

Port Emission Inventories and Modeling of Port Emissions for Use in State
Implementation Plans (SIPs)

White Paper #3

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This white paper is one of a series written for the U.S. EPA, Sector Strategies Program, in support of its partnership with the American Association of Port Authorities (AAPA). AAPA's Harbors, Navigation, and Environment Committee has expressed a desire to work collaboratively with EPA to address the issues discussed in this paper. The purpose of this white paper is to clarify current practice and concerns and to propose recommendations for follow-on activities that will support improved environmental performance.

1. Introduction

In areas that do not comply with the health-based National Ambient Air Quality Standards (NAAQS), the Clean Air Act (CAA) requires the preparation of a State Implementation Plan (SIP) to demonstrate how the area will come into compliance with NAAQS. Part of the process of developing a SIP involves the creation of an emission inventory. Emission inventories are also developed as part of the CAA requirement to demonstrate "rate of progress" toward NAAQS attainment. In addition, where port growth will affect an area's attainment status or rate of progress, emission inventories are sometimes done for environmental impact statements (EIS) as part of the National Environmental Policy Act (NEPA).¹

The emission inventory is a quantification of all emissions of criteria pollutants 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., auto, trucks, buses) and non-road sources (e.g., construction equipment, snowmobiles, aircraft, locomotives, marine vessels). Port emissions are generated by marine vessels and by land-based sources at ports. Marine emissions come primarily from diesel engines operating on ocean going vessels, tugs and tows, dredges, and other vessels operating within a port area. Land-based emission sources include ground equipment such as yard tractors, cranes, container handlers, and forklifts as well as heavy-duty trucks and locomotives operating within a port area. The port emissions of greatest concern are nitrogen oxides (NO_x) and particulate matter (PM).

The port emissions inventories developed by state and local air agencies have historically been less accurate than those of other sectors, due in part to the limitations of the methodologies employed. Ports can be a major contributor to regional NO_x and PM emissions. Without an accurate inventory, it is difficult to assess opportunities for emission reduction at ports and to make comparisons with emission reduction strategies in other sectors. In addition, an accurate emissions inventory is necessary to properly assess the impacts of port improvement projects or growth in marine activity, as well as to plan emission control strategies.

Estimating emissions generally involves applying emission factors to measures of port activity. Currently, 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 emissions inventories suffer from both poor quantification of port activity and from use of outdated emission factors. This paper discusses current methods of determining emissions from ports and offers recommendations for improvements.

For SIP inventory purposes, only marine vessel emissions are explicitly identified and estimated, so this paper focuses primarily on the marine vessel inventory development process (Section 2). Land-based port emission sources are usually combined with other land-based non-road sources of similar type throughout the region for SIP purposes. For NEPA or general conformity purposes, however, the effects of a proposed action at a port (such as a port expansion project) are often calculated, and this typically

¹ In California, the California Environmental Quality Act (CEQA) may require preparation of an environmental impact report (EIR).

includes explicit treatment of land-based emission at ports. An overview of the methods for estimating land-based port emissions is provided in Section 3.

2. Marine Vessel Inventory Development Methods

EPA has provided some guidance for calculating port inventory emissions for ocean going and harbor vessels operating at port areas in their current rulemakings.^{2 3} The old top-down approach based upon EPA's 1992 emissions inventory guidance document, in which fuel-based emission factors are multiplied by fuel sales for an area containing the port, is no longer recommended.⁴ In the old method, fuel sales information were gathered from Department of Energy marine fuel sales for diesel and residual within a state and then allocated to counties in which ports are located. The problem with this method is that fuel sales are a relatively poor indicator of fuel consumption, because ships can store fuel in large tanks (averaging 25,000 gallons), and the shipping agent will generally purchase fuel based upon the lowest price, not necessarily where the ship is docked at port. Also fuel sales statistics may lead to over-estimation of emissions because ships burn only a fraction of their fuel while in a given port, since their destinations may be several thousands of miles away.

The newer approach involves a bottom-up calculation of ship emissions that relies on actual operational data. This involves apportioning the time spent by a vessel in a port area to different operating modes, calculating the power used during each operating mode, and using power specific emission factors for determination of the emissions associated with each ship call on a port. The equation below gives the general formula to calculate port emissions from marine vessels.

$$\text{Emissions} = \text{Trips} \times \text{Power} \times \text{LF in mode} \times \text{Time in mode} \times \text{EF}$$

Where: Trips = number of trips or vessel calls by vessel and engine type
Power = rated power of propulsion engine by vessel and engine type
LF = load factor (fraction of rated power) by mode
Time = average time for each mode by vessel and engine type
EF = emission factor in mode and by engine type

Several documents have been recently prepared which enhance this process and provide guidance to ports in estimating emissions.

Categories of Marine Diesel Engines

EPA defines a marine diesel engine as one that is installed or intended to be installed on a marine vessel. These are differentiated into three categories of engines, because some marine diesel engine types are typically derivatives of land-based diesel engines that are subject to different emission standards, testing procedures, and dates at which the standards become effective. The definitions for the different categories of marine diesel engines are contained in 40 CFR 94.2 and summarized in Table 1.

² U.S. EPA, *Control of Air Pollution from Marine Compression-Ignition Engines*, Part 94, Code of Federal Regulations, December 1999. (Published in the Federal Register December 29, 1999.)

³ U.S. EPA, *Control of Emissions from New Marine Compression-Ignition Engines*, Part 94, Code of Federal Regulations, February 2003. (Published in the Federal Register February 28, 2003.)

⁴ US EPA, *Procedures for Emission Inventory Preparation*, Volume IV: Mobile Sources, EPA420-R-92-009, December 1992.

Table 1: Marine Engine Category Definitions

Category	Displacement per Cylinder	Power Range (kW)	RPM Range
1	Displacement < 5 liters (and power \geq 37 kW)	37 – 2,300	1,800 – 3,000
2	5 liters \leq Displacement < 30 liters	1,500 – 8,000	750 – 1,500
3	Displacement \geq 30 liters	2,500 – 80,000	60 – 900

Category 1 engines can be used as propulsion engines on harbor craft and fishing vessels and as auxiliary engines on all vessels. Category 2 engines can be used as propulsion engines on tugs and pushboats and as auxiliary engines on ocean going marine vessels. Category 3 engines are used as propulsion engines on ocean going marine vessels. The 1999 Rulemaking⁵ encompassed Category 1 and 2 diesel engines, while the 2003 Rulemaking⁶ encompassed Category 3 diesel engines.

Vessel Activity Estimation

Each port records at least the ship name, ship type, cargo weight in tons, time entering the breakwater (port entrance), and time leaving the breakwater. These data are also available from the Army Corps of Engineers Waterborne Data Center for most U.S. ports, and from other sources such as harbor pilots, the U.S. Coast Guard, and the Vessel Traffic System (VTS). Larger ports also record the time at which a ship docked at a given berth, the time it left that berth, and any time spent maneuvering between anchorages and berths. Many times a ship is anchored within a port but not berthed, such as if the ship arrives at a late hour or the berth at which the ship needs to dock is currently occupied. In most ports, this data is now electronically available, although some very small ports still keep log books that are not electronic.

For smaller ports, the emissions inventory numbers that were generated during EPA's 1999 and 2003 rulemakings can be used directly. In the Category 3 rulemaking, EPA developed port specific inventories using a port matching process.⁷ In the Category 1 and 2 rulemaking, only national inventory numbers were developed. The national inventory values can be apportioned to specific ports based upon the ratio of the port's Category 3 emission levels to the national inventory of Category 3 emissions. While better guidance needs to be developed to apportion these emissions more accurately, this gives a reasonable estimate of Category 1 and 2 emission levels for a given port.

Midsize ports can use a matching process explained in detail in an ARCADIS marine activity guidance document⁸ and improved upon in an ENVIRON report⁹ on preparing commercial marine vessel inventories. The ARCADIS report gives details on eight U.S. ports, providing distributions of vessels by vessel type, length of calls, average ship service speed, and proportions of call times spent in each of the four modes. It also lists the 95 largest U.S. deep-sea ports and matches each of these ports to the eight

⁵ U.S. EPA, *Control of Air Pollution from Marine Compression-Ignition Engines*, Part 94, Code of Federal Regulations, December 1999. (Published in the Federal Register December 29, 1999.)

⁶ U.S. EPA, *Control of Emissions from New Marine Compression-Ignition Engines*, Part 94, Code of Federal Regulations, February 2003. (Published in the Federal Register February 28, 2003.)

⁷ ENVIRON, *Commercial Marine Emission Inventory Development*, April 2002.

⁸ ARCADIS, *Commercial Marine Activity for Deep Sea Ports in the United States*, EPA420-R-99-020, September 1999.

⁹ ENVIRON, *Commercial Marine Emission Inventory Development*, April 2002.

typical deep-sea ports in the report. Another ARCADIS report provides a methodology for inland river and Great Lake ports and provides matching to the top 55 Great Lake and river ports in the U.S.¹⁰

The simplest way for a port to calculate emissions is to use the emissions per call per ship type from the ENVIRON report¹¹ used in the 2003 Rulemaking and multiply it by the number of calls per year per ship type calling on the individual port. A slightly more sophisticated approach is to determine the time spent for each call (time between leaving the breakwater and arriving at the breakwater) and subtract the reduced speed zone and maneuvering time per call listed for the typical port. The remaining time is hoteling time, which can vary greatly by call. Cruise times generally do not vary greatly between ship calls, because this represents time spent at service speed traveling the last 25 miles in the open ocean to the breakwater and back out again.

A detailed inventory also accounts for non-port marine emissions, which include ship movements outside of the 25-mile port radius but within 175 miles of the coast. EPA used the 175-mile radius in developing their regulatory impact analysis for 2003 Category 3 marine diesel engines, and included vessels passing through the region in transit. Apportionment of these emissions is discussed in EPA's rulemaking. Some ports, however, have used a much smaller radius when developing an emissions inventory (such as three nautical miles), while others use anywhere between 25 and 100 miles out to sea.

For large ports, detailed activity data should be determined based upon actual time in port information collected by the ports. This time is apportioned to the various operational modes (cruise, reduced speed zone, maneuvering, and hoteling) based upon distances, ship type, speed, and other information collected by the port. Details on ship type, service speed, and engine horsepower and type can be obtained from Lloyd's Maritime Information Services if the ship's individual Lloyd's number is recorded. Detailed studies of the Ports of Los Angeles/Long Beach,¹² Ports of Houston/Galveston,¹³ Ports of New York/New Jersey,¹⁴ the Port of Seattle, and the Ports of Beaumont/Port Arthur have been done in this manner. This methodology is similar to that used in developing the national inventory for EPA's 2003 rulemaking.

Emission Factors

Marine vessel emission inventories in the early 1990s were prepared using emission factors released by EPA in their emission inventory preparation guidance document.¹⁵ In that document, EPA distinguished between large ships, divided into motor ships and steamships, and smaller ships divided by engine size. Smaller ships generally included pushboats, towboats, tugboats, ferryboats, work boats, and fishing vessels. EPA did not distinguish between slow-speed (generally 2 stroke engines with maximum speed of less than 300 rpm) and medium speed (generally 4 stroke engines with maximum speeds greater than 300 rpm) engines. Emission rates were given in terms of kilograms of emission per ton of fuel.

¹⁰ ARCADIS, *Commercial Marine Activity for Great Lake and Inland River Ports in the United States*, EPA420-R-99-019, September 1999.

¹¹ ENVIRON, *Commercial Marine Emission Inventory Development*, April 2002.

¹² Acurex Environmental Corporation, *Marine Vessel Emissions Inventory and Control Strategy*, December 1996. This study was later revised by ARCADIS (previously Acurex), *Marine Vessels Emissions Inventory: UPDATE to 1996 Report: Marine Vessel Emissions Inventory and Control Strategies*, September 1999.

¹³ Starcrest Consulting Group, *Houston-Galveston Area Vessel Emissions Inventory*, November 2000.

¹⁴ Starcrest Consulting Group, *The New York, Northern New Jersey, Long Island Nonattainment Area Commercial Marine Vessel Emissions Inventory*, April 2003.

¹⁵ US EPA, *Procedures for Emission Inventory Preparation*, Volume IV: Mobile Sources, EPA420-R-92-009, December 1992.

Such emission factors require either a knowledge or estimation of fuel consumption rates. Fuel consumption rates are not usually measured, but are estimated from engine design and loading data, where engine loading itself can only be estimated. The data that underlie these emission factors is limited and is an aggregation of engine tests on a variety of engine types and sizes. Furthermore, none of the engine tests in the datasets used to derive emission factors represents engines that meet the MARPOL Annex VI NO_x emission standards. MARPOL Annex VI defines NO_x limits for engines built on or after January 1, 2000, including those that underwent a major rebuild after January 1, 2000. Although Annex VI emission limits are not currently enforced (because an insufficient number of International Maritime Organization member states have ratified the agreement), most ship engine manufacturers are building engines compliant with Annex VI.

In its recent rulemakings, EPA modified its marine engine emission factors based upon new findings.¹⁶ The rulemakings also list emission factors for those engines that are compliant with Annex VI emission levels. These emission factors are given in units of grams of pollutant per kilowatt-hour. Such emission factors can be used directly with the power required in each operating mode and the length of time in each operating mode to produce emissions per call. These factors are the EPA-approved emission factors for inventory preparation.

It should be noted, however, that the emission factors are still derived from limited data. Emission testing of ocean-going vessels 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. As more data become available, EPA will revise their approved emissions factors to be used in port emissions inventories.

Future Year Projections

In order to project future year emission inventories for Category 3 marine diesel engines, several factors need to be taken into account. These include the overall expected growth in cargo movements, the type and size of vessel that would handle the increased freight movements, and the effect of the Annex VI emission regulations on the fleet emissions as older vessels are scrapped and replaced by newer vessels.

Expected freight movements can be estimated using freight forecasts of by the U.S. Maritime Administration (MARAD). MARAD supplies estimated freight forecasts for several types of vessels. MARAD estimates, based upon historic freight growth between 1996 and 1999, vary between 2.2 and 6.6 percent per year, depending on vessel type.

In their 2003 rulemaking, EPA increased the overall dead weight tonnage (DWT) calling annually at ports and traversing waterways in proportion to the projected freight increases based on MARAD estimates. The additional vessel calls needed to accommodate the increased tonnage were added to the largest DWT category by vessel type.

In addition to the effects of increased freight tonnage and future changes in fleet makeup, the effects of the internationally negotiated NO_x limits were included in EPA's future year projections. The internationally negotiated NO_x limits are related to rated engine speed as shown in Table 2.

¹⁶ These include ENVIRON, 2000, Starcrest 2000, and Corbett and Fischbeck, *Commercial Marine Emission Inventory for EPA Category 2 and 3 Compression Ignition Marine Engines in the United States Continental and Inland Waterways*, EPA 420-R-98-020, 1998.

Table 2: MARPOL Annex VI NOx Emission Standards (g/kW-hr)

Engine Speed (n)		
n ≥ 2000 rpm	2000 > n ≥ 130 rpm	n < 130 rpm
9.8	45.0 x n ^{-0.2}	17.0

For Category 1 and 2 engines, EPA used, in their 1999 rulemaking, data supplied by Power Systems Research (a commercial provider of engine data) to determine growth factors for recreational, commercial, and auxiliary marine diesel engines based upon U.S. production of marine engines. Normalized scrappage curves were also developed assuming average useful lives for each of the three applications.

3. Land-Based Inventory Development Methods

Land-based port emissions can come from three general sources: on-dock equipment, on-road trucks, and locomotives. On-dock equipment can represent a sizable portion of total port emissions, as much as one-third to one-half of the ocean-going ship emissions according to some estimates. Yard trucks may be operated 16 hours a day, seven days a week to move containers from the dock to trucks and rail. Significant emission reductions may be possible from on-dock equipment through alternative fuels, repowering the equipment with a newer, lower emission engine, or accelerated turnover, and these reductions are often easier to gain than those from foreign flag ocean-going vessels. Note that on- and off-road vehicles are regulated by state and federal emission standards.

In SIPs, land-based non-road emissions are calculated using the NONROAD model (OFFROAD in California), while the on-road component is calculated using MOBILE (EMFAC in California). Generally, SIP documents assign these sources to the counties or air districts in which these emissions occur, rather than explicit attribution to a port, but can be port-specific for very large ports. Because the marine terminal and not the port usually own the on-dock equipment, a detailed inventory of this equipment is often unavailable. Instead, the NONROAD model makes use of data from Power Systems Research on national engine and equipment populations by horsepower and fuel type. The NONROAD model then uses economic and demographic data, such as population and employment, to allocate non-road equipment to states and counties.¹⁷ It cannot be used directly to estimate the land-based non-road emissions attributable to a port without significant modification. By using the emission factors in NONROAD together with accurate port equipment populations and activity levels, estimates of emissions from land-based port equipment can be made at a port level. Another possibility is to allocate county non-road emissions to a port similar to the method the NONROAD model uses to allocate national inventories to counties.

The NONROAD model uses information about equipment age, horsepower, and numbers, as well as duty cycle, to determine emissions from non-road sources. The model year and horsepower determine which emissions standard each piece of equipment meets – uncontrolled, Tier 0, Tier 1, Tier 2, or Tier 3. The duty cycle determines the transient correction factor, and its age determines how much deterioration has occurred.

On-road truck emissions operating within a port are calculated using MOBILE6 (EMFAC in California). These again are usually lumped in with the other on-road truck emissions and not directly assigned to ports in a SIP. Because of these gross allocation schemes, emissions from ports may be over or

¹⁷ U.S. EPA, *Geographic Allocation of State Level Nonroad Engine Population Data to the County Level*, EPA Report NR-014b (EPA420-P-02-009, posted Dec 11, 2002)

underestimated by a considerable amount in SIPs.

For more detailed port emission calculations, such as those needed for NEPA and general conformity assessments, or in instances where states may want to take SIP credit for emission reduction programs they implement at specific ports, better and more detailed inventory development of land-based non-road and on-road emissions are necessary. Development of an EIS (or an EIR in California) for a port project may require a detailed inventory of land-based dock equipment such as yard trucks (hostlers), rubber tire gantries, rail mounted gantries, aerial cranes, top and side picks, and other equipment – an inventory that includes the model year, horsepower, fuel type, and operating characteristics of each piece of equipment. Collecting this information is very time consuming because most port handling equipment is owned by the terminal operator, not the port. If these data can be collected, total emissions for land-based port equipment can be determined using emission factors for each type of equipment.

It is important to note that the in-use duty cycle of much of the port equipment does not necessarily match the emission test duty cycle. For example, port equipment tends to idle a much greater percentage of the time than the test cycle, so emission factors using the test cycle certification results could overstate overall emission factors for port equipment.

For an EIS, on-road truck emissions at ports are also typically modeled more precisely than in the SIP process. This involves determining the volume of truck traffic that picks up loads at the port and the typical duty cycle of those trucks. Trucks entering ports may wait in lines idling for long periods, and this idling is not generally encompassed in the normal emission factors generated by MOBILE. Emissions factors need to be developed that include lengthy idling times to better represent on-road truck emissions at ports. Generally on-road truck traffic is a small portion of the emissions picture at ports (compared to marine vessels and on-dock equipment) because of the small distance they travel within the port area.

When a port emissions inventory is done for an EIS/EIR, there is no consistent approach to estimating emissions from trucks once they leave the port vicinity. Some inventories have estimated the emissions from port-serving trucks throughout the region; other inventories consider only the truck emissions that occur at the port facility.

To date, the NONROAD model has not been structured to produce locomotive emission estimates. Most state and local environmental agencies prepare such emission estimates using diesel fuel consumption for the region and emission factors developed by EPA.¹⁸ It is possible to develop more refined and localized estimates of locomotive fuel consumption by obtaining data on the time spent by locomotives in each power notch setting. Because locomotives usually operate only a limited time and distance within a port, the emissions from this sector are relatively small.

4. Conclusion and Recommendations

Recommendation 1 – It is recommended that all ports develop an emission inventory and update that inventory periodically so that it reflects current activity and emission rates. It is recommended that the inventory include both marine emission sources as well as land-based sources at ports. An accurate emission inventory is necessary for ports to understand the environmental impacts of their operations, to assess the impacts of port improvements projects or growth in port activity, and to plan emission control strategies. While many ports may be required to develop such an inventory as part of preparation of a SIP or environmental review under NEPA, there are compelling non-regulatory reasons for maintaining an accurate assessment of port-related emissions. An emission inventory is necessary for ports to be engaged in national and regional discussions about environmental issues. Ports will also be better prepared to

¹⁸ U.S. EPA, *Emission Factors for Locomotives*, EPA Report EPA420-F-97-051, December 1997.

respond to new environmental initiatives or regulations if they understand the sources of emissions at their facilities. This is particularly true for ports that are growing or ports located in an area that may be designated as a new air quality nonattainment area.

Recommendation 2 – To improve emissions inventories at ports, it is recommended that EPA develop detailed guidance for ports and air quality agencies to use that standardize emission calculations for inventory purposes. Smaller and mid-size ports typically have limited resources to develop detailed inventories. Now that a number of ports have experience with more sophisticated methodologies, it is recommended that EPA provide improved guidance to ports and air quality agencies for developing emission inventories for ports. It is recommended that the guidance clarify issues related to how far out to sea the inventory area should cover, and how to treat emissions from land-side equipment that leaves the port area (e.g., trucks and locomotives). It is recommended that any guidance also stress the importance of port collaboration with the state air quality agency and the metropolitan planning organization (MPO) when developing the inventory.

Recommendation 3 – In addition to developing better guidance for ocean going vessels, it is recommended that EPA draft guidance for estimating emissions from Category 1 and 2 marine vessels. The 1999 EPA Rulemaking provides some guidance for developing estimates, but a good allocation method for allocating national emissions to a port or state level needs to be developed. In addition, the Category 2 national inventory needs to be revised based upon better information. There is a clear need for an integrated guidance document that provides sophisticated methodology for large ports and more simplified methodology for mid-size and smaller ports to use in preparing their inventory for SIP purposes.

Recommendation 4 – There is little information on the number and size of auxiliary engines on Category 3 ships. Since hoteling 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 1999 EPA Rulemaking 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 5 – There is also a need for the development of updated and more accurate marine vessel emission factors. The current emission factors are based upon limited test data. Tests of newer vessels that meet the IMO Annex VI NO_x standard are not available. 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 ocean-going vessels as they participate in worldwide commerce. It is recommended that emission factors specific to PM-2.5 also be developed. Currently emission factors for PM-2.5 are an approximation based upon PM-10 emission factors.

Recommendation 6 – 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. There is a need for an improved methodology to determine the amount of activity of Category 2 vessels in port areas and the U.S. airshed.

Recommendation 7 – For NEPA 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.

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