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Pollution prevention at ports: clearing the air

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Abstract

Seaports are major hubs of economic activity and of environmental pollution in coastal urban areas. Due to increasing global trade, transport of goods through ports has been steadily increasing and will likely continue to increase in the future. Evaluating air pollution impacts of ports requires consideration of numerous sources, including marine vessels, trucks, locomotives, and off-road equipment used for moving cargo. The air quality impacts of ports are significant, with particularly large emissions of diesel exhaust, particulate matter, and nitrogen oxides. The health effects of these air pollutants to residents of local communities include asthma, other respiratory diseases, cardiovascular disease, lung cancer, and premature mortality. In children, there are links with asthma, bronchitis, missed school days, and emergency room visits. The significance of these environmental health impacts requires aggressive efforts to mitigate the problem. Approaches to mitigation encompass a range of possibilities from currently available, low-cost approaches, to more significant investments for cleaner air. Examples of the former include restrictions on truck idling and the use of low-sulfur diesel fuel; the latter includes shore-side power for docked ships, and alternative fuels. A precautionary approach to port-related air pollution would encourage local production of goods in order to reduce marine traffic, greener design for new terminals, and state-of-the art approaches to emissions-control that have been successfully demonstrated at ports throughout the world.

Keywords: Port; Diesel; Shipping; Air Pollution; Pollution prevention; Nitrogen oxides

1. Introduction

Marine ports in the United States are major industrial centers providing jobs and steady revenue streams yet contributing significantly to pollution. Ships with

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huge engines running on bunker fuel without emission controls, thousands of diesel trucks per day, diesel locomotives, and other polluting equipment and activities at modern seaports cause an array of environmental impacts that can seriously affect local communities and marine and land-based ecosystems throughout a region. These impacts range from increased cancer risk[1] in nearby communities and increased regional smog, to contamination of water bodies, the introduction of destructive foreign species and aesthetic effects on local communities and public lands (see Table 1). The growth of international trade has resulted in corresponding rapid growth in the tonnage of goods shipped by sea. Most of the major ports in the United States are currently undergoing expansion to accommodate even greater traffic. Despite the enormous growth within the marine shipping sector, most pollution prevention and control efforts have focused on other sectors, while the environmental impacts of ports have grown.

There are more than 2000 ports around the world, which handle more than 80% of trade with origins or destinations in developing countries (The World Bank Group, 2003). The economic activity at ports is substantial, with an estimated 13 million jobs related to the US port industry and port users, and an estimated US$1.5 trillion in business sales traveling through US ports (US Dept. of Transportation, 1996). The number of cargo containers moved by ship in the United States doubled between 1990 and 2001 and the trend is growing even more dramatic, with an 8.5% increase in container traffic between 2001 and 2002 (Bureau of Transportation Statistics, 2002). According to the US Customs Service, the volume of imported cargo moving through US ports is expected to triple by the year 2020 (AAPA, 2003a,b). This trend is also true worldwide, with over 5 billion tons of goods shipped internationally in 1998, and an estimated growth rate of 4–5% per year, generating the need for 200–300 new full-fledged container terminals around the world over the next 7 years (The World Bank Group, 2003). A small number of international operators and a few large shipping lines increasingly dominate port operations worldwide (The World Bank Group, 2003). In the absence of focused efforts to reduce the pollution associated with this expansion in trade, seaports may increasingly cause environmental and health concerns in coastal communities.

Although there are many environmental and health effects related to ports, we will focus on the example of air quality to illustrate the regional and local impacts, and the wide range of options to move toward “greener” seaports. As with any polluting industry, there is a menu of measures available to mitigate or eliminate health impacts. In the case of ports, these measures range from narrow local changes such as idling limits for trucks, to sweeping global changes in international trade. The choice of alternatives relies on consideration of public

[1] The California Air Resources Board Diesel Risk Reduction Plan reported that diesel exhaust particulate contributes to more than 70% of potential cancer risk from outdoor ambient levels of air toxics in 2000. Commercial marine vessels alone accounted for roughly 16% of the entire California inventory of diesel exhaust PM. (CARB, 2000; pp. 12, 16, and III 10).

Table 1
Environmental concerns at ports

Marine ports are often situated in or near residential communities and/or environmentally sensitive estuaries. The following environmental concerns are common (AAPA, 1998):
•Air pollution from port operations, including smog and particulate pollution
•Loss or degradation of wetlands
•Destruction of fisheries and endangered species
•Wastewater and stormwater discharges
•Severe traffic congestion
•Noise and light pollution
•Loss of cultural resources
•Contamination of soil and water from leaking storage tanks
•Air releases from chemical storage or fumigation activities
•Solid and hazardous waste generation
•Soil runoff and erosion

health, feasibility, and cost. Because ports are very complex pollution sources, with many on-site processes and smokestacks, there is no single solution that can address all problems. Instead, the best approach is to define the alternatives that can make significant improvements in air quality, and set goals for best environmental practices that are stringent, yet achievable.

2. Sources of air pollution at ports

Ports are major sources of air pollutants that affect the health of people living in nearby communities, as well as contributing significantly to regional air pollution problems. The major air pollutants related to port activities that can affect human health include diesel exhaust, particulate matter (PM), volatile organic compounds (VOCs), nitrogen oxides (NO_x), ozone, and sulfur oxides (SO_x). Other air pollutants from port operations, such as carbon monoxide (CO), formaldehyde, heavy metals, dioxins, and pesticides used to fumigate produce, can also be a problem.

Worldwide, marine vessels pour out 14% of the NO_x, and 5% of the SO_x from all fossil fuel sources (Corbett et al., 2001). In 2000, commercial marine vessels accounted for roughly 7% of NO_x and 6% of PM emissions from all mobile sources in the United States (USEPA, 2002a). These numbers are expected to increase substantially over time. Projecting forward to 2007, large commercial ships are expected to emit 6–65 times more NO_x per unit of engine power than diesel transit buses[2]. According to the US Environmental Protection Agency (EPA), the contribution of marine vessels to PM and NO_x are expected to double by 2020 (USEPA, 2003a). This increase is due in part to increased trade, but

[2] Based on EPA standards as reported on Dieselnet.com, and using a factor of 1.3 to convert grams per brake horsepower hour to grams per kilowatt hour.

while other pollution sources are becoming better regulated, regulations controlling emissions from ships lag far behind.[3] Commercial ships are expected to account for one fifth of all diesel particulate matter generated in 2020, comprising the second largest source of this toxic soot. In addition to large cargo, tanker and cruise ships calling at ports, other harbor craft, such as tugboats and towboats, are large polluters as well. In the Los Angeles area, ocean-going ships, harbor tugs and commercial boats emit twice as many smog forming emissions as all of the area's power plants combined (Mitchell, 2001).

The vast majority of on-land equipment used at ports runs on diesel fuel. Cargo-handling equipment is used to load and unload large cargo containers from ships, locomotives and trucks, as well as shuttle those containers around for storage. Cargo-handling equipment includes gantry cranes used to load and unload ships, yard trucks that shuttle containers, and various others such as "top-picks," "side-picks," and forklifts. Regulation of off-road equipment lags behind on-road trucks and buses by several decades (CARB, 2000, p. III-19; USEPA, 2004a). Emission standards for heavy diesel equipment were not required at all until 1996 (CARB, 2000, p. III-9), and even those standards are very weak. In fact, by 2007, new heavy diesel equipment will emit 15 times more PM and NOx than new highway trucks or buses (CARB, 2000, p. III-18-19).[4]

The US EPA regulates most air pollution sources at ports, including US flagged ocean-going ships, tugboats, locomotives, cargo-handling equipment and heavy-duty trucks (CARB, 2000). However, the regulations currently in effect are weak, and the stricter standards have not yet been phased in. The EPA recently adopted more stringent standards covering off-road equipment that will begin to take effect in 2011. Because EPA standards only govern new engines, existing dirtier diesel engines will continue to pollute for many years to come. The US EPA, together with several other governmental agencies, also has some voluntary new marine port related programs that could prove to be promising tools in pollution prevention, including an Environmental Management Systems program and a "Portfields" program to reuse vacant industrial land (USEPA, 2003b; AAPA, 2003a,b).

3. Health effects of air pollution

3.1. Diesel exhaust

Diesel exhaust is a mixture of particles, vapors and gases emitted from burning diesel fuel (CARB, 1998). In addition to containing the pollutants outlined above

[3] Note that large ocean going vessels were not regulated until 2004 and these new regulations only apply to NO_x; all other pollutants are unregulated (CARB, 2000).

[4] 2007 on road standards of 0.20 g NO_x/bhp h and 0.01 g PM/bhp h compared to the cleanest off rd standard in 2007, 4.8 g NO_x/bhp h and 0.15 g PM/bhp h.

with their associated health impacts, diesel exhaust contains an estimated total of 450 different compounds, about 40 of which are listed as toxic air contaminants with negative effects on health and the environment (Mauderly, 1992). Studies of people exposed to diesel exhaust have reported eye and nose irritation, bronchitis, cough and phlegm, wheezing, and deterioration in lung function (Ulfvarson et al., 1991; Rudell et al., 1996). Exposure to diesel exhaust also causes elevated levels of immune cells in the airways (Salvi et al., 1999). New important scientific evidence suggests that diesel exhaust may have a causal role in the initiation of allergies and asthma (Pandya et al., 2002).

Dozens of studies have shown that long-term exposure to diesel exhaust significantly increases risk of lung cancer (Bhatia et al., 1998). Workers exposed to diesel exhaust long term generally face increased lung cancer risks of 50–300% (Silverman, 1998, Dawson and Alexeef, 2001). Some studies have also reported links between diesel exposure and other cancers, including bladder, kidney, stomach, multiple myeloma, leukemia, Hodgkin's disease, non-Hodgkin's lymphoma, and cancers of the oral cavity, pharynx, and larynx (Boffetta et al., 2001). Numerous government agencies have listed diesel exhaust as a likely or known lung carcinogen (Dawson, 1998). A study by the South Coast Air Quality Management District in California calculated that 71% of the cancer risk from air pollution in the South Coast Air Basin comes from diesel-particulate pollution. Other agencies have made similar findings in a range of geographic areas (SCAQMD, 2000).

3.2. Particulate matter

Particulate matter (PM) pollution ranges from a coarse dust to very tiny sooty particles formed when gasoline or diesel are burned. It is the tiniest PM that cause the greatest health hazards (Bagley, 1996). Dozens of studies link fine PM concentrations to increased hospital admissions for asthma attacks, chronic obstructive lung disease, bronchitis, pneumonia, heart disease, and premature deaths (Dockery et al., 1989, Peters et al., 2001). School absenteeism due to respiratory symptoms has also been linked to PM pollution (Park et al., 2002). Numerous research studies have found that daily variations in PM pollution can have lethal effects. Studies in six US cities and in Canada have shown that daily elevations in PM are associated with increased deaths on the days immediately following (Schwartz et al., 1996; Burnett et al., 1997, 2000; Lippmann et al., 2000; Moolgavkar, 2000c). A major study of 1.2 million adults followed for two decades found a strong association between PM pollution and lung cancer (Pope et al., 2002).

3.3. Volatile organic compounds

Volatile organic compounds (VOCs) include a long list of chemicals used in industry, as well as chemicals emitted from motor vehicles such as diesel trucks and buses. VOCs are characterized by their ability to evaporate into the air and produce ozone smog, as well as by their inherent toxicity. Common VOCs produced by diesel engines include benzene, toluene, formaldehyde, and 1,3-butadiene (CARB, 1998). Benzene and butadiene are known to cause cancer in humans. Formaldehyde is very irritating to the airways, and is a probable carcinogen. Toluene at occupational exposure levels has been associated with birth defects and miscarriages (CalEPA, 2003). Other VOCs emitted by vehicles have also been linked to cancer, reproductive harm, asthma, or neurological disorders (Delfino, 2002).

3.4. Nitrogen oxides

Numerous studies have found that NO_x can cause toxic effects on the airways, leading to inflammation and to asthmatic reactions (Davies et al., 1997). In fact, people with allergies or asthma have far stronger reactions to common allergens such as pollen when they are also exposed to NO_x (Davies et al., 1998). A European study of nearly 850 7-year-old children living in nonurban communities found that children living where the nitrogen dioxide levels are consistently high, such as near major roads or ports, were up to eight times more likely to be diagnosed with asthma (Studnicka et al., 1997). Children who already have asthma are more likely to cough, wheeze, and suffer from decreased pulmonary function when ambient levels of nitrogen dioxide in the air are high (Nicolai, 1999; Chauhan et al., 2003).

3.5. Ozone (smog)

Ozone, also known as ozone smog, is a reactive gas produced when VOCs or NO_x interact with sunlight and split apart oxygen molecules in the air. Thousands of scientific studies have been published on the health effects of ozone (USEPA, 1996). Ozone can make people more susceptible to respiratory infections and can aggravate preexisting respiratory diseases, such as asthma (USEPA, 1996; Devlin et al., 1991; Koren et al., 1989, 1991). Ozone can also cause irreversible changes in lung structure, which eventually lead to chronic respiratory illnesses, such as emphysema and chronic bronchitis (USEPA, 1996; Hodgkin et al., 1984; Abbey et al., 1993). The inflammatory reaction from ozone may make elderly and other sensitive individuals more susceptible to the adverse effects of other air pollutants, such as particulate matter (Devlin et al., 1997; Koren et al., 1989; Thurston and Ito, 2001). Peak daily ozone levels have been linked to increased numbers of deaths in eight European cities (Touloumi et al., 1997). Recent research has identified a link between long-term ozone concentrations in air and new-onset asthma in both adults and children (McDonnell et al., 1999, 2002). A study in Toronto reported a relationship between short-term elevations in ozone concentrations and hospital admissions for respiratory symptoms in children under age 2 (Burnett et al., 2001). Respiratory disease serious enough to cause school absences has been associated with ozone concentrations in studies from Nevada and Southern California (Chen et al., 2000; Gilliland et al., 2001).

3.6. Sulfur oxides

Sulfur oxides (SO_x) are produced from the burning of sulfur-containing fuels such as diesel and particularly from high sulfur marine fuels (bunker fuel). These compounds include sulfur dioxide and a range of related chemical air pollutants. SO_x react with water vapor in the air to create acidic aerosols that irritate the airways, sometimes causing discomfort and coughing in healthy people, and often causing severe respiratory symptoms in asthmatics (Nicolai, 1999). When asthmatics were exposed under controlled conditions to levels of sulfur dioxide similar to those found near pollution sources such as ports, they developed an average decrease of 25–30% in their lung function (Gong et al., 1996). Several studies indicate that the combination of SO_x and NO_x in the air is particularly noxious, because these compounds appear to act together to increase allergic responses to common allergens such as pollen and dust mites (Peden, 1997; Devalia et al., 1994).

3.7. The susceptibility of the fetus and child to air pollution

Recent research has demonstrated that cancer-causing chemicals from diesel exhaust can cross the placenta in humans (Whyatt et al., 2001). Although fetal exposures to these chemicals are 10-fold lower than maternal exposures, genetic damage is detectable in newborn blood samples at levels significantly higher than in maternal blood. These indications of DNA damage demonstrate that the fetus may be significantly more susceptible than the mother to diesel-related pollutants.

Children are more susceptible to air pollutants because their lungs are still developing and because their airways are narrower than those of adults. In addition, children often play outdoors during the day and thus may be more exposed. Children raised in heavily polluted areas have reduced lung capacity, prematurely aged lungs and increased risk of bronchitis and asthma compared to peers living in less polluted areas (Dockery et al., 1989; Peters et al., 1999). The frequency of cough, bronchitis, and lower respiratory illness in preadolescent children is significantly associated with increased levels of acidic fine PM in outdoor air where they live (Ware, 1986). In addition, some studies have suggested that children with preexisting respiratory conditions (wheezing, asthma) are at even greater risk of developing symptoms from exposures to air pollutants (Pope and Dockery, 1992; Mortimer et al., 2002).

Children living near busy diesel trucking routes have decreased lung function in comparison with children living near roads with mostly automobile traffic (Brunekreef et al., 1997). A survey of nearly 40,000 children in Italy found that those living on streets with heavy truck traffic were 60–90% more likely to have wheezing, phlegm, bronchitis and pneumonia (Ciccone et al., 1998). A German study of nearly 4000 adolescent students found that those living on streets with ‘constant’ truck traffic were 71% more likely to have allergies and more than twice as likely to report wheezing (Duhme et al., 1996).

4. Alternatives assessment at ports: the problem of globalization

The Wingspread Statement on the Precautionary Principle (1998) summarized four guiding components of a precautionary approach to pollution: (1) action to prevent harm despite uncertainty; (2) shifting the burden of proof to proponents of a potentially harmful activity; (3) examination of a full range of alternatives to potentially harmful activities; and (4) democratic decision making to ensure inclusion of those affected.

In the case of ports, a precautionary approach would require us to first take a step back to consider whether there are alternatives to the dramatic expansion of trade that is ongoing in the world today. US exports in 2003 totaled US$1 trillion, up from US$700 billion in 2002, while imports reached US$1.5 trillion, an increase of about 400 billion over the previous year. (Census Bureau, 2003). Some multinational corporations have chosen to move manufacturing operations to countries far from their major markets to avail themselves of cheaper labor. The trend toward decreasing tariffs and other trade restrictions has greatly accelerated the movement of goods over huge distances (Cavanagh et al., 2002). Meanwhile, the costs of shipping freight have decreased steadily since 1980 as a percentage of import values (Cavanagh et al., 2002). Based on these facts, an argument could be made that pollution from ports could be mitigated by increasing trade restrictions, creating incentives for local production of goods, and requiring that the costs of pollution related to long-distance shipping of goods be reflected in the shipping costs for freight.

The International Forum on Globalization (IFG) has articulated “ten principles for democratic and sustainable societies” (Cavanagh et al., 2002). According to the IFG, “Economic systems should favor local production and markets rather than invariably being designed to serve long distance trade. This means shortening the length of lines for economic activity: fewer food miles; fewer oil supply miles; fewer travel-to-work miles”(Cavanagh et al., 2002). Policy changes that discourage production of goods far from their point of sale have the potential to prevent pollution. Such policies could include the reintroduction of protective safeguards to aid local economic renewal, subsidies for local enterprises, the removal of subsidies for multinational enterprises, and controls on corporate activity (Cavanagh et al., 2002).

States and communities can promote local production and supply. In California, for example, the Governor signed legislation in 2001 to provide US$5 million of state funds to the Buy California program. This program created a partnership between government and industry to promote consumption of California-grown agricultural products to California consumers (Buy California, 2004). Beyond such promotional campaigns, most state and local governments and community groups have very limited ability to alter the international forces of trade and globalization.

In addition, while some local communities do not welcome the expansion of port capacity and the development of new port terminals, others are eager for the economic benefits that can come with such developments. When expansion of port facilities to accommodate larger volumes of trade is planned at a port, local and state governments and community groups can push for mitigation of the environmental and health impacts, and this will be the focus of the remainder of this article.

When a port produces an environmental impact assessment for a proposed expansion, there are specific criteria by which such a project can be judged. A mitigation approach can occur in tandem with, or instead of, a fully precautionary approach to reducing environmental impacts from ports. This secondary approach actually comprises a large variety of alternatives, some of which are more and others less protective of health and the environment. The adoption of less polluting alternatives in various locations has demonstrated the feasibility of having some level of traffic through a seaport with limited effects on the environment and local communities.

5. New terminal facilities: the importance of site selection

Port Authorities[5] have a variety of options to reduce pollution from their seaport operations, ranging from a precautionary approach to new port developments to targeted pollution control measures employed at existing terminals. Siting new terminals away from residential areas is of the utmost importance in order to protect communities from the pollution, noise and other stressful impacts associated with the heavy industrial nature of port terminals. Some of the most important mitigation measures for new port terminal developments include siting the new terminal close to the mouth of the harbor, close to existing transportation infrastructure, and far from residential areas.

While it may sometimes be difficult to locate a suitable site with all of the above attributes, the Vuosaari Harbor development in Finland serves as a good example. This new development will replace all of Helsinki's port operations,

[5] Ports vary widely in their organizational structure and in their scope of authority. Most ports in the United States are established by enactments of state governments and may be structured as port authorities, bistate authorities, special districts, or departments of state, county, and municipal governments (AAPA, 2000). Commissioners of some port authorities, such as the Port of Seattle, are elected, theoretically making them more accountable to the public. Others, such as the Port of Miami, are controlled within a branch of local government. Many ports have authority over a broad array of commerce and transportation related items including airports, seaports, bridges and tunnels, and ferries.

relieving downtown Helsinki from the pollution, noise and traffic of those operations (Port of Helsinki, 2004). Operations at the new Harbor will be 2 km—an ample buffer—from the nearest residential area. While this new site is not significantly closer to the harbor entrance than the former site, it will have convenient land and sea connections, and is situated on a major ring road around Helsinki, close to the airport. The development will also employ a number of mitigation measures to protect the local natural habitat, such as burying some segments of road and rail lines.

The location of new terminals close to a harbor entrance is a simple way to avoid significant amounts of pollution from ships traveling extra distances from the shipping lanes in the open ocean. For example the largest single-terminal container complex on the East Coast, at the Port of Savannah, is located 36 miles from the harbor entrance, more than half of which is up a river (Georgia Ports Authority, 1998, 2003). The Port of Miami, on the other hand, is located just a few miles from the open ocean.

Proximity of new terminal developments to land transportation infrastructure is also extremely important. Developments that reuse abandoned industrial properties or former military installations are often close to existing highways and main rail lines and at the same time avoid new construction on a more pristine site. Sufficient roadway infrastructure is important in order to prevent persistent traffic and safety concerns on smaller roads. Well-planned railroad infrastructure is particularly important at new port terminals. An environmental analysis shows that rail transport is environmentally preferable to truck transport (FRA, FHWA, and EPA, 1997; Forkenbrock, 2001). However, rail transport is still a significant pollution source, and longer, less direct rail lines result in more pollution. Recognizing these issues, the Port Authority of New York and New Jersey has decided to invest US$500 million in rail infrastructure to serve their terminals, replacing more polluting truck traffic with a direct rail line (Port Authority of New York/New Jersey, 2003). However, the Port of Charleston failed to plan their railroad infrastructure with environmental considerations in mind in a proposal to build a new container terminal on Daniel Island, a location that would require a circuitous 50-mile rail loop just to cross a river (Contain the Port, 2003). The Port of Charleston has since selected a new site for development, on the other side of the river from Daniel Island, close to existing transportation infrastructure.

"On-dock rail" or rails that go all the way onto the docks where ships are unloaded, can significantly reduce pollution by eliminating the need for many truck trips that normally would shuttle containers from the docks to a railyard. Ports have increasingly begun to embrace on-dock rail for new terminal developments as it increases the efficiency of their operations. The recent container terminal development at the Port of Seattle was built with on-dock rail, routing the majority of containers out via rail rather than truck. The Port of Seattle reports that on-dock rail, combined with other rail improvements, has replaced 200,000 miles of truck trips in Seattle annually (Blomberg, 2003).

6. Air pollution control measures at existing ports

6.1. Easily achievable approaches

Ports around the world have adopted approaches that can significantly reduce their contribution to air pollution. Some of these measures, such as the use of somewhat cleaner fuels and the enforcement of idling limits, are relatively easy and inexpensive to adopt (NRDC, 2004). Ports could reasonably switch to these proven approaches that make a modest contribution toward cleaner air. Cleaner fuels can be used in all port operations. Cargo handling equipment, locomotives and ships at most ports currently run on a much dirtier grade of diesel fuel than the on-road diesel used in trucks. Ocean-going ships typically run on bunker oil, which has over 100 times the amount of sulfur of on-road diesel (CARB, 2003). Cleaner grades of diesel fuel, or synthetic fuels lower emissions and also enable the use of advanced pollution control devices (CARB, 2003).

6.2. Cleaner diesel fuels

Several cleaner fuel options are available that are compatible with existing diesel engines, including low sulfur diesel ($\leq$ 15 ppm sulfur), diesel emulsions, biodiesel and Fischer–Tropsch diesel. Although low sulfur diesel is the most widely available and the cheapest, the other options offer higher emission reductions for certain pollutants (Table 2).

Low sulfur diesel is generally intended to be used in combination with emission controls, but does offer substantial emission reductions even when

Table 2
Emission reductions of various cleaner diesels

Technologies	NO_x	PM	SOx	CO	ROG	Fuel penalty	Extra cost (per gal)
Low sulfur diesel (LSD) fuel	3–11%	3–15%	> 90%	6–10%	8–13%	~ 3%	~ 5 cents
Diesel Emulsions[a]	9–20%	16–63%		–	–	15–20%	US$0.24–0.29
Biodiesel (100%)[b]	(10)–(15)%	30–50%	>90%	50%	>90%	4–11%	~ US$1
Fischer–Tropsch diesel	4–12%	24–26%		18–36%	20–40%	2–3%	Unknown

Emission Reductions are in Comparison to CARB diesel (< 150 ppm sulfur).
Reactive organic gases (ROG).
Sources: CARB, 2000, Appendix IV; CARB, 2004; USEPA, 2004c; Blume, 2002.
[a] CO and ROG emissions vary widely, some tests show substantial increases and some great decreases.
[b] Compared to conventional diesel (500 ppm sulfur); Biodiesel increases NOx emissions.

used alone as a replacement for bunker fuel in ships. It is currently available in most major metropolitan areas, and will be available throughout the United States by mid-2006, when it will be required for all on-road vehicles (USEPA, 2004b). Many ports throughout the world have committed to using lower sulfur diesel in various operations to reduce diesel exhaust pollution (Seum and Sylte, 2003). The Port of Helsinki uses lower sulfur diesel (30 ppm) in its own equipment and several marine vessels, as an example to the terminal operators (Seum and Sylte, 2003). In the United States, the Port of Oakland has convinced most of its terminal operators to adopt low sulfur diesel (15 ppm) for cargo handling equipment (Seum and Sylte, 2003).

Diesel emulsions (aqueous diesel) can be used as an emissions reduction tool at ports. Three brands of aqueous diesel have been verified by the California Air Resources Board (ARB) (CARB, 2004). Although there is only a slight decrease in NO_x, some studies have reported significant decreases in PM with use of this fuel, whereas others, namely on off-road equipment, have not shown such impressive results (USEPA, 2002c p. 28; CARB, 2004). Demonstration projects are in place or pending at the Ports of Houston, Los Angeles, Long Beach and Oakland.

Biodiesel is most commonly sold as a blend with 80% or more conventional diesel (Clean Cities, 2001). Emission benefits of these blends show a 10–20% improvement over regular diesel (USDOE, 2000). Pure biodiesel does offer more substantial PM and CO_2 reductions—on the order of 50%—but at the expense of an increase in NO_x (by as much as 10%) (USEPA, 2004a,b,c; USDOE, 2000). Many engine manufacturers do not warrant their products for use with pure biodiesel, because it can cause corrosion in some engines (McCormick, 2003).[6] Biodiesel is distributed in many regions throughout the United States, though prices vary widely, as does the feedstock used to make biodiesel fuel, which can include used oils and grease, or farmed products such as corn. The biodegradability of biodiesel makes it well suited for marine uses because spills are not a serious problem.

Fischer–Tropsch diesel is usually made from coal, but is sometimes made from natural gas, leading to the recent acronym Gas to liquids (GTL) fuel (USEPA, 2002b). Much of the Fischer–Tropsch diesel in the United States is imported from Malaysia, however, plans may be underway to build a full-scale US plant soon (CEC, 2002). Fischer–Tropsch fuel can reduce emissions of NO_x by more than 10% and of several other pollutants in the range of 30% (CARB, 2000, Appendix IV). The costs and overall environmental benefits are contingent on transport and feedstocks, and are not yet well known.

[6] Biodiesel has stronger solvent properties than diesel. A transition to pure biodiesel requires maintenance including frequent fuel filter changes initially and a replacement of all rubber parts (typically used in older vehicles as opposed to modern synthetic materials like Viton).

Table 3
Estimated emission reductions from a 10-min idling limit at the port of Los Angeles

	C	CO_2[a]	HC[b]	NO_x[a]	PM_{10}[b]
Average truck's idle pollutants (g/h)	94	8224	12.5	144	2.57
Total tons idle exhaust per year at Port of LA	316	27,651	42	484	8.6
Reductions per year from 10-min limit (tons)	263	23,043	35	403	7.2

Assumptions: (1) In 2002, over 6.1 million "20-ft equivalent units" (TEUs—roughly equivalent to one-half a container each) moved in and out of the Port. (2) Truckers spend 1 h idling while running loads to and from the Port (truckers report spending at least 1 h or more).
Total tons/year of Idle Exhaust at the Port of LA=(Idle EF)(CF_{g-t})(#TT/yr)(I_{avg})
Where Idle EF = Idle Emission Factor (g/h), from above sources.
CF_{g-t} = Conversion Factor from grams to tons $(454 \times 2000)^{-1}$.
#TT/yr = Number of Truck Trips per year: 6.1 million TEUs/2 TEUs per truck trip.
I_{avg} = Average Idle time per truck, 1 h.
Reductions per year from 10-min Idle Limit=[(60 – 10 min)/60 min/h] × Total tons/year Idle Exhaust.
[a] USEPA, 2002d.
[b] Stodolsky et al., 2000.

6.3. Idling limits

Well-enforced idling restrictions can save hundreds of gallons of fuel per vehicle annually and are a cost effective way to substantially reduce diesel emissions from trucks and locomotives, because these sources normally tend to idle for long periods of time at ports.

Using the Port of Los Angeles as an example, the air quality benefits of a ten-minute idling limit are significant (Table 3). In addition to reducing over 400 tons per year of NO_x, this measure would also save over 2 million gal of fuel annually.[7] The cost of idling restrictions would total roughly US$800,000 per year to cover signage and additional personnel to monitor compliance,[8] yielding a cost ratio of roughly US$2000 per ton of NO_x reduced, which is extremely cost competitive with other measures. Additionally, the cost estimates do not include the other pollutants that are significantly reduced, such as diesel PM and carbon dioxide. Finally, the measure saves millions of dollars in fuel costs as well as engine maintenance costs.[9] (EPA, 2001) California implemented a statewide idling law in 2003, limiting idling for all trucks at ports in major metropolitan

[7] Calculated using the EPA estimate that the average truck wastes 0.8 gal of fuel per h of idling (USEPA, 2003c) and using the same assumptions listed under Table 3.

[8] The cost is based on eight terminal operators who will have to each hire personnel to monitor compliance, post signs and train both their new and existing personnel for enforcement at an estimated cost of US$100,000 a year per terminal (possibly more during the first year, but subsequent years will cost much less).

[9] Experts estimate that engine wear on trucks due to idling for 1 h per day is the equivalent of 6400 miles of travel annually, which equates to an additional US$300 per year in added maintenance on the vehicle.

areas to 30 min (BAAQMD, 2003). Some other ports, such as the Port of Seattle, are starting to post no-idling signs and implement idling restrictions.

Locomotives can also substantially reduce pollution through automatic idling control devices. Switching engines, used to move trains around within railyards, are generally highly polluting and tend to idle about 75% of the time, making them perfect candidates for automatic idling controls (ANL, 2003). These controls reduce fuel use, diesel emissions, and noise. EPA estimates that 10% of all rail fuel could be saved, which translates to 366 million gal and US$240 million (MacGregor, 2001). Most automatic idling controls for locomotives cost roughly US$6000–US$10,000, with more elaborate devices costing up to US$40,000 (Bubbosh, 2003; Detro, 2002; Nudds, 2002). Some companies that make these controls claim that the cost is paid back in a year or two through fuel savings (ZTR, 2004).

7. Air pollution measures requiring capital investments

Some air pollution mitigation measures require infrastructure and more capital investment than switching fuels or imposing idling controls. However, ports can use these approaches to further reduce their impacts on local air quality. Measures include programs to retrofit, repower and retire vehicles, equipment, locomotives and ships; as well as the purchase of equipment that runs on alternative fuels such as compressed natural gas (CNG).

7.1. Retrofits, repowers and retirement of trucks and yard equipment

The oldest, most polluting vehicles, equipment and vessels can be replaced with new models that comply with modern emission standards. Vehicles, equipment and vessels with a significant amount of useful life left can often be repowered with cleaner new engines, simply swapping the old engine for a new one. In many cases, exhaust systems can be retrofitted with emission controls, also known as aftertreatments, which significantly reduce exhaust emissions.

While replacement of older vehicles and equipment is often preferable, retrofits and repowers offer a more practical solution for an existing fleet. Repowers are sometimes limited by the age and configuration of a vehicle or piece of equipment; however, in most cases at least one control technology, typically an oxidation catalyst, can be retrofitted onto virtually any vehicle or piece of equipment (MECA, 2003). The various control technologies that are currently available are listed in Table 4. These produce different levels of emission reductions at varying costs and are specified in certain cases to engines ages or types as noted in Table 5.

The Port of Oakland has a program to clean up yard equipment, funded through a settlement that the Port reached with the surrounding community over a

Table 4
Pollutants reduced by various retrofit technologies

Technologies	NO_x	PM	CO	ROG	Fuel sulfur tolerance	Fuel penalty
Active diesel particulate filter (DPF) and lean NO_x catalyst (LNC)[a]	25–35%	50–90%	50–90%	50–90%	Up to 15 ppm	3–7%
Passive diesel particulate filter (DPF)	–[b]	85%	60–90+%	60–90+%	Up to 15 ppm	2–4%
Electrically regenerated DPF	–	80–95%	–[c]	–[c]	Up to 15 ppm	1–2%
Diesel oxidation catalysts (OC)	–	25%[d]	30–90%	40–90%	Up to 500 ppm	0–2%
Exhaust gas recirculation (EGR)	20–50%	N/A[e]	N/A	N/A	Up to 500 ppm	0–5%
Lean NO_x catalyst	10–20%	N/A	N/A	N/A	Up to 250 ppm	4–7%

Sources: MECA, 2003, 2002; CARB, 2000, App. IX; USEPA, 2004c.

[a] This retrofit, called "Longview" by tradename has been verified by ARB for use on select on-road vehicles. The technology has been used by construction and other off-road vehicles, however, specific reductions for off-road applications are not yet available. Emission reductions are as reported by Cleaire, the manufacturer.

[b] Verified DPFs are prone to producing more nitrogen dioxide as its creation is required for proper regeneration of the system. CARB believes the NO_2 increase is offset by NO_x benefits achieved by the DPF systems.

[c] Highly variable; may depend on fuel sulfur levels.

[d] OCs have been verified for off-road use by CARB at this level. However, PM emissions reductions can be improved with very low sulfur levels. It should also be noted that when OCs are used with regular EPA grade off-road diesel, which averages over 3000 ppm sulfur, PM emissions are likely to increase.

[e] PM emissions may increase slightly, especially with higher NO_x reductions; EGR should not be used without particulate controls.

recent expansion (BAAQMD, 2003). Terminal operators can use the funds of this voluntary program to retrofit, repower or make new cleaner purchases of terminal equipment. The Port of Oakland plans to start a similar program for offsite trucks visiting the port terminals, with the remaining settlement money. The Port of Göteborg in Sweden also has a program to clean up yard equipment; to date they have fitted their terminal tractors and roughly one-third of straddle carriers with particulate traps (Port of Göteborg, 2003).

7.2. Repowering locomotives

Old, highly polluting switching locomotives can be repowered with several low-emitting new engine options, including natural gas (NG) and hybrid battery-electric. In particular, the replacement of pre-1973 locomotive engines or those engines not yet meeting federal standards provides the most significant emission benefits. Switching locomotives are good candidates for repowers because they typically idle for long periods and are "work-horses" in most railyards.

Table 5
Costs and restrictions of repower and retrofit technologies

Technologies	Unit cost (US$1000)	Target vehicles/ equipment	Comments
Replace with new-used truck (model year 1994 or newer)	35–45	On-Road	Replacement truck should be fitted with additional controls.
New engine repower	11–32	Off-Road	New engine must be compatible in size and electronic vs. manual control systems
Active diesel particulate filter (DPF) and NO_x reduction catalyst (NRC)	15–18	On-Road and Off-Road	Engine model year must be mid-90s or newer and must be compatible. Requires 15 ppm low sulfur diesel.
Passive diesel particulate filter (DPF)	4.2–5.5	On-Road	Engine model year must be mid-90s or newer and must be compatible. Requires 15 ppm low sulfur diesel.
Electrically regenerated DPF	4.5–14	Off-Road	Requires 15 ppm low sulfur diesel.
Diesel oxidation catalysts (OC)	1–3	On-Road and Off-Road	Requires 500 ppm or lower sulfur diesel.
Exhaust gas recirculation (EGR)	13–15	On-Road	Off-Road may also be possible in the future; may cause increase in PM.
Lean NO_x catalyst	6.5–10	On-Road	Emerging technology

Sources: MECA, 2003, 2002; CARB, 2000, App. IX; USEPA, 2004c; McKinnon, 2000; Gorski, 2003; Cleaire, 2003; Donaldson Corporation, 2003; Port of Oakland, 2003.

Several alternative fuel and hybrid-electric locomotives are on the market and available for purchase; others are under development. A number of projects have converted diesel locomotives to natural gas fuel, overhauling both the engine and fueling system. Cost for such a conversion, including the new natural gas fuel system ranges from US$400,000 to US$800,000 per locomotive (Gladstein, 2003). Repowering a locomotive with a low-emission LNG (Liquefied NG) engine could reduce NO_x by 4.8 tons per year (Gladstein, 2003). Where natural gas infrastructure exists, this option may be very appealing.

The “Green Goat,” a new hybrid electric switching locomotive, retails for US$750,000, roughly half the cost of a conventional locomotive, and reduces both PM and NO_x by roughly 85%, or 13.5 tons per year. (Clarke, 2002) The Green Goat uses a 200-hp generator (as compared to $\sim$2000 hp locomotive engines) to replenish power to a bank of batteries, cutting fuel use by at least one-third and lowering noise. The cheapest “Green Goat” uses a tier II certified diesel generator, though natural gas microturbines and fuel cell power will apparently also be options in the future. Union Pacific recently completed a 1-year demonstration of this technology at its Roseville, CA switching yard (Railpower Technologies, 2002).

7.3. Tugboat repowers

If switching locomotives are the workhorses of railyards, tugboats are the workhorses of the harbor, contributing to the overall pollution from the port. According to a San Francisco Bay Area survey, many tugboats stay in service well over 30 years (Moffatt and Nichol Engineers, 2001). These older, more polluting engines, particularly those of two-cycle design, and particularly those used on a frequent basis, are prime candidates to be repowered. Specific emission reductions vary by tug, depending on the emissions rate of existing and replacement engines, and the type and amount of service it provides. Replacement engines can cost roughly US$400,000 and yield up to 73 tons per year of NO_x reductions (Friesen and Sylte, 2002). California's Carl Moyer Program has subsidized numerous tugboat repower projects (CARB, 2003). The Port of New York/New Jersey is also exploring this measure (Dorrler, 2003).

7.4. Alternative fuels for yard equipment

Alternative fuels such as compressed natural gas (CNG) and propane may be considered for fleets of vehicles, such as terminal tractors and other cargo handling equipment, that are centrally fueled. Emission benefits can be substantial when diesel fueled engines are replaced with alternative fuel systems. Switching to alternative fuels completely eliminates emissions of diesel particulate matter (PM) and significantly reduces NO_x emissions (USEPA, 2002b). For example, CNG powered buses have demonstrated in-use PM emissions that are 20–100 times lower than their diesel counterparts (CARB, 1999). Likewise, the California Air Resources Board reported that compared to conventional diesel technology, natural gas technology has shown in-use emissions reductions in the range of 50% for NO_x and 90% for PM. While natural gas engines have significantly lower NO_x and PM, they will likely have higher CO and CO_2 emissions and slightly higher hydrocarbon emissions. However, the increase in emissions is small compared to the decrease in NO_x and PM emissions (CARB, 1999).

Certified CNG engines are widely used in bus fleets throughout the country. The Port of Los Angeles successfully completed a demonstration with a propane terminal tractor and under a recent legal settlement committed to 35 more alternative fuel terminal tractors (Gladstein, 2003).

8. Technologies on the horizon

Many new technologies that can provide substantial pollution reductions at Ports are still in somewhat of a demonstration phase, but should be available in the future. Measures that incorporate emerging technologies or methods include pollution controls for large ocean-going ships, shore-side power for ships while docked, zero-emission technologies such as fuel cells, and automated container handling.

8.1. Emission controls on ships

In Europe, much work has been done to explore emission controls for ships. Selective Catalytic Reduction (SCR), a control technology that drastically reduces the smog-forming NO_x coming from ship smokestacks[10] has been installed on over 100 large ships, mostly in the Baltic Sea area (CARB, 2002a,b). Several US examples exist as well. In California, four large ocean going vessels and one "Cutterhead" dredge use SCR systems (Starcrest Consulting Group, 2002). While this technology still has several hurdles to overcome, including cost, it may eventually prove to be an effective pollution control measure for mainstream use.

8.2. Shore-side power for ships while at dock

Ships normally use diesel fueled auxiliary engines while docked, in order to run onboard systems such as lights, pumps and fans (CARB, 2003). This engine idling, which can last for days, creates large amounts of air pollution as well as noise. Swedish ports have found a way to eliminate this extra pollution by plugging ships in to a "shore-side" power source. At the Swedish port of Göteborg alone, 80 tons of NO_x, 60 tons of SO_x and 2 tons of PM emissions are avoided annually due to shore-side power use by ferries and several cargo vessels (Port of Göteborg, 2000, 2003). Efforts are currently underway to replace fossil fuel based shore-side energy with nearby wind energy (Wilske, 2003). Other Northern European ports, such as Lübeck, Germany, have plans for similar electric ship-to-shore projects (Seum and Sylte, 2003).

In 2001, shore-based power was installed at a cruise terminal in Juneau, AK (Alaska DEC, 2001). Princess Tours, a cruise line, spent US$2 million to retrofit four cruise ships and an additional US$2.5 million on shore-side construction, so that its cruise ships could plug in while docked for 10–12 h (Plenda, 2001). The company installed the shore-side power after paying fines for excessive smoke from its ships (Koch, 2003).

California ports are slowly following suit. The Port of Oakland installed power plug-ins on a new tugboat wharf in 2001, so that tugboats could shut down their engines while at berth (Bay Area Monitor, 2001). Oakland considers this too expensive for larger ocean-going vessels (BAAQMD, 2003); however, the Ports of Los Angeles and Long Beach are both actively exploring this possibility (AP/Monterey Herald, 2003). Under a recent legal settlement, the Port of Los Angeles will installed shore-side electrical power for hoteling

[10] NO_x reductions can be 80% or higher. However, concerns remain over ammonia, the active ingredient of this control, "slipping" out as pollution itself.

(docking) of ships at one to two berths and invested US$5 million to retrofit ships regularly using those berths, so that they can use electrical power while at dock (Port of Los Angeles, 2004). This will prevent each vessel that uses the shore-side power from emitting 1 ton of NO_x and almost 100 lb of particulate matter each day (NRDC, 2003).

8.3. Clean power

In order for shore-side power measures to be successful, sufficient power must exist or be developed for use at the wharves. Options to bring power to wharves include new or upgraded substations, fuel cell units, or a ‘‘Power barge’’ (Friesen and Sylte, 2002). Installation or upgrade of a port area substation is most appropriate for terminals requiring high power loads, such as cruise terminals or very large cargo areas (Friesen and Sylte, 2002). In order to provide emission benefits, the emissions associated with the electrical generation supplied by the substation must be significantly less than the emissions generated by auxiliary engines on the receiving vessels to ensure meaningful emission reductions.

The second power generation option is the installation of one or two fuel cell units (200–250 kW size) at berths where smaller ships (e.g., tugboats, commercial fishing boats, and crew/supply boats) are hoteling and where natural gas is available as a fuel source. Fuel cell technology offers many advantages over existing diesel generators, including very low exhaust emissions, quieter operation, and improved thermal efficiency (Friesen and Sylte, 2002). The US Navy, as well as many foreign navies, is considering the use of integrated electric plants that employ fuel cells in future ship designs (Friesen and Sylte, 2002). However, ships employing fuel cells for propulsion and fuel cells for auxiliary power or dockside power generation are still in development stages (Friesen and Sylte, 2002).

The third option for power generation is a demonstration project to install fuel cells on a barge that could maneuver within a port to supply power at multiple locations. This type of project may work well for cargo ships in berth where diesel generators producing auxiliary loads are in the 1–2 MW range, as opposed to the cruise ships where the load is an order of magnitude higher (Friesen and Sylte, 2002).

9. Conclusions

Ports are a major and growing source of pollution, and can impose significant health risks on nearby communities. Approaches to addressing the pollution from ports can range from very broad to very tailored. A truly precautionary approach would require addressing the root causes of this pollution source, particularly the expansion in international trade driven by increasing globalization of markets. A more mitigation-oriented approach focuses on pushing for the adoption of the best currently available technologies to reduce port pollution even in the face of port expansion.

In the case of air pollutants there are a broad range of mitigation approaches potentially available in this complex sector. Some approaches are inexpensive but have a correspondingly modest effect on improving air quality. Examples of such modest approaches include switching to cleaner versions of diesel fuel and restricting idling. Somewhat more aggressive approaches to mitigating air quality impacts include transitioning to alternative fuels such as natural gas or propane; and retrofitting, repowering, or retiring older diesel equipment and vehicles. Measures that incorporate emerging technologies include pollution controls for ocean-going ships, shore-side power for docked ships, zero-emission technologies such as fuel cells, and automated container handling.

Ultimately, if ports are to move toward a sustainable model that serves a local region without damaging the health and integrity of local communities and ecosystems, numerous approaches will be necessary to reduce pollution. Meanwhile, the technologies are advancing fairly rapidly, and emerging approaches will be needed to reduce emissions from particularly difficult sources such as ocean-going ships. A technological approach oriented toward best environmental practices is compatible both with a risk-assessment driven process, and with a truly precautionary approach that seeks to reduce health risks to local communities.

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