed.[18] Idle times should be calculated both inside and outside the port gates as well as entering and leaving distribution centers and other intermodal points.

Truck speeds also are important for estimating truck emissions within the port and outside the port. Emissions of NOx, VOC, and CO tend to vary with speed (PM emission rates do not vary with speed in the MOBILE model). Average roadway speed data can be obtained from local government traffic engineers or the region's metropolitan planning organization (MPO).

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

Great Lake and Inland River Ports

The port boundaries and ships that call on Great Lake and inland river ports differ from deep sea ports. Those preparing emission inventories for Great Lake and inland river ports also should calculate land-side emissions similar to the methods described above

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There are several ship types common to the Great Lakes. Most Great Lake ports have a combination of cargo ships called “Lakers” and “Salties,” as well as a substantial amount of barge traffic. Excursion vessels are also common on the Great Lakes.

Commercial traffic on rivers consists almost exclusively of tug and barge movements. There are some excursion vessels, such as paddle boats, dinner cruises, or other entertainment-centered river traffic, but the majority of trips and vast majority of tonnage recorded by USACE are centered on tug/barge movements. The tug/barge combination often is referred to as a “tow.” The following is a discussion of excursion vessels, tugs, and barges that operate on rivers.

Generally, Great Lake port boundaries extend 10 miles into the lake from the breakwater. As with deep sea ports, Great Lake ports usually have MEPAs that collect data on ships that enter and leave their port. This information can be used with the Lloyd’s Data to determine ship time-in-mode and power.

The EPA guidance document for Great Lakes and inland river ports provides a methodology for determining activity, power, and speed of tugs.[19] **Error! Bookmark not defined.** This methodology should be followed and used with harbor craft emission factors to determine an inventory of inland river ports. Additional guidance can be found in ENVIRON’s Lake Michigan Air Directors Consortium (LADCO) report.[20]

While a detailed inventory is the most accurate methodology for determining emission impacts at ports, many mid-size and smaller ports do not have the resources to accomplish such a task. This section discusses both a mid-tier and streamlined approach.

Mid-Tier Approach

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[21] and Great Lake and inland river ports.[19]**Error! Bookmark not defined.** ENVIRON offers additional guidance in its report.[3]

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.

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.[19,21] 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.[22] ENVIRON used this method to prepare a national inventory for an EPA rulemaking.[3] 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.

Cargo Handling Equipment Estimation

Few preparers of port inventories have developed estimates of CHE emissions. In the development of SIPs, port CHE is considered together with other non-road sources, and emissions are calculated using EPA's NONROAD model (California uses ARB's OFFROAD model). Generally, SIP documents assign these sources to the counties or air districts in which these emissions occur, rather than to a port. A small number of the nation's largest ports have developed estimates of CHE emissions, sometimes for an EIS/EIR or in an attempt to help identify effective mitigation strategies. These ports include the Ports of Los Angeles, Long Beach, Houston, and New York/New Jersey.

Unlike vessel emissions, there is no EPA guidance or other standardized methodology for developing estimates of port CHE emissions. Developing a CHE inventory from scratch requires extensive time and resources in order to survey all port tenants regarding their equipment. Such an effort is not always feasible. As an alternative, CHE emissions can be estimated from other CHE inventories prepared for other ports. The method described below is recommended for both mid-tier and streamlined inventory preparation.

Of the ports that have developed CHE inventories, the Ports of Long Beach and Los Angeles are the only ports with emissions estimates from land-side activity provided with sufficient detail to allow application of ratios to other ports. To estimate the CHE emissions at other ports of interest, one can scale the 2002 CHE emissions for the Ports of Long Beach and Los Angeles by the ratio of freight activity. For three of the four cargo categories – liquid bulk, dry and break bulk, and vehicles – this ratio is determined by the total tonnage handled in each category. For the fourth category – container cargo – the ratio is determined by the number of boxes handled at each facility. The emissions at each of the four possible terminal types then can be determined from scaling both the Long Beach and Los Angeles values to those of the port under consideration and averaging the two results. Using an average of these two values provides more reasonable emissions estimates than scaling off either one of the ports alone. The total emissions at each port then can be determined by summing over each of the four terminal types.

The total tonnage at a given port in each of the four cargo categories can be determined from USACE data.[22] Total petroleum minus petroleum coke should be taken as a surrogate for liquid cargo. "Vehicles and Parts" should be taken as a surrogate for automobiles. Number of boxes should be taken to best represent containerized cargo. The scaling ratios used to determine emissions then are determined for the port in question.

There are some reservations on using this method as the Ports of Long Beach and Los Angeles are unique from the rest of the country. In particular, they handle mostly container traffic and larger ships so the CHE might have higher horsepower engines, be newer, operate on different fuels, etc. While not as detailed, information from the New York/New Jersey and the Houston CHE inventories also can be scaled to check the results from the PoLA or Port of Long Beach emission scaling exercise.

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 do not fully represent newer vessels that meet the IMO Annex VI NOx standard. 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 used in the Entec dataset. 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.

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 the ARB survey[4] has made estimates of these 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 also be developed for incinerators and boilers.

Recommendation 3 – 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, or Mexico. 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 4 – 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 5 – For those preparing port emission inventories using the streamlined approach, EPA needs to update the emissions from ports using the method prescribed in this document. The 1999 marine inventory document prepared by ENVIRON uses older emission factors and methodology.[3] Therefore, it is recommended that the national inventory be redone using the methodology and emission factors suggested in this report. It is recommended that this revised inventory be used as the basis for emission factors provided by the future release of EPA's new emission factor model, MOVES.

Recommendation 6 – The U.S. Coast Guard (USCG) has begun operating in most major ports an upgraded version of its Vessel Tracking System (VTS) that could substantially improve emission inventories for ocean going vessels. This new system allows for real time tracking of all ocean going vessels beginning approximately twenty miles outside of the port. It can measure distance traveled and speed. The EPA and USCG believe that the upgraded VTS system could be used to help generate real-time air pollution emission inventories. While a substantial amount of work would have to be done to convert the distance and speed information to NOx, PM 2.5, VOC, SOx, CO, and CO_2 emissions, there do not appear to be any major technical challenges. It is recommended that EPA and USCG collaborate with Canada, ports, terminal operators, and shipping companies to adapt VTS for the calculation calculating ship emissions.

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KEY WORDS

Emission Inventories
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