The Philadelphia Port – Diesel Particulate Emissions Sources and Potential Control Measures

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Disclaimer

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Executive Summary

The U.S. Environmental Protection Agency (EPA) Region III office is evaluating particulate matter emissions from diesel engines in the Philadelphia, Pennsylvania metropolitan area. This evaluation includes an assessment of diesel particulate emissions from the Port of Philadelphia, as well as other ports within the Philadelphia metropolitan area.

Located roughly at the transition between the Delaware Bay and the Delaware River – about 150 kilometers (82 nautical miles) from the Atlantic Ocean – Philadelphia is ranked the 20^{th} largest port in the U.S. Six other cities in the Philadelphia metropolitan area are also ranked among the top 150 largest ports in the U.S., including Paulsboro, New Jersey – ranked 26^{th} – and Marcus Hook, Pennsylvania – ranked 29^{th}.

S.1 Background

The EPA estimates national emissions of particulate matter from marine vessels and allocates these emissions to major ports as part of the National Emissions Inventory (NEI). Because of Philadelphia's large cargo throughput, the 1999 NEI allocated 470 Mg (518 tons) of marine vessel diesel emissions to the city. An additional 815 Mg (909 tons) was allocated to other ports in the Philadelphia metropolitan area. These estimates include both diesel-powered harbor vessels and oceangoing vessels. Oceangoing cargo vessels generally burn heavy bunker fuel oil, but are powered by compression-ignition engines, which are diesel engines. In the draft 2002 inventory, the estimates of marine vessel emissions in Philadelphia and the neighboring ports increase somewhat from 1999, while emissions from other sources such as highway vehicles are projected to decline.

The NEI values for marine vessel emissions in 1999 constituted almost 50% of total diesel particulate estimate for the city of Philadelphia, and about 26% of the total for the metropolitan area. However, these estimates are subject to considerable uncertainty. In fact, preliminary calculations by the Pennsylvania Department of Environmental Protection have indicated that marine vessel emissions are much lower.

Port facilities also include a number of land-based operations which emit diesel particulate matter. These are not calculated explicitly in the NEI, but are included in overall estimates for nonroad mobile sources.

S.2 Purpose

The overall purpose of this project is to evaluate diesel particulate emissions and possible control technologies for the Port of Philadelphia. The current report evaluates diesel particulate emissions from marine vessels and land-based operations at the port. This includes an assessment of the validity of assumptions used in the NEI. In addition, although this analysis focuses on the Port of Philadelphia, emissions estimates are also provided for other ports in the

Philadelphia metropolitan area. Potential control strategies for diesel emissions from the Port of Philadelphia are also identified and discussed.

S.3 Estimated Diesel Particulate Emissions from Port Operations

Emissions have been estimated for port operations in the Philadelphia metropolitan area using methodologies developed for recent activity-based, or "bottom up," of port emissions for other cities. In particular, we have drawn on emission factors and algorithms used in emissions inventories the Port of New York and New Jersey and for the Port of Los Angeles. Information on port activities has also been obtained from the Philadelphia Regional Port Authority,[1, 2] the Maritime Exchange for the Delaware River and Bay, the Pilots Association for the Delaware Bay and Delaware River, the Philadelphia office of Moran Towing Company, and the U.S. Army Corps of Engineers Waterborne Commerce publications. Data were also drawn from the Delaware River case study in EPA's 1999 analysis of *Commercial Marine Activity for Deep Sea Ports in the United States* (by Arcadis).

Table S-1 summarizes the activity-based emissions estimates for diesel particulate matter from oceangoing vessels, tugboats and tow boats, land-based cargo equipment at port facilities, and passenger ferries. Land-based cargo handling equipment at port facilities in Philadelphia county accounts for an estimated 42 Mg/year (47 tons/year) of emissions, which is about half of our overall emissions estimate for port facilities in the county. However, the emissions estimates from land-based cargo handling are very uncertain. Information was not available on the sizes of diesel engines used in this equipment, on the age of the equipment, or on average engine loads. In addition, operating hours were not directly available, but were estimated from the ship traffic at each port facility. The NEI does not explicitly estimate emissions from land-based cargo handling at port facilities, but this equipment generally falls into the NEI category of construction and mining equipment. Our estimate for land-based cargo handling is compatible with the overall NEI estimate of 125 Mg/yr (138 tons/yr) from diesel construction and mining equipment in Philadelphia county.

The oceangoing vessel category in Table S-1 corresponds to residual oil fueled vessels in the NEI,[*] while the tugboat and ferry boat categories would correspond to diesel oil fueled commercial vessels in the NEI. Our estimates indicate that oceangoing vessels account for the largest share of diesel particulate emissions from port facilities, both in Philadelphia county and in the overall metropolitan area. However, these estimated emissions are much lower than the corresponding estimate in the NEI – about 28.0 Mg/year (30.9 tons/year), compared to 383 Mg/year (422 tons/year) in the draft 2002 NEI for residual oil fueled vessels in Philadelphia county. The difference between the estimates for commercial vessels fueled by diesel oil is even more pronounced. The combined activity-based emissions estimate for tugs and ferries in Philadelphia county is only about 12 Mg/year (13 tons/year) compared with 368 Mg/year (406 tons/year) for the overall diesel-powered commercial marine vessel category in the draft 2002 NEI.

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[*]Though fueled by residual oil, most oceangoing vessels use diesel engines.

Table S-1. Summary of Estimated Emissions from Port Operations in the Philadelphia Metropolitan Area Counties, 2003
(Metric units)

Emission source	Estimated emissions by county (Mg/yr)							
	Phila-delphia	Delaware, PA	Bucks, PA	Camden, NJ	Gloucester, NJ	Burlington, NJ	New Castle, DE	Total
Oceangoing vessels [a]								
Traveling	5.3	10.3	0.5	1.4	13.7	0.7	55.0	86.3
Maneuvering	3.7	2.4	0.5	2.5	1.8	0.1	2.4	13.3
Hoteling	19.1	11.9	2.7	12.9	8.3	0.5	12.3	67.3
Subtotal	28.0	24.5	3.2	16.7	23.8	1.2	69.5	167
Tug boats								
Traveling to dock	3.7	0.7	0.9	1.1	0.5	1.5	0.2	8.6
Traveling with barges	5.5	0.5	1.9	2.4	0.6	3.5	10.2	24.7
Docking assistance	2.2	0.4	0.3	0.4	0.3	0.3	0.2	4.1
Subtotal	11.4	1.6	3.1	3.9	1.4	5.3	10.6	37.4
Land-based cargo equipment								
Container cranes	1.4	b	b	b	b	b	b	1.4
Top loaders	3.2	b	b	b	b	b	b	3.2
Forklifts	6.6	b	b	b	b	b	b	6.6
Yard tractors	15	b	b	b	b	b	b	15
Other equipment	16	b	b	b	b	b	b	16
Subtotal	42							42
Passenger ferries	0.41	b	b	0.4	b	b	b	0.41
Totals	82	26	6.3	21	25	6.5	80	247

[a] Includes diesel engine vessels powered by residual oil.
[b] Not estimated.

– continued –

Table S-1. Summary of Estimated Emissions from Port Operations in the Philadelphia Metropolitan Area Counties, 2003
(continued – English units)

Emission source	Estimated emissions by county (tons/yr)							
	Phila-delphia	Delaware, PA	Bucks, PA	Camden, NJ	Gloucester, NJ	Burlington, NJ	New Castle, DE	Total
Oceangoing vessels[a]								
Traveling	5.8	11.4	0.5	1.5	15.1	0.8	60.6	95.1
Maneuvering	4.1	2.6	0.6	2.8	2.0	0.1	2.7	14.7
Hoteling	21.1	13.1	3.0	14.2	9.2	0.5	13.6	74.2
Subtotal	30.9	27.0	3.5	18.4	26.2	1.3	76.6	184
Tug boats								
Traveling to dock	4.1	0.8	1.0	1.2	0.5	1.6	0.2	9.5
Traveling with barges	6.1	0.6	2.1	2.6	0.7	3.9	11.3	27.2
Docking assistance	2.4	0.5	0.3	0.5	0.4	0.3	0.2	4.5
Subtotal	12.6	1.8	3.4	4.3	1.5	5.8	11.7	41.2
Land-based cargo equipment								
Container cranes	1.6	b	b	b	b	b	b	1.6
Top loaders	3.5	b	b	b	b	b	b	3.5
Forklifts	7.3	b	b	b	b	b	b	7.3
Yard tractors	17	b	b	b	b	b	b	17
Other equipment	18	b	b	b	b	b	b	18
Subtotal	47							47
Passenger ferries	0.46	b	b	0.5	b	b	b	0.46
Totals	91	29	6.9	23	28	7.1	88	273

[a] Includes diesel engine vessels powered by residual oil.
[b] Not estimated.

The differences between the activity-based emissions estimates and the NEI estimates for commercial vessels are believed to be the result of the default allocation methodology used in the NEI. The NEI estimates total emissions for marine vessels in U.S. waters, and then allocates these emissions to major ports. The allocation methodology assumes that the amount of fuel used by vessels within a port is proportional to the amount of cargo handled. In addition, the NEI methodology makes a default assumption that 25% of marine bunker fuel is consumed in port, and 75% of marine diesel fuel is consumed in port.

For oceangoing vessels calling at ports in the Philadelphia metropolitan area, we have estimated that, on average, only about 17% of emissions in U.S. waters occur within the metropolitan area. The remaining 83% occurs while the ships travel through the 200 nautical mile economic exclusion zone and the lower Delaware Bay.

For commercial diesel vessels, we believe that the default allocation methodology has overestimated the share of national emissions that occur in the Philadelphia area. This may be due to the lack of a major fishing fleet in Philadelphia and the other ports in the Philadelphia metropolitan area. As noted above, the national allocation methodology is based on cargo handling. However, commercial fishing would also have an important impact on the consumption of marine diesel fuel. None of the ports in the Philadelphia area is listed by the Corps of Engineers as a major commercial fishing port. The nearest is Cape May, New Jersey, which was the 15^{th} largest commercial fishing port in 2003. Cape May is outside of the Philadelphia metropolitan area, about 108 kilometers (59 nautical miles) downstream from Philadelphia.

S.4 Summary of Control Options

As shown in Section 4 (Table 19), we have estimated overall diesel particulate emissions from port operations in Philadelphia county at about 82 Mg (91 tons). Land based cargo handling equipment is estimated to account for about 51% of this total, oceangoing vessels are estimated to account for about 34%, and harbor vessels about 14%.

Substantial emission reductions could be achieved in all three of these sectors by the use of cleaner diesel fuels, such as low sulfur marine gas oil, highway diesel fuel, emulsified diesel, biodiesel, or ultralow sulfur diesel. Total potential emission reductions from the use of these fuels range from 22 to 36 Mg/year (24–40 tons/year). Emissions from the hoteling vessels could be reduced by an estimated 58–75%, or 12–16 Mg/year (13–17 tons/year) by the use of these fuels in ships' auxiliary engines. Emissions from tugboats and towboats could be reduced by an estimated 17–40%, or 1.9–4.4 Mg/year (2.1–4.8 tons/year); and emissions from land-based cargo handling equipment could be reduced by an estimated 16–58% or 7.7–16 Mg/yr (8.4–18 tons/year). With the exception of oceangoing vessels, these fuel substitutions can be made without modifying engine fueling systems. However, fuel leakage due to oil-seal-related problems could occur from switching between fuel types with significantly different fuel properties. For oceangoing vessels, modifications would be needed to separate the auxiliary engine fuel from bunker fuels used for the main propulsion engines.

Further emission reductions (up to 95%) could be achieved by the application of diesel particulate filters to land-based cargo handling equipment and passenger ferries (with Category 1 diesel engines). In addition, reductions of up to 98% could be achieved by replacing older cargo-handling engines with onroad certified engines, beginning in 2007. Diesel powered cargo handling equipment could also be replaced with LPG or electric equipment. In fact, terminals in Philadelphia are already using LPG or electric engines for most of their light-duty fork lifts.

Emissions from ocean-going vessels could be reduced by about 18% or a total of 5 Mg (4.5 tons) by the creation of a regional SECA. In addition, up to 20 Mg/year (22 tons/year) of hoteling emissions from oceangoing vessels could be eliminated by the implementation of cold ironing. However, this option could require substantial capital costs for modifications to both piers and ships. The implementation of air pollution control strategies for oceangoing vessels is complicated by the fact that only a fraction of the emissions from these vessels is released near land, and an even smaller fraction is released in any given port city. In addition, most oceangoing vessels are foreign-flagged.

Successes and barriers to controlling emissions from ports have been discovered as ports begin to implement their control strategy programs. Port representatives at stakeholder meetings and workshops have suggested incentive programs to overcome barriers to implementation. Barriers to implementation may include technology, such as lack of verified retrofit technologies: there may not be a market for retrofits on some equipment unique to port applications. Capital and operating costs may be prohibitive or may not make business sense. Lack of emissions inventories or regulatory enforcement could also hinder implementation.

1. Introduction

The U.S. Environmental Protection Agency (EPA) Region III office is evaluating particulate matter emissions from diesel engines in the Philadelphia, Pennsylvania metropolitan area. Diesel particulate emissions are an important target of EPA's Integrated Urban Strategy under the National Air Toxics Program. These emissions also contribute to overall ambient concentrations of fine particulate matter ($PM_{2.5}$),[b] which is regulated by National Ambient Air Quality Standards (NAAQS). The Philadelphia metropolitan area has been designated as nonattainment for $PM_{2.5}$.

The EPA National Emissions Inventory (NEI) estimates that marine vessels emitted 470 Megagrams (Mg) or 518 tons of diesel particulate matter in the city of Philadelphia in 1999. This is almost 50% of the total estimated diesel particulate emissions in the city, and about 23% of total $PM_{2.5}$ emissions in the city. The draft 2002 NEI estimates diesel particulate emissions from marine vessels in Philadelphia at 490 Mg (440 tons), which is more than 50% of total estimated emissions in the city. However, the NEI entries for marine vessels in Philadelphia are default estimates derived by an allocation of national fuel consumption figures. Thus, the marine vessel estimates are subject to considerable uncertainty. In fact, preliminary calculations by the Pennsylvania Department of Environmental Protection have indicated that marine vessel emissions are much lower. Port facilities also include a number of land-based operations which emit diesel particulate matter and $PM_{2.5}$.

The overall purpose of this project is to evaluate diesel particulate emissions and possible control technologies for the Port of Philadelphia. The current report evaluates diesel particulate emissions from marine vessels and land-based operations at the port. This includes an assessment of the validity of assumptions used in the NEI. In addition, although this analysis focuses on the Port of Philadelphia, emissions estimates are also provided for other ports in the Philadelphia metropolitan area. Potential control strategies for diesel emissions from the Port of Philadelphia are also identified and discussed.

[b] $PM_{2.5}$ is defined as the portion of particulate matter (PM) with an aerodynamic diameter less than or equal to 2.5 microns.

2. Port Activities in the Philadelphia Region and Sources of Diesel Particulate Emissions

The City of Philadelphia is located at the junction of the Delaware and Schuylkill Rivers, at the northern end of the Delaware River Estuary. Based on statistics compiled by the Army Corps of Engineers, Philadelphia is the 20th largest port in the U.S., handling about 30 Teragrams (Tg) of cargo (33 million tons) in 2003.[3] Most of this cargo is imported, although a small fraction – about 0.5% – is exported.

In addition to Philadelphia, six other Delaware River cities are ranked on the Army Corps of Engineers list of the 150 largest ports in the U.S. Table 1 shows the amount of cargo handled at these ports in 2003, and gives their approximate distances from Philadelphia. Camden and Gloucester City, New Jersey are located directly across the Delaware River from Philadelphia, and are combined in the Corps of Engineers statistics. Port facilities in these cities handled about 20% of the cargo handled in Philadelphia. Paulsboro and Marcus Hook, Pennsylvania each handle about 80% as much cargo as Philadelphia. Paulsboro is about 5.9 kilometers (3.2 nautical miles) down the Delaware River from Philadelphia on the New Jersey side; and Marcus Hook is about 18 kilometers (10 nautical miles) down-river in Pennsylvania.

Table 1. Cargo Throughputs for Philadelphia and Other Nationally Ranked Ports on the Delaware River

	Estimated total cargo shipments in 2003 [a]			Approximate distance from Philadelphia	
Port city	Tg/year	million tons/year	National rank	kilometers	Nautical miles
Philadelphia	30.2	33.2	20	0	0
Camden and Gloucester city [b]	6.2	6.8	65	0.7	0.4
Paulsboro	24.8	27.3	26	5.9	3.2
Chester	1.8	2	118	12.3	6.7
Marcus Hook	23.7	26.2	29	18.1	9.9
Wilmington	6.2	6.8	74	32.2	17.6
New Castle	7.7	8.5	58	38.2	20.9

[a] Source: U.S. Army Corps of Engineers – Waterborne Commerce, National Summaries.[3]
[b] Camden, New Jersey is combined with the adjacent city of Gloucester, New Jersey in the Waterborne Commerce statistics.

This section gives an overview of port operations in Philadelphia and the other ports in the Philadelphia area, and summarizes available information on marine vessel traffic in the ports. In addition, potential sources of diesel particulate matter are identified.

2.1 Port Operations in Philadelphia

The Port of Philadelphia is not confined to a single location within the city, but instead consists of several distinct facilities separated by commercial and residential properties that are also located on the waterfront. Figure 1 shows the locations of port facilities and other maritime operations in Philadelphia, on both the Delaware and Schuylkill Rivers.

The Pennsylvania legislature created the Philadelphia Regional Port Authority (PRPA) in 1989 to manage, maintain, and promote the public port facilities along the Delaware River in Philadelphia, as well as to protect maritime-industrial activity in the port district. The Port Authority manages a large number of publicly-owned facilities, including the Packer Avenue Marine Terminal, Piers 96 and 98, Pier 84, Pier 82, Piers 78 and 80, Piers 38 and 40, and the Tioga Marine Terminal.[4] The largest of these facilities is the Packer Island Marine Terminal, which unloads a variety of types of cargo from container ships, break-bulk carriers, and other types of ships. The other facilities are more specialized. Pier 84 handles cocoa and some steel, Pier 82 handles mostly fruit, Piers 80, 38, and 40 handle mostly paper, and the Tioga Marine Terminal handles mostly fruit and lumber. Piers 96 and 98 are currently inactive.

In addition to the publicly-owned Port Authority facilities, a number of private terminals are operated within Philadelphia, on both the Delaware and Schuylkill Rivers. Oil and chemical tankers are received at Kinder Morgan, Port Richmond, Maritank, and three Sun Oil facilities – Fort Mifflin, Girard Point and Hog Island. Pier 122 handles fertilizer, ore, and minerals. Table 2 summarizes the cargo handled at the different Philadelphia facilities, and the number of ships calling at each facility in 2003. This information is compiled by the Maritime Exchange for the Delaware River and Bay.[5]

The historic Philadelphia Naval Base was located at the junction of the Schuylkill and Delaware Rivers. The base was closed in 1996, and has been redeveloped as the Philadelphia Naval Business Center. This center includes the Kvaerner Philadelphia Shipyard and the Philadelphia Cruise Terminal. About 32 cruise ships are expected to call at the Cruise Terminal in 2005. In addition, two tugboat companies are located at the Naval Business Center: Moran Towing and McAlister Towing.

A recreational marina, the Philadelphia Marine Center, is located near the Ben Franklin Bridge. In addition, a passenger ferry runs between Philadelphia and Camden, New Jersey, docking at Penn's Landing. Although some fishing boats may be located at the Marine Center, Philadelphia is not listed as an important commercial fishing port by the Army Corps of Engineers.[3]

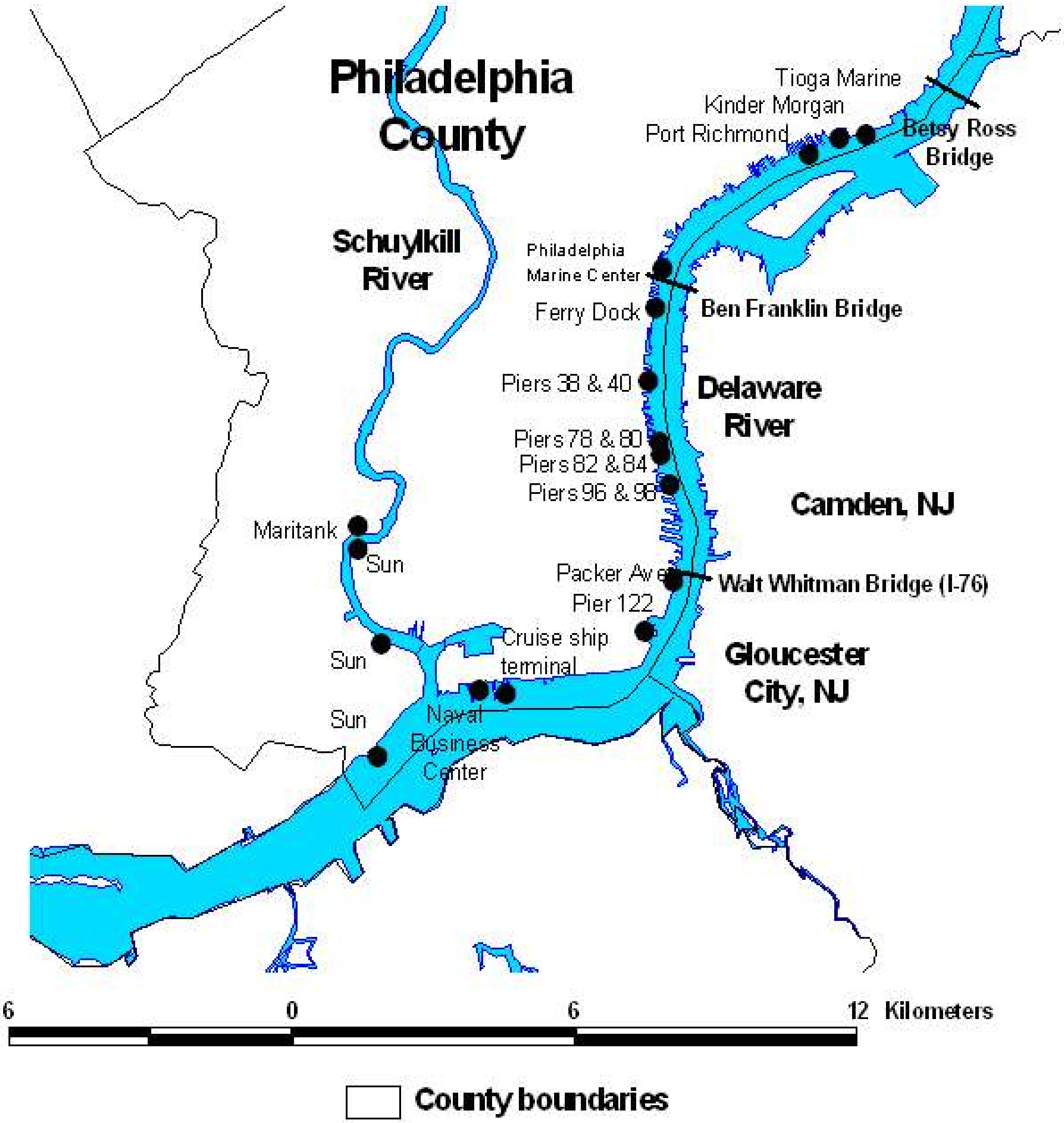

Figure 1. Location of Port Operations in Philadelphia

Table 2. Summary of Cargo Handled at Philadelphia Port Facilities and Numbers of Ships Calling in 2003

Port facility	Cargo handled	Number of ships in 2003 [a]
Philadelphia, Delaware River		
Cruise Terminal	Passengers	31
Packer Ave.	Steel, containers, dairy, general	211
Pier 122	Fertilizer, ore, minerals	2
Pier 80	Paper	90
Pier 82	Fruit	52
Pier 84	Cocoa, steel	13
Pier 96	Unknown	1
Piers 38 & 40	Paper	20
Tioga Marine	Fruit, lumber	83
Peco	Coal	12
Other	Miscellaneous	2
Kinder Morgan	Oil or petrochemicals	51
Port Richmond	Oil or petrochemicals	54
Sun Fort Mifflin	Oil or petrochemicals	134
Sun Hog Island	Oil or petrochemicals	34
Philadelphia, Schuylkill River		
Maritank	Oil or petrochemicals	1
Sun Girard Point	Oil or petrochemicals	27

[a] Source: Maritime Exchange for the Delaware River and Bay.[5]

2.2 Other Ports in the Philadelphia Area

Figure 2 shows the locations of other ports and port facilities the Philadelphia area. As noted in Table 1, six nationally ranked ports, in addition to Philadelphia, are located along the Delaware River. These are: Camden (including Gloucester city), New Jersey; Paulsboro, New Jersey; Chester, Pennsylvania; Marcus Hook, Pennsylvania; Wilmington, Delaware; and New Castle, Delaware. All of these port cities are located within the Philadelphia-Wilmington $PM_{2.5}$ nonattainment area. Cargo is also handled at Delaware city, Delaware, and at several locations in Bucks county Pennsylvania; Burlington county, New Jersey; and Salem county, New Jersey. Bucks county and Burlington county are both in the Philadelphia-Wilmington $PM_{2.5}$ nonattainment area, and Salem county, New Jersey is directly across the Delaware River from the Delaware portion of the nonattainment area. The Corps of Engineers records tugboat and barge traffic as far inland as Trenton, New Jersey. Trenton is not in the $PM_{2.5}$ nonattainment area, but tugs traveling to Trenton would pass by Philadelphia. Trenton is also directly across the Delaware River from Bucks county.

None of the ports in the Philadelphia area is listed by the Corps of Engineers as a major commercial fishing port.[3] The nearest major fishing port is Cape May, New Jersey, which is at the ocean end of the Delaware Estuary about 108 kilometers (59 nautical miles) downstream from Philadelphia. Cape May was ranked as the 15th largest commercial fishing port in 2003.

Table 3 summarizes the cargo handled at the other ports in the Philadelphia area, and the number of ships calling at each facility in 2003.[5] Port facilities in Camden Gloucester, New Jersey; Chester, Pennsylvania; and Wilmington, Delaware handle a variety of dry cargo. Dry cargo is also received at the facilities in Bucks county, Pennsylvania; Burlington county, New Jersey; and Salem county, New Jersey.

Paulsboro and Marcus Hook both handle large quantities of oil and petrochemicals. As noted in Table 1, each of these ports is almost as large as Philadelphia, in terms of the total weight of cargo handled. Tankers are also handled at the Hess refinery in Camden.

2.3 Summary of Ship Activity in Philadelphia and Area Ports

The Army Corps of Engineers gathers information on ship movements in the Delaware River and the Delaware Bay. Statistics are provided on vessel trips to and from Philadelphia, Camden, and Wilmington. Within Philadelphia, the Corps differentiates between port facilities on the Schuylkill River and port facilities on the Delaware River. In addition, the Corps distinguishes between the section of the Delaware River below Philadelphia (from Philadelphia to the sea) and the section above Philadelphia (to Trenton). Statistics are compiled for five categories of vessels: self-propelled dry cargo and passenger ships, self-propelled tanker ships, tugboats and tow boats, unpowered dry cargo barges, and unpowered tanker barges. In addition, vessels are classified into different size categories based on draft, and are divided into domestic and foreign vessels.[6]

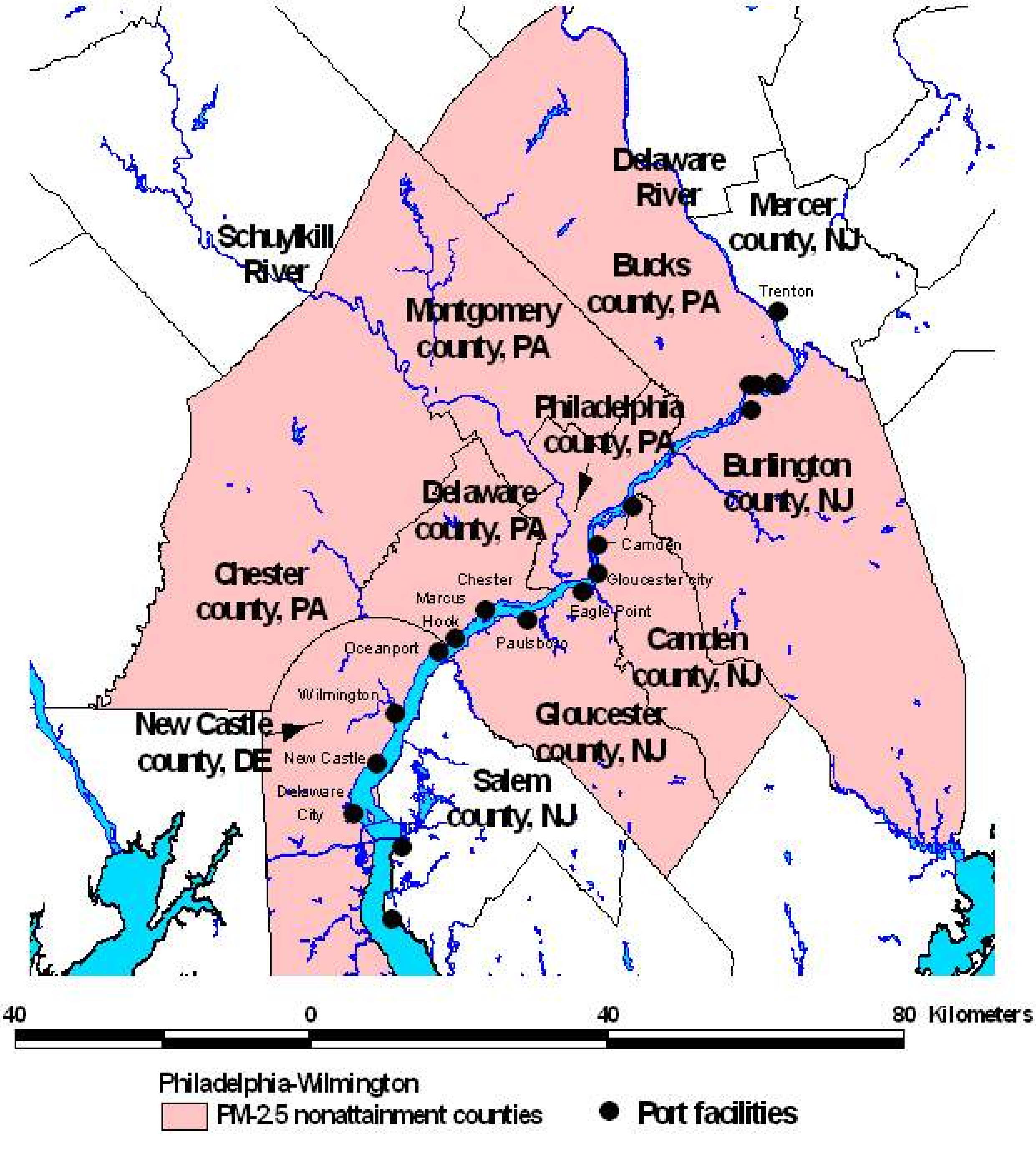

Figure 2. Locations of Other Port Operations in the Philadelphia Metropolitan Area

Table 3. Summary of Cargo Handled at Other Philadelphia Area Ports and Numbers of Ships Calling in 2003

Port facility	Cargo handled	Number of ships in 2003 [a]
Camden and Gloucester City, NJ		
1 Broadway	Steel, wood	31
5 Broadway	Fruit	119
Camden Terminal	Plywood, steel, cocoa	130
Gloucester Terminal	Clothes, wood, used autos, fruit, steel	187
Hess	Oil or petrochemicals	49
Paulsboro and Gloucester county, NJ		
Citgo Asphalt	Oil or petrochemicals	57
Eagle Point	Oil or petrochemicals	137
ST Paulsboro	Oil or petrochemicals	57
Valero	Oil or petrochemicals	132
Chester, Pennsylvania		
Penn Terminal	Project, steel, autos, clothes, containers	213
Marcus Hook, Pennsylvania		
Conoco Philips	Oil or petrochemicals	135
Sun	Oil or petrochemicals	140
Oceanport, Delaware	Salt	24
Wilmington, Delaware	Autos, containers, fish, fruit, juice, lumber, meat, minerals, steel	371
Delaware City, Delaware	Oil	136
Bucks county, Pennsylvania		
Grows	Salt, steel	18
Novolog	Steel, project	44
Riverside	Cement, gypsum	9
Burlington county, New Jersey		
Georgia Pacific	Gypsum	7
National Gypsum	Gypsum	13
Salem county, New Jersey [b]		
Bermuda International	Containers	51
Salem Terminal	Miscellaneous	3
Trans Ocean	General	22

[a] Source: Maritime Exchange for the Delaware River and Bay.[5]
[b] Salem county, New Jersey is not part of the Philadelphia-Wilmington $PM_{2.5}$ nonattainment area.

The Maritime Exchange for the Delaware River and Bay also gathers information on ships visiting Philadelphia and the other Delaware River ports, as shown in Tables 2 and 3.[5] Ship and tanker visits are tabulated for each port facility, and the exchange management estimates that it achieves almost 100% coverage of self-propelled cargo vessels. The Maritime Exchange does not track barges or tugboats.

Table 4 summarizes cargo ship traffic for Philadelphia and other ports on the Delaware River. We have used the Maritime Exchange data base for self-propelled cargo ships and tankers, and the Army Corps of Engineers data for unpowered barges and tugboats. The Maritime Exchange data base provides more geographical detail than the Corps of Engineers data base for self-propelled vessels. In addition, the Corps of Engineers data base lumps together dry cargo ships and passenger ships. The two data bases are in rough agreement for tankers within the geographical divisions used by the Corps of Engineers.

The Maritime Exchange also compiles information on the types of ships entering the Delaware River. Table 5 shows the distribution of ship types for self powered dry cargo ships calling at Delaware River ports. The Maritime Exchange does not compile these data for individual ports.[5]

2.4 Sources of Diesel Particulate Emissions

Oceangoing cargo vessels generally burn heavy bunker fuel oil (typically about 2.7%, or 27,000 parts per million sulfur) rather than diesel fuel. Some of these vessels are steamers, but most are typically powered by compression-ignition engines, which are diesel engines.[7, 8] In fact, more than 98% of the oceangoing cargo vessels calling at Delaware River ports were diesel-powered in 1996. Thus, these ships are a source of diesel particulate emissions. In addition to their propulsion engines, most oceangoing cargo vessels have auxiliary diesel engines which are used to produce electrical power for the ship and to run pumps and other equipment. Auxiliary engines are generally run during the entire time that a ship remains at the dock – this is called hoteling. These engines are also used while the ship is maneuvering, when the main propulsion engines are operating at an inconsistent load. Both the propulsion engines and auxiliary engines generally are vented about 30 meters (98 feet) above the waterline.

Tow boats, tugboats, and ferry boats are also sources of diesel particulate matter. These vessels also use diesel engines both for propulsion and for auxiliary power, and generally burn diesel fuel oil.

Port facilities use a variety of diesel equipment to unload dry cargo ships. In the case of a container ship, a crane is used to transfer each container to an on-site yard tractors, which moves the container to a holding area. A top loader then removes the container from the yard tractor to a stack, and later moves the container from the stack to an on-road truck. All of this equipment is diesel-powered, with the exception of some electric cranes at the Tioga Terminal. Break-bulk cargo often unloaded using sailboard cranes, which are ultimately powered using the ship's auxiliary diesel engines. Diesel-powered forklifts and vehicles are also used to move and load the cargo. Table 6 gives a summary of the cargo handling equipment used at the Port Authority facilities in Philadelphia.[4] In contrast, tankers require much less equipment for unloading, since the cargo is transferred by pipeline.

All of the port facilities in Philadelphia have access to rail transport, however truck transport is more commonly used. When rail transport is used, diesel emissions would be produced by both switching locomotives and line haul locomotives.

Table 4. Summary of Ship, Barge, and Tugboat Trips to Philadelphia and Area Ports

<table>
<tr><th rowspan="2">City or area</th><th colspan="5">Number of trips in 2003 [a]</th></tr>
<tr><th>Dry cargo ships [b]</th><th>Tanker ships [b]</th><th>Tow or tugboats</th><th>Dry cargo barges [c]</th><th>Tanker barges [c]</th></tr>
<tr><td>Philadelphia, Delaware River docks</td><td>486</td><td>273</td><td>5,238</td><td>40</td><td>927</td></tr>
<tr><td>Philadelphia, Schuylkill River docks</td><td>0</td><td>28</td><td>1,849</td><td>1</td><td>982</td></tr>
<tr><td>Camden & Gloucester city, New Jersey</td><td>467</td><td>49</td><td>1,799</td><td>181</td><td>752</td></tr>
<tr><td>Paulsboro & Gloucester county, New Jersey</td><td>0</td><td>383</td><td rowspan="6">2,916</td><td rowspan="6">2,107</td><td rowspan="6">1,869</td></tr>
<tr><td>Chester, Pennsylvania</td><td>213</td><td>0</td></tr>
<tr><td>Marcus Hook, Pennsylvania</td><td>0</td><td>275</td></tr>
<tr><td>Oceanport, Delaware</td><td>24</td><td>0</td></tr>
<tr><td>Delaware City, Delaware</td><td>0</td><td>136</td></tr>
<tr><td>Salem county, New Jersey [d]</td><td>76</td><td>0</td></tr>
<tr><td>Wilmington Harbor</td><td>371</td><td>0</td><td>621</td><td>3</td><td>579</td></tr>
<tr><td>Chesapeake and Delaware Canal</td><td>201</td><td>12</td><td>1,908</td><td>1,352</td><td>875</td></tr>
<tr><td>Bucks county, Pennsylvania</td><td>71</td><td>0</td><td rowspan="2">2,598</td><td rowspan="2">17</td><td rowspan="2">1,184</td></tr>
<tr><td>Burlington county, New Jersey</td><td>21</td><td>0</td></tr>
<tr><td>Trenton Harbor [d]</td><td>0</td><td>0</td><td>167</td><td>92</td><td>50</td></tr>
<tr><td>Totals</td><td>1,930</td><td>1,156</td><td>17,096</td><td>3,793</td><td>7,218</td></tr>
</table>

[a] Sources:

Dry cargo ship and tanker ship trips are based on statistics compiled by the Maritime Exchange for the Delaware River and Bay (see also Tables 2 and 3).

Barge and tugboat trips are based on statistics compiled by the U.S. Army Corps of Engineers.

[b] Self-propelled vessels

[c] Unpowered vessels

[d] Trenton and Salem county, New Jersey are not part of the Philadelphia-Wilmington $PM_{2.5}$ nonattainment area, but are directly across the Delaware River.

Table 5. Overall Distribution of Dry Cargo Ships Visiting Delaware River Ports

Type of ship	Contribution to total dry cargo ships (%)
Container ships	19.8
Refrigerated carriers	28.7
Bulk carriers	19.0
Automobile carriers	7.4
Roll-on / roll-off ships	4.8
General cargo ships	20.3
Total	100.0

Source: Maritime Exchange for the Delaware River and Bay[5]

Table 6. Summary of Cargo Handling Equipment Used at Philadelphia Port Authority Facilities

	Number of pieces of equipment				
Equipment	Packer Ave.	Pier 84	Pier 78/80	Pier 38/40	Tioga
Container cranes, 375 tons	1				
Container cranes 45-65 tons	6				2
Toploaders, 47 tons	6				3
Toploaders, 15 tons	5				
Forklifts	100	25	100	25	101
Yard tractors	25		40	30	10
5^{th} Wheels			5		
Flatbeds			35	35	
Vans			30	20	

Source: Philadelphia Regional Port Authority.[4, 9]

3. National Emissions Inventory Estimates for Port Emissions

Table 7 presents the diesel particulate emissions estimates given in the 1999 National Emissions Inventory (NEI) for marine vessels in the Philadelphia area. Table 8 gives diesel particulate emissions estimates from the 2002 draft NEI. Emissions are given by county for the nine counties in the Philadelphia-Wilmington $PM_{2.5}$ nonattainment area. For comparison, the tables also show the NEI estimates for other emission source categories, including railroad equipment and diesel trucks. However, it must be noted that the NEI does not break down onroad and nonroad mobile source emissions below the county level. Therefore, the inventory does not allow us to estimate the fractions of railroad and trucking emissions that are associated with port facilities. The NEI also includes emissions for cranes, forklifts, and other freight handling equipment. This equipment is included in the totals for “other nonroad diesel exhaust.”

The NEI estimates indicate that marine vessels account for a very large share of diesel particulates in the region, and especially in Philadelphia itself. This section reviews the assumptions and methodologies used in the NEI for marine vessels.

3.1 National Emissions Inventory Methodology for Marine Vessels

The NEI methodology does not entail port-specific calculations of marine vessel emissions from each port. Instead, emissions are estimated on a national basis, and then allocated to the major ports in the U.S. based on their cargo throughput. The flow diagram in Figure 3 depicts the general process of estimating port emissions.

3.1.1 Calculation of National Estimates

The Environmental Protection Agency has divided commercial marine diesel engines into three categories. The three categories are as follows:

Category 1 – displacement < 5 liters and power $\geq$ 37 kilowatts (50 horsepower)
Category 2 – displacement between 5 liters and 30 liters
Category 3 – displacement $\geq$ 30 liters

In the document, *Final Regulatory Impact Analysis: Control of Emissions from Marine Diesel Engines*, (*RIA*) national emissions of particulate matter for each category of marine diesel engines are estimated.[10] Methods used for the different categories of engines are discussed in the following subsections.

Table 7. Diesel Particulate Estimates in the 1999 NEI for Marine Vessels and Other Sources in the Philadelphia Region

Description	Source classification code (SCC)	Phila-delphia, PA	Dela-ware, PA	Bucks, PA	Mont-gomery, PA	Chester, PA	Camden, NJ	Bur-lington, NJ	Glou-cester, NJ	New Castle, DE	Total
					Annual Emissions by County (Mg/yr)						
Marine vessels, commercial, diesel oil	2280002200	368.0	203.2	0.7	0.0	0.0	56.4	1.0	252.0	130.0	1,011.3
Marine vessels, commercial, residual oil	2280003200	102.1	56.5	0.2	0.0	0.0	15.9	0.4	69.9	38.5	283.5
Pleasure craft, inboard/sterndrive	2282020005	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.5	1.3
Pleasure craft, outboard	2282020010	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Railroads, line haul, Class I	2285002006	1.4	1.6	0.9	4.0	3.2	0.0	0.0	0.0	3.0	14.2
Railroads, line haul, Class II / III	2285002007	2.5	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	2.9
Railroads, yard locomotives	2285002010	0.6	0.7	0.4	1.6	1.3	0.0	0.0	0.0	1.2	5.7
Railroads, railway maintenance	2285002015	2.6	1.0	1.1	1.3	0.7	0.9	0.8	0.5	0.9	9.7
Diesel construction equipment	2270002xxx	137.0	44.5	65.9	80.1	68.7	50.4	57.1	46.3	110.7	660.7
Other nonroad diesel exhaust	various	68.7	31.8	46.5	68.7	29.3	30.8	25.6	13.9	34.5	349.8
Onroad diesel exhaust	various	322.8	113.5	163.3	175.3	131.9	143.8	157.5	96.6	180.7	1,485.5
Point source diesel exhaust	various	2.2	1.6	0.0	0.8	0.1	0.0	0.0	0.0	0.0	4.7
Total		1,008.0	454.5	279.1	332.2	235.3	298.3	242.6	479.3	500.0	3,829.4
					Annual Emissions by County (tons/year)						
Marine vessels, commercial, diesel oil	2280002200	405.6	224.0	0.7	0.0	0.0	62.2	1.1	277.8	143.3	1,114.8
Marine vessels, commercial, residual oil	2280003200	112.5	62.3	0.3	0.0	0.0	17.5	0.4	77.1	42.4	312.5
Pleasure craft, inboard/sterndrive	2282020005	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.5	1.4
Pleasure craft, outboard	2282020010	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Railroads, line haul, Class I	2285002006	1.5	1.8	1.0	4.5	3.5	0.0	0.0	0.0	3.3	15.6
Railroads, line haul, Class II / III	2285002007	2.8	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	3.1
Railroads, yard locomotives	2285002010	0.6	0.7	0.4	1.8	1.4	0.0	0.0	0.0	1.3	6.3
Railroads, railway maintenance	2285002015	2.9	1.1	1.2	1.4	0.8	1.0	0.9	0.5	1.0	10.7
Diesel construction equipment	2270002xxx	151.0	49.1	72.6	88.3	75.7	55.6	62.9	51.0	122.0	728.3
Other nonroad diesel exhaust	various	75.7	35.1	51.3	75.7	32.3	34.0	28.2	15.3	38.0	385.6
Onroad diesel exhaust	various	355.9	125.1	180.0	193.3	145.3	158.5	173.7	106.5	199.2	1,637.5
Point source diesel exhaust	various	2.4	1.8	0.0	0.9	0.1	0.0	0.0	0.0	0.0	5.2
Total		1,111.0	501.0	307.6	366.3	259.2	328.8	267.5	528.5	551.1	4,221.1

Table 8. Diesel Particulate Estimates in the 2002 NEI for Marine Vessels and Other Sources in the Philadelphia Region

Description	Source classification code (SCC)	Phila-delphia, PA	Dela-ware, PA	Bucks, PA	Mont-gomery, PA	Chester, PA	Camden, NJ	Bur-lington, NJ	Glou-cester, NJ	New Castle, DE	Total
Annual Emissions by County (Mg/yr)											
Marine vessels, commercial, diesel oil	2280002200	383.2	218.2	0.7	0.0	0.0	48.2	1.0	235.6	54.3	941.2
Marine vessels, commercial, residual oil	2280003200	106.3	60.6	0.2	0.0	0.0	13.6	0.4	65.4	118.3	364.9
Pleasure craft, inboard/sterndrive	2282020005	0.1	0.1	0.3	0.1	0.1	0.1	0.2	0.2	0.4	1.5
Pleasure craft, outboard	2282020010	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Railroads, line haul, Class I	2285002006	1.3	1.5	0.9	4.0	3.2	5.8	0.3	2.2	8.2	27.3
Railroads, line haul, Class II / III	2285002007	2.3	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.1	2.8
Railroads, yard locomotives	2285002010	0.5	0.6	0.3	1.6	1.3	0.0	0.0	0.0	10.6	15.0
Railroads, railway maintenance	2285002015	2.5	1.0	1.0	1.3	0.7	0.9	0.8	0.4	0.8	9.4
Diesel construction equipment	2270002xxx	125.0	40.6	60.1	70.7	61.6	47.1	53.4	43.3	101.0	602.8
Other nonroad diesel exhaust	various	62.6	29.4	43.3	65.9	32.1	29.1	24.2	13.1	31.7	331.4
Onroad diesel exhaust	various	130.8	78.0	125.1	149.1	112.1	101.9	117.5	68.7	118.6	1,001.8
Point source diesel exhaust	various	na	0.5	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.8
Total		814.6	430.5	231.9	293.2	211.1	246.7	197.8	428.9	444.0	3,299.0
Annual Emissions by County (tons/year)											
Marine vessels, commercial, diesel oil	2280002200	422.4	240.5	0.8	0.0	0.0	53.1	1.2	259.7	59.9	1,037.5
Marine vessels, commercial, residual oil	2280003200	117.2	66.8	0.3	0.0	0.0	15.0	0.4	72.1	130.4	402.2
Pleasure craft, inboard/sterndrive	2282020005	0.2	0.1	0.3	0.1	0.1	0.1	0.2	0.2	0.4	1.7
Pleasure craft, outboard	2282020010	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Railroads, line haul, Class I	2285002006	1.4	1.7	1.0	4.5	3.5	6.4	0.3	2.4	9.0	30.1
Railroads, line haul, Class II / III	2285002007	2.6	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.1	3.1
Railroads, yard locomotives	2285002010	0.6	0.7	0.4	1.8	1.4	0.0	0.0	0.0	11.7	16.5
Railroads, railway maintenance	2285002015	2.8	1.1	1.1	1.4	0.8	1.0	0.8	0.5	0.9	10.4
Diesel construction equipment	2270002xxx	137.8	44.8	66.2	77.9	67.9	51.9	58.9	47.7	111.3	664.5
Other nonroad diesel exhaust	various	69.0	32.4	47.7	72.6	35.4	32.1	26.7	14.4	34.9	365.3
Onroad diesel exhaust	various	144.1	85.9	137.9	164.3	123.6	112.4	129.6	75.7	130.7	1,104.3
Point source diesel exhaust	various	na	0.6	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.9
Total		898.1	474.6	255.8	323.3	232.7	272.0	218.0	472.8	489.4	3,636.6

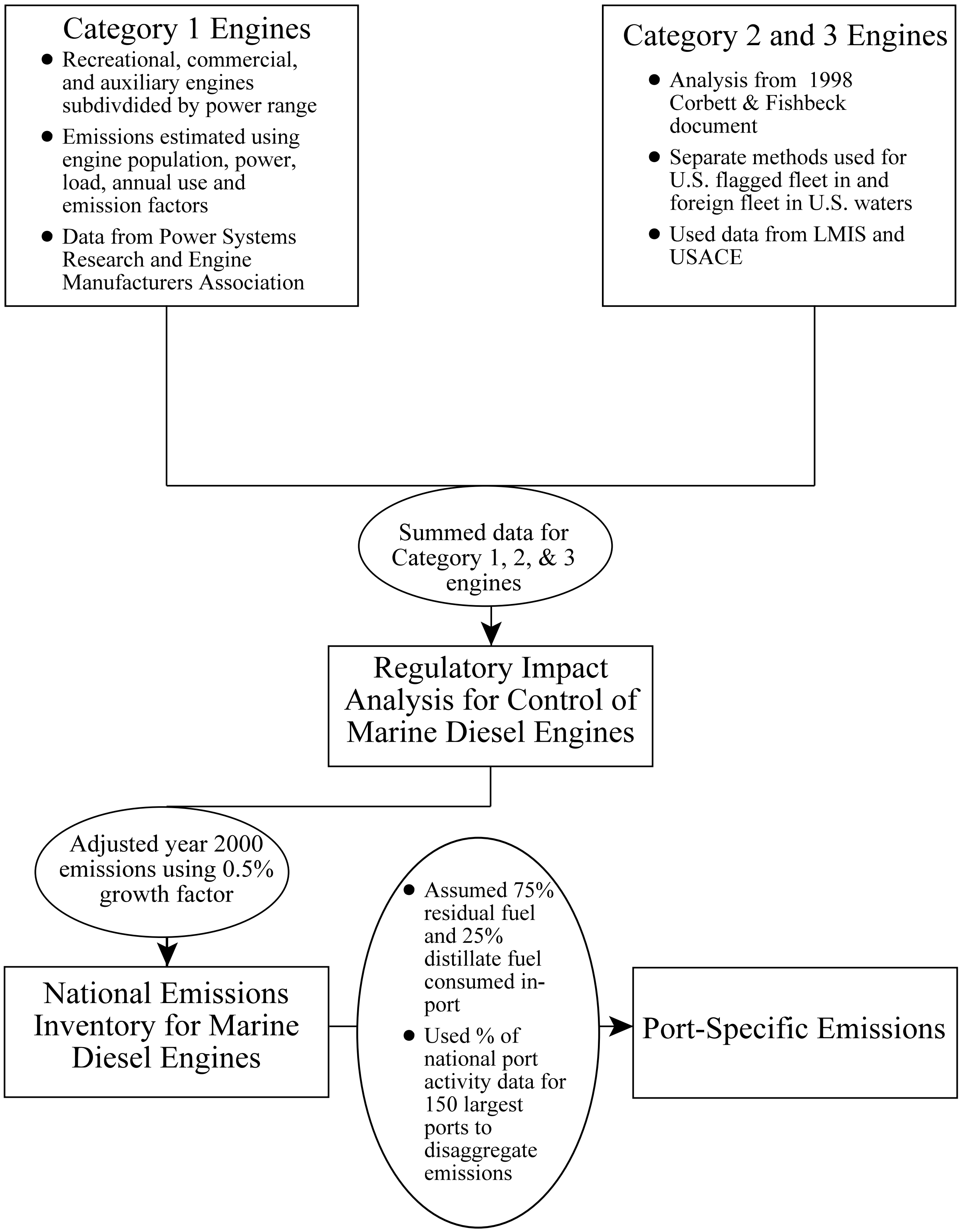

Figure 3. Methodology used to estimate marine vessel emissions in the NEI.

3.3.1.1 Category 1 Marine Diesel Engines

Category 1 marine diesel engines are divided by application into recreational, commercial, and auxiliary engines. These groups were then further subdivided into power ranges. The algorithm used to determine emissions from Category 1 engines can be summarized as follows:[12]

$$\text{Emissions} = \Sigma_{(\text{rec., com., aux})} [\Sigma_{(\text{ranges})} (\text{population} \times \text{power} \times \text{load} \times \text{annual use} \times \text{emission factor})]$$

where:

Population	refers to the number of marine diesel engines greater than or equal to 37 kW but with a displacement per cylinder of five liters or less estimated to be in the U.S. in a given year.
power	refers to the population-weighted average rated power for a given power range
load	is the ratio between the average operational power output and the rated power
annual use	is the average hours of operation per year

Engine populations were taken form the 1997 Power Systems Research (PSR) Parts Link database. EPA used normalized scrapage rates from PSR and assumed average useful lives of the recreational, commercial, and auxiliary engine applications to project future year engine populations. EPA estimated growth using data from PSR providing information on U.S. production of marine diesel engines. Engine usage data (load and annual use) for recreational and commercial engine applications were obtained from the Engine Manufacturers Association (EMA). The data included average annual hours of use, load factors, and emission factors broken down by ranges of rated power and rated speed. Information on auxiliary marine engines was obtained from individual manufacturers.

EPA developed emission factors from the EMA data and sample data already obtained for uncontrolled marine diesel engines. Emission factors were applied on the basis of engine power rating, and represent the weighted value between levels from baseline and controlled marine engines operating in a given calendar year. The baseline emission factors presented in Table 9 were used to estimate emissions from uncontrolled Category 1 marine engines.[10]

Table 9. Baseline Emission Factors Used in the NEI for Category 1 Engines

Power range		Emission factor	
Kilowatts	Horsepower	g/kW-hr	lb/1000 hp-hr
37 – 75	50 – 100	0.9	1.48
75 – 130	100 – 174	0.4	0.66
130 – 225	175 – 300	0.4	0.66
225 – 450	300 – 600	0.3	0.49
450 – 560	600 – 750	0.3	0.49
560 – 1,000	750 – 1340	0.3	0.49
1,000+	1340+	0.3	0.49

Projected Category 1 baseline PM emissions projected for the year 2000 from recreational, commercial, and auxiliary engines were estimated at 13.5 Gigagrams (Gg) or 14,900 tons using this process. This estimate was projected backward to 1999 and forward to 2002 using a growth rate of 0.5% per year.

3.3.1.2 Categories 2 and 3 Marine Diesel Engines

Emissions from Category 2 and 3 engines were calculated in the 1999 NEI using the methods presented in a August 1998 document titled by Corbett and Fischbeck, entitled *Commercial Marine Emissions Inventory for EPA Category 2 and 3 Compression Ignition Engines in the United States Continental and Inland Waterways.*[11] This document estimated emissions from main propulsion engines within U.S. waters, including inland waterways, the U.S. portion of the Great Lakes, and ocean waters within the 200 nautical mile (366 km) economic exclusion zone. Emissions from auxiliary engines were not included.

Fuel-based emission factors reported by Lloyd’s Register Engineering Services in the Marine Exhaust Emissions Research Program were used as they were considered the “most current emissions factors for large compression ignition marine engines in commercial use today.” These emissions factors are listed in Table 10.

Table 10. Emission Factors Used in the NEI for Category 2 and 3 Engines

	Diesel PM emission factor	
Speed of engine	**g/kg of fuel**	**lb/ton of fuel**
Slow-speed	7.6	15
Medium-speed	1.2	2.4

Corbett and Fischbeck use separate techniques to estimate overall emissions from the U.S. flag fleet and from foreign vessels operating in U.S. waters.

3.1.2.1.1 U.S. Flag Fleet

For the U.S. flag gleet, daily fuel consumption was estimated for different types and sizes of ships, as shown in Table 11. The estimates of fuel consumption in Table 4 were combined with the fuel-consumption based emission factors. It was assumed that all Category 2 engines were medium-speed engines. The larger engines in Category 3, represented by Category 3B, were assumed to be slow-speed engines. Half of the smaller engines in Category 3, represented by Category 3A, were assumed to be medium-speed and half were assumed to be slow-speed engines.

Table 11. Estimated Fuel Consumption Used in the NEI for Category 2 and 3 Engines in the U.S. Fleet

	Daily fuel use by category					
	Category 2		Category 3A		Category 3B	
Vessel Service	**Mg/day**	**ton/day**	**Mg/day**	**ton/day**	**Mg/day**	**ton/day**
Container	4.5	5			50.8	56
Fishing	4.5	5	11.8	13	9.1	10
Passenger			9.1	10	18.1	20
RoRo	5.4	6	43.5	48	36.3	40
Transport	5.4	6	28.1	31	26.3	29
Tug	4.5	5	21.8	24	28.1	31
Utility	3.6	4	18.1	20	10.9	12

The number of ships in the U.S. commercial fleet with engines in each category were estimated using engine manufacturer and model data gathered for commercial ships greater than 100 gross registered tons (GRT) and listed in Lloyds Maritime Information Service (LMIS) database of registered vessels. Engine data was available from LMIS for 42% of the data set, the remaining vessels were distributed using statistical methods.

Brake horsepower was available from LMIS for nearly all of the engines. Break horsepower was multiplied by a typical brake-specific-fuel-consumption (BSFC) factor for the indicated horsepower range. General assumptions were made for the speed of Category 2 and Category 3 engines which were used for fuel consumption estimates. Fuel-based emission factors were multiplied by the estimated fuel-consumption to estimate daily emissions in kilogram per day. Daily emissions per ship were multiplied by the number of ships and number of days per year to estimate annual emissions.

The annual emissions estimate was reduced by 20% to account for the assumption that vessels are underway 80% of the time during the year. The estimate was further reduced by 48%, a percentage based on the number of U.S. vessels carrying foreign cargo and the time those vessels spend in U.S. waters, to account for emissions occurring outside of U.S. waters. The total estimate of PM emissions for all Category 2 and 3 marine diesel engines in the U.S. fleet was 14.2 Gg (15,700 tons) using this method.

3.1.2.1.2 Foreign Vessels Operating in U.S. Waters

To estimate emissions from foreign-flagged vessels operating in U.S. waters, Corbett and Fischbeck combined 1993 data from the U.S. Army Corps of Engineers (USACE) National Waterway Network, which contains geographic information on links, with 1993 USACE Waterborne Commerce Statistics Center data on shipments. Using the two data sources, cargo movements in ton-miles for each region were calculated by summing the product of the number of tons shipped along each link in a region by the length of the link. The estimated daily emissions from the U.S. flag fleet operating in U.S. waters were applied to the vessel average dead weight tonnage (DWT) and speed data from LMIS. Since DWT is a measure of the weight of the entire contents of a ship, not just cargo, the DWT from LMIS was multiplied by 80% to estimate the maximum cargo capacity and then by 50% for vessels operating on ocean routes and 60% for vessels operating on inland rivers and Great Lakes to estimate the typical cargo capacity. Speed data from LMIS represents the design rated speed of the vessel, so that marine duty-cycle load factors were applied to speed as it was to BHP for U.S. flagged vessels. Emissions per ton-mile and emissions per year were then calculated. The total estimate of PM emissions for all Category 2 and 3 marine diesel engines in foreign vessels operating in U.S. waters was 9.4 Gg (10,400 tons) using this method.

3.1.2 Allocation of Estimates to Individual Ports

The estimate of national emissions from commercial marine diesel emissions were disaggregated into national underway emissions and national in-port emissions based on assumptions from EPA SIP guidance that 75% of distillate fuel and 25% of residual fuel is consumed within the port and the remaining is consumed while underway. The national port emissions estimate was then allocated to specific ports using activity data from U.S. Army Corps of Engineers 2001 version of *Waterborne Commerce of the United States, Part 5-Waterways and Harbors National Summaries.*[3] The percentage of total traffic from each port was calculated by dividing the port-level traffic by the total traffic. The percentage of national traffic for each port was then applied to the national port emissions estimate.[12]

Underway emissions were calculated using a GIS data set from the Department of Transportation. The data set identified shipping lanes and estimated shipping activity in terms of ton miles. Shipping lanes were then matched to a county. Each county was assigned a weighting factor by summing the product of the waterway length (miles) in the county and the waterway-cargo traffic (tons) for each segment of the waterway, and then dividing the sum total by the national total. The weight factor was then applied to the national estimate of underway emissions to attribute them to each county. The NEI documentation indicates that some underway emissions are attributed to the port areas.

3.2 Analysis of the National Emissions Inventory Methodology

The NEI methodology provides for detailed analysis of different categories of vessels, with the application of appropriate average emission factors and load assumptions. This approach produces a good estimate of total emissions on a national scale.

However, the final step of allocating emissions to individual ports important drawbacks. The allocation methodology for in-port emissions in the NEI is based on total cargo handling in the top 150 ports. This methodology inherently assumes that the amount of fuel used by vessels within a port is proportional to the amount of cargo handled. In addition, the methodology assumes that smaller ports to not account for significant fuel usage.

Finally, for all of the traffic allocated to each port, the NEI methodology makes a default assumption that 75% of diesel oil and 25% of residual oil is consumed within the port. In the case of Philadelphia, a typical cargo vessel (fueled by residual oil) will pass through the 200 nautical mile (366 km) economic zone and then travel 150 km (82 nautical miles) up the Delaware Bay and Delaware River. On average, the ship then travels only about 11 km (6.2 nautical miles) in Philadelphia county before arriving at the dock. Thus, even allowing for the reduced speed zone in Philadelphia county, the ship would spend less than 5% of its time in U.S. waters within Philadelphia county. This is much lower than the NEI assumption that 25% of the ship's fuel is consumed within the port.

4. Diesel Particulate Emissions Estimates for Philadelphia and Area Ports

"Bottom up" activity-based emissions inventories have been developed for a number of other ports, including the combined ports of New York City and northern New Jersey; Los Angeles, California; Long Beach, California; and Houston, Texas. In addition to marine vessels, these assessments cover other emission sources associated with the port, including ground based cargo equipment, railroad locomotives, and on-road trucks picking up cargo. The assessments are sometimes very detailed, extending to load factors and operating schedules for specific pieces of equipment. This type of detailed analysis is beyond the scope of the current effort for Philadelphia. However, these previous inventories provide a number of useful inputs to develop activity-based emissions estimates for Philadelphia and other nearby ports.

In addition, EPA's 1999 analysis of *Commercial Marine Activity for Deep Sea Ports in the United States* (by Arcadis) includes a specific case study of the Delaware River ports.[7] Information on port activities has also been obtained from the Philadelphia Regional Port Authority,[13, 14] the Maritime Exchange for the Delaware River and Bay,[15] the Pilots Association for the Delaware Bay and Delaware River,[16] the Philadelphia office of Moran Towing Company,[17] and the U.S. Army Corps of Engineers Waterborne Commerce publications.

The following sections estimate annual emissions of diesel particulate matter from oceangoing vessels, tugboats and tow boats, land-based cargo equipment at port facilities, on-road trucks operating on port facilities, ferries, and other passenger boats.

4.1 Oceangoing Vessels

Recent bottom-up marine vessel emissions inventories have adopted an approach based on ship activity, rather than the fuel-use based approach used in the NEI.[18, 19] In the activity-based approach, emissions are calculated based on the engine power used in different situations. We have also used this approach for ocean-going vessels calling at Philadelphia and other ports in the area. Emissions were estimated for the full range of operating modes, including cruising, traveling at reduced speed, maneuvering to the dock, and hoteling.

Total emissions were determined by aggregating emissions for different ship types and modes of operation. The algorithm can be summarized as follows:

$$E_T = \sum_i N_i \sum_j E_{i,j}$$

$$E_{i,j} = P_i \times L_{i,j} \times t_{j,j} \times EF_i$$

$$EF_i = \left(f_i \times EF_S\right) + \left[\left(1 - f_i\right) \times EF_F\right]$$

where:

E_T = total emissions
N_i = number of trips for ship type *i*
$E_{i,j}$ = emissions from ship type *i* in operating mode *j*
P_i = average engine power rating for ship type *i*
$L_{i,j}$ = average load factor for ship type *i* in operating mode *j*
$t_{i,j}$ = average time per trip for ship type *i* in operating mode *j*
EF_i = average emission factor for ship type *i*
f_i = fraction of ships in type *I* with engine speed less than 130 rpm
EF_S = emission factor for slow-speed engines
EF_F = emission factor for high-speed engines

Numbers of trips for different ship types were obtained from the Maritime Exchange for the overall Delaware River region.[5] Trips were apportioned to different port facilities in the region as shown in Table 12, based on the types of cargo handled at each port (from Tables 1 and 2), and on statistics compiled by the Corps of Engineers for container shipments.[5, 20]

Diesel particulate emission factors for oceangoing vessel engines were taken from the recent Los Angeles port inventory.[18] They were derived from a 2002 study by ENTEC for the European Commission, which included specific operational details of approximately 30,000 ships.[21] Separate factors were used for slow-speed diesel propulsion engines, other propulsion engines (including medium- and high-speed diesel as well as turbines), and auxiliary engines. Table 13 summarizes the emission factors used in the current estimates, both in terms of emissions per engine power developed and in terms of emissions per fuel usage. The fuel usage factors are presented for comparison with the emission factors used in the EPA NEI, which were previously summarized in Table 10. The ENTEC-derived factors used in this inventory are about 33% higher than the NEI for slow-speed diesels, and almost a factor of 3 higher for other diesel engines. All of the emission factors in Table 13 are based on a residual oil fuel, with an average sulfur content of 2.7% or 27,000 parts per million (ppm).

The fractions of ships using slow-speed diesel engines were taken from the EPA/Arcadis case study of Delaware River ports, which compiled detailed information on ships calling in the region in 1996.[7] These fractions were applied to the emission factors for slow-speed diesels and other propulsion engines to compute an average main engine emission factor for each type of ship, as shown in Table 14.

Data on the sizes of main propulsion engines, average vessel cruising speeds, maneuvering times, and hoteling times for various ship types were also taken from the EPA/Arcadis activity study (see Table 15).[7] The study did not include auxiliary engine sizes. These were taken from the Los Angeles port inventory.[18]

Table 12. Allocation of Ship Visits to Different Ports in the Philadelphia Area

	Estimated number of trips for different vessel types[a]								
Port	Bulk carrier	Con-tainer ship	General cargo	Pass-enger	Refrig-erated	Roll-on roll-off	Tanker	Vehicle carrier	Total
Philadelphia	96	140	72	31	114	63	301	1	825
Camden, NJ	125	72	45	0	205	0	49	20	516
Paulsboro, NJ	0	0	0	0	0	0	383	0	383
Chester, PA	40	78	35	0	0	0	0	60	213
Marcus Hook, PA	0	0	0	0	0	0	275	0	275
Bucks county, PA	0	0	71	0	0	0	0	0	62
Burlington county, NJ	0	0	20	0	0	0	0	0	20
Salem, NJ	32	10	34	0	0	0	0	0	76
Wilmington, DE	52	76	43	0	146	15	0	39	371
Delaware City, DE	0	0	0	0	0	0	126	0	126
Oceanport, DE	12	0	12	0	0	0	0	0	24
Total	357	376	330	31	465	78	1,134	120	2,891

[a] Overall numbers of trips for different ship types were obtained from the Maritime Exchange. Trips were apportioned to different port facilities based on the types of cargo handled at each port (see Tables 1 and 2), and cargo statistics compiled by the Corps of Engineers.[5, 20]

Table 13. Diesel Particulate Emission Factors for Ocean-Going Vessels

	Emission factors based on engine power		Emission factors based on fuel usage	
Engine type	g/kW-hr	lb/1000 hp-hr	g/kg fuel	lb/ton fuel
Main propulsion engines				
Slow-speed, <130 rpm	1.92	3.16	9.14	18.3
Medium or high-speed	0.72	1.18	3.43	6.86
Auxiliary engines	0.3	0.49	1.43	2.86

Source: Emission factors based on engine power are based on factors from the Los Angeles port inventory,[18] which in turn are derived from a European ENTEC study.[21] These were converted to a fuel usage basis using a fuel efficiency factor of 210 g-fuel/kW-hr (350 lb-fuel/1000 hp-hr), from the ENTEC study.

Table 14. Fraction of Slow-speed Diesel Engines and Estimated Average Emission Factors

Ship type	Fraction of slow-speed engines, <130 rpm (%)[a]	Estimated average emission factor for ship type[b]	
		g/kW-hr	lb/1000 hp-hr
Bulk carrier	64	1.49	2.45
Container ship	62	1.46	2.41
General cargo	10	0.84	1.38
Passenger	0	0.72	1.18
Reefer	59	1.43	2.35
Roll-on roll-off	31	1.09	1.80
Tanker	81	1.69	2.78
Vehicle carrier	92	1.82	3.00
Unspecified dry cargo	64	1.49	2.45

[a] Source: Arcadis, 1999 [5]

[b] Averages of the factors in Table 12, weighted by the fraction of low speed diesel engines and the remaining fraction of diesel engines.

Table 15. Average Data for Oceangoing Vessels in Philadelphia Area River Ports (1996)

Ship type	Main engine power		Auxiliary engine power		Average cruising speed		Average maneuver-ing time per trip (hrs)	Average hoteling time per trip (hrs)
	MW	1000 hp	MW	1000 hp	km/hr	knots		
Bulk carrier	8.2	11.0	1.2	1.6	27	15	1.7	95.8
Container ship	11.5	15.4	5.7	7.7	35	19	1.1	33.5
General cargo	4.7	6.3	1.8	2.4	26	14	1.6	91.3
Passenger	25.7	34.4	11.0	14.8	40	22	1.1	20.5
Reefer	8.2	11.0	1.3	1.7	35	19	1.5	63
Roll-on roll-off	6.6	8.8	5.0	6.7	29	16	1.2	60.7
Tanker	11.3	15.1	2.0	2.7	27	15	2.4	85.1
Vehicle carrier	9.6	12.9	2.0	2.7	33	18	1.2	22.7
Unspecified	8.2	11.0	1.7	2.3	27	15	1.7	95.8

Source: Arcadis, 1999 [7]

Ships are assumed to travel at their cruising speed in the Delaware Bay, and to reduce their engine power to 60% at the Pennsylvania border. They are assumed to be maneuvering once they are within 5.5 km (3 nautical miles) of the dock. The vessels are assumed to be hoteling during the entire time that they remain at the dock, with their auxiliary engines at 60% of capacity. Auxiliary engines are also assumed to be run at 60% of capacity while the vessels are maneuvering to the dock.

A propeller power demand curve was used to relate engine load to speed during maneuvering and while vessels are traveling in the reduced speed zone. In the standard propeller power curve, power demand is proportional to the cube of ship speed. For this inventory, adjustment terms are added to reflect the assumptions that cruising speed is attained at 80% of the rated engine power, and that the ship is idling below about 10% load:

$$L_{i,j} = 0.10 + \left[0.70 \times \left({S_j}/{CS_i} \right)^3 \right]$$

where:

$L_{i,j}$ = load factor for ship type *I* in operating mode *j*
S_j = speed in operating mode *j*
CS_i = cruising speed for ship type *I*

The algorithm was also used in the recent emissions inventory for the port of New York and New Jersey.[19]

Table 16 summarizes calculated diesel particulate emissions for ocean-going vessels in Philadelphia and other Delaware River ports. Emissions are broken down by county and for different operating modes. The table gives subtotals for the counties the Philadelphia-Wilmington $PM_{2.5}$ nonattainment area.. In addition to the nonattainment area, emissions are estimated for Salem county, New Jersey, which is across the river from the nonattainment area, for the lower Delaware Bay, and for offshore waters within the 200 nautical mile (366 km) economic exclusion zone.

Table 16. Estimated 2003 Diesel Particulate Emissions for Oceangoing Vessels Calling at Delaware River Ports

County	Traveling	Maneu-vering	Hoteling	Total
	Estimated emissions (Mg/yr)			
Philadelphia, PA	5.3	3.7	19.1	28.0
Delaware, PA	10.3	2.4	11.9	24.5
Bucks, PA	0.5	0.5	2.7	3.2
Camden, NJ	1.4	2.5	12.9	16.7
Gloucester, NJ	13.7	1.8	8.3	23.8
Burlington, NJ	0.7	0.1	0.5	1.2
New Castle, DE	55.0	2.4	12.3	69.5
Subtotal	86.3	13.3	67.3	166.8
Salem, NJ	52.9	0.3	1.5	54.6
Lower Delaware Bay	136	0	0	136
Exclusion Zone	654	0	0	654
	Estimated emissions (tons/yr)			
Philadelphia, PA	5.8	4.1	21.1	30.9
Delaware, PA	11.4	2.6	13.1	27.0
Bucks, PA	0.5	0.6	3.0	3.5
Camden, NJ	1.5	2.8	14.2	18.4
Gloucester, NJ	15.1	2.0	9.2	26.2
Burlington, NJ	0.8	0.1	0.5	1.3
New Castle, DE	60.6	2.7	13.6	76.6
Subtotal	95.1	14.7	74.2	183.9
Salem, NJ	58.3	0.3	1.7	60.2
Lower Delaware Bay	150	0	0	150
Exclusion Zone	721	0	0	721

[a] Subtotal for the Philadelphia-Wilmington $PM_{2.5}$ nonattainment area
[b] Offshore between the 200 nautical mile economic exclusion limit and the entrance to Delaware Bay

4.2 Tugboats and Tow Boats

Philadelphia and the nearby ports are served by three tugboat companies. Moran Towing and McAlister Towing are located in the southern portion of Philadelphia harbor, at the Naval Business Center. Wilmington Tug is located in Wilmington, Delaware. Tugboats provide assistance to large ships while they are docking and leaving the dock. When providing this assistance, the tugs do not accompany the ships up the river, but instead meet them at the docks.[17] Two tugs are typically used to assist each ship. Tugs also push or tow unpowered barges up and down the Delaware and Schuylkill Rivers, and through the Chesapeake and Delaware Canal.[a] Additional tugs may also be used to provide docking assistance for barges.

In order to estimate emissions, we divided tugboat activities into three simplified operating modes: traveling (unloaded) to meet ships, providing docking or undocking assistance, and towing or pushing unpowered barges. Emissions were computed for each operating mode using the following algorithm:

$$E_i = N_i \times \left({D_i}/{S_i} \right) \times P \times L_i \times EF$$

where:

E_i = estimated total emissions for operating mode *I*
N_i = total number of trips that include operating mode *I*
D_i = average distance in operating mode *I* per trip (km)
S_i = average speed for operating mode *I* (km/hour)
P = engine operating capacity (kW)
L_i = engine load factor for operating mode *I* (fraction of operating capacity)
EF = diesel particulate emission factor (g/kW-hr)

Numbers of tugboat trips for Philadelphia and the surrounding area were obtained from the U.S. Army Corps of Engineers waterborne commerce statistics for the Atlantic Coast region (see Table 4).[6] We divided the trips into docking assist and barge towing trips based on the numbers of barge movements (also from Table 4) and the numbers of dockings for powered ships (from Tables 2 and 3). In general, the number of docking assists was assumed to be equal to the number of tug movements minus the number of barge movements; but was always set to at least twice the number of dockings for powered ships.

The average engine operating capacity for tugs in Philadelphia was estimated 2,386 kW (3,200 hp).[17] In addition to their propulsion engines, the tugs use two auxiliary engines to generate electricity for instruments and lights. Information was not available on the typical auxiliary engine size for Philadelphia area tugboats. Based on the Los Angeles port inventory, we estimated that two engines are used per tug, with a total power rating of 10% of the main engine.[18]

[a]The Chesapeake and Delaware Canal passes through New Castle county, Delaware.

Based on their size and speed, tugboat main engines generally fall into the classification of medium-speed Category 2 diesels, for which emission factors are somewhat uncertain. The Los Angeles port inventory used an emission factor of 0.7 g/kW-hr,[18] and the New York and New Jersey inventory used an emission factor of 0.5 g/kW-hr.[19] Both of these values were derived from the European ENTEC study (discussed in the section on *Oceangoing Vessels*).[21] However, the ENTEC factors were adjusted to reflect the U.S. fleet in the New York and New Jersey inventory. The EPA *Final Regulatory Impact Analysis: Control of Emissions from Marine Diesel Engines* (RIA), used an emission factor of 1.2 g/kg of fuel (2.4 lb/ton).[10] Based on an average fuel usage of 210 g/kW-hr (from the ENTEC study), the RIA emission factor would correspond to about 0.25 g/kW-hr, however this value has little documentation. We have adopted the emission factor of 0.5 g/kW-hr for the main engines, based on the New York and New Jersey inventory.

The auxiliary engines are Category 1 diesels, falling into the size range of 75–130 kW (100–175 hp). The EPA RIA emission factor for this category is 0.4 g/kW. Both the Los Angles and New York/New Jersey inventories also adopted the EPA RIA factors for tugboat auxiliary engines.

The Los Angeles port inventory included a detailed survey of engine load factors for tugs operating under various conditions. This survey indicated an average load factor of about 40% when a tug is alone, and about 68% when a tug is providing assistance to a ship or barge.[18] These average values were confirmed as roughly representative by a Philadelphia tugboat operator.[17] Tugs are estimated to travel at 9.1–12.8 km/hour (5–7 knots) in the Philadelphia area.[17] We assumed an average speed of 12.8 km/hour (7 knots) when a tug is traveling to meet ships at the dock, and 9.1 km/hour (5 knots) when the tug is towing or pushing a barge. Docking assists were assumed to require about 30 minutes. Auxiliary engines were assumed to be operated at 50% of capacity whenever the main engine is operating.

Table 17 summarizes the emissions estimates for tugboats in the Philadelphia area in 2003. The table gives emissions for each county and for the three tugboat operating modes.

Table 17. Estimated 2003 Diesel Particulate Emissions for Tugboats in the Philadelphia Area

County	Traveling to meet vessels at docks	Towing barges	Docking	Total
	Estimated emissions (Mg/yr)			
Philadelphia, PA	3.7	5.5	2.2	11.4
Delaware, PA	0.7	0.5	0.4	1.6
Bucks, PA	0.9	1.9	0.3	3.1
Camden, NJ	1.1	2.4	0.4	3.9
Gloucester, NJ	0.5	0.6	0.3	1.4
Burlington, NJ	1.5	3.5	0.3	5.3
New Castle, DE	0.2	10.2	0.2	10.6
	Estimated emissions (tons/yr)			
Philadelphia, PA	4.1	6.1	2.4	12.6
Delaware, PA	0.8	0.6	0.5	1.8
Bucks, PA	1	2.1	0.3	3.4
Camden, NJ	1.2	2.6	0.5	4.3
Gloucester, NJ	0.5	0.7	0.4	1.5
Burlington, NJ	1.6	3.9	0.3	5.8
New Castle, DE	0.2	11.3	0.2	11.7

4.3 Land-based Cargo Equipment at Port Facilities

Emissions have been estimated for land-based cargo handling equipment at facilities managed by the Philadelphia Port Authority. These are the main dry cargo handling facilities in Philadelphia. The only other dry cargo handling facility, Pier 122, unloaded just two ships in 2003. The remaining facilities in Philadelphia are tanker facilities, and diesel particulate emissions from cargo handling at these facilities are believed to be minor. The scope of this project did not allow time for compiling the information necessary to estimate cargo handling emissions for other ports in the Philadelphia metropolitan area.

Table 18 summarizes the parameters used to estimate emissions from land-based cargo handling equipment in Philadelphia, as well as the resulting emissions estimates. The Philadelphia Port Authority has published lists of the machinery available to unload cargo at each of the facilities that it manages.[4] These equipment counts have been given earlier (in Table 6) and are summarized again in Table 18. The Port Authority also has given rough estimates of the time needed to unload different types of cargo ships. Container ships are typically unloaded quickly in about one day, in a round-the-clock operation (about 24 hours). The unloading of bulk carriers is a more complex operation and is therefore usually performed more slowly during daylight hours. This typically requires about three days.[2, 14, 14] These estimates correspond with the typical hoteling times for container ships and bulk carriers found in the Arcadis *Port Activity* study for Philadelphia.[7] The information on unloading times was used with the information on the numbers of ship calls to estimate the hours of operation for unloading equipment at the Port Authority facilities.

In order to estimate emissions from land-based equipment, information is also needed on engine sizes, engine load factors, and emission factors. Information was not available on the diesel engine sizes used in cargo handling equipment. Therefore, engine sizes were estimated based on the Los Angeles port inventory, which covered similar equipment.[18] Table 18 shows the range of engine sizes found in the Los Angeles inventory for various types of equipment, as well as the best estimate of engine size used to estimate emissions for Philadelphia.

Diesel particulate emission factors were calculated based on the documentation for EPA's NONROAD emission model.[22] In calculating emission factor deterioration rates, we assumed that the average age of the cargo handling equipment was, on average, about half of its useful life. Engine load factors were estimated at about 50%.

Table 18. Estimation of Diesel Particulate Emissions from Land-Based Cargo Handling Equipment at Philadelphia Port Authority Docks

Equipment	Number of units	Annual operating hours	Estimation of engine sizes: Potential range (hp)	Best estimates: hp	Best estimates: kW	Load factor (%)	Emission factor: g/kW-hr	Emission factor: lb/1000 hp-hr	Estimated emissions: Mg/yr	Estimated emissions: tons/yr
Packer Avenue										
Container cranes, 375 tons	1	3,360	185-625	625	466	50	0.67	1.10	0.5	0.6
Container cranes 45-65 tons	6	3,360	185-625	185	138	50	0.67	1.10	0.9	1.0
Toploaders, 47 tons	6	3,360	174-330	330	246	50	0.67	1.10	1.7	1.8
Toploaders, 15 tons	5	3,360	174-330	174	130	50	0.67	1.10	0.7	0.8
Forklifts (diesel)	25	2,130	35-280	170	127	50	0.82	1.35	2.8	3.1
Forklifts (propane or electric)	75	2130	35-280	60	45	50	0.00	0.00	0.0	0.0
Yard tractors	25	3,360	182-240	191	142	50	0.82	1.35	4.9	5.4
Subtotal									11	13
Piers 78 and 80										
Forklifts (diesel)	25	2,130	35-280	170	127	50	0.82	1.35	2.8	3.1
Forklifts (propane or electric)	75	2130	35-280	60	45	50	0.00	0.00	0.0	0.0
Yard tractors	40	2700	182-240	191	142	50	0.82	1.35	6.3	6.9
5th Wheels	5	2700		240	179	50	0.82	1.35	1.0	1.1
Flatbeds	35	2700		240	179	50	0.82	1.35	6.9	7.6
Vans	30	2700		240	179	50	0.82	1.35	5.9	6.6
Subtotal									23	25
Tioga Marine										
Container cranes (electric)	2	2490	185-625	185	138	50	0.00	0.00	0.0	0.0
Toploaders, 47 tons	3	2490	174-330	330	246	50	0.67	1.10	0.6	0.7
Forklifts	6	2490	35-280	170	127	50	0.82	1.35	0.8	0.9
Forklifts (propane)	95	2490	35-280	60	45	50	0.00	0.00	0.0	0.0
Yard tractors	10	2490	182-240	191	142	50	0.82	1.35	1.4	1.6
Subtotal									2.8	3.1

(continued)

Table 18. Estimation of Diesel Particulate Emissions from Land-Based Cargo Handling Equipment at Philadelphia Port Authority Docks (continued)

Equipment	Number of units	Annual operating hours	Estimation of engine sizes: Potential range (hp)	Best estimates: hp	Best estimates: kW	Load factor (%)	Emission factor: g/kW-hr	Emission factor: lb/1000 hp-hr	Estimated emissions: Mg/yr	Estimated emissions: tons/yr
Piers 38 and 40										
Forklifts (diesel)	8	600	35-280	170	127	50	0.82	1.35	0.3	0.3
Forklifts (propane or electric)	17	2130	35-280	60	45	50	0.00	0.00	0.0	0.0
Yard tractors	30	600	182-240	191	142	50	0.82	1.35	1.0	1.2
Flatbeds	35	600		240	179	50	0.82	1.35	1.5	1.7
Vans	20	600		240	179	50	0.82	1.35	0.9	1.0
Subtotal									3.7	4.1
Pier 84										
Forklifts (diesel)	8	1,950	35-280	170	127	50	0.82	1.35	0.8	0.9
Forklifts (propane or electric)	17	2130	35-280	60	45	50	0.00	0.00	0.0	0.0
Totals by equipment type										
Container cranes	9								1.4	1.6
Toploaders	15								3.2	3.5
Forklifts	351								6.6	7.3
Yard tractors	115								15	17
5th Wheels, flatbeds & vans	125								16	18
Total									42	47

4.4 Passenger Ferries

Two passenger ferries travel between Philadelphia and Camden, New Jersey seven times per day for eight months of the year. The boats have an engine size of about 969 kW (1300 hp). This falls into the high end of Category 1 engines, where the EPA RIA emission factor for diesel particulate matter is 0.3 g/kW-hr (0.49 lb/1000 hp-hr). Based on the port inventory surveys for New York and New Jersey, ferries of this size also use auxiliary engines ranging from 60–450 kW (80–600 hp). We have assumed an auxiliary engine size of about 250 kW (335 hp). The RIA emission factor for Category 1 engines of this size is also 0.3 g/kW-hr (0.49 lb/1000 hp-hr).

The two ferries operate for a combined total of 3,520 hours per year, with about half of this time is spent in Philadelphia, and the other half in Camden. The average operating factor for the main propulsion engine is assumed to be about 68% and the operating factor for the auxiliary engine is assumed to be about 50%. Based on the above engine specifications and operating information, the two ferries are estimated to emit a combined total of 0.83 Mg (0.91 tons) of diesel particulate per year. About half of this, or 0.42 Mg (0.46 tons) is estimated to be emitted in Philadelphia, and an equal amount is estimated to be emitted in Camden.

4.5 Summary of Estimated Emissions from Port Operations and Comparison with Estimates from the National Emissions Inventory

Table 19 summarizes the activity-based emissions estimates for diesel particulate matter from oceangoing vessels, tugboats and tow boats, land-based cargo equipment at port facilities, and passenger ferries. Land-based cargo handling equipment at port facilities in Philadelphia county accounts for an estimated 42 Mg/year (47 tons/year) of emissions, which is about half of our overall emissions estimate for port facilities in the county. However, the emissions estimates from land-based cargo handling are very uncertain. Information was not available on the sizes of diesel engines used in this equipment, on the age of the equipment, or on average engine loads. In addition, operating hours were not directly available, but were estimated from the ship traffic at each port facility. The NEI does not explicitly estimate emissions from land-based cargo handling at port facilities, but this equipment generally falls into the NEI category of construction and mining equipment. Our estimate for land-based cargo handling is compatible with the overall NEI estimate of 125 Mg/yr (138 tons/yr) from diesel construction and mining equipment in Philadelphia county.

Table 19. Summary of Estimated Emissions from Port Operations in the Philadelphia Metropolitan Area Counties, 2003
(Metric units)

Emission source	Estimated emissions by county (Mg/yr)							
	Phila-delphia	Delaware, PA	Bucks, PA	Camden, NJ	Gloucester, NJ	Burlington, NJ	New Castle, DE	Total
Oceangoing vessels[a]								
Traveling	5.3	10	0.5	1.4	14	0.7	55	86
Maneuvering	3.7	2.4	0.5	2.5	1.8	0.1	2.4	13
Hoteling	19	12	2.7	13	8.3	0.5	12	67
Subtotal	28	25	3.2	17	24	1.2	70	167
Tug boats								
Traveling to dock	3.7	0.7	0.9	1.1	0.5	1.5	0.2	8.6
Traveling with barges	5.5	0.5	1.9	2.4	0.6	3.5	10	25
Docking assistance	2.2	0.4	0.3	0.4	0.3	0.3	0.2	4.1
Subtotal	11	1.6	3.1	3.9	1.4	5.3	11	37
Land-based cargo equipment								
Container cranes	1.4	b	b	b	b	b	b	1.4
Top loaders	3.2	b	b	b	b	b	b	3.2
Forklifts	6.6	b	b	b	b	b	b	6.6
Yard tractors	15	b	b	b	b	b	b	15
Other equipment	16	b	b	b	b	b	b	16
Subtotal	42							58
Passenger ferries	0.41	b	b	0.4	b	b	b	0.41
Totals	82	26	6.3	21	25	6.5	80	263

[a] Includes diesel engine vessels powered by residual oil.
[b] Not estimated.

– continued –

Table 19. Summary of Estimated Emissions from Port Operations in the Philadelphia Metropolitan Area Counties, 2003
(continued – English units)

Emission source	Estimated emissions by county (tons/yr)							
	Phila-delphia	Delaware, PA	Bucks, PA	Camden, NJ	Gloucester, NJ	Burlington, NJ	New Castle, DE	Total
Oceangoing vessels [a]								
Traveling	5.8	11	0.5	1.5	15	0.8	61	95
Maneuvering	4.1	2.6	0.6	2.8	2.0	0.1	2.7	14.7
Hoteling	21	13	3.0	14	9.2	0.5	14	74.2
Subtotal	31	27	3.5	18	26	1.3	77	184
Tug boats								
Traveling to dock	4.1	0.8	1.0	1.2	0.5	1.6	0.2	9.5
Traveling with barges	6.1	0.6	2.1	2.6	0.7	3.9	11	27
Docking assistance	2.4	0.5	0.3	0.5	0.4	0.3	0.2	4.5
Subtotal	13	1.8	3.4	4.3	1.5	5.8	12	41
Land-based cargo equipment								
Container cranes	1.6	b	b	b	b	b	b	1.6
Top loaders	3.5	b	b	b	b	b	b	3.5
Forklifts	7.3	b	b	b	b	b	b	7.3
Yard tractors	17	b	b	b	b	b	b	17
Other equipment	18	b	b	b	b	b	b	18
Subtotal	47							64
Passenger ferries	0.46	b	b	0.5	b	b	b	0.46
Totals	91	29	6.9	23	28	7.1	88	290

[a] Includes diesel engine vessels powered by residual oil.
[b] Not estimated.

The oceangoing vessel category in Table 19 correspond to residual oil fueled vessels in the NEI,[a] while the tugboat and ferry boat categories would correspond to diesel oil fueled commercial vessels in the NEI. Our estimates indicate that oceangoing vessels account for a substantial share of diesel particulate emissions from port facilities. However, these estimated emissions are much lower than the corresponding estimate in the NEI – about 28.0 Mg/year (30.9 tons/year), compared to 383 Mg/year (422 tons/year) in the draft 2002 NEI for residual oil fueled vessels in Philadelphia county. The difference between the estimates for commercial vessels fueled by diesel oil is even more pronounced. The combined activity-based emissions estimate for tugs and ferries in Philadelphia county is only about 12 Mg/year (13 tons/year) compared with 368 Mg/year (406 tons/year) for the overall diesel-powered commercial marine vessel category in the draft 2002 NEI.

The differences between the activity-based emissions estimates and the NEI estimates for commercial vessels are believed to be the result of the default allocation methodology used in the NEI. The NEI estimates total emissions for marine vessels in U.S. waters, and then allocates these emissions to major ports. The allocation methodology assumes that the amount of fuel used by vessels within a port is proportional to the amount of cargo handled. In addition, the NEI methodology makes a default assumption that 25% of marine bunker fuel is consumed in port, and 75% of marine diesel fuel is consumed in port.

For oceangoing vessels calling at ports in the Philadelphia metropolitan area, we have estimated that, on average, only about 17% of emissions in U.S. waters occur within the metropolitan area. The remaining 83% occurs while the ships they travel through the 200 nautical mile economic exclusion zone and the lower Delaware Bay.

For commercial diesel vessels, we believe that the default allocation methodology has overestimated the share of national emissions that occur in the Philadelphia area. This may be due to the lack of a major fishing fleet in Philadelphia and the other ports in the Philadelphia metropolitan area. As noted above, the national allocation methodology is based on cargo handling. However, commercial fishing would also have an important impact on the consumption of marine diesel fuel. None of the ports in the Philadelphia area is listed by the Corps of Engineers as a major commercial fishing port. The nearest is Cape May, New Jersey, which was the 15th largest commercial fishing port in 2003. Cape May is outside of the Philadelphia metropolitan area, about 108 kilometers (59 nautical miles) downstream from Philadelphia.

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[a]Though fueled by residual oil, most oceangoing vessels use diesel engines.

5. Potential Control Measures for Diesel Emissions in the Port of Philadelphia

National, Regional, and local initiatives like the National Clean Diesel Campaign (which includes both regulatory and voluntary initiatives),[23] Clean Fleets USA,[24] and the "No Net Increase" challenge in Los Angeles have spurned innovative technological and operational control strategies to reduce pollutant emissions in ports. This section gives a brief introduction to control strategies, available control options that could be employed at the Philadelphia Port, and implementation issues.

It should be emphasized that each port is unique, and may benefit differently from different control strategies. Cost-effectiveness of control strategies or technologies may also vary widely among ports, or among terminals at the same port. However, programs at different ports may serve as a model for a program that could be successfully implemented at the Port of Philadelphia. Several factors may be considered when developing cost-effective control strategies:

- Take advantage of natural business cycles and meet business needs (e.g., upgrades made to ports for homeland security purposes could also consider environmental benefits)
- Use strategies that will comply with future Federal and State mandates
- Use strategies that are supported by current infrastructure, or that could be used in multiple applications (for instance, an alternative fuel infrastructure could be used by cargo handling equipment and harbor craft)[a]
- Use strategies that are sustainable in the long term

Some examples that follow these guidelines include: 1) replacing equipment instead of retrofitting, as new technology meets EPA standards and is cost effective; 2) buying on-road engines when possible, as they have higher EPA ratings and are supported by the South Coast Air Quality Management District (SCAQMD) in California and the National Resources Defense Council (NRDC); and 3) efficient fuel use, including using on-road diesel, idle shut-down programs, programmable engines, and decreased operating hours.

In analyzing the cost-effectiveness of emissions control strategies that could be employed at the Philadelphia Port, we have drawn largely from strategies either employed or proposed at other ports. The Port of Seattle, the Port of Los Angeles, and the Port of Long Beach (POLB) have provided cost-effectiveness information on control strategies for oceangoing vessels, harbor craft such as tug boats and passenger ferries, dockside equipment such as yard tractors, fork lifts, and cranes, and on-road heavy-duty trucks and rails. Information has also been provided by the Port Authority of New York and New Jersey (PANYNJ).

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[a]Examples of port-wide control strategies can be found in the Port Emissions Primer, which was developed at the Clean Ports USA Corpus Christi workshop on January 26, 2005.

Table 20 summarizes potential control options for diesel emissions from port operations in Philadelphia. For each control measure, the table lists the potential reduction of diesel particulate emissions, as a percentage of the emissions from the equipment being controlled and also in terms of the magnitude of the potential diesel particulate emission reduction for the Port of Philadelphia. The table also gives the estimated capital cost of the control measure per piece of equipment controlled (e.g., each pier, ship, forklift, or yard tractors). The table gives the estimated cost effectiveness of each control option in terms of the cost per mass of diesel particulate emission reduction. In addition to reducing emissions of diesel particulate matter, many of the control options also would reduce emissions of other criteria pollutants. Therefore, Table 20 also estimates the cost effectiveness of each potential control measure in terms of the cost per mass of emission reduction for a suite of criteria pollutants including $PM_{2.5}$, sulfur dioxide (SO_2), nitrogen oxides (NO_X), and volatile organic compounds (VOC). A detailed cost analysis specific to the Port of Philadelphia was beyond the scope of this project. Therefore, the control costs and cost effectiveness values summarized in Table 20 are based on more detailed analyses for other ports. The following sections describe various control strategies by emission source category.

5.1 Oceangoing Vessels

The implementation of air pollution control strategies for oceangoing vessels is complicated by the fact that only a fraction of the emissions from these vessels is released near land, and an even smaller fraction is released in any given port city. In addition, most oceangoing vessels are foreign-flagged. Nevertheless, a number of options have been evaluated to diesel particulate emissions from these vessels (see Table 20).

The most common techniques would involve the use of cleaner fuels. Many ports across the U.S. are interested in the creation a National Sulfur Emission Control Area (SECA) under Annex VI of the International Convention on the Prevention of Pollution from Ships (better known as MARPOL). The creation of a SECA region could reduce the sulfur content of bunker fuel used by oceangoing vessels from the current average of about 2.7% (27,000 ppm) to an upper limit of 1.5% (15,000 ppm). Analyses for the Port of Los Angeles have estimated that such a reduction in fuel sulfur would reduce overall diesel particulate emissions by 18%.[25] A 45% reduction in sulfur dioxide (SO_2) emissions would also be realized, but emissions of nitrogen oxides (NO_X) and volatile organic compounds (VOC) are not expected to be substantially affected. The incremental cost of 1.5% sulfur oil over the current 2.7% sulfur oil could range from \$100 to \$250 per Mg of fuel (\$90–220/ton) based on fuel prices over the past three years.[26] However, it is difficult to estimate the cost effectiveness of this fuel change for emissions in port, since ships also need to use the cleaner fuels at sea. Because of the cost-competition among ports, a SECA rule would need to cover a large region. The Port of Los Angeles has proposed to create a regional SECA that could go into effect around 2009.[26] The SECA could cover the West Coast, the entire nation, or the North American region.

Table 20. Potential Control Measures for Diesel Particulate Emissions in the Port of Philadelphia
(Metric units)

Control measure	Estimated control efficiency (%)	Potential emission reduction (Mg/year)	Estimated capital costs per piece of equipment ($1000)	Estimated cost effectiveness ($1000/Mg) [a]		References
				Diesel PM only	All criteria pollutants	
Oceangoing Vessels						
Regional SECA	18	5.0	NA	NA	NA	26
Use cleaner fuels for hoteling						
Marine gas oil (0.58% sulfur)	58	12	50/ship	42 – 97	1.4 – 3.2	25
Emulsified diesel	63	13	50/ship	20 – 41	2 – 4	27, 28
Low sulfur marine gas oil (0.1% sulfur)	65	14	50/ship	40 – 89	1.4 – 3.2	25
Highway diesel (0.03% sulfur)	68	14	50/ship	40 – 83	1.5 – 3.1	25
Ultralow sulfur diesel (0.0015% sulfur)	75	16	50/ship	52 – 105	2.0 – 4.0	25
Natural gas	97	20	NA	36 – 177	2 – 10	28
Cold ironing						
Cruise terminal [b]						
Ships already modified	100	1.5	up to 1,000	77 – 170	4 – 8	28
Ships require modification			+500/ship	up to 220	up to 11	
Other terminals	100	20	1,000/pier +500/ship	190 – 310	9 – 15	

Table 20. Potential Control Measures for Diesel Particulate Emissions in the Port of Philadelphia
(Metric units – continued)

Control measure	Estimated control efficiency (%)	Potential emission reduction (Mg/year)	Estimated capital costs per piece of equipment ($1000)	Estimated cost effectiveness ($1000/Mg) [a]		References
				Diesel PM only	All criteria pollutants	
Tugboats and Towboats						
Use cleaner fuels						
Low sulfur marine gas oil (0.1% sulfur)	17	1.9	0	22 – 67	0.6 – 1.7	25
Highway diesel (0.03% sulfur)	24	2.6	0	5.3 – 76	0.1 – 1.8	25
Emulsified diesel	38	4.2	50	36	5.2	26, 27
Ultralow sulfur diesel (0.0015% sulfur)	40	4.4	0	96 – 152	2.5 – 4.0	25
CNG or LNG	100	11	500	147	NA	29
Retrofit with add-on control equipment						
Diesel particulate filter	85 – 95	9.9	NA	NA	NA	26, 34
Diesel oxidation catalyst [c]	25	2.8	NA	NA	NA	26, 34
Repower engines						
Use Tier 2 nonroad engines [d]	25	2.8	NA	82	NA	26
Use Tier 2 onroad engines [d]	97	11	NA	NA	NA	30

Table 20. Potential Control Measures for Diesel Particulate Emissions in the Port of Philadelphia
(Metric units – continued)

Control measure	Estimated control efficiency (%)	Potential emission reduction (Mg/year)	Estimated capital costs per piece of equipment ($1000)	Estimated cost effectiveness ($1000/Mg)[a]		References
				Diesel PM only	All criteria pollutants	
Land-Based Cargo Equipment						
Use cleaner fuels						
Highway diesel (0.03% sulfur)	16 – 20	7.7	0	8.1 – 47	1.3 – 8.0	22, 25
Ultralow sulfur diesel (0.0015% sulfur)	18 – 22	8.5	0	73 – 140	13 – 24	22, 25
Emulsified diesel	17 – 58	16	NA	10	2.1	26, 27
Biodiesel blends	10 – 50	13	NA	NA	NA	33
Retrofit equipment						
Diesel oxidation catalyst[c, e]	25	11	1 – 3.5	13 – 65	2.1 – 11	34
Diesel particulate filter - passive regeneration[e]	85–95	38	6 – 8	8.5 – 11	8.5 – 11	34, 35,
Diesel particulate filter - active regeneration[e]	85–95	38	10 – 20	14 – 28	14 – 28	36
Replace or repower equipment						
Cranes						
Tier 2 nonroad engines[d]	43	0.6	NA	NA	NA	26
Electric, propane, or natural gas	100	1.4	30 – 70	NA	NA	31
Top loaders						
Tier 2 nonroad engines[d]	43	1.4	NA	NA	NA	26
Propane or natural gas engines	100	3.2	30 – 70	NA	NA	31
Forklifts						
Tier 2 nonroad engines[d]	43	2.8	NA	NA	NA	26
Electric, propane or natural gas engines	100	6.6	30 – 70	NA	NA	31
Yard tractors and other vehicles						
Tier 2 nonroad engines[d]	43	13	NA	NA	NA	26
Tier 2 onroad engines[d]	98	30	NA	NA	NA	30
Propane or natural gas engines	100	31	30 – 70	NA	NA	31
Idle reduction measures	NA	NA	NA	NA	NA	38, 39
Improved gate efficiency	NA	NA	NA	NA	NA	39

Table 20. Potential Control Measures for Diesel Particulate Emissions in the Port of Philadelphia
(Metric units – continued)

Control measure	Estimated control efficiency (%)	Potential emission reduction (Mg/year)	Estimated capital costs per piece of equipment ($1000)	Estimated cost effectiveness ($1000/Mg)[a]		Ref-erences
				Diesel PM only	All criteria pollutants	
Passenger Ferries						
Use cleaner fuels						
Low sulfur marine gas oil (0.1% sulfur)	17	0.07	0	22 – 67	0.6 – 1.7	25
Highway diesel (0.03% sulfur)	24	0.10	0	5.3 – 76	0.1 – 1.8	25
Emulsified diesel	38	0.16	50	36	5.2	26, 27
Ultralow sulfur diesel (0.0015% sulfur)	40	0.16	0	96 – 152	2.5 – 4.0	25
CNG or LNG	100	0.41	500	147	NA	29
Retrofit with add-on control equipment						
Diesel particulate filter	85 – 95	0.35	NA	NA	NA	26, 34
Diesel oxidation catalyst[c]	25	0.10	NA	NA	NA	26, 34
Repower engines						
Use Tier 2 nonroad engines[d]	25	0.10	75	8.6	NA	26
Use Tier 2 engines with cartridge filters[d]	93	0.38	57	41	NA	29
Use Tier 2 onroad engines[d]	97	0.40	NA	NA	NA	30

[a] A detailed cost analysis was beyond the scope of this project. In addition, insufficient information is available on engine sizes and operating patterns to support a specific cost analysis for the Port of Philadelphia. Therefore, except where otherwise noted, cost-effectiveness values in this table are based on studies performed for other ports.

[b] Cost-effectiveness values for cold-ironing were estimated based on an interest rate of 7%, and modification costs of $1,000,000 for the pier, and $500,000 for one cruise ship, which is assumed to return to the port at least 20 times per year.

[c] Diesel oxidation catalyst performs best if used with low sulfur diesel fuel (equivalent to highway diesel or better).

[d] Tier 2 engines are engines meeting EPA's Tier 2 emissions standards, 0.5 g/kW-hr (0.82 lb/1000 hp-hr) for nonroad engines, and 0.13 g/kW-hr (2.1 lb/1000 hp-hr) for onroad engines, beginning in 2007.

[e] Cost-effectiveness values for retrofit controls were estimated using equipment purchase costs from the Manufacturers of Emission Control Association (MECA),[34] with an interest rate of 7% and assuming a total installed cost of double the purchase cost. Incremental fuel costs were also added where applicable.

Table 20. Potential Control Measures for Diesel Particulate Emissions in the Port of Philadelphia
(English units)

Control measure	Estimated control efficiency (%)	Potential emission reduction (ton/year)	Estimated capital costs per piece of equipment ($1000)	Estimated cost effectiveness ($1000/ton)		Ref-erences
				Diesel PM only	All criteria pollutants	
Oceangoing Vessels						
Regional SECA	18	5.5	NA	NA	NA	26
Use cleaner fuels for hoteling						
Marine gas oil (0.58% sulfur)	58	13	50	38 – 87	1.2 – 2.9	25
Emulsified diesel	63	15	50	18 – 37	1.8 – 3.6	27, 28
Low sulfur marine gas oil (0.1% sulfur)	65	15	50	36 – 81	1.2 – 2.9	25
Highway diesel (0.03% sulfur)	68	16	50	36 – 75	1.5 – 2.8	25
Ultralow sulfur diesel (0.0015% sulfur)	75	17	50	47 – 95	2.0 – 3.6	25
Natural gas	97	22	1,000–4,600	16 – 155	0.9 – 9	28
Cold ironing						
Cruise terminal [b]						
Ships already modified	100	1.7	up to 1,000	70 – 150	4 – 7	28
Ships require modification			+500/ship	up to 200	up to 10	
Other terminals	100	21	1,000/pier +500/ship	170 – 280	8 – 13	

Table 20. Potential Control Measures for Diesel Particulate Emissions in the Port of Philadelphia
(English units – continued)

Control measure	Estimated control efficiency (%)	Potential emission reduction (ton/year)	Estimated capital costs per piece of equipment ($1000)	Estimated cost effectiveness ($1000/ton)		References
				Diesel PM only	All criteria pollutants	
Tugboats and Towboats						
Use cleaner fuels						
Low sulfur marine gas oil (0.1% sulfur)	17	2.1	0	22 – 67	0.5 – 1.5	25
Highway diesel (0.03% sulfur)	24	2.9	0	5.3 – 76	0.1 – 1.6	25
Emulsified diesel	38	4.6	50	36	4.7	26, 27
Ultralow sulfur diesel (0.0015% sulfur)	40	4.8	0	96 – 152	2.3 – 3.6	25
CNG or LNG	100	12	500	132	NA	29
Retrofit with add-on control equipment						
Diesel particulate filter	85 – 95	11	NA	NA	NA	26, 34
Diesel oxidation catalyst	25	3.0	NA	NA	NA	26, 34
Repower engines						
Use Tier 2 nonroad engines	25	3.0	NA	74	NA	26
Use Tier 2 onroad engines	97	12	NA	NA	NA	30

Table 20. Potential Control Measures for Diesel Particulate Emissions in the Port of Philadelphia
(English units – continued)

Control measure	Estimated control efficiency (%)	Potential emission reduction (ton/year)	Estimated capital costs per piece of equipment ($1000)	Estimated cost effectiveness ($1000/ton)		Ref-erences
				Diesel PM only	All criteria pollutants	
Land-Based Cargo Equipment						
Use cleaner fuels						
Highway diesel (0.03% sulfur)	16 – 20	8.4	0	7.3 – 42	1.2 – 7.2	22, 25
Ultralow sulfur diesel (0.0015% sulfur)	18 – 22	9.4	0	66 – 130	12 – 22	22, 25
Emulsified diesel	17 – 58	18	NA	9.1	1.9	26, 27
Biodiesel blends	10 – 50	14	NA	NA	NA	33
Retrofit equipment						
Diesel oxidation catalyst [c, d]	25	12	1 – 3.5	13 – 59	2.1 – 10	34
Diesel particulate filter - passive regeneration [d]	85–95	42	6 – 8	8.5 – 10	8.5 – 10	34, 35,
Diesel particulate filter - active regeneration [d]	85–95	42	10 – 20	14 – 25	14 – 25	36
Replace or repower equipment						
Cranes						
Tier 2 nonroad engines	43	0.7	NA	NA	NA	26
Electric, propane, or natural gas	100	1.5	30 – 70	NA	NA	31
Top loaders						
Tier 2 nonroad engines	43	1.5	NA	NA	NA	26
Propane or natural gas engines	100	3.5	30 – 70	NA	NA	31
Forklifts						
Tier 2 nonroad engines	43	3.1	NA	NA	NA	26
Electric, propane or natural gas engines	100	7.3	30 – 70	NA	NA	31
Yard tractors and other vehicles						
Tier 2 nonroad engines	43	15	NA	NA	NA	26
Tier 2 onroad engines	98	33	NA	NA	NA	30
Propane or natural gas engines	100	34	30 – 70	NA	NA	31
Idle reduction measures	NA	NA	NA	NA	NA	38, 39
Improved gate efficiency	NA	NA	NA	NA	NA	39

Table 20. Potential Control Measures for Diesel Particulate Emissions in the Port of Philadelphia
(English units – continued)

Control measure	Estimated control efficiency (%)	Potential emission reduction (ton/year)	Estimated capital costs per piece of equipment ($1000)	Estimated cost effectiveness ($1000/ton)		Ref- erences
				Diesel PM only	All criteria pollutants	
Passenger Ferries						
Use cleaner fuels						
Low sulfur marine gas oil (0.1% sulfur)	17	0.08	0	20 – 61	0.5 – 1.5	25
Highway diesel (0.03% sulfur)	24	0.11	0	4.8 – 69	0.1 – 1.6	25
Emulsified diesel	38	0.17	50	33	4.7	26, 27
Ultralow sulfur diesel (0.0015% sulfur)	40	0.18	0	87 – 137	2.3 – 3.6	25
Retrofit with add-on control equipment						
Diesel particulate filter	85 – 95	0.38	NA	NA	NA	26, 34
Diesel oxidation catalyst [c]	25	0.11	NA	NA	NA	26, 34
Repower engines						
Use Tier 2 nonroad engines [d]	25	0.11	75	7.8	NA	26
Use Tier 2 engines with cartridge filters [d]	93	0.42	57	37	NA	29
Use Tier 2 onroad engines [d]	97	0.44	NA	NA	NA	30

[a] A detailed cost analysis was beyond the scope of this project. In addition, insufficient information is available on engine sizes and operating patterns to support a specific cost analysis for the Port of Philadelphia. Therefore, except where otherwise noted, cost-effectiveness values in this table are based on studies performed for other ports.
[b] Cost-effectiveness values for cold-ironing were estimated based on an interest rate of 7%, and modification costs of $1,000,000 for the pier, and $500,000 for one cruise ship, which is assumed to return to the port at least 20 times per year.
[c] Diesel oxidation catalyst also requires the use of a clean fuel equivalent to highway diesel or better.
[d] Tier 2 engines are engines meeting EPA's Tier 2 emissions standards, 0.5 g/kW-hr (0.82 lb/1000 hp-hr) for nonroad engines, and 0.13 g/kW-hr (2.1 lb/1000 hp-hr) for onroad engines, beginning in 2007.
[e] Cost effectiveness values were estimated using equipment purchase costs from the Manufacturers of Emission Control Association (MECA),[34] with an interest rate of 7% and assuming a total installed cost of double the purchase cost. Incremental fuel costs were also added where applicable.

A number of options have been evaluated for using cleaner fuels in ships' auxiliary engines. This would reduce hoteling emissions, which result from the use of the auxiliary engines to provide electrical power while the ship is docked. Los Angeles has evaluated the use of marine gas oil (about 0.58% or 5800 ppm sulfur); an emulsified mixture of diesel fuel and water (emulsified diesel);[27] low sulfur marine gas oil (0.1% or 1000 ppm sulfur); highway diesel (0.03% or 300 ppm sulfur); ultralow sulfur diesel (0.0015% or 15 ppm), which is expected to become available in 2007; and natural gas. In general, these options would require the installation of separate fuel tanks and fuel lines for the auxiliary engines, at a cost of about $50,000 per ship. The incremental costs of cleaner auxiliary diesel fuels (above bunker fuel) are estimated at $100–240/Mg ($90–218/ton) for marine diesel oil, $120–240 ($109–218/ton) for low sulfur marine gas oil or highway diesel, and $150–330 ($136–300/ton) for ultralow sulfur diesel. These estimates are based on historic fuel prices for bunker fuel and different types of diesel oil over the last three years, summarized in Table 21.[25] The natural gas option would carry an additional cost for altering the refueling infrastructure of the port.[28] Capital costs of this option for Philadelphia are not known.

Hoteling emissions can also be eliminated by a measure called "cold ironing." This involves the use of shore power to provide for the electrical requirements of the ship, allowing the main and auxiliary engines to be shut down while the ship is docked. However, significant modifications are required for cold ironing, both on the dock and on the ship. Capital costs for providing electrical power to ships have been estimated at least $1 million per pier, and $500 thousand per ship.[28] In addition, electricity is more expensive to purchase at the pier than the auxiliary diesel fuel that would be required to produce it. The cost effectiveness of this option will vary from pier to pier, depending on the number of times that particular ships return to the pier, the duration of their stay, and the amount of fuel that they would ordinarily burn while docked. In Los Angeles, cost effectiveness values have been estimated at $187,000–313,000/Mg of diesel particulate emission reduction ($268,000–282,000/ton) or $9,000–15,000/Mg of overall criteria pollutants reduced ($8,000–13,000/ton). These estimates were based on ships calling at the port 2–4 times per year.

In the case of Philadelphia, the cruise ship pier may be a more cost-effective candidate for cold ironing. Some newer cruise ships already are equipped to accept shore power. In addition, the practice of cold ironing was originated with the Navy, and the cruise terminal is located at the site of the former Philadelphia Navy Yard. Some of the infrastructure necessary for cold ironing may still exist at the cruise ship pier; however, information was not available on the electrical infrastructure of the pier as of the writing of this report. If only minor modifications are required to the dock and ship, the cost of cold ironing for the cruise terminal would be approximately equal to the cost differential between electricity and diesel oil for the auxiliary engines. This is about $77/Mg ($70/ton) of diesel particulate emissions avoided, or about $4/Mg ($3.7/ton) of total criteria pollutant emissions avoided. Based on the current cruise ship schedule, we have estimated that cold ironing at the cruise ship terminal could reduce diesel particulate emissions in the Port of Philadelphia by about 1.5 Mg/year (1.7 tons/year) of diesel particulate emissions could be avoided by cold ironing. However, a plan to make Philadelphia a cruise ship home port may increase hoteling emissions (and the potential emission reduction from cold ironing) in the future.

Table 21. Cost Comparison for Bunker Fuel Oil and Different Types of Diesel over the Last 3 Years

Fuel type	Expected sulfur content (%)	Average fuel prices from 2003 through March 2005					
		Metric units ($/Mg)			English units ($/ton)		
		3-year average	3-month average	3-year maximum	3-year average	3-month average	3-year maximum
Bunker fuel	2.7	170	200	280	155	182	255
Reduced sulfur bunker fuel	1.5	NA	260	NA	NA	236	NA
Marine diesel oil	0.58	270	400	520	245	364	473
Low sulfur marine gas oil	0.10	290	420	520	264	382	473
Highway diesel	0.03	290	430	520	264	391	473
Ultralow sulfur diesel	0.0015	320	490	610	291	445	555

Source: Reference 25.

5.2 Tugboats and Towboats

Harbor vessels typically use marine diesel oil (about 0.58% or 5800 ppm sulfur), which is cleaner than the bunker fuels used by oceangoing vessels (about 2.7% or 27,000 ppm sulfur). However, lower sulfur diesel fuels are becoming available and studies for the Port of Los Angeles have estimated that diesel particulate emissions from harbor vessels can be reduced by using these cleaner fuels. Potential diesel particulate emission reductions are estimated at about 17% for low sulfur marine gas oil, 24% for highway diesel, 38% for emulsified diesel, and 40% for ultralow sulfur diesel fuel.[25] (Table 20 summarizes emission reductions and cost effectiveness of various control measures.) Based on historic fuel prices over the last three years (see Table 21), the incremental costs of cleaner auxiliary diesel fuels (above marine diesel fuel) are estimated at $0–20/Mg ($0-18/ton) for low sulfur marine gas oil or highway diesel, and $50–90 ($46–82/ton) for ultralow sulfur diesel.[25] It is believed that low sulfur marine gas oil, highway diesel, or ultralow sulfur diesel could be substituted directly for marine diesel oil without fuel system modifications. However, fuel leakage due to oil-seal-related problems could occur from switching between fuel types with significantly different fuel properties.[28] The substitution of emulsified diesel would require some modifications to the fuel system, at an estimated cost of $50,000 per vessel.[26]

Some tugs and ferries in California and Texas currently use on-road low-sulfur diesel fuel with a sulfur content of no greater than 0.05% (500 ppm). The California Air Resources Board (CARB) has mandated that diesel fuel supplied to all harbor craft in the South Coast Air Basin must meet on-road vehicle fuel standards (i.e., ultra-low sulfur diesel) by January 2006, and statewide by January 2007. The Port of Los Angeles also proposes to subsidize the use of this fuel in harbor craft that spend over half of operating time in or near the Port until the CARB mandate is implemented.[26] They are also using emulsified diesel starting in 2006 for tugs.

Tug and ferry engines have also been repowered with alternate fuels such as liquefied natural gas (LPG) or compressed natural gas (CNG) in Canada and Europe. A few ferries are also currently running on CNG in Elizabeth City, Virginia. Modification costs have been estimated at about $500,000 in a study for the San Francisco Bay area.[29]

The Port of Los Angeles has also evaluated the retrofit of tugboat engines with diesel particulate filters (DPF) and diesel oxidation catalysts (DOC). Diesel particulate filters remove particulate matter directly from the engine exhaust stream, with an efficiency of 85 to 95%.[26] The collected material is then burned using either a passive regeneration system or an active system. In passive regeneration, heat from the exhaust stream is used to burn the particulate matter. In active regeneration, the heat must be provided from an outside source. Both active and passive systems require monitors to track exhaust back-pressure and temperature. The filters also generally require periodic cleaning of accumulated ash, which requires special handling. A number of passive and active DPF systems have been verified under the EPA and CARB verification programs. Passive systems perform better with cleaner fuels.

Diesel oxidation catalysts are designed to burn residual VOC in the exhaust stream, but also remove about 25% of diesel particulate matter emissions. In fact, diesel oxidation catalysts have been used on diesel-powered vehicles for over 30 years, and have been installed on non-road diesel engines ranging from under 37 kW (50 hp) to above 1,500 kW (2,000 hp). Many oxidation catalysts are designed to replace the original equipment manufacturer's muffler.[34]

Older engines can be replaced with lower emitting engines meeting the EPA Tier 2 marine diesel engine standards, which will limit particulate emissions to 0.5 g/kW-hr (0.82 lb/1000 hp-hr) beginning in 2007. The use of onboard engines for tugboats has also been considered. These engines will be required to meet a standard of 0.13 g/kW-hr (2.1 lb/1000 hp-hr).[30]

5.4 Land-based Cargo Equipment at Port Facilities

Table 20 summarizes emission control efficiencies and cost effectiveness values for various control options that can be applied to land-based cargo handling equipment. Strategies for controlling emissions on cargo handling equipment may be easier to implement than on marine vessels.[31, 32] Some emission reductions can be achieved without engine modifications through the use of lower-sulfur fuels in nonroad engines. EPA test data for nonroad engines indicate that diesel particulate emissions increase with increasing fuel sulfur content. Based on this correlation, we have estimated these emission reductions at 16–22%, depending on the fuel that is used.[22] (Costs of lower sulfur diesel fuels are summarized in Table 21.)

EPA has also measured diesel particulate emission reductions of up to 60% as a result of the use of biodiesel oil. Average emission reductions were about 48% for pure biodiesel oil, and 10% for a blend of 20% biodiesel oil and 80% conventional diesel oil.[33] Emissions reductions of 17–58% have been measured for the use of emulsified diesel – a mixture of diesel oil, water, and an emulsifier.[26] The water in emulsified diesel promotes a finer atomization of the fuel mixture during injection and modifies combustion, resulting in substantial reductions of particulate emissions and NO_X.[27] Incremental costs of biodiesel are estimated at \$0.0025–0.05/liter (\$0.01–0.20/gallon) above standard nonroad diesel.[26]

Retrofit controls are also available to reduce diesel particulate matter and other criteria pollutants from cargo handling equipment. Several of these types of controls have been verified by CARB or EPA, and are commercially available for on-road and off-road applications. Diesel oxidation catalysts are estimated to achieve emission reductions of about 25%, and diesel particulate filters are estimated to achieve reductions of 85–95%. (These techniques are described in more detail in the previous section on Tugboats and Towboats.) Diesel oxidation catalysts have been used on diesel-powered vehicles for over 30 years, and have been installed on nonroad diesel engines ranging from under 38 kW (50 hp) to above 1,500 kW (2,000 hp). Many oxidation catalysts are designed to replace the original equipment manufacturer's muffler. Diesel particulate filtration technology has been installed on nonroad equipment since 1986, including material-handling equipment such as forklifts.[34, 35, 36]

A number of options are available for replacing the diesel engines in cargo handling equipment with lower emitting power sources. These include electric power, natural gas, and propane. Cleaner burning diesel engines meeting EPA's Tier 2 nonroad emission standards can also be used. In addition, onroad engines can be used in many types of nonroad equipment. In general, we have not estimated the costs of these options, since information was not available on the power ratings of the cargo handling equipment used in Philadelphia.

Some of the terminals in Philadelphia are already using electric cranes, electric forklifts, and propane forklifts. These options eliminate diesel particulate emissions altogether. Propane engines can also be used in yard tractors and other vehicles (although costs are probably higher than other options).

Older equipment can be replaced with lower emitting engines meeting the EPA Tier 2 marine diesel engine standards, which will limit particulate emissions to 0.5 g/kW-hr (0.82 lb/1000 hp-hr) beginning in 2007. There is also an effort in the Port of Los Angeles to modernize the yard tractor fleet by replacing them with the cleanest engines available and accelerate the use of ultralow sulfur diesel through an incentive-based program.[26]

The use of onboard engines for yard tractors and other nonroad vehicles has also been considered. For example, the Port Authority of New York and New Jersey is replacing scrapped equipment with new equipment containing engines installed by the manufacturer that meet on-road standards.[37] The onboard engines meet the same power requirements as the nonroad engines, and generally have superior warrantees. Nonroad engines will be required to meet a standard of 0.13 g/kW-hr (2.1 lb/1000 hp-hr).

Idle shut-down programs can be implemented to reduce idling emissions from nonroad equipment. This can be done manually or with programmable engines. Idle shut down programs can also be used to reduce emissions from the onroad vehicles delivering cargo to and from the port.[38] Insufficient information on was available on engine sizes and operating patterns to evaluate the potential impact of an idle reduction program for Philadelphia.

A number of ports in the U.S. have adopted programs to improve the efficiency of their gate check-in process and queuing process of onroad truck traffic. For example, the Georgia Port Authority (GPA) has implemented a web-based program that allows users to update and view data 24 hours a day, seven days a week.[39] Such gate efficiency programs provide a number of benefits, including improved security, increased port efficiency, and reduced idling emissions. Operators have indicated that the truck traffic at the Philadelphia port facilities is low. Based on this information, we have estimated idling emissions from onroad trucks as considerably lower than emissions from nonroad equipment on an annual basis. However, truck idling emissions may be significant during short term periods of increased traffic.

5.5 Passenger Ferries

All of the control options for tugboats and towboats can also be applied to passenger ferries. In addition, in the case of the smaller diesel engines typically used in passenger ferries, it has been estimated that a diesel particulate emission reduction of 93% could be achieved through the use of new engines meeting EPA Tier 2 emission standards, and equipped with diesel particulate filters.[29]

5.6 Summary of Control Options

As shown in Section 4 (Table 19), we have estimated overall diesel particulate emissions from port operations in Philadelphia county at about 82 Mg (91 tons). Land based cargo handling equipment is estimated to account for about 51% of this total, oceangoing vessels are estimated to account for about 34%, and harbor vessels about 14%.

Substantial emission reductions could be achieved in all three of these sectors by the use of cleaner diesel fuels, such as low sulfur marine gas oil, highway diesel fuel, emulsified diesel, biodiesel, or ultralow sulfur diesel. Total potential emission reductions from the use of these fuels range from 22 to 36 Mg/year (24–40 tons/year). Emissions from the hoteling vessels could be reduced by an estimated 58–75%, or 12–16 Mg/year (13–17 tons/year) by the use of these fuels in ships' auxiliary engines. Emissions from tugboats and towboats could be reduced by an estimated 17–40%, or 1.9–4.4 Mg/year (2.1–4.8 tons/year); and emissions from land-based cargo handling equipment could be reduced by an estimated 16–58% or 7.7–16 Mg/yr (8.4–18 tons/year). With the exception of oceangoing vessels, these fuel substitutions can be made without modifying engine fueling systems. For oceangoing vessels, modifications would be needed to separate the auxiliary engine fuel from bunker fuels used for the main propulsion engines.

Further emission reductions (up to 95%) could be achieved by the application of diesel particulate filters to land-based cargo handling equipment and passenger ferries (with Category 1 diesel engines). In addition, reductions of up to 98% could be achieved by replacing older cargo-handling engines with onroad certified engines, beginning in 2007. Diesel powered cargo handling equipment could also be replaced with LPG or electric equipment. In fact, terminals in Philadelphia are already using LPG or electric engines for most of their light-duty fork lifts.

Emissions from oceangoing vessels could be reduced by about 18% or a total of 5 Mg (4.5 tons) by the creation of a regional SECA. In addition, up to 20 Mg/year (22 tons/year) of hoteling emissions from oceangoing vessels could be eliminated by the implementation of cold ironing. However, this option could require substantial capital costs for modifications to both piers and ships. The implementation of air pollution control strategies for oceangoing vessels is complicated by the fact that only a fraction of the emissions from these vessels is released near land, and an even smaller fraction is released in any given port city. In addition, most oceangoing vessels are foreign-flagged.

5.7 Implementation Issues

Successes and barriers to controlling emissions from ports have been discovered as ports begin to implement their control strategy programs. Port representatives at stakeholder meetings and workshops have suggested incentive programs to overcome barriers to implementation.

Barriers to implementation may include technology, such as lack of verified retrofit technologies: there may not be a market for retrofits on some equipment unique to port applications. Capital and operating costs may be prohibitive or may not make business sense. Lack of emissions inventories or regulatory enforcement could also hinder implementation.

However, incentive programs are in development to overcome barriers to reducing emissions. The report *Emission Reduction Incentives for Off-Road Diesel Equipment Used in the Port and Construction Sectors* describes in detail incentives such as Federal, State, and local grant programs like Carl Moyer and the Texas Emission Reduction Program (TERP), tax incentives, modified contracting procedures, environmental stewardship and other non-monetary incentives, and other programs like State Implementation Plan (SIP) and General Conformity credits.

Some recommendations to improve implementation have resulted from stakeholder meetings. These include bundling paperwork, regional administration or oversight of programs (e.g., Gateway Cities charges 15% for administrative work), streamlined grants for easier and quicker disbursement of funds, grants that are timed with a port's natural business cycle, and establishing pollutant priorities.

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