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Prevention and Control of Shipping and Port Air Emissions in China

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LIST OF ABBREVIATIONS

AQ	Air Quality
AQG	Air Quality Guidelines
AQO	Air Quality Objectives
$CaCO_3$	Calcium Carbonate
CARB	California Air Resources Board
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DFDE	Dual Fuel Diesel Electric
ECA	Emission Control Area
EF	Energy Foundation
EGR	Exhaust Gas Recirculation
ESI	Environmental Standard Institute
EU	European Union
GDDEP	Guangdong Provincial Department of Environmental Protection
GDDT	Guangdong Provincial Department of Transport
GDAES	Guangdong Provincial Academy of Environmental Sciences
GHG	Greenhouse Gas
GZIEP	Guangzhou Institute of Environmental Protection
HC	Hydrocarbon
HEI	Health Effects Institute
HKEPD	Hong Kong Environmental Protection Department
HKU	University of Hong Kong
HKUST	Hong Kong University of Science and Technology
HSEC	Human Settlements and Environment Commission
IMO	International Maritime Organization
Jing-Jin-Ji	Beijing-Tianjin-Hebei Area
LNG	Liquefied Natural Gas
MARPOL	International Convention for the Prevention of Marine Pollution from Ships
MEP	Ministry of Environmental Protection
MOT	Ministry of Transport
nm	Nautical Miles
NO_2	Nitrogen Dioxide
NO_x	Nitrogen Oxide
O_3	Ozone
OECD	Organisation for Economic Co-operation and Development
OGV	Oceangoing Vessel
PAH	Polycyclic Aromatic Hydrocarbon
PM	Particulate Matter
POLA	Port of Los Angeles
POLB	Port of Long Beach
POSD	Port of San Diego
PM	Particulate matter
ppm	Parts Per Million
PRD	Pearl River Delta
RF	Radiative Forcing
RSP	Respirable Suspended Particulates
RTG	Rubber Tire Gantry Crane
SCR	Selective Catalytic Reduction
SO_2	Sulfur Dioxide
SO_3	Sulfur Trioxide
SOx	Sulfur Oxide
SZAES	Shenzhen Academy of Environmental Sciences
SZTC	Shenzhen Transportation Commission
UNCTAD	United Nations Conference on Trade and Development
USEPA	U.S. Environmental Protection Agency
VECC	Vehicle Emission Control Center
VOC	Volatile Organic Compound
VSR	Vessel Speed Reduction
WHO	World Health Organization
WTI	Waterborne Transport Research Institute
YRD	Yangtze River Delta

GLOSSARY OF TERMS

Low-sulfur fuel switching
This is a practice of switching from using high-sulfur bunker fuel (with fuel sulfur content as high as 35,000 ppm, or 3.5%) to using lower-sulfur diesel fuel (1,000 to 15,000 ppm, or 0.1% to 1.5%) in the main and/or auxiliary engines.

Shore power
The use of shore power allows ships to turn off engines onboard and instead use shoreside electricity to power refrigeration, lights, pumps, and other equipment being used while at berth.

Vessel speed reduction (VSR)
VSR refers to the practice of operating an oceangoing vessel at a speed significantly lower than its maximum speed. Such practice helps to save fuel and reduce emissions.

EXECUTIVE SUMMARY

China is home to 7 of the world's top 10 container ports, and about 30% of the world's containers pass through China's ports every year. However, with every ship and truck entering these ports comes not only cargo but also air pollution. Most ships at Chinese ports are fueled by bunker fuel, also known as residual fuel. Almost all port vehicles and equipment are powered by diesel fuel. The exhaust from all of these engines contains high levels of diesel particulate matter (PM), oxides of nitrogen (NO_x), and oxides of sulfur (SOx). These emissions are known to cause cancer and are associated with a wide range of respiratory and cardiovascular illnesses.[1] A portion of PM from diesel or bunker fuel combustion is black carbon, which is a short-lived climate pollutant that is accelerating glacial and polar ice melting and exacerbating climate change. NO_x emissions from diesel engines also contribute to increasing regional ozone (O_3) and fine PM, threatening human health and the environment. The high levels of sulfur in dirty diesel and marine fuels can impair or destroy advanced emission control systems on trucks and vessels; they also lead to high emissions of sulfate-based PM and sulfur dioxide (SO_2) emissions that cause damage to ecosystems and contribute to ocean acidification.

China is paying a high price for pollution associated with shipping. An estimated 1.2 million premature deaths in China in 2010 were caused by ambient air pollution, and shipping is a significant source of these air pollution and health problems, particularly in port cities, according to studies conducted in Hong Kong and Shenzhen.[2] Since Chinese ports are among the world's busiest, and since their host cities are among the most densely populated in the world, air pollution from ships and port activities likely contributes to much higher public health risks in China than in other port regions around the world.

Recognizing the health and environmental impacts of shipping, governments in North America, Europe, and Asia (such as Singapore and Hong Kong) have taken steps to regulate ship and port emissions and/or launched programs to encourage the use of low-sulfur fuel and clean technologies. For ocean shipping, the International Maritime Organization (IMO) under the United Nations has adopted SOx, PM, and NO_x standards targeting oceangoing ships.[i] The IMO has also designated four regions as Emission Control Areas (ECAs). In the Baltic and North Sea ECAs, ships must comply with stricter SOx (and indirectly PM) emissions limits; in the North American and U.S. Caribbean ECAs, ships are subject to stricter standards for SOx, PM, and NO_x emissions. Sulfur levels in ship fuel used near and at ports in North America and Northern Europe (i.e., within ECA waters) are currently capped at 10,000 ppm (parts per million) (1%), and this fuel sulfur cap will be lowered to 1,000 ppm (0.1%) beginning on January 1, 2015. This is much lower than the world's average marine fuel sulfur level of 26,000 ppm (2.6%) and the global cap of 35,000 ppm (3.5%).[3] Any oceangoing vessel (OGVs) constructed in 2016 or later which operates within the North American ECA (within 200 nautical miles of the North American coast) and the U.S. Caribbean ECA will be required to emit 75% less NO_x than emissions from new OGVs built today. Inland waterway vessels in the EU and U.S.-registered non-oceangoing vessels[4] that operate within the U.S. are required to meet even stricter fuel sulfur and NO_x emission standards than are applied to non-road engines. Hong Kong and Singapore reduce port dues for oceangoing vessels that voluntarily switch to clean fuel while at berth, or during their stay in the Port of Singapore.[5]

i The International Maritime Organization (IMO) enacts environmental regulations through the International Convention for the Prevention of Marine Pollution from Ships (MARPOL). Annex VI of the Convention specifically deals with the prevention of air pollution from vessels. The countries and regions mentioned here have all ratified MARPOL Annex VI and are taking regulative steps under the framework of Annex VI. See more details in Section 4.9.

The ECA regulations are expected to be highly cost-effective: The low-sulfur marine fuel standards enforced in the North Sea and Baltic Sea ECAs are expected to result in public health and environmental benefits worth four times the cost of compliance; for the North American ECA, the estimated benefits from the NO_x, SOx and PM standards will have a value more than 10 times the compliance costs.

These regulations and incentive programs have driven the development and deployment of alternative fuel and advanced emissions control technologies on ships. While switching to lower-sulfur marine fuel remains the most common approach to meeting the fuel sulfur mandates, some ship operators are testing the feasibility of scrubbers for cleaning up tailpipe SOx emissions. Advanced NO_x emissions control technologies, such as Selective Reduction Catalyst or Exhaust Gas Recirculation devices, have been deployed on ships because of incentives and the strict NO_x emissions requirement to go into effect in North America. Ships powered by liquefied natural gas (LNG) are gaining traction in the U.S., EU, and China, owing to the lower NO_x, SOx, and PM emissions from LNG vessels and the lower costs in the U.S. and EU compared with low-sulfur marine diesel. An increasing number of ports in Europe and the U.S. are building LNG bunkering facilities. Some ports in the U.S. and EU also promote, or even mandate, the use of shore power and vessel speed reduction in order to further cut vessel emissions at or near ports.

In China, severe air pollution episodes occurring in recent years have prompted the government to adopt a new set of ambient air quality standards and implement a series of measures for improving air quality. However, only a few port cities and provinces have begun to pay attention to emissions from ships and port activities. Hong Kong was the first to strictly enforce the use of low-sulfur fuel (500 ppm, or 0.05% sulfur content) by local vessels and will soon be the first in China to require OGVs to use lower-sulfur marine fuel while docking. Shenzhen has followed Hong Kong, announcing a comprehensive list of measures for cleaning up ships, trucks, and port equipment. Other port cities and regions like Shanghai, Qingdao, Guangdong, Jiangsu, and Shandong provinces have also issued plans to promote shore power, electrification of port equipment, and the use of electric or natural gas–powered trucks. All in all, research into and adoption of measures to control air emissions from shipping and ports are still at an early stage in China. There is much room for enhancing the emissions control performance of vessels, trucks, and port equipment. Cleaning up ships, trucks, and port equipment therefore can contribute significantly to the important air quality improvement efforts undertaken in coastal regions.

While the announcement of clean port/clean shipping plans is encouraging, implementation of these plans may face challenges. Due to a lack of data, most of these plans were developed without the support of detailed, port-specific analysis. As the plans only lay out high-level goals, and implementation details, such as penalties or incentives to ensure attainment of these goals, would need to be worked out by the city or provincial agencies in charge, and be agreed upon by various stakeholders including the industry. Without solid analysis to support the proposed goals, these plans are susceptible to opposition from the port and shipping industry. Further, unless port cities cooperate on regional emission control measures, the fear that ships may shift to less regulated ports may prevent port cities from adopting stricter measures, such as mandating, as opposed to encouraging, the use of low-sulfur fuel. If regulation were to drive ships to other ports, such "leakage" would only shift pollution from one port to another and seriously undermine the overall effectiveness of clean port and shipping measures that have been adopted.

To address these challenges and knowledge gaps, more research to establish emission inventories and to evaluate costs and benefits of various pollution control measures specific to a port or region is needed. As the costs and benefits of measures like shore power or the use of liquefied natural gas-powered vessels could vary substantially depending on port-specific conditions, such analysis could help ports prioritize and best direct resources to strategies that maximize emissions reductions. This analysis could then be used to formulate clean port plans that guide efforts to reduce air pollution from shipping and port activities. Research to assess the impacts of regulation on port competitiveness and ways to address those impacts would also help garner broader support for port and shipping emissions control programs. Ultimately, a regional and even national approach to reduce marine and port emissions, such as the establishment of an Emission Control Area, would be the best way to prevent ships from evading their responsibility by transferring to ports with lax environmental requirements, and would ensure that any program adopted in China would achieve the expected emissions control and health outcomes.

1. INTRODUCTION

1.1 PORTS AND SHIPPING IN CHINA

In 2012, the global throughput of containers at ports around the world was about 600 million TEUs (1 TEU = the equivalent of a container 20 feet long and 8 feet wide),[ii] of which about 30 percent, or close to 178 million TEUs, were handled by Chinese ports.[iii] China currently has 7 of the world's 10 busiest ports as well as 10 of the world's top 20.[6] The 10 Chinese ports in the world's top 20 handled about 26 percent of global throughput, or more than 168 million TEUs (see Table 1). The seven top Chinese port cities also have the highest population density among all major port regions. The high concentration of ship movements and maritime activities in areas with high population density suggests that air pollution from ships likely has significantly more health impacts on residents in these port cities than in other port regions around the world.

Just 35 years ago, there were no large container ports operating in mainland China; Hong Kong was the primary international container port serving the import and export needs of China. Today, well-established container ports in China, such as Shanghai, not only support the country's import-export trade, but have become import-export hubs for all of northeastern Asia.[7] The three container ports in the Pearl River Delta (PRD)—the ports of Shenzhen, Hong Kong, and Guangzhou—serve primarily as the gateway to the manufacturing and consumer base in southern China and are ranked the third-, fourth-, and eighth-busiest container ports in the world, respectively, as shown in Table 1.[8]

Table 1: Top 20 container terminals and their throughput for 2013[9]

Rank	Port name	Country	Volume, million TEU	Share of world container volume
1	**Shanghai**	**China**	**33.6**	**5%**
2	Singapore	Singapore	32.6	5%
3	**Shenzhen**	**China**	**23.3**	**4%**
4	**Hong Kong**	**China**	**22.3**	**3%**
5	Busan	South Korea	17.7	3%
6	**Ningbo-Zhoushan**	**China**	**17.4**	**3%**
7	**Qingdao**	**China**	**15.5**	**2%**
8	**Guangzhou**	**China**	**15.3**	**2%**
9	Dubai	United Arab Emirates	13.5	2%
10	**Tianjin**	**China**	**13.0**	**2%**
11	Rotterdam	Netherlands	11.6	2%
12	Port Klang	Malaysia	10.2	2%
13	**Dalian**	**China**	**10.0**	**2%**
14	**Kaohsiung, Taiwan**	**China**	**9.9**	**2%**
15	Hamburg	Germany	9.2	1%
16	Antwerp	Belgium	8.6	1%
17	**Xiamen**	**China**	**8.0**	**1%**
18	Los Angeles	United States	7.9	1%
19	Tanjung Pelepas	Malaysia	7.5	1%
20	Long Beach	United States	6.7	1%
Total for Chinese ports in top 20			**168.3**	**26%**
World's top 20			**293.8**	**46%**
World total			**641.0**	**100%**

ii The container height is not considered in TEU, and it ranges from 4 feet to 9 feet 6 inches for a standard container.

iii Including all ports in mainland China, Hong Kong, and Taiwan.

Between 2002 and 2012, the annual average growth rate of cargo volume handled by ports in Guangzhou (18%), Shenzhen (16%), and Shanghai (18%) have outpaced those of Hong Kong (4%).[10] Higher haulage costs and terminal handling charges at the Hong Kong container terminals, along with a shortage of land for port upgrades and expansions, are considered the key factors causing Hong Kong's stagnation relative to its competitors in the region.[11] Because of projections that this modest growth rate will drop further, a plan to develop a 10th container terminal in Hong Kong was not considered financially viable and has been put on hold.[12] In contrast, port regions in mainland China, such as Guangdong Province, Shanghai, and Zhejiang, have laid out ambitious plans and committed substantial resources to expanding their network of ports, railways, and inland waterways, with the goal of improving the connectivity and efficiency (and hence the competitive position) of ports in Guangdong and the Yangtze River Delta region.[13]

1.2 REPORT OVERVIEW

Even though the continuing expansion of the Chinese port system contributes to economic growth, it also adds new sources of pollution to the country's serious air pollution crisis. Right now, shipping emissions are essentially unregulated in China, but some local governments have started looking into measures for reducing air pollution from the port and shipping industry.

This white paper aims to offer regulatory agencies and stakeholders who are interested in curbing shipping and port emissions a summary of the environmental and health impacts of marine emissions, current regulations that govern air pollution and shipping emissions, and solutions for reducing marine air pollution. Background information provided here is meant to help government officials better devise strategies for controlling shipping emissions. As the situation of each individual port or port region is different, this paper does not offer recommendations on the specific strategies that Chinese ports or port regions should adopt. More detailed, port-specific analysis is needed in order to choose the most cost-effective set of solutions for each of the major ports in China, and for China as a whole.

Chapter 1 is an introduction that briefly discusses the development of oceangoing shipping in China. Chapter 2 summarizes the key sources of marine air pollutants, their contribution to air pollution in China, and the associated health and environmental impacts. Chapter 3 offers an overview of the legislative framework governing air quality and port emissions in Hong Kong and mainland China, as well as existing and planned incentives and voluntary initiatives for curbing emissions. Chapter 4 discusses the strengths and implementation challenges of various regulatory and technical measures for controlling marine emissions. Finally, Chapter 5 provides conclusions and discusses next steps.

2. MARINE EMISSIONS AND IMPACTS

2.1 MARINE EMISSIONS

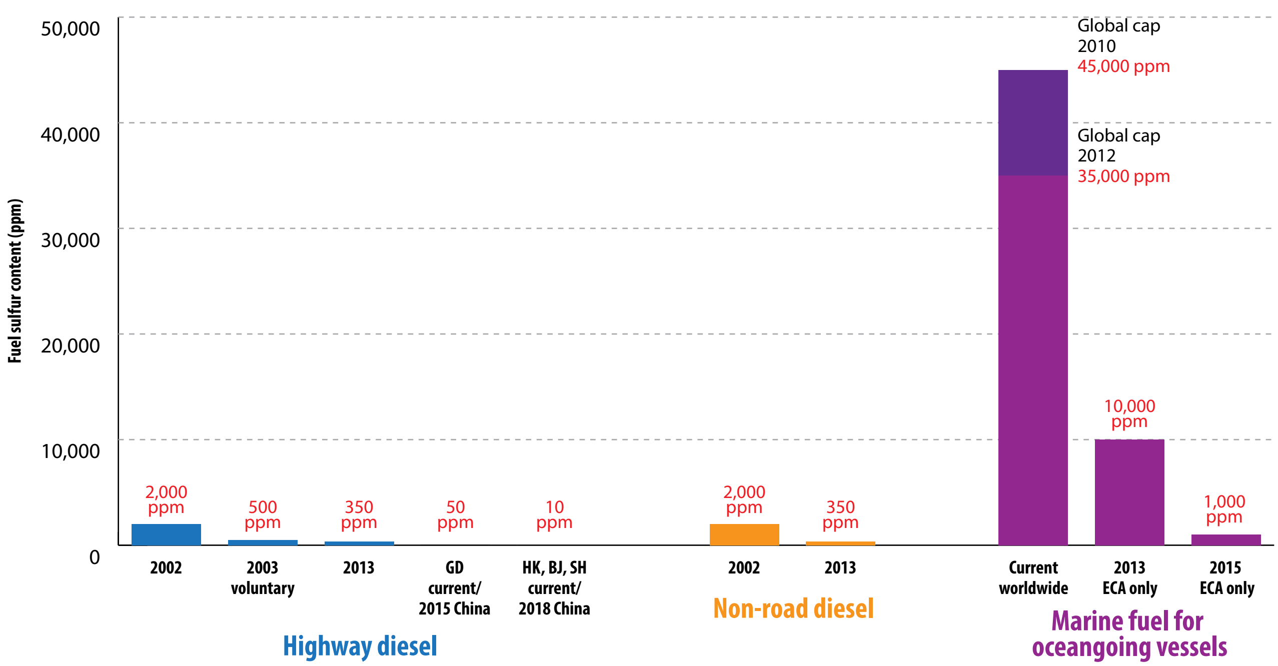
2.1.1 Key marine air pollutants

OGVs are powered predominantly by large compression-ignition engines that emit extremely high levels of PM, SOx, and NO_x. OGVs use mainly bunker fuel (also known as residual oil or heavy fuel oil) to provide propulsion, heat, and electricity. Bunker fuel is a residual product from the refinery process and is characterized by high sulfur content, high viscosity, and the presence of heavy metals such as cadmium, vanadium, and lead.

After combustion in the engines, sulfur in marine fuel converts into sulfur dioxide (SO_2), and a small portion is oxidized to sulfur trioxide (SO_3) that leads to sulfuric acid and sulfate aerosols and is emitted as direct PM emissions. SOx emissions, together with NO_x, also exacerbate secondary formation of $PM_{2.5}$—fine particulate matter less than 2.5 micrometers in diameter.[14] The concentration of SO_2 and sulfate-based PM in the engine exhaust is proportional to the fuel sulfur content. Therefore, even without any emissions control equipment, switching to lower-sulfur fuel would directly result in reduced SO_2 and PM emissions.[15] In the on-road sector, capping diesel sulfur at low levels (<350 ppm [0.035%] or, even better, at <10 ppm [0.001%]) has enabled the use of high-efficiency emission control technologies, such as selective catalytic reduction (SCR) and diesel PM filters, that reduce emissions by more than 90%.[16]

Regulation of air emissions from ships is virtually nonexistent today in China and the rest of the developing world. As a member of the International Maritime Organization (IMO), China ratified and enforces the environmental regulations on international shipping enacted by IMO through the International Convention for the Prevention of Marine Pollution from Ships (MARPOL), including Annex VI of the Convention that specifically deals with the prevention of air pollution from vessels. Current IMO regulations permit OGVs to burn bunker fuel with a sulfur content of up to 35,000 ppm (3.5%).[iv] In contrast, China restricts the sulfur content of diesel used by road vehicles and off-road engines (like agricultural tractors and construction equipment) to no more than 350 ppm (0.035%). In the main cities of the Pearl River Delta and Yangtze River Delta (YRD) regions, the sulfur content of on-road diesel and gasoline is capped at 50 ppm (0.005%), and the fuel sulfur standards in Beijing, Shanghai, and Hong Kong have been further tightened to 10 ppm (0.001%), approximately the same level as in the U.S., European Union (EU), and Japan.[17] See Figure 1 for comparisons.

Figure 1: Fuel sulfur standards for diesel trucks (highway diesel) and non-road engines (non-road diesel) adopted in China, and IMO fuel standards for oceangoing vessels[18]



SH denotes Shanghai, GD denotes Guangdong, HK denotes Hong Kong and BJ denotes Beijing. Lower sulfur limits have been enforced in key regions, including Beijing, Shanghai, Guangdong, and Hong Kong.

iv Unless an Emission Control Area (ECA) is in place. See IMO, "Sulfur Oxides" (in endnote 3).

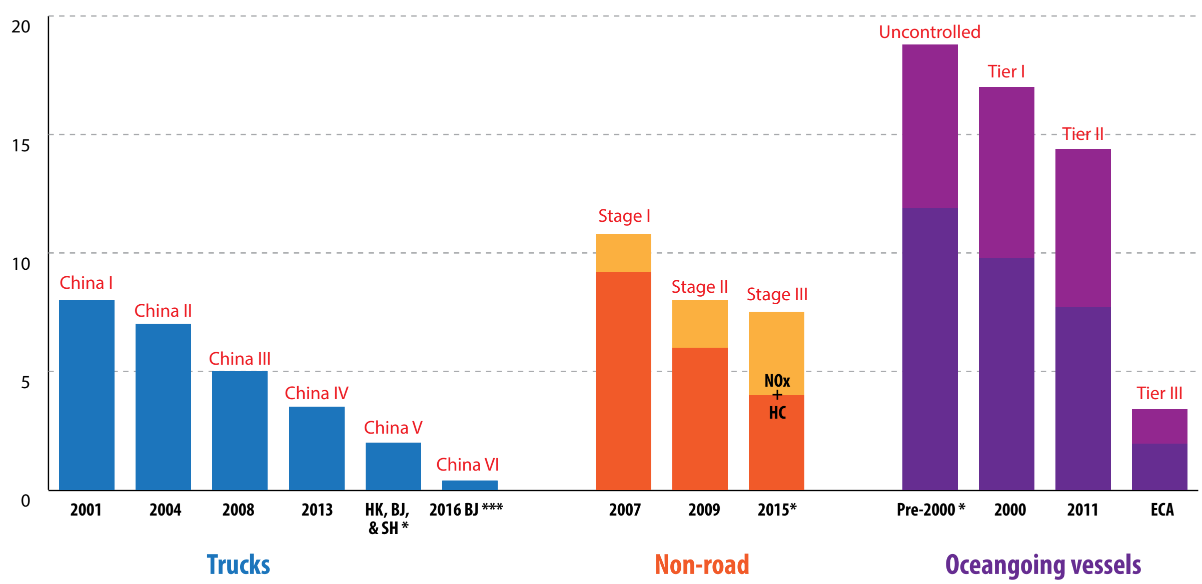
With ships allowed to burn bunker fuel with sulfur levels that are 100 to 3,500 times higher than permitted in on-road diesel fuel, SO_2 and PM emissions from OGVs are far higher than emissions from on-road vehicles on a per-unit-energy basis.[v] As a result, a medium- to large-size container ship running at 70% maximum power for one day using bunker fuel with 35,000 ppm (3.5%) sulfur emits as much $PM_{2.5}$ as the average of half a million new trucks in China during that same day.[19]

Regarding NO_x emissions, the shipping sector has traditionally faced less stringent air emission regulations than have the on-road and non-road sectors. Almost all marine engines operate at high temperatures and pressures without effective emissions control, so NO_x emissions from ships are also higher than those from on-road vehicles on a per-unit-energy basis.[20]

Figure 2 compares the current and upcoming NO_x emissions limits for on-road and non-road diesel engines in China with those adopted by the IMO that apply to OGVs. While the IMO NO_x limits (purple bars) vary by engine speed, the current limits for new marine engines (Tier II), which apply to all OGV engines constructed on or after 2011, are about 2 to 4 times higher than the current standard for new diesel trucks in China (blue bar labeled "China IV") that went into effect in 2013, nearly 4 to 7 times higher than the China V standards already in force in Hong Kong, Beijing and Shanghai, and 17 to 31 times the Euro VI standard Beijing proposed to adopt in 2016 (shortest blue bar). Only if standards were tightened to the Tier III Emission Control Area (ECA) standard (purple bar labeled ECA) would the emission standards for new marine engines be comparable to the current truck standard in Hong Kong, Beijing, and Shanghai and the standard that is scheduled to take effect in the PRD in 2015.

The soot in diesel exhaust—diesel PM—has been designated as a known carcinogen by the World Health Organization's cancer research institute.[21] Diesel PM is especially toxic due to the very small size of the soot particles, and because these particles contain roughly 40 different toxic air contaminants, 15 of which are recognized carcinogens.[22] One particularly toxic class of chemicals, polycyclic aromatic hydrocarbons (PAH), can be adsorbed onto fine PM and travel for long distances (as far as 10,000 km).[23] In addition, OGVs emit volatile organic compounds (VOCs), particularly from tankers, as well as heavy metals and other pollutants. Section 2.2 discusses in more detail the health and environmental impacts of these marine emissions.

Figure 2: NOx emissions standards for on-road and non-road diesel engines adopted in China, and marine engine emissions standard adopted by the IMO[24]



Where present, the lighter colors at the top of the bars indicate the range of NOx standards that vary by engine power or speed. The NOx standards for China non-road engines are set on the basis of power output, and the IMO NOx standards for OGVs vary by maximum engine speed. SH denotes Shanghai, HK denotes Hong Kong, and BJ denotes Beijing.

* A national China V standard for diesel trucks (depicted by the yellow bar labeled "HK, BJ, & SH") has been adopted, but enforcement across the nation has been delayed, and an implementation timeline has not been announced; the standard is in effect in Hong Kong, Beijing, and Shanghai only. The latest standard for non-road diesel engines, which sets a limit for the sum of NOx and HC emissions, has been released for enforcement on October 1, 2015.

** Uncontrolled OGV emissions levels are calculated on the basis of the emissions factor of container cargo ships.[25]

*** The China VI standard is presented here since Beijing has committed to enforce emission standard more stringent than China V by 2016.

v There is an exception for fuel used by smaller craft in the EU (inland waterway vessels) and the U.S. (those equipped with Category 1 and 2 engines). Fuel used by these inland waterway vessels and smaller craft in the U.S. are required to limit sulfur to 10 ppm (0.001%). The sulfur requirement is of the same stringency as that imposed on on-road diesel fuel.

2.1.2 Marine emissions in China

Shanghai and Hong Kong were the first two port cities in China to acknowledge the impacts of marine air pollution. The first shipping emissions inventory of Chinese ports was developed by the Shanghai Environmental Monitoring Center for Shanghai ports for the year 2003.[26] The Shanghai inventory was subsequently updated in 2011. The latest inventory also covers emissions from port activities, including emissions from trucks and cargo-handling equipment as well as evaporative emissions from oil and fuel terminals.[27]

In Hong Kong, a comprehensive marine emission inventory for 2007 was commissioned by the government.[28] Building on findings of this inventory, Civic Exchange, the Hong Kong University of Science and Technology (HKUST), and the University of Hong Kong (HKU) jointly developed a study that estimated marine air emissions for the PRD region, evaluated the health impacts of these emissions, and assessed the potential benefits of measures for reducing marine emissions.[29]

2.1.2.1 Marine emissions in Hong Kong

Emission and fuel standards for vehicles and power plants have become increasingly stringent over time, and land-based SO_2 and PM emissions were reduced in Hong Kong by 53% and 61%, respectively, from 1990 to 2007. In contrast, air emissions of SO_2 and PM from marine sources increased by 48% and 41%, respectively, over the same period.[30]

According to the most recent data from the Hong Kong Environmental Protection Department (HKEPD), ship emissions in 2012 were the city's largest emission source of respirable suspended particulates (RSP, also known as PM_{10}), NO_x, and SO_2 emissions, accounting for 37%, 32%, and 50% of total emissions, respectively (see Figure 3). Vessels also were the source of 11% of total VOC emissions and 17% of total carbon monoxide (CO) emissions in 2012.[31]

Hong Kong's comprehensive 2007 marine emission inventory provides more detailed analysis of the ship sector's emissions.[32] OGVs are the biggest contributor to overall shipping emissions, accounting for 79% of SO_2, 44% of NO_x, and over two-thirds of RSP emissions from all types of ships. Local vessels are the second-largest contributor to NO_x, RSP, and VOC emissions (see Figure 4).

Looking at OGV emissions by operation mode, a relatively large share were emitted during hotelling[vi] (40% of SOx, 30% of NO_x, and one-third of RSP), followed by slow cruising (28% of SOx, 32% of NO_x, and 31% of RSP) and fairway cruising[vii] (28% of SOx, 32% of NO_x, and 31% of RSP). This highlights the importance of adopting measures that target emissions at dock, such as switching to low-sulfur fuel or shore power while at berth, as well as measures to reduce emissions during slow cruising and fairway cruising, such as vessel speed reduction or fuel switching within Hong Kong waters. These measures are all discussed more fully in Section 4.

The 2007 marine emission inventory also looked at the dispersion of marine emissions along major shipping routes in Hong Kong waters, in order to identify areas that are most affected by shipping pollution (see Figure 5).[33]

Important hot spots for emissions from container vessels include:

- Kwai Chung Container Terminal (berthing points for container vessels)
- East Lamma Channel–Western Fairway–Ma Wan Fairway (main route for OGVs if coming from open sea and western Shenzhen)
- East and southeast of Hong Kong (OGV movements to/from Yantian)

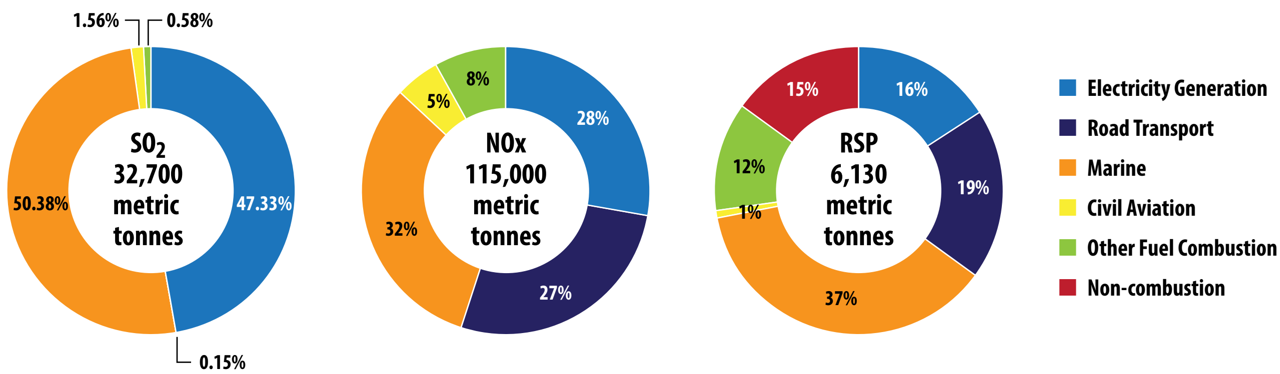
Important hot spots for emissions from cruise/ferry vessels (the second largest OGV emitter) were:

- Ocean Terminal and government buoys off Kowloon (berthing points for cruise ships)
- Berthing location off to the southeast via the Hung Hom Fairway and the Eastern Fairway in Victoria Harbor and Tathong Channel

vi Hotelling refers to ship operations while stationary at dock.

vii In the Hong Kong marine emissions inventory, a vessel is considered in slow cruise mode when it operates at 8 to 12 knots, and in the fairway cruising mode when operating above 12 knots.

Figure 3: Contribution of marine emissions to the total emission profile of Hong Kong, 2012 data[34]



It is clear that pollution travels with the vessels as they approach Hong Kong waters and maneuver to terminals. Hong Kong's densely populated city neighborhoods along Victoria Harbor, and in particular Kwai Chung and Tsim Sha Tsui, are likely to be the areas most affected by marine emissions, although no permanent air quality (AQ) monitoring station is currently operating in the Tsim Sha Tsui area to measure air pollution levels.[35]

The Kwai Chung area (the largest dark red spot in Figure 5) is particularly close to the container terminal, where SO_2 pollution regularly exceeds the World Health Organization (WHO) recommended maximum levels.[37] A 2010 study by the HKUST on street-level air quality in Hong Kong's 18 districts found that marine emissions from the container terminal are indeed an important source of air pollution in Kwai Chung, resulting in an exposure threat at street level for vulnerable members of the community (children, the ill, and the elderly) at locations near Lai Kill Hill Road including schools, hospitals, and public housing estates (see Figure 6).[38]

Emissions from cruise ships have also started to raise concerns. The longtime cruise terminal in Hong Kong is located in Tsim Sha Tsui, right at the center of the city. The newer Kai Tak Cruise Terminal, opened in June 2013 and designed to handle the world's largest cruise ships, is also located in close proximity to densely populated areas in Kowloon East and the East District of Hong Kong Island. Even though total at-berth emissions at the Kai Tak Cruise Terminal in its first year of operation are estimated at less than 0.02% of the city's total emissions from OGVs, or 8–9% of total at-berth emissions of cruise vessels in Hong Kong, such emissions could scale up quickly once the Kai Tak Terminal develops to full capacity, especially since cruise ships typically have the highest power demands of any vessel during hotelling.[39]

Figure 4: Shipping emissions in Hong Kong by ship type, 2007 data[36]

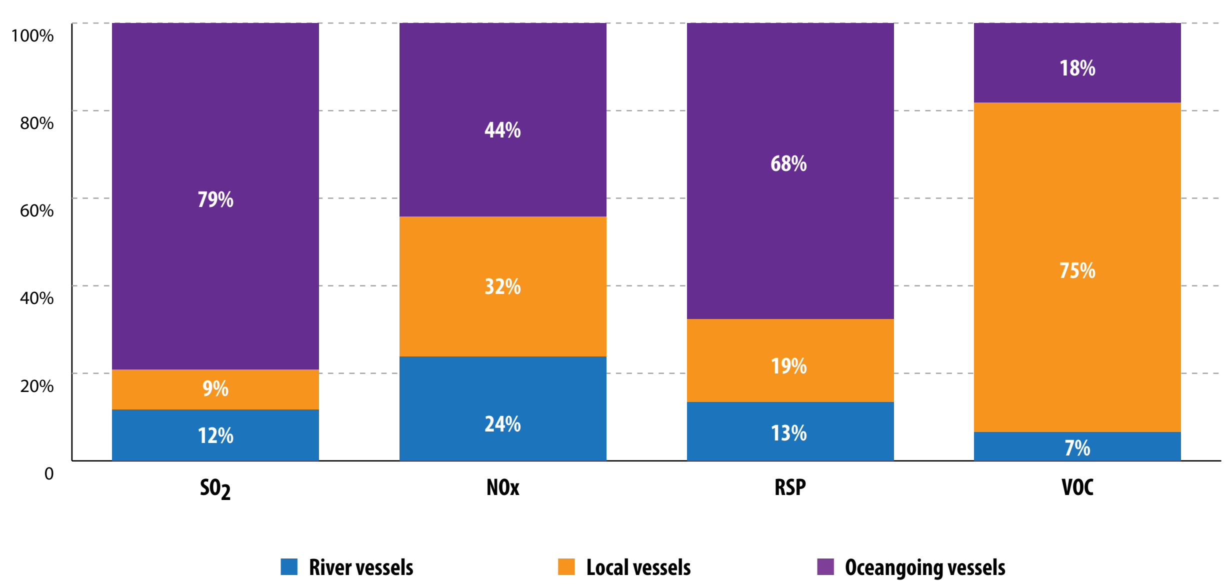


Figure 5: Dispersion of SO_2 emissions (tonnes per year) from OGVs in Hong Kong waters, 2007[40]

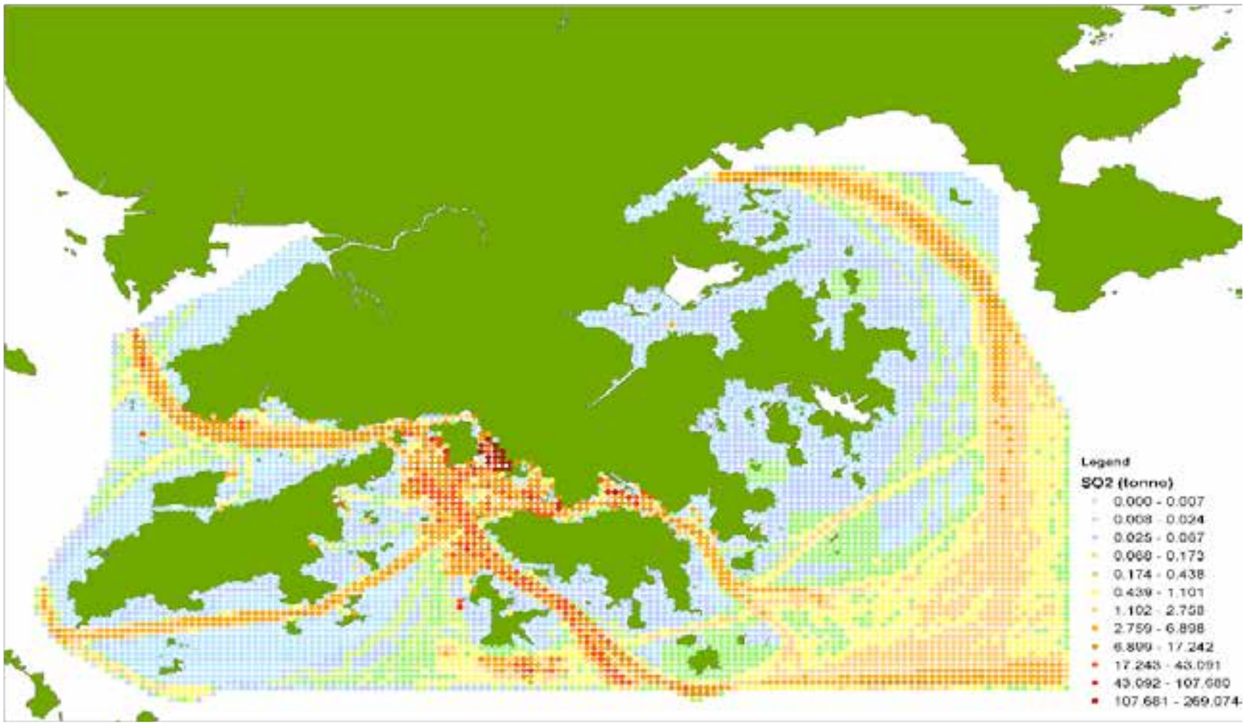
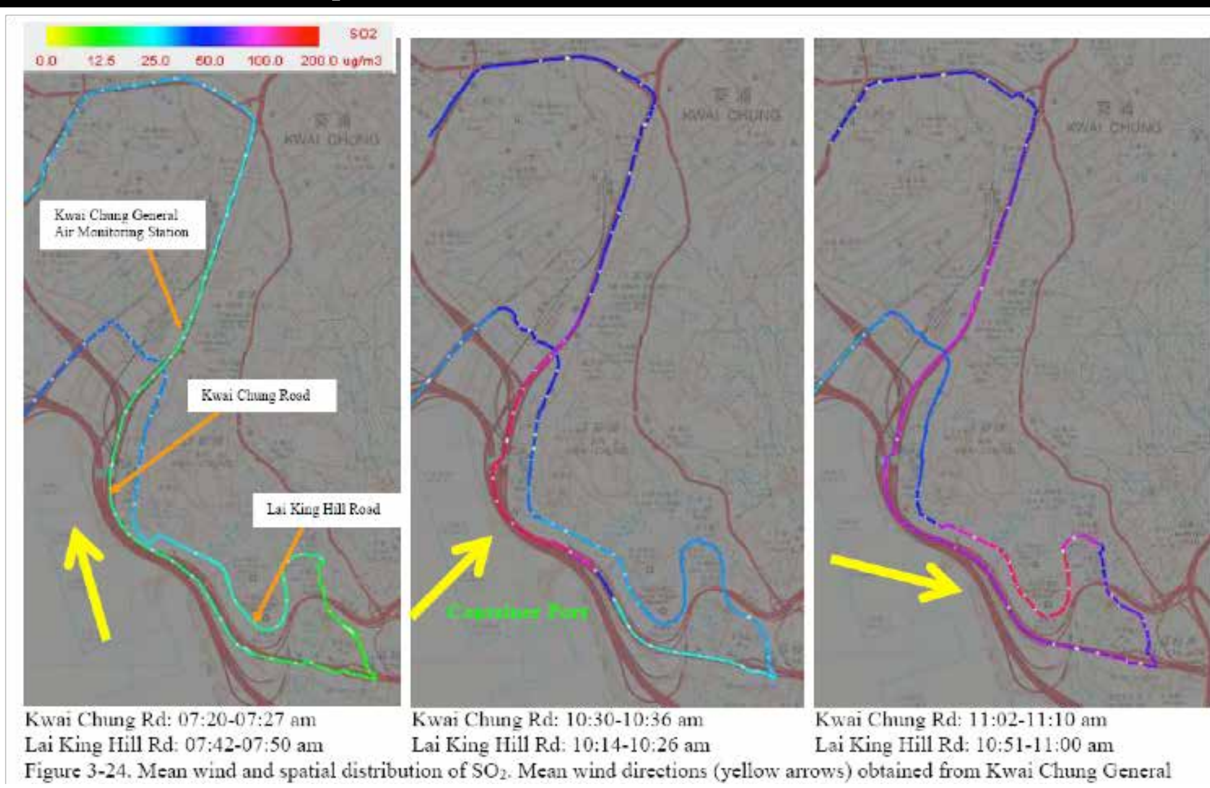


Figure 6: Spatial distribution of SO_2 emissions in the Kwai Chung area near Hong Kong's container port in 2009[41]



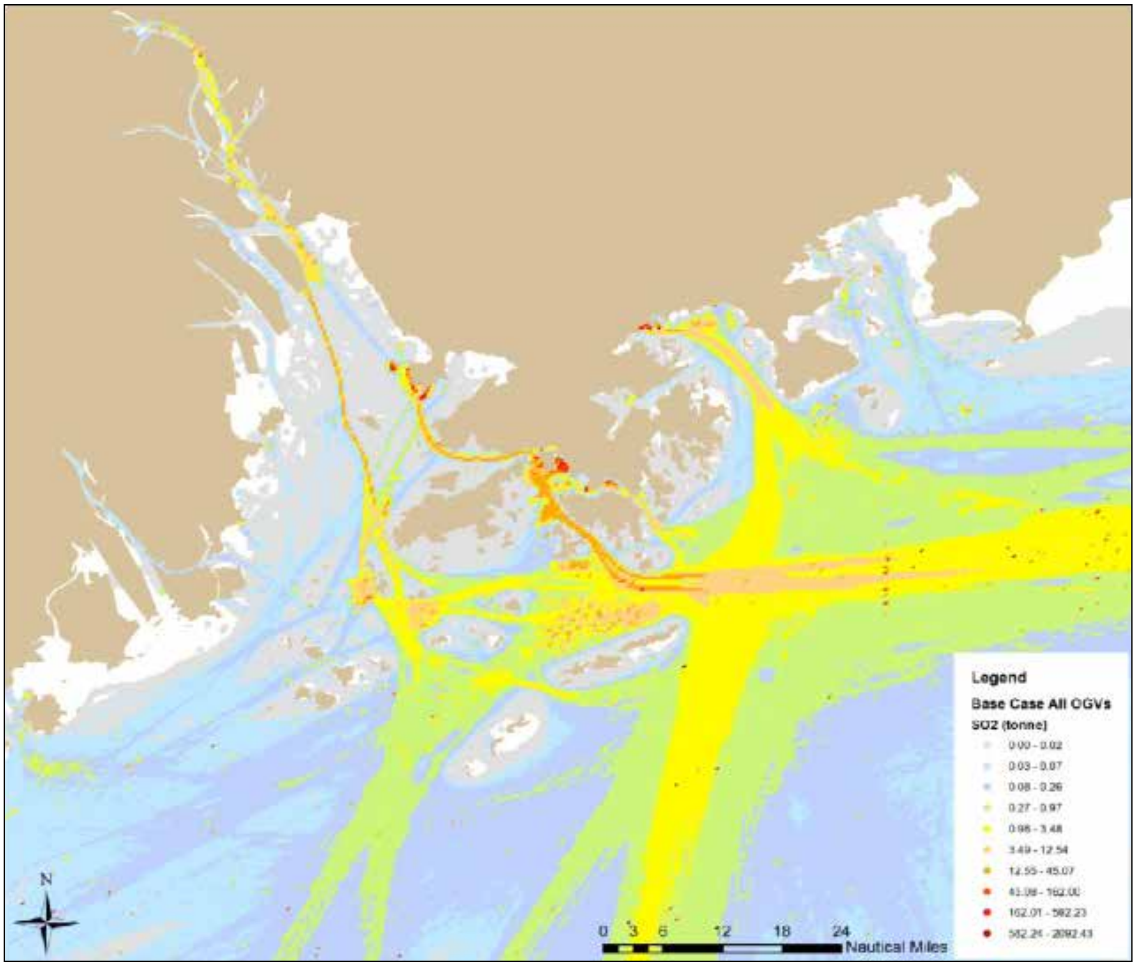
Hong Kong's Air Quality Objective (AQO) stipulates a 24-hour average SO_2 concentration limit of 125 ug/m^3, while the World Health Organization (WHO) Guideline sets a limit of 20 ug/m^3. Hong Kong's AQO for SO_2 is very lenient considering that the 24-hour average is adopted from WHO Interim Target-1, which is the interim goal for developing countries with severe pollution that are taking incremental steps to improve air quality.

2.1.2.2 Marine emissions in mainland China

On the basis of research conducted to develop Hong Kong's 2007 marine emission inventory, Civic Exchange, HKUST, and HKU jointly expanded the analysis to estimate air emissions from all OGV activities within the waters of Hong Kong and the rest of the PRD region, and estimated the associated health impacts.[42] This is the first published study of health impacts of shipping in mainland China to date.

Figure 7, which shows the location of OGV-generated SO_2 emissions, gives a broad indication of the ports and berthing locations (in red), the most widely used fairways, and the primary routes used by ships entering and leaving the PRD.[43] The closer a prefecture is to the concentration of terminals and approach routes of Hong Kong and Shenzhen, the greater the influence of marine emissions on ambient SO_2 concentration.[44]

Figure 7: Spatial distribution of SO_2 emissions (tonnes per year) from OGVs in the PRD region, 2007[45]



Consistent with this finding, a source apportionment study conducted for the Shenzhen city government found that shipping contributes to about two-thirds of SO_2, 14% of NO_x, and 6% of PM emissions from all sources in Shenzhen.[46]

In Shanghai, the world's largest port, the latest emissions inventory developed by the Shanghai Environmental Monitoring Center suggested that emissions from ships and port activities (including emissions from drayage trucks[viii] and cargo handling equipment) accounted for 12.4% of SO_2, 11.6% of NO_x, and 5.6% of $PM_{2.5}$, of all Shanghai sources in 2010.[47] The contribution of marine emissions in Shanghai is much lower than that in Hong Kong because there are other large pollution sources in Shanghai, such as industrial facilities and power plants.

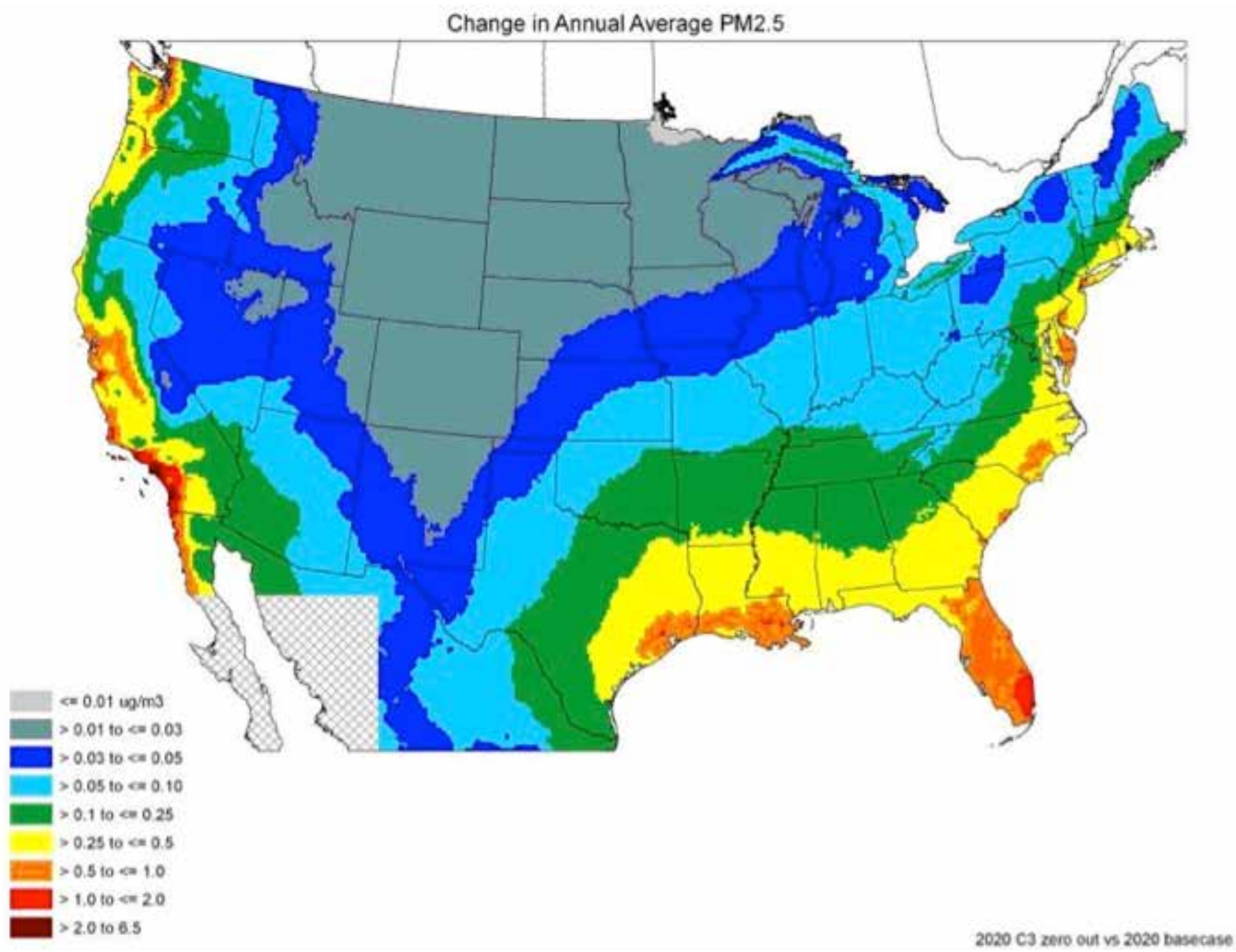
viii In the shipping industry, drayage refers to the transport of goods over a short distance, often as part of a longer overall move, and is typically completed in a single work shift. A drayage truck picks up cargo from or delivers cargo to a seaport, border point, inland port, or intermodal terminal with both the trip origin and destination in the same urban area.

Other than Hong Kong and Shanghai, comprehensive marine emissions inventories for other port cities in mainland China are still lacking. However, the issue has drawn increasing interest since 2013. Emission inventories at the national scale, regional scale, and municipal scale are being established to fill in gaps of marine emissions data in mainland China. Because most of the ongoing emission inventory research projects in mainland China are at the inception stage, knowledge exchange from international experiences would be very valuable.

2.2 KEY IMPACTS FROM MARINE EMISSIONS

About 70% of emissions from international shipping occur within 400 km of coastlines along main trade routes.[48] Models indicate that shipping emissions may travel up to hundreds of kilometers inland as a result of land-sea winds, as shown in Figure 8. Clearly, emissions from OGVs can affect air quality, human health, and the environment not only in coastal regions but inland as well, even when emissions from international ships are generated at sea.[49]

Figure 8: Projected contribution of ships to annual average $PM_{2.5}$ concentrations in the U.S. in 2020 without an Emission Control Area[50]



2.2.1 Health impacts of marine emissions

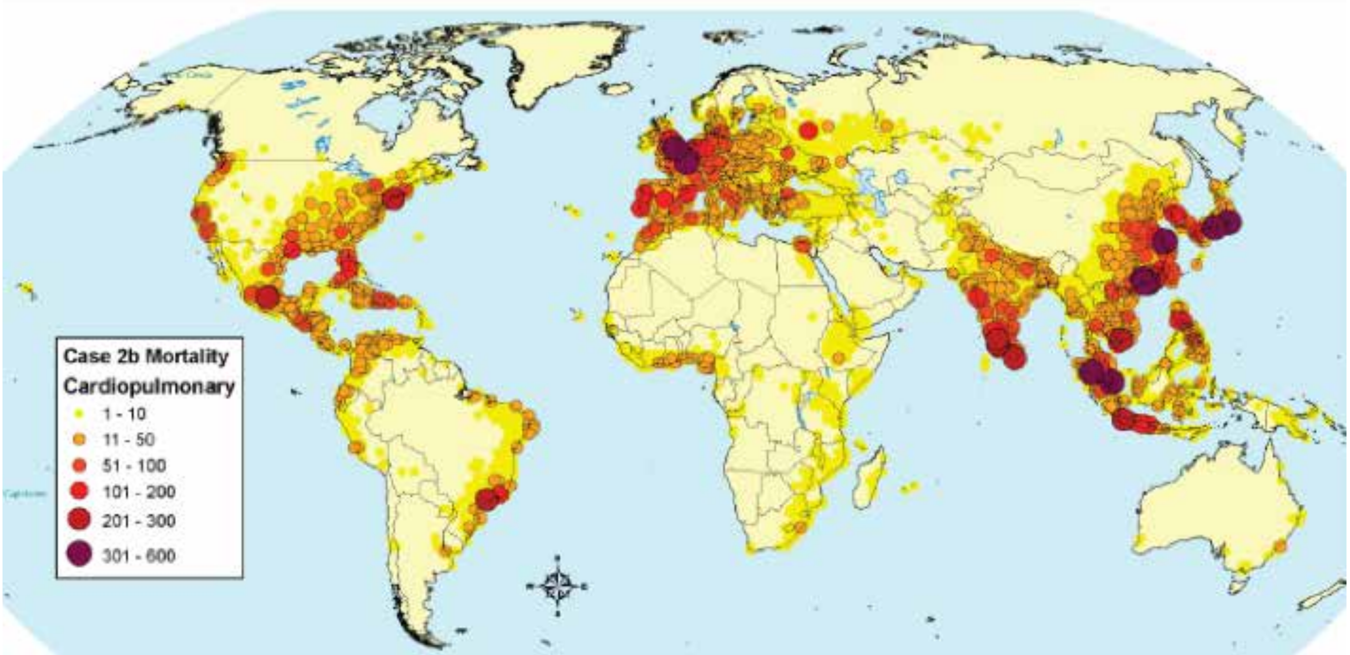
Air pollution from both shipping and land-based port equipment (primarily diesel exhaust) is known to contribute to premature deaths as well as other serious health and environmental impacts, especially among children and the elderly.[51] PM, nitrogen dioxide (NO_2), SO_2, and ozone emissions indirectly generated from the diesel engines in vessels, trucks, locomotives, and cargo-handling equipment contribute to increased asthma emergencies and strokes. In particular, PM emissions from these diesel engines cause lung cancer and increased risk of bladder cancer, as officially acknowledged by the WHO.[52] Diesel exhaust from ships and other port-side sources can also aggravate existing lung and heart illnesses.[53] Such adverse public health effects of shipping and land-based port emissions directly affect the residents of port cities in China.

2.2.1.1 Premature deaths due to marine emissions

There is not a lot of good data to quantify premature mortality due to OGVs worldwide. A 2007 study based on limited data from 2001 found that global emissions from OGVs were responsible for an estimated 60,000 premature deaths each year from cardiorespiratory disease and lung cancer. That same study estimated that more than 15,000 cardiopulmonary and lung cancer deaths caused by OGV emissions had occurred in East Asia in 2001 (including China, Japan and Korea).[54] Significant health impacts caused by OGV emissions are estimated in Asia, where shipping activities are increasingly concentrated, as shown in Figure 9.

The actual number of premature deaths due to OGVs is likely higher. For example, the USEPA has stated that implementing an ECA around most of the U.S. coastline will eliminate up to 31,000 premature deaths from OGVs in 2030, compared with projected premature deaths if no ECA were in place.[55] In the EU, international shipping caused an estimated 46,000 premature deaths in 2011.[56] Given the U.S. and EU figures, the numbers for China—with more OGVs, more people, higher pollution levels, and a lack of local or regional controls on ship fuel and emissions outside of Hong Kong—should be much higher than what the abovementioned 2007 study found.[57]

Figure 9: Distribution of premature deaths from cardiopulmonary diseases attributable to marine $PM_{2.5}$ emissions worldwide[58]



2.2.1.2 Health impacts from marine emissions in China

As noted earlier, Hong Kong's study assessing the impacts of emissions from OGVs throughout Hong Kong and the rest of the PRD region[59] was the first such published study in mainland China. The health impact estimates provided in this study were underestimated due to a lack of comprehensive data on pollution, population, and health.[ix]

In an updated study covering both OGV and inland vessels operating in the PRD region, SO_2, NO_2, O_3, and PM_{10} emissions from OGVs and river vessels were found to have led to an estimated 1,202 premature deaths in Hong Kong alone, and more than 1,600 premature deaths in the PRD region (including Hong Kong and Macau) in 2008.[x] Shipping emissions were also estimated to have resulted in 8,262 and 9,702 additional hospital admissions in Hong Kong and the PRD, respectively, based on 2008 hospital admission data for cardiovascular and respiratory disease and the increased risk of contracting these two diseases due to SO_2, NO_2, O_3, and PM_{10} from ships. In fact, these impacts are likely underestimated because the study did not account for the long-term health effects of shipping pollution nor the specific impacts of other shipping emissions, such as $PM_{2.5}$, metal species, CO, and VOCs.[60]

ix This study found that marine sources of SO_2 emissions contributed to 519 premature deaths per annum in the PRD in 2008, but health impacts were not measured for other pollutants (e.g., $PM_{2.5}$, ozone, VOCs, toxic metal species in fuel, etc.). Moreover, there was a lack of comprehensive population and health data of PRD areas outside Hong Kong; see Hak-kan Lai et al. (2012) cited in endnote 44.

x The estimated premature deaths in PRD are calculated by multiplying the total PRD population (36.6 million in 2008) with the total excess death rate of 45 per million people. See Table 4 of Hak-kan Lai et al. (2013) cited in endnote 2.

2.2.2 Impacts of marine emissions on the ecosystem

Ship emissions affect the ecosystem through the deposition of sulfur and nitrogen compounds, which can cause acidification, eutrophication, and nutrient enrichment.[61] Ozone indirectly produced from shipping emissions also can impair native vegetation and the ecosystem as well as reduce crop yield.[62]

International shipping contributes 5% of total global sulfur deposition and 3% of deposition over land, but higher shares of deposition from ships are found in regions with heavy ship traffic. For instance, shipping increases sulfate and nitrate deposition over Europe by about 15%.[63] Acidification caused by nitrogen and sulfur deposition alters biogeochemistry, leads to changes in diversity of plants and aquatic life, and causes declines in acid-sensitive fish and plant species.[64] Nitrogen deposition causes ecosystem nutrient enrichment and eutrophication, which results in toxic algal blooms and fish kills and alters the competitive interactions among species.[65]

In addition to impacting terrestrial ecosystems and freshwater bodies, SOx and NO_x emissions from OGVs have recently been found to cause significant ocean acidification in parts of the Northern Hemisphere where there is heavy ship traffic during the summer months. The potential effects on surface water acidity (pH) of shipping emissions in those heavily trafficked waters can be of the same order of magnitude as carbon dioxide–induced acidification.[66] Studies have confirmed that ocean acidification can have a wide range of negative impacts on the marine ecosystem, including damaging shells and corals and interfering with the sense of smell, brain neurotransmitters, and eyesight of fish.[67]

2.2.3 Impacts of marine emissions on the climate

The contribution of shipping emissions to climate change is complex in nature, and our understanding to date is far from complete. The latest research has found that emissions from shipping cause both warming and cooling effects on the global climate. CO_2, ozone produced from NO_x emissions, and soot (also known as black carbon, the second-most-potent global warming pollutant[xi]) cause global warming, but other shipping pollutants like sulfate aerosols, NO_x, and organic aerosols can have cooling effects.[68,xii]

While the latest literature suggests, with great uncertainty, that shipping may cause a net cooling impact on a global scale, the warming effects of CO_2 and black carbon emissions from ships are expected to grow with the projected increase in global shipping activities.[69] In particular, warming effects caused by shipping activities in the Arctic region could be especially significant. With the retreat of Arctic sea ice caused by global warming, more ships are expected to travel through the Arctic, leading to greater black carbon deposition on ice and snow there.[70] Given that the warming effect of black carbon is particularly potent near ice and snow, the rise in the number of ships traversing the Arctic would further accelerate snowmelt and sea ice loss, exacerbating Arctic warming and the adverse global warming impacts that are already being experienced by countries around the world, including China.[71]

xi Black carbon is the light-absorbing solid fraction of particulate matter emitted during incomplete combustion. Black carbon is the second-largest man-made contributor to global warming, second only to CO_2. See Bond et. al. (2013) cited in endnote 71.

xii CO_2 is the biggest contributor to global warming from shipping, followed by ozone (produced from NO_x emissions) and soot (also known as black carbon). Meanwhile, the biggest contributor to cooling is the aerosol indirect effect, which is caused by ship-generated aerosols that make clouds more reflective and longer-lasting (thus reflecting more sunlight). Other shipping pollutants that cause cooling include NO_x emissions, which shorten the lifetime of methane (a potent greenhouse gas), as well as sulfate aerosols and particulate organic matter that reflect sunlight. More detailed information about the climate impacts of shipping emissions can be found in Fuglestvedt et. al. (2009) cited in endnote 68, and Eyring et al. (2010) cited in endnote 49.

3. REGULATORY FRAMEWORK

3.1 INTERNATIONAL REGULATIONS

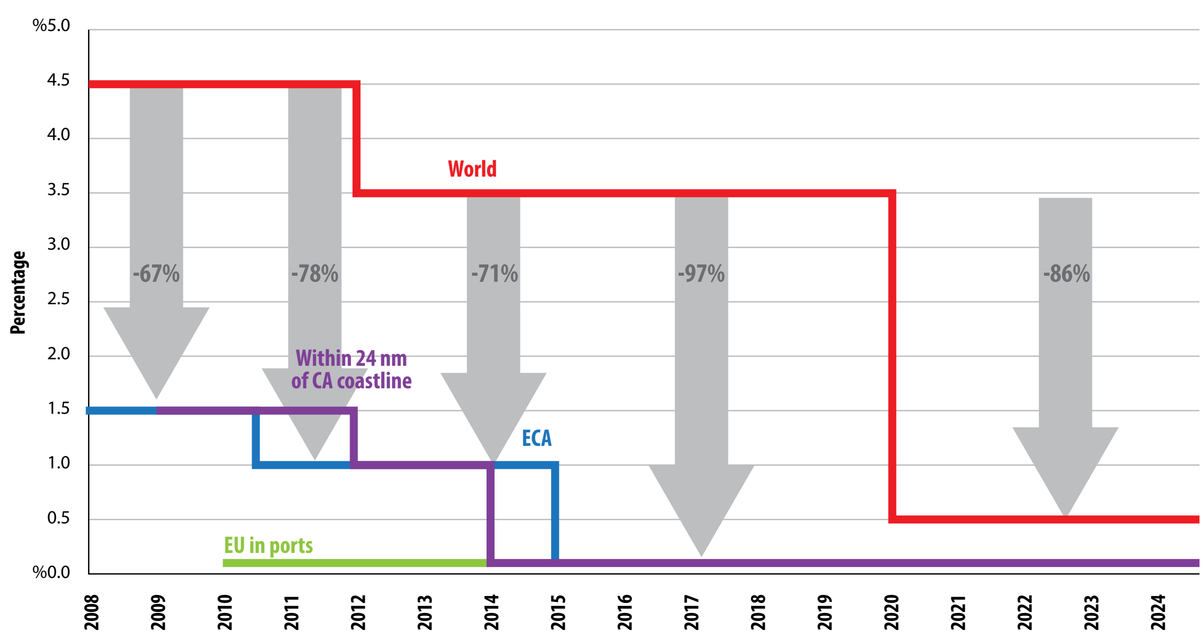
The International Maritime Organization (IMO), a United Nations agency dedicated to the safety and security of shipping as well as the prevention of marine pollution by ships, enacts regulations in relation to the environment through the International Convention for the Prevention of Marine Pollution from Ships (MARPOL).[72]

Annex VI of the Convention, which was last revised in 2008, specifically deals with the prevention of air pollution from vessels. It covers SOx and NO_x emissions and indirectly covers emissions of secondary PM through the SOx limits. SOx emissions are controlled mainly through a global sulfur cap of 35,000 ppm (3.5%) for bunker fuel, which will be progressively reduced to 5,000 ppm (0.5%) by 2020, subject to a feasibility review to be conducted by 2018 (see Figure 10).

Additionally, Annex VI allows signatory countries to apply to the IMO for the designation of an ECA with more stringent control of ship emissions. For ECAs, the sulfur limit is at present set at 10,000 ppm (1%), which will be further tightened to 1,000 ppm (0.1%) effective January 1, 2015. For those countries that choose to include it, a Tier III NO_x standard can also be included in the ECA. This Tier III NO_x standard reduces NO_x emissions by 75% from the current Tier II standard (see Figure 2).[73] To achieve this significant reduction, the use of NO_x emission control technologies is required. The leading examples of these technologies are selective catalytic reduction (SCR), exhaust gas recirculation (EGR), and switching from conventional residual oil to liquefied natural gas (LNG) fuel. China is one of the signatory countries to Annex VI.

It is important to note that at its March/April 2014 meeting, the Marine Environment Protection Committee of the IMO amended the ECA rules related to the Tier III NO_x standard. Previously, any OGV built in 2016 and later that entered any ECA for NO_x would have to meet the Tier III NO_x standard. The recent amendment allows the previously adopted North American ECA and Caribbean ECA to apply the 2016 date to vessels entering their ECAs. However, for future ECAs, the Tier III standard will be applied only to ships constructed after the date upon which a country's proposal for an ECA designation has been adopted by the IMO, or after a later date as determined by the country applying for the ECA designation. To illustrate, say China proposes an ECA in 2018. This is circulated for approval by the IMO in 2020, is adopted in 2022, and goes into effect in 2025. Ships built after 2022 would have to meet the Tier III NO_x standard for that ECA.

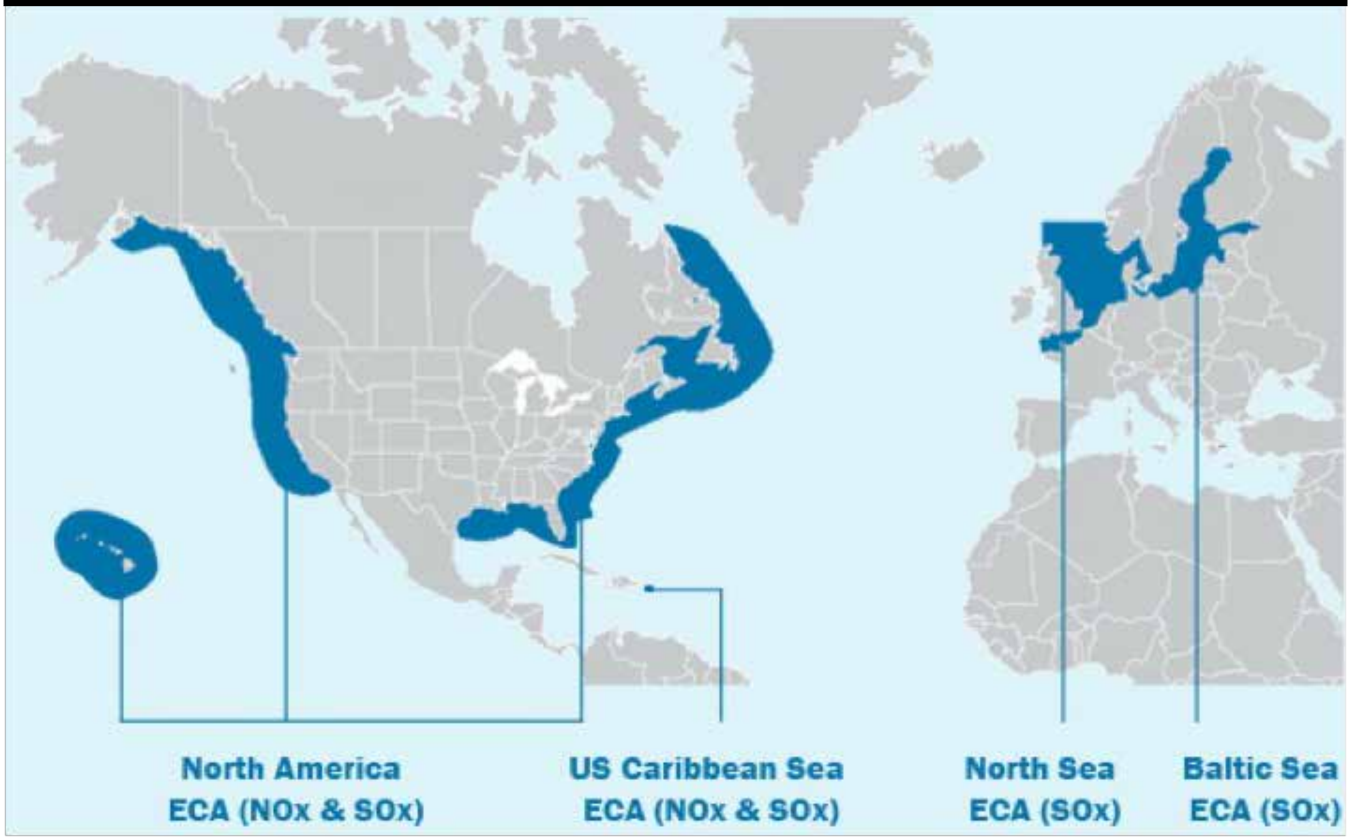
Figure 10: IMO fuel sulfur standards for vessel fuel, and fuel sulfur limits at EU ports and in California waters for the years 2008 to 2025[74]



The above line for the California (CA) fuel sulfur standard shows the sulfur standards for marine gas oil (DMA); a stricter standard for marine diesel oil (DMB) requires a sulfur level not exceeding 0.5% beginning July 1, 2009, and 0.1% from January 1, 2014 onward. The Baltic Sea and the North Sea ECAs went into effect in 2006 and 2007 respectively. The North American ECA started implementation on August 1, 2012, the same day that the California 1% fuel sulfur requirement went into effect.

There are currently four regions in the world designated as ECAs: the Baltic and North Sea ECAs, which enforce only the SOx (and indirectly PM) emissions limit, and the North American and U.S. Caribbean ECAs, which regulate SOx, PM and NO_x emissions. Figure 11 show the area covered by each of the ECAs. Discussions are under way to designate the current Baltic Sea and North Sea SOx ECAs as NO_x ECAs as well.[75]

Figure 11: Coverage of the four ECAs: Baltic Sea, North Sea, North American and U.S. Caribbean



Emissions of secondary PM emissions are indirectly regulated through the SOx limits enforced in the SOx ECAs.

Tier III standards for NO_x will go into effect on January 1, 2016 in the North American and Caribbean ECAs, meaning vessels built in 2016 or later operating in these two ECAs must have NO_x control technology onboard. Technologies that enable ships to meet the ECA emission limits are discussed in Section 4.

3.2 REGULATIONS AND INCENTIVES IN CHINA

This section discusses legislation and incentives concerning shipping and port emissions control in Hong Kong and mainland China (which have different legal and political systems).

3.2.1 Programs and standards in Hong Kong

Although Hong Kong currently has no legislation mandating the use of low-sulfur fuel while OGVs are in Hong Kong waters and/or at berth, in September 2012 the government launched a three-year incentive program to encourage OGVs to switch to low-sulfur fuel (with no more than 5,000 ppm, or 0.5%, sulfur content) when berthed in Hong Kong. By June 2014, only about 12% of OGVs had registered, with operators indicating that the rebates covered only around 40% of the cost of switching.[76,77] The government is finalizing proposed legislation that mandates the use of 5,000 ppm (0.5%) sulfur fuel by OGVs at berth starting in 2015.[78] Mandatory fuel switching at berth is expected to result in a reduction in Hong Kong emissions of 14% for sulfur and 6% for PM_{10}, compared with 2011 levels.[79]

In addition to the proposed regulation for reducing OGV emissions, the Legislative Council has just approved a regulation that lowers the sulfur limit of marine light diesel sold in Hong Kong from 5,000 ppm (0.5%) to 500 ppm (0.05%).[80,xiii] The new rule went into effect on April 1, 2014.[81] Ships operating within Hong Kong waters (and refueling in Hong Kong) using 500 ppm (0.05%) sulfur fuel are expected to reduce SO_2 emissions by 90% and PM_{10} by 30%, compared with using fuel with 5,000 ppm (0.5%) sulfur.[82]

Excessive smoke emissions from vessels usually indicate improper engine operation or maintenance. Hong Kong has long had legislation regulating emissions of smoke from vessels. However, there was no clear and objective definition of the smoke emission limit. Also, the same maximum fine was imposed regardless of vessel type and whether a vessel is a repeated offender. In a push to get vessel owners to maintain their engines properly and punctually, the government recently introduced a bill stipulating that ships will be fined if their emissions are as dark as (or darker than) Shade 2 on the Ringelmann Chart (a method for measuring smoke opacity) for three minutes or more.[83] The rule also raises the noncompliance penalty to a maximum fine of HKD 10,000–25,000 for local vessels and HKD 25,000–50,000 for OGVs, to help ensure that vessel owners comply.[84]

Hong Kong has not enforced any NO_x emission standard for engines used by non-OGVs. Therefore, many local vessels, like ferries, fishing boats, or tugboats, are still using old, home-made engines that have no controls for NO_x or other forms of pollution. For OGVs, Hong Kong has the authority to conduct inspections to ensure that those operating within Hong Kong waters comply with IMO NO_x and fuel sulfur requirements.[85]

The Hong Kong government's initiatives for reducing emissions from local vessels and OGVs have been driven primarily by the recognition that shipping emissions are the dominant source of local air pollution (see Section 2.1.2); the government's commitment to achieving the new Air Quality Objectives (AQO) by 2020; and Hong Kong's targets stipulated in the 2012 Hong Kong–Guangdong Regional Air Pollution Emission Reduction Plan (see Box 1).

Besides the new and proposed legislation, the city's government has also launched a number of voluntary initiatives to promote reductions in port emissions. See Section 3.2.3 for more details.

xiii Locally sold marine light diesel is used mainly by harbor craft, such as fishing vessels, ferries, tugs, and container feeders.

Box 1: Hong Kong-Guangdong Regional Air Pollution Emission Reduction Plan and Hong Kong's New Air Quality Objectives

Hong Kong has a range of Air Quality Objectives (AQO) as well as emission reduction targets. The latter were set in collaboration with Guangdong Province, which encompasses the mainland portion of the PRD.

In late 2012, emission reduction targets for 2015–2020, pending a midterm review in 2015, were endorsed at a meeting of the Hong Kong–Guangdong Joint Working Group on Sustainable Development and Environmental Protection. The year 2010 was set as the base year.[86]

The following table provides the emission baselines for 2010 for Hong Kong and the PRD on SO_2, NOx, RSP, and VOC, as well as the emission reduction targets set for 2015 and projected ranges for 2020:[87]

Pollutant	Area	2010 Emission (tonnes)	2015 Emission Reduction Targets (as compared with 2010)	2020 Emission Reduction Target Ranges (as compared with 2010)
SO_2	Hong Kong	35,500	25%	35% ~ 75%
	PRD Economic Zone	507,000	16%	20% ~35%
NO_2	Hong Kong	108,600	10%	20% ~ 30%
	PRD Economic Zone	889,000	18%	20% ~ 40%
RSP (PM_{10})	Hong Kong	6,340	10%	15% ~ 40%
	PRD Economic Zone	637,000	10%	15% ~ 25%
VOC	Hong Kong	33,700	5%	15%
	PRD Economic Zone	903,000	10%	15% ~ 25%

In addition, the Hong Kong government adopted a new AQO to replace the previous index set back in 1987 in order to gradually move Hong Kong's Air Quality standards closer to the air quality goals set by the WHO.

The following table provides an overview of Hong Kong's former and new AQOs and a comparison with the WHO Air Quality Guidelines (AQG). The new AQOs, which became effective on January 1, 2014 are highlighted in gray. As stated in the Clean Air Plan for Hong Kong released in March 2013, the government plans to achieve the new AQOs by 2020.[88]

Pollutant	Average Time	Former AQO (ug/m^3)	WHO AQGs (HK new AQO in gray) (ug/m^3)				No. of Exceedances
			IT-1	IT-2	IT-3	AQG	
Sulfur dioxide (SO_2)	10 min	--		--		500	3
	24 hr	350	125	50		20	3
RSP (PM_{10})	24 hr	180	150	100	75	50	9
	Annual	55	70	50	30	20	N/A
$PM_{2.5}$	24 hr	--	75	50	37.5	25	9
	Annual	--	35	25	15	10	N/A
Nitrogen oxide (NOx)	1 hr	300		--		200	18
	Annual	80		--		40	N/A
Ozone	8-hr	240 (1 hr)		160		100	9
Carbon monoxide	1 hr	30,000		--		30,000	0
	8 hr	10,000		--		10,000	0
Lead	Annual	1.5 (3 month)		--		0.5	N/A

IT-1, IT-2 and IT-3 refer to the three levels of interim air quality targets (IT), which have been defined by WHO to help countries gradually achieve progress over time. AQG refers to the maximum air pollution levels recommended by WHO.

Note that the intermediate target for SO_2 (IT-1) would still result in SO_2 emissions more than six times higher than the recommended WHO AQG, and the intermediate target for $PM_{2.5}$ (IT-1) would be three times as much as the WHO AQG. As WHO's intermediate targets were offered as entry level air quality improvement goals for developing countries with severe pollution and a serious lack of resources and expertise, many argued that the government's approach of adopting the IT-1 criteria for major pollutants, such as $PM_{2.5}$ and SO_2, would not foster serious measures for improving Hong Kong's air quality.[89,90]

3.2.2 Regulation and measures in mainland China

3.2.2.1 National/ministerial regulations and measures

1. Ambient Air Quality Standards

Since the adoption of China's 12th Five-Year Plan for Environmental Protection (2011–2015), the Ministry of Environmental Protection (MEP) has issued a series of aggressive measures to tackle air pollution.

In February 2012, new Ambient Air Quality Standards replaced China's 1996 air quality standards. The new standards added $PM_{2.5}$ to the six basic air quality indexes and require mandatory monitoring for all major Chinese cities starting on January 1, 2016.[91]

Shanghai, Tianjin, Shenzhen, and Guangzhou are among the first cities required to establish a comprehensive monitoring system for implementing the new standards and to disclose data as part of an ambient Air Quality Index (AQI), with hourly averages and daily average concentrations of SO_2, NO_2, PM_{10}, $PM_{2.5}$, O_3, and CO.[92]

Regarding shipping pollution standards, the Effluent Standard for Pollutants from Ships (GB 3552-83), enacted in 1983, is currently the only standard that targets pollution from vessels, and it covers effluent and garbage discharge only. Air emissions from small marine diesel engines (below 37 kW) are regulated by standards for emissions from non-road machinery.[93] Emission standards for other types of vessels are still lacking. The Environmental Standard Institute (ESI) of MEP has developed Proposed Standards for Air Pollutant Emissions from Marine Diesel Engines, and public consultation on the proposal was completed on August 15, 2014.

To implement the national strategy, the Ministry of Transport (MOT) has developed a set of technical standards and specifications for green ports, including Green Ship Specifications, Ship Energy Efficiency Management Certification Standards, and Rules for Inland Waterway Green Ships, developed by the China Classification Society, as well as green technologies in the transport sector, with research being carried out by the Waterborne Transport Research Institute (WTI). However, these green port-related programs focus primarily on energy conservation and GHG emission reduction.

2. Plans and Regulations

According to the National 12th Five-Year Plan for Environmental Protection and the National 12th Five-Year Plan for Energy Saving and Emission Reduction, emissions from ports and the shipping industry will be reduced primarily through two categories of project:

- Phasing out outdated, polluting vessels.
- Upgrading port infrastructure with green technologies, including electricity-powered gantry cranes and shore power for vessels at berth; upgrading port transportation vehicles and cargo-handling machinery; and vapor recovery

On September 12, 2013, the State Council issued a national "Air Pollution Prevention Action Plan" that serves as the guidance for national efforts to prevent and control air pollution for the present and the near future.[94,95] The Action Plan sets a road map for air pollution control in China with a focus on three key regions: the Beijing-Tianjin-Hebei region (Jing-Jin-Ji), the YRD, and the PRD. It aims at reducing PM_{10} concentration in all Chinese cities by 10% by 2017 and cutting fine particulates ($PM_{2.5}$) by 15%, 20%, and 25% in the PRD, YRD, and Jing-Jin-Ji regions, respectively, compared with 2012 levels. Including PM reduction goals in the new Action Plan can be considered a big step forward because the 12th Five-Year Plan on Environmental Protection proposed in 2009 set goals only for reducing SO_2 and NO_x emissions by 2015.

The Action Plan contains the toughest-ever measures to combat airborne pollution,[96] including controlling air emissions from vessels. Provincial and local governments are responsible for the air quality within their administrative areas. Local governments are also required to develop their own implementation programs in terms of key tasks, annual goals, policies, and measures, among others.

3.2.2.2 Provincial and municipal regulations and measures

Some provinces have issued provincial air pollution prevention action plans following the national action plan. Among others, the action plans of Shanghai Municipality, Jiangsu Province, Shandong Province, and Guangdong Province include specific requirements for air pollution control of shipping and ports. For example, the action plans of Jiangsu and Shandong promote or mandate switching from diesel to clean fuel—"oil to electricity" or "oil to liquefied natural gas"—for rubber tire gantry cranes (RTGs) and other cargo handling equipment, cargo trucks, and inland vessels; they also accelerate the launching of green port pilots. Jiangsu Province also focuses on building shore power[xiv] supply infrastructure, and Shandong Province will start developing a vessel emission inventory.

Following the announcement of its action plan, the Shanghai Municipal People's Congress, which is the legislature of the municipality, issued the Shanghai Municipal Regulation on Air Pollution Prevention (hereinafter "the Regulation") in July 2014. The Regulation shows a stronger commitment to clean up ports and ships and includes a number of mandatory measures. It clearly defines government agencies' responsibilities for preventing shipping pollution, including monitoring and inspection obligations. It requires vessels calling at Shanghai to meet national and municipal emission standards and mandates that fuel sold in Shanghai meet relevant standards. The Regulation stipulates that the Port of Shanghai will promote low-sulfur fuel switching and use of shore power gradually. The Regulation also includes penalty rules. For example, fines will be imposed on vessels that emit dark smoke. The Shanghai Environmental Protection Bureau is tasked with preparing a detailed implementation plan and related standards. It is foreseeable that shore power will be one of Shanghai's priorities. According to the action plan, Shanghai proposes to promote shore power pilots at the Wusongkou International Cruise Terminal and the Yangshan Guandong International Container Terminal. In addition, under the U.S.-China 10-Year Framework for Cooperation on Energy and Environment, the Port of Los Angeles and Port of Shanghai formed an EcoPartnership in July 2014 that allows the two ports to exchange information and share technical expertise and best practices to further the use of shore power at the Port of Shanghai.[97]

Guangdong Province released its Guangdong Provincial Air Pollution Prevention Action Plan on February 7, 2014. Submitted by the Guangdong Provincial Department of Environmental Protection (GDDEP) and drafted by the Guangdong Provincial Academy of Environmental Sciences (GDAES), it establishes air quality and pollutant reduction goals for the province. In the same month, the Guangdong Provincial Department of Transport (GDDT) issued a Green Port Action Plan of Guangdong Province (2014–2020), which sets objectives for energy efficiency and CO_2 reduction. The two action plans both require the development of green ports and reduction of emissions from shipping, ports, and port equipment. The two plans call for increased collaboration among Guangdong, Hong Kong, and Macau to control emissions from OGVs. According to the Air Pollution Prevention Action Plan, shore power facilities must be installed in all newly built cruise terminals in the PRD. All new container terminals with capacity over 10 tonnes are required to install shore power supply infrastructure or provide space for installing the infrastructure. Furthermore, the two action plans address integrated VOC vapor management at liquid bulk terminals, increased use of clean energy, the use of LNG vessels, and the transition of "oil to electricity" and "oil to gas" for trucks and cargo handling equipment. The Green Port Action Plan proposes to transform five or more terminals into green models by 2015 and more than 100 terminals by 2020. Research on speed limits for vessels in the Pearl River estuary, Yamenkou and Shantou Bay waters will be conducted. It is worth noting that the Port of Shenzhen have been chosen by the MOT as two of the four green port pilots for shore power, LNG trailers, and LNG tugs.

Because the abovementioned provincial air pollution prevention action plans were published by the provincial governments, these plans are expected will be implemented properly. However, measures for shipping and port emissions control specified in these plans are relatively generic. The objectives of transitioning from "oil to electricity" or "oil to gas" for vessels, trucks, and port equipment as well as providing shore power are vague—in fact, no targets are set for specific ports in those provinces. Regarding Guangdong Province, GDDT provides only operational guidance for municipal port authorities, which are affiliated with and report to municipal governments. Funding for related research could be provided but is limited and does not cover infrastructure construction in ports. These institutional and fiscal weaknesses may prevent the PRD from fully realizing the benefits of measures laid out in the port action plans.

Since the effectiveness of provincial action plans may be limited, municipal initiatives become more important to marine emissions prevention. The Qingdao municipal government published its Qingdao Air Pollution Prevention Action Plan 2013 in June of that year, before the release of the national action plan, and it proposes to electrify RTGs, other cargo handling equipment, and trucks.

On September 20, 2013, the Shenzhen municipal government published its Shenzhen Air Quality Enhancement Plan, the first municipal response to the State Council's new Air Pollution Prevention Action Plan. The plan has several key marine air pollution control measures, among them:

- *Improving shore power facilities.* Install at least eight berths with shore power connection by 2014 and at least 15 by 2015, with a goal of 15% of all container ships using shore power. Study incentives for shore power construction, and aim to subsidize 50% of construction costs.

xiv Shore power refers to the provision of shoreside electrical power to a ship at berth so that its main and auxiliary engines can be turned off to reduce air pollution. See more details in Section 4.2.

- *Reducing emissions from port pollution.* From September 2013 onward, require that all new port trailers and RTGs use LNG and electric power, respectively, and that by 2015, all such equipment complete the transition.
- *Tightening controls on sulfur content in marine fuel:* Aim to establish a sulfur ECA in the PRD region to require the use of 1,000 ppm (0.1%) sulfur fuel within 24 nautical miles of shore. Implement subsidy policies for encouraging OGVs switching to low-sulfur fuel while berthed, and strive to get more than 85% of vessels switched by 2015.
- *Promoting the use of LNG vessels.* By July 2014, launch a pilot project at a port in western Shenzhen to evaluate the feasibility of diesel-LNG hybrid ships. After the national government issues related standards, require that 10% of vessels and trawlers switch to LNG or hybrid power each year. Promote use of LNG for other port operations.
- *Enforcing a speed limit for vessels and promoting multimodal transport.* By the end of 2013, except for high-speed passenger vessels, limit the speed of vessels in Shenzhen waters to 12 knots.

In order to achieve Shenzhen's $PM_{2.5}$ reduction targets, its Air Quality Enhancement Plan not only spells out all the pollution control measures but also identifies the government agencies responsible for implementing each of them.

Following the enhancement plan, the Shenzhen Fuel Switching and Shore Power Subsidy Administrative Measures were developed by the Human Settlements and Environment Commission (HSEC) in coordination with the Transportation Commission of Shenzhen Municipality (SZTC) and the Shenzhen Finance Committee. Under the subsidy scheme, a ship that switches to fuels with a sulfur content no more than 5,000 ppm (0.5%) while berthing will be eligible to have 75–100% of the extra cost covered by the city. The city government will also subsidize up to 30% of the costs of installing shore power supply infrastructure at the terminals, and will repay ship owners part of the cost of using shore electricity.[98] Correspondingly, five container terminals—the ports of Shekou, Yantian, Mawan, Chiwan, and Da Chan Bay—have initiated feasibility studies of shore power facilities with SZTC's guidance and support. Consultants have also been commissioned by SZTC to carry out studies on policies related to fuel switching.

The HSEC developed the Air Quality Enhancement Plan that the Shenzhen Government subsequently released. HSEC is leading the implementation of the plan and is responsible for evaluating its effectiveness. Each government agency's responsibilities are well defined in this plan, so obligations of air pollution prevention lie not only with HSEC but also with other agencies. On most port-related measures, SZTC is required to work with the ports to complete tasks on time, and HSEC will evaluate whether measures are well implemented and objectives met.

At the time of writing, the Shenzhen government is still in discussion with multiple stakeholders on the implementation details of some of the proposed measures. According to HSEC, the pace of installing shore power infrastructure will be slower than specified in the plan.[99] The current plan is to start construction of two sets of shore power equipment in 2015. As of July 2014, all of the RTGs at Shenzhen Port have switched to electricity, and the conversion of trailers to LNG will be completed by the end of 2014. The voluntary at-berth fuel switching program will be launched once the abovementioned Fuel Switching Subsidy Administrative Measure is adopted, likely in the fall of 2014. Regarding LNG vessels, the plan to promote diesel-LNG hybrid ships has changed; a pilot program for dedicated LNG vessels will be carried out instead. Vessel speed reduction has not yet been implemented in Shenzhen. After discussion between the HSEC and Shenzhen Maritime Safety Administration, the speed limit would likely be set at 15 knots within Shenzhen waters (as in Hong Kong), but the implementation date has not been finalized yet.

3.2.3 Voluntary incentives and other port emissions control measures

In addition to the legislation and policies outlined in Section 3.2.1, the Hong Kong government is undertaking the following initiatives to curb emissions from vessels and ports:[100]

- *Voluntary fuel switching at berth.* Beginning in January 2011, major ship lines voluntarily agreed to switch to lower-sulfur fuel (not more than 5,000 ppm, or 0.5%, sulfur) while at berth in Hong Kong. The voluntary initiative, called the Fair Winds Charter, will be effective until December 31, 2014 (see Box 2 for more details). Prompted by the Fair Winds Charter, in late September 2012, the HKEPD launched a three-year incentive program for vessels switching to 5,000 ppm (0.5%) sulfur fuel while at berth. The program offers a 50% reduction in port facility and light dues for OGVs that switch fuel at berth; it will end in September 2015. The incentive scheme and the Fair Winds Charter should dovetail well with the proposed legislation of mandatory fuel switching slated to take effect in early 2015.
- *Controlling vessel speed.* Although introduced primarily in designated port and harbor areas as a traffic control measure and for ensuring navigational safety, this measure has the added benefit of reducing emissions.

- *Reducing emissions from port machinery.* Nearly all quay cranes and 70% of gantry cranes in ports now run on electricity. Virtually all machinery inside the container terminals runs on 10 ppm (0.001%) sulfur diesel, the same sulfur limit as for road vehicles in Hong Kong.
- *Government fleet using ultra low sulfur fuel.* Out of 800 government vessels, 114 have switched to ultra low sulfur diesel since 2001, with a sulfur content of 10 ppm (0.001%).
- *Regional collaboration.* The Hong Kong government has ongoing discussions with other ports in the PRD on the feasibility of mandating fuel switching at berth at Hong Kong and PRD ports, as well as setting up an ECA in PRD waters in the long run.

Box 2: The Fair Winds Charter and Low-Sulfur Switch Rebate

The Fair Winds Charter, a voluntary initiative led by the industry, was introduced in November 2010. On January 1, 2011, the signatories[xv] committed to switching to fuel with a maximum of 5,000 ppm (0.5%) sulfur content when at berth in Hong Kong. The initiative targets OGVs such as container ships and cruise liners. These measures, if adopted by all shipping operators, could reduce the number of premature deaths caused by shipping emissions in Hong Kong by nearly half, to 197 per year.[101]

When the Fair Winds Charter was first released, it also called on the Hong Kong government to offer incentives to support participating shipping lines, and it urged the Hong Kong government to work with the Guangdong government to mandate fuel switching at berth in the PRD region in order to create a level playing field.

On September 26, 2012, the government agreed to launch a three-year incentive program for promoting fuel switching at berth. However, the government's incentive program covers only about 40% of the costs associated with switching to lower-sulfur fuel. Without mandatory legislation, the participating ship operators were at a cost disadvantage in a market where freight rates are tight. As of September 2014, the cost of bunker fuel was about US$604.5 per tonne and low-sulfur fuel about US$897.5 per tonne.[102]

As of June 2014, only 12% of all OGVs coming to Hong Kong participate in the incentive scheme, according to statistics from the Environmental Protection Department (EPD). The modest participation rate suggests that the incentive program has achieved only limited success in cutting shipping emissions.[103] Facing pressures from major ship operators (such as Maersk) that threatened to stop using low-sulfur fuel if fuel switching at berth does not become mandatory, the government proposed legislation in mid-2013. The rule is slated for a Legislative Council vote in late 2014 and would take effect in 2015.[104]

xv Seventeen major lines have signed the Fair Winds Charter: Maersk Line, Evergreen, OOCL, Yang Ming (Taiwan), APL, CMA CGM,COSCO, MOL, Hapag-Lloyd, Hanjin, Hyundai, NYK, Hamburg Sud, Alianca, Hoegh, Crystal Cruises, and Prestige Cruise Holdings

4. POTENTIAL SOLUTIONS AND CHALLENGES

Various strategies have been deployed to reduce emissions from ships in major port regions. Table 2 provides an overview of the main strategies along with issues to consider when deciding which are best suited for mainland China.

Major port cities or regions in the EU and U.S. have adopted some of these strategies, either through mandating or encouraging individual strategies or by adopting a collection of measures as part of a clean port plan. The San Pedro Bay Clean Air Action Plan jointly implemented by the Port of Los Angeles and the Port of Long Beach, which laid out a road map for the adoption of many of the clean shipping measures listed below, is a notable example of such clean air action plans. Designation of an ECA, which sets technology-neutral NO_x and SOx standards, is another means to promote the adoption of clean ship strategies. Adopting an ECA could achieve greater emissions reduction benefits than implementing these measures through regional or national laws or a clean port plan, because an ECA could cover a broader geographical area beyond the waters of a region's or country's jurisdiction. More details of these strategies and how they could support meeting ECA requirements are discussed in the section below.

It should be noted that, besides ships, there are many other potential shoreside sources of pollution from ports, including trucks, cargo-handling equipment, locomotives, and fuel terminals (hydrocarbon emissions). While shoreside pollution from ports can be significant, this chapter focuses mainly on mitigation measures for shipping emissions.

It is worth noting too that the costs presented here are merely indicative of the likely order of magnitude. Cost numbers come from U.S. and EU projects, which are likely higher than the cost of comparable projects in China. Also, these costs are for OGVs and are likely higher than the costs of adopting the same technologies for smaller craft, like inland waterway vessels, harbor boats, or coastal vessels. Thus, these numbers will need further refinement before being applied to the China context.

Table 2: Main strategies for controlling ship emissions[105]

Type of control strategy	Control strategy	Target pollutants		Costs (indicative, for OGVs)	Implementation considerations	Regions where measures are in place
		PM / SOx	NOx			
Heightened emissions standards for vessels	Engine standards (for domestic ships and OGVs)		√	**SCR** *Capital cost:* US$40–135 per kW *Operational cost:* 7–10% of fuel cost	• Best to use with 1,000 ppm (0.1%) sulfur fuel	U.S. and EU; proposed marine engine standards in China
			√	**EGR** *Capital cost:* US$60–80 per kW *Operational cost:* 4–6% of fuel cost	• May need to be coupled with SOx scrubber to remove sulfur and other impurities from the recirculated exhaust gas	
		√		**Scrubbers** *Capital cost:* US$700,000–4 million *Operational cost:* 1–3% of fuel cost, plus costs for maintenance and other consumables, like caustic soda, where applicable	• Take up space • Wet scrubber discharges may cause ocean acidification	

<table>
<tr><th colspan="7">Table 2: Main strategies for controlling ship emissions[105]</th></tr>
<tr><th rowspan="2">Type of control strategy</th><th rowspan="2">Control strategy</th><th colspan="2">Target pollutants</th><th rowspan="2">Costs (indicative, for OGVs)</th><th rowspan="2">Implementation considerations</th><th rowspan="2">Regions where measures are in place</th></tr>
<tr><th>PM / SOx</th><th>NOx</th></tr>
<tr><td rowspan="4">Change of fuel</td><td>National or regional fuel sulfur limit</td><td>√</td><td></td><td rowspan="2">Low-sulfur distillate cost: ~ US$293 per tonne above price of bunker fuel,* plus installation cost of extra fuel tank, if needed</td><td>• Little extra infrastructure needed
• Fuel availability
• Challenges in monitoring fuel quality</td><td>U.S., EU, Hong Kong</td></tr>
<tr><td>Fuel sulfur limit for OGVs at berth</td><td>√ (during hotelling only)</td><td></td><td>• Little extra infrastructure needed
• Concerns on port competitiveness
• Fuel availability
• Enforcement challenges[xvi]</td><td>Mandatory: U.S. and EU
Voluntary: Hong Kong, Singapore</td></tr>
<tr><td>Liquefied natural gas (LNG)</td><td>√</td><td>√</td><td>Engine and fuel system can cost 10-20% of total vessel cost, but if cheaper natural gas is available, lower fuel prices can create payback in 2.6–7.4 years and significant savings thereafter**</td><td>• High up-front capital cost: onboard fuel storage and fuel supply infrastructure
• Require larger fuel tanks onboard, so difficult for retrofit
• Currently limited LNG refilling infrastructure
• Availability and price volatility of LNG</td><td>Mostly in Norway, fast-growing in EU and North America</td></tr>
<tr><td>Shore power</td><td>√ (during hotelling only)</td><td>√ (during hotelling only)</td><td>Shoreside: US$1 million–15 million per berth (in U.S.) US$170,000–8 million per berth (in Europe)
Shipside: US$300,000–2 million per ship</td><td>• High up-front capital cost: dockside power supply, onboard shore power system</td><td>Mandated in California; infrastructure established in major U.S. and EU ports; pilot projects under way in Shekou port in Shenzhen, Waigaoqiao port in Shanghai, Lianyungang port in Jiangsu, and Qingdao port in Shandong</td></tr>
<tr><td>Operational change</td><td>Vessel speed reduction</td><td>√</td><td>√</td><td>Fuel saving</td><td>• Extended shipping time
• Small benefits if speed limits already imposed due to safety concerns or constrained waterway</td><td>California, New York/ New Jersey</td></tr>
</table>

* Fuel cost based on Bunkerworld Index as of September 12, 2014.

** LNG cost based on analysis conducted for American Clean Skies Foundation[106] and analysis conducted by Gladstein Neandross & Associates (GNA) on the basis of industry survey.

xvi The biggest challenge in enforcing a fuel sulfur limit is monitoring fuel quality, since OGVs stay at the port for less than a day, and fuel sampling and testing may not be completed before a vessel needs to leave the port. This makes it difficult for regulators to impose fines when violations are found.

4.1 LOW-SULFUR FUEL SWITCHING

One of the most common measures to reduce air pollution from vessel exhaust is to switch from bunker fuel to a fuel that contains a much lower percentage of sulfur. Both California and the EU have imposed the strictest at-berth fuel switch requirements, mandating that OGVs use fuel with maximum sulfur content of 1,000 ppm (0.1%) while at dock. The fuel switching regulation in California is even more stringent, extending to 24 nautical miles (nm) from the California shore. Within the four existing ECAs, all OGVs now have to use fuel with a maximum 10,000 ppm (1%) sulfur content; the limit will be lowered to 1,000 ppm (0.1%) in January 2015. In 2011 the Port of Singapore, the world's busiest container port, introduced a voluntary Green Port Programme offering a 25% reduction in port dues for OGVs that used approved abatement/scrubber technology or burned clean fuels (with no more than 1,000 ppm sulfur) both at berth and within Singapore waters. Beginning in mid-2013, the Green Port Programme was expanded–OGVs burning clean fuels only while at berth are also eligible for a port dues reduction of 15%.[107]

As noted earlier, incentives for fuel switching at berth have been implemented in Hong Kong and a similar program has just been launched in Shenzhen, but no other port cities in China have plans to adopt it. In Hong Kong, signatories of the Fair Winds Charter voluntarily switch to fuel with a 5,000 ppm (0.5%) sulfur content. The Hong Kong government currently offers subsidies to OGVs that switch to 5,000 ppm (0.5%) sulfur fuel at berth, but this will become mandatory beginning in 2015.

Because the Hong Kong mandatory fuel switching regulation and the Shenzhen incentive program now under discussion will apply only to fuel used at berth, OGVs can still burn bunker fuel with up to 35,000 ppm (3.5%) sulfur while navigating through PRD waters, as well as when they are operating in close proximity to urban areas. If an ECA were to be established, vessels would have to switch to fuel with a maximum of 1,000 ppm (0.1%) sulfur (or apply other measures that result in similar level of SOx reduction, such as scrubbers) while at berth and while operating within the designated control areas.

Fuel availability

One issue that is often raised as a reason to delay enforcing ECA fuel requirements is a concern about the availability of low-sulfur fuel around the world. The shipping industry expects that the supply of 1,000 ppm (0.1%) sulfur fuel should likely be sufficient for the existing ECAs, given that ships are required to switch fuel only while they are operating within ECAs, and so the projected increase in demand for such fuel will be limited.[108] So far, ship operators have had very few problems in obtaining low-sulfur fuel to comply with California's OGV fuel regulation. The regulation, which took effect on January 1, 2014, requires all OGVs to use 1,000 ppm (0.1%) sulfur fuel within 24 nm of the California coast (the California Regulated Waters); it is the first in the world to impose this requirement when OGVs are approaching a port. As of May 2014, there have been a dozen reports of ships failing to enter the California Regulated Waters with compliant fuel.[109] With thousands of vessels calling at the ports in California every year, the low rate of noncompliance (less than 1%) suggests that purchasing compliant fuel before entering California waters is not a problem.[110]

It is expected that the marine fuel market in China will see increased demand for low-sulfur fuel in 2015, when the 1,000 ppm (0.1%) ECA fuel sulfur limit becomes effective, because some vessels bound for one of the four existing ECAs will want to take on 1,000 ppm (0.1%) sulfur fuel in China before departing. Right now, the Yangshan port in Shanghai and the Zhoushan port in Jiangsu both offer low-sulfur marine fuel with no more than 1,000 ppm (1%) sulfur.[111] Hong Kong could also serve as one of the refueling ports for ECA-bound OGVs, as marine fuel suppliers in Hong Kong can only carry marine light diesel with sulfur content not more than 500 ppm (0.05%), which complies with the future ECA fuel sulfur limit of 1,000 ppm.

If an ECA were set up in China, the global demand for ECA-compliant fuel would rise. Judging from prior ECA applications, it is reasonable to assume that the time that would elapse between preparation of the ECA proposal and final approval would provide refiners with ample lead time to upgrade their equipment to produce sufficient quantities of ECA-compliant fuel.

Technical issues

Some operators have raised concerns that switching from residual oil to lower-sulfur fuel may result in operational and safety problems, as OGV engines, boilers, and fuel systems are typically designed for use with residual oil. To address those concerns, marine engine manufacturers, oil companies, and classification societies have issued fuel changeover guidelines detailing procedures that would minimize technical and safety problems.[112] Ports that have implemented fuel switching programs, like the Port of Los Angeles, have also organized workshops for ship operators to share experiences on fuel switching. EU and North American ECAs so far have been implemented smoothly.[113] A small number of ships have experienced operational issues, like loss of propulsion, during fuel changeover, but these problems can all be easily prevented with planning, sufficient crew training and practice, and replacement of worn fuel system parts.[114] Among various types of OGVs that call at Chinese ports, intra-Asia carriers may be the least experienced in fuel switching, and they would benefit from the experience of shipping lines that regularly call at ports in the EU and U.S.[115]

Costs

As of September 12, 2014, the price of 0.1% sulfur marine distillate was about $293 per tonne higher than the price of bunker fuel, or 48% more expensive.[116] However, low-sulfur distillate would be used only when a ship approached the port and/or when berthing, so the cost comparison should be made on a voyage basis. A detailed analysis of engineering and operational costs, conducted as part of the North American ECA proposal, found that:[117]

- The price of a new vessel equipped with fuel switching equipment and other modifications for using low-sulfur fuel (such as an extra fuel tank for distillate)[xvii] would increase by 0.5% to 2%, depending on the vessel type.
- The operating cost increase would vary, depending on route and time spent in an ECA. The cost of operating a vessel servicing Singapore, Seattle, and Los Angeles/Long Beach, which includes about 1,700 nm of operation in waterways covered by the ECA, would increase by about 3%.
- The total costs would represent an US$18 increase in the shipping cost per container for a container ship. For a seven-day cruise on a vessel operating entirely within the ECA, the price per passenger would increase by about US$7 per day.

It is worth noting that the costs of an ECA in the PRD would be specific to local conditions in China. Before an ECA proposal is finalized, locally based cost estimates would certainly be developed.

4.2 SHORE POWER/COLD IRONING

Shore power or cold ironing refers to the practice of using shoreside electricity, as opposed to burning onboard fuels, while berthed. While docked at berth, ships normally shut off their propulsion engines but use their auxiliary engines to power refrigeration, lights, pumps, and other equipment.[xviii] If a ship connects to a shoreside power supply instead, there should be no emissions from the ship's auxiliary engines.[xix] However, the increased demand for electricity may lead to higher emissions where the generating power plant is located, depending on how electricity is generated (e.g., coal, natural gas).

The benefits of using shore power also depend on whether ships visiting the port have onboard shore power capability, how long a ship stays at dock, and how much energy a ship uses during hotelling. Cruise ship terminals may provide greater emission benefits than other terminals because cruise ships use much more energy than other OGVs at berth, and many cruise ships have home ports that they regularly visit. However, outfitting a cruise ship terminal is probably more challenging than other terminals because of the much higher power demands.

To illustrate how the life cycle environmental benefits of using shore power may vary by how electricity is generated, a preliminary analysis was conducted by Gladstein, Neandross & Associates (GNA) for NRDC comparing the life cycle emissions of shore power with emissions from using bunker fuel or low-sulfur distillate at berth. The analysis uses U.S. average energy mix projected for 2020 and 100% natural gas-powered generation to represent two scenarios of grid mix. More details about this analysis can be found in the Appendix.

As shown in Figure 12 below, life cycle emissions from a vessel at berth can be divided into two parts: upstream emissions (red bars in the figure) and direct vessel emissions from the ship at berth (blue bars). "Upstream emissions" refers to emissions from electricity generation in the case of shore power use, or emissions from oil extraction, refining, and distribution in the case of bunker fuel or distillate fuel use. Shore power eliminates direct emissions of NO_x, PM, and SOx from vessels. Relative to high-sulfur bunker fuel (HFO) with 25,000 ppm (2.5%) sulfur content, shore power also provides significant life cycle emissions benefits for NO_x, PM, and SOx. Shore power also results in considerably less NO_x emissions than if a ship uses distillate fuel. This is the case whether a ship is equipped with Tier 1 engines or the cleaner Tier 2 engines, as shown in the first graph. While shore power and low-sulfur distillate fuels both offer significant reductions in SOx and $PM_{2.5}$ emissions relative to HFO, 0.1% sulfur distillate (marine diesel

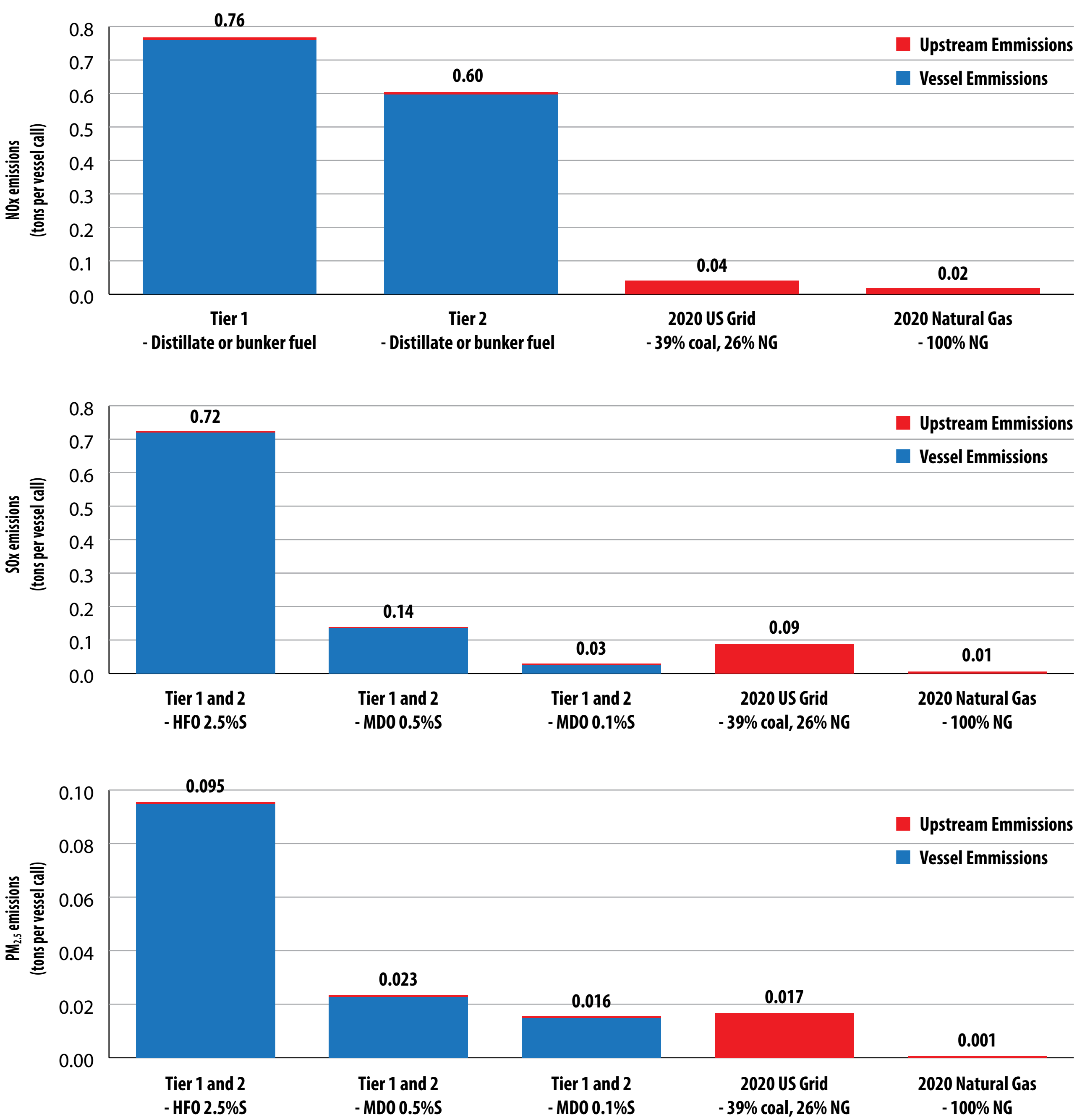
xvii Modifications include installing additional distillate fuel tanks, fuel separators and blending units, viscosity meters, and filters. See USEPA (2009) cited in endnote 19.

xviii Operations that require power while ships are at dock include the driving of hydraulic pumps, heating of fuel oil storage tanks, preheating of cooling water for combustion engines, power supply for reefer containers, communications/nautical equipment, deck machinery/cranes, air conditioning, amenities onboard cruise ships (cooking, lighting, etc.), loading/unloading pumps onboard tankers, and production of inert gas for oil tanks.

xix Even when using shore power, there could still be emissions from boilers for generating steam, unless a ship is connected to a dockside steam generator or uses an electric steam generator.

oil, or MDO) may offer lower SOx and $PM_{2.5}$ emissions than using shore power with electricity generated from an average 2020 grid mix. Life cycle emissions from shore power generated from 100% natural gas are the lowest among all scenarios. This suggests that the more shore power can be generated from clean energy sources, the higher the emissions benefits of using shore power.

Figure 12: Comparison of life cycle emissions of using 25,000 ppm (2.5%) sulfur bunker fuel, distillate fuel, and shore power at berth



In China, nearly 70% of electricity is generated from coal, with a target in the Clean Air Plan to lower the share to 65% by 2017.[118] The percentage for Hong Kong is slightly over 50%.[119] Mainland China and Hong Kong should carefully examine the life cycle benefits of installing shore power at container terminals with an analysis similar to the one presented above, using China and Hong Kong–specific assumptions, including the electricity grid mix and power plant emissions control performance. Any assessment of the overall benefits of shore power in mainland China and Hong Kong would also have to take into account the fact that the turnaround time at the PRD ports is generally half that of ports in the U.S.

At least four container ports in China have installed shore power infrastructure, including Lianyungang in Jiangsu, the Port of Shekou in Shenzhen, the Port of Qingdao in Shandong, and the Port of Waigaoqiao in Shanghai. While an international standard that defines the technical requirements for high-voltage shore power connection was released in 2013, some technical challenges remain for the wide adoption of shore power.[120] For instance, it is not always well defined who will be responsible for the safety of port personnel and ship crews, and who for establishing and operating connections.[121]

Technical/equipment requirements—vessels

To enable the use of shore power, a range of additional shipboard installations may be required, including:[122]

- power supply line;
- switchgear;
- power supply transformer;
- additional switchboard;
- communication system;
- cables, foundation;
- possible modifications on voltage controllers and speed governors of onboard generator sets;
- sufficient onboard space suitable for operational and safety requirements for existing vessels.

Technical/equipment requirements—berth

On the berth side, it is important that different types of vessels calling at port and requiring shore power can be served without difficulties. This implies the availability of:[123]

- transformers to suit different onboard voltages (440V, 6,600V, and up to 11,000V);
- alternating-current converters for 60Hz and 50Hz onboard systems;
- connecting cables for different power and voltage requirements;
- lifting devices for the handling of cables;
- provision for situations in which a vessel has to disconnect cables swiftly due to security or safety reasons.

For the supplying utility, depending on port requirements, the following may be required:

- extension and/or expansion of high voltage power supply mains;
- additional power generation capacity to handle peak loads;
- enhanced control to prevent any adverse effects on grid stability from energy-intensive demands of vessels during on-loading and off-loading.

These technical and equipment requirements onboard and at berth suggest that detailed analysis is needed to determine whether shore power is a cost-effective emissions mitigation option in China, and which terminal(s) would be best suited for offering shore power.

Costs

Although China-specific costs are not yet known, the investment costs for onboard shore power equipment in the United States and Europe can range from US$300,000 to $2 million, depending on vessel type and size, ship design, and the need for an onboard transformer.[124]

The cost for building shoreside infrastructure at a berth in the U.S. can range from US$1 million to $15 million and can range from US$170,000 to $8 million in Europe. These costs vary substantially, depending on the extent of terminal remodeling needed, the proximity to high-power electricity supplies, and the difficulty of locating shore power infrastructure.[125]

4.3 LIQUEFIED NATURAL GAS

Vessel engines can operate on liquefied natural gas (LNG), which does not contain any sulfur. Using LNG instead of bunker fuel can cut NO_x and PM emissions by 80% or more and can virtually eliminate SOx emissions.[126] Depending on the source of the natural gas, the potential exists for lower GHG emissions across its life cycle, particularly if best practices are deployed to reduce methane leakage. However, the environmental impacts of LNG extraction, through hydraulic fracturing of shale gas (fracking) or coal gasification, remain highly contentious.[127] The significant adverse environmental and potential health impacts of fracking for natural gas or coal-fueled synthetic natural gas production without adequate safeguards should not be overlooked.

There is a growing interest in using LNG as marine fuel in North America and Europe, where the price of natural gas is low. In many cases, the cost of running on LNG can be lower than using low-sulfur distillate even after accounting for the capital cost of converting to LNG.[128] Since natural gas vessels can meet the SOx, PM, and NO_x ECA requirements, there are an increasing number of programs in North America and the EU to evaluate the feasibility and cost effectiveness of LNG vessels. Natural gas is gradually gaining traction in the marine sector in China because of its potentially lower air pollution impacts. The main focus so far is on inland waterway vessels.[129] The Ministry of Transport has issued a guidance document in 2013 specifying targets of LNG adoption in the marine sector and steps for achieving these goals.[130]

Technical requirements

The use of LNG is likely to be more economically viable and feasible for new ships than for existing ships that require retrofitting. When liquefied, the storage volume required for natural gas is at least two times higher than for an energy-equivalent amount of conventional fuels. There is also a need for well-insulated tanks and a safe area in case of accidental spillage, resulting in a fuel system that requires up to four times the storage space of conventional fuels.[131] This increase in storage space requirements may impact the available cargo volume of the vessel; moreover, some existing ships may not have enough space to retrofit LNG tanks.

There are a number of alternative tank arrangements that could be adopted, as well as a number of engine system alternatives by which LNG can be utilized for propulsion purposes. One option involves using a slow-speed, gas injection engine with LNG delivered under pressure to the engine. The fuel is vaporized at the engine, thereby making the process safer, easier to install, and easier to operate than a system delivering high-pressure natural gas from the fuel tanks and vaporizing the fuel before supplying to the engine.

Another alternative arrangement is a low-pressure, two-stroke, dual-fuel engine. This has low-pressure LNG gas admitted by valves around the cylinder at the bottom of the stroke, which is then ignited by pilot fuel at the end of compression. A further option is the established DFDE (Dual Fuel Diesel Electric) system used on LNG carriers and also on passenger ferries. If a cruise ship uses LNG as a propulsion fuel, evaporating the fuel could be used to provide cooling in the air conditioning system.[132]

Refueling infrastructure

While some small-scale LNG bunkering facilities are now available in Norway and Sweden and dozens more are planned for Europe, the U.S., Canada, and China, the LNG refueling infrastructure is still scattered, and many of the planned bunkering facilities aim to serve only inland or short-sea shipping.[133,xx] Limited LNG refueling infrastructure, particularly outside of North America and Europe, may constrain the adoption of LNG for long-haul shipping in the near term.

Furthermore, the delay in the adoption of an IMO safety protocol for LNG-fueled ships could present significant obstacles for LNG to overcome before becoming a serious alternative to distillate fuels, especially for deep-sea shipping in the near term.[134] This is an issue that bears watching.

Safety at berth

In cases where a vessel is lying at anchor or experiencing a delay in port (without being operational) and a re-liquefaction plant has not been fitted onboard, methane may have to be vented or burned off to maintain acceptable tank pressure levels. This could result in reduced operational efficiency as well as additional GHG emissions.[135]

xx For instance, liquefaction and bunkering infrastructure has been planned at sites in North America (including Tacoma, Los Angeles, along the Mississippi River, and the Great Lakes region) and in Northern Europe (including Norway, Denmark, Sweden, Germany, the Netherlands, Belgium, France, and the United Kingdom). See Deal (2013) cited in endnote 133 and Bilkom (2014) cited in endnote 105.

4.4 SCRUBBERS

Scrubbers can remove SOx, PM, and other pollutants from the engine exhaust and have been successfully used in industrial applications for many years, although the technology has been adopted on only a limited number of vessels.

There are two main types of scrubbers: wet and dry. Among wet scrubbers, there are two types of technologies: open-loop scrubbers that use seawater as washwater, and closed-loop scrubbers that use freshwater treated with an alkaline substance like sodium hydroxide (commonly known as caustic soda).[136] For a seawater scrubber, when SOx in the exhaust comes into contact with seawater, a fast and efficient reaction takes place between the SOx in the exhaust and the calcium carbonate ($CaCO_3$) in the seawater, resulting in calcium sulfate (gypsum) and CO_2, thereby neutralizing the acidity of the SOx. Washwater is treated by removing solids and raising the pH before being discharged back to the sea.[137]

A freshwater scrubber operates in a similar way, but instead of using seawater, freshwater treated with alkaline material is injected to neutralize SOx in the exhaust. Freshwater scrubbers, which allow direct control of washwater alkalinity, are typically used when high SOx removal efficiency is needed, or in areas where low or variable alkalinity of seawater precludes the use of seawater scrubbers. As freshwater scrubbers can be operated under "zero discharge" mode, they are suited for vessels that operate in sensitive or vulnerable water bodies (like the Baltic Sea).[138] Dry scrubbers operate by exposing lime-treated granulates to the exhaust gas, as opposed to using washwater to capture sulfur oxides in the exhaust.[139]

Results from trials reported that scrubbers could be highly effective in reducing SOx emissions (more than 90%), and moderately to highly effective in cutting PM emissions from vessel exhaust (about 30% to 98%, depending on the scrubber technology and design).[140] Therefore, if designed well, scrubbers can enable ships running on high-sulfur bunker fuel to meet the 0.1% ECA fuel sulfur requirement. However, they have negligible impacts on NO_x emissions.[141]

Cost

In the U.S. and EU, the costs for purchasing and installing scrubbers vary from US$700,000 to $4 million per vessel, depending on vessel size, vessel type, and the scrubbing technology used.[142] Operation costs include additional fuel consumption to operate a scrubber, which is estimated to be 1% to 3% of energy fuel consumption, plus costs for scrubber maintenance.[143] For freshwater and dry scrubbers, there are also the costs of purchasing caustic soda or lime-treated granulates.[144]

Depending on the cost difference between low-sulfur distillate and bunker fuel, scrubbers can be highly cost-effective and can pay back within one year, compared with using low-sulfur distillate, according to a study conducted by the European Maritime Safety Agency.[145] The world's largest cruise company, Carnival, recently announced plans to install scrubbers on 70 vessels (or 70% of its entire fleet), in order to comply with the ECA sulfur requirement. This can be seen as proof of the technical feasibility and financial viability of scrubber technology.[146]

Concerns on environmental impacts of wet scrubber discharges

While scrubbers appear to be a cost-effective option to comply with ECA sulfur requirements, the acidity of discharged washwater could become an environmental concern that hinders further adoption of open-loop wet scrubbers, the cheaper scrubber technology.[147] While the current IMO discharge standard requires the pH value of scrubber discharge washwater to be 6.5 or higher, washwater discharged from open-loop scrubbers typically has a pH of around 3.5. This means that substantial dilution onboard (and hence more energy consumption) is needed. Assuming the operation of an auxiliary engine with an output of 1 MW, running on fuel with 3% sulfur content and near 100% abatement through the use of a scrubber, 82 tons of seawater would be required per hour, producing 460 kg of calcium sulfate or similar salts per day.[148]

4.5 OTHER TECHNOLOGIES AND ENGINE MODIFICATIONS

In addition to the approaches discussed above, there are other technologies and engine modification options that have been introduced or tested on ships to reduce exhaust emissions. These technologies include selective catalytic reduction (SCR), exhaust gas recirculation (EGR), direct water injection, humid air motor, variable valve timing and lift, and dimethyl ether. The information below focuses on SCR and EGR because these two technologies are more established for marine applications; information on other emissions control options can be found in IMO's report on the development of Tier III NO_x emission standard–compliant technologies.[149]

Selective Catalytic Reduction (SCR)

SCR is an after-treatment device that uses a catalyst to chemically reduce NO_x into N^2 and water, typically with ammonia as a reagent. It has been used extensively for NO_x emissions control at power plants and on heavy-duty diesel vehicles to achieve substantial NO_x reduction (more than 90%). The emissions reduction efficiency of SCR on vessels ranges from 70% to 90%, depending on operational profile, but at ideal conditions efficiency can exceed 90%.[150] Hundreds of ships have been equipped with SCR devices, and it is considered the only technology to date that can meet the strict Tier III NO_x requirement as a sole control strategy for most, if not all, marine engines and vessel applications.[151] To achieve best emissions control performance and prolong the catalyst lifetime of the SCR, ships equipped with SCR should use fuel with sulfur content of 1,000 ppm or less.[152]

Capital costs of an SCR system vary, depending on the engine power and vessel type, and operational costs (mainly expenditures on urea and on regenerating spent catalyst) depend on how long a vessel travels within an ECA. The capital investment for an SCR for a big marine engine is about US$40 to $135 per kW, and the operating cost due to urea consumption is about 7% to 10% of fuel costs when operating within an ECA.[153]

Exhaust gas recirculation (EGR)

EGR reduces NO_x emissions by routing a portion of the exhaust gas to the combustion chamber. The exhaust gas absorbs heat during the combustion process, lowering peak combustion temperature and reducing NO_x. Diluting the incoming air with the noncombustible exhaust also lowers the oxygen content of the combustion air, thus reducing the rate of NO_x formation.[154]

Like SCR, EGR technology has been successfully adopted as a NO_x reduction strategy on vehicles for decades. EGR has been shown to achieve 75% NO_x reduction even with the use of high-sulfur bunker fuel and has been used as a sole control strategy for meeting the Tier III NO_x standard in some marine applications.[155,156] An EGR-equipped engine using high-sulfur oil can be fitted with an EGR scrubber to remove sulfate and particulate matter from the exhaust before it is recirculated back to the engine, in order to meet the ECA NO_x, SOx, and PM limits.[157]

Based on EU experiences, the capital cost of an EGR system is typically around US$60 to $80 per kW, and the operating costs represent about 4% to 6% of the fuel costs when the ships operate in a NO_x ECA.[158]

4.6 VESSEL SPEED REDUCTION OR SLOW STEAMING

Vessel speed reduction refers to the practice of OGVs operating at a speed significantly lower than their maximum speed. Currently the majority of global shipping lines use slow steaming while out on the open sea as a practice to reduce fuel consumption and to save money in the face of rapidly rising fuel costs. With reduced fuel consumption, exhaust emissions tend to drop as well.

While the potential emission reduction from reducing vessel speed depends on the extent of the speed reduction, the fuel type, and the engine profile, a rule of thumb is that every 10% reduction in vessel speed results in a 15% to 20% reduction in fuel consumption (and hence emissions).[159] Most container ships are designed to travel at speeds around 20 to 25 knots. Slow steaming generally refers to speeds of around 18 to 20 knots (33.3 to 37.0 kilometers per hour). Extra- or super-slow steaming (15 to 18 knots; 27.8 to 33.3 km/hr) represents a substantial decline in speed for the purpose of achieving a minimal level of fuel consumption and can be applied on specific short-distance routes. The lowest ship speed that is technically feasible for OGVs (12 to 15 knots; 22.2 to 27.8 km/hr), which is also known as "minimal cost" speed class, is considered too slow to be commercially acceptable, so it is unlikely that shipping companies would adopt such speeds.[160] According to the Maersk Line, which introduced the practice in 2009, slow steaming is conducted at 18 knots or less, while speeds under 18 knots are super-slow steaming. Marine engine manufacturer Wärtsilä estimates that fuel consumption can be reduced by 59% by reducing cargo vessel speed from 27 knots to 18 knots, at the cost of an additional week's sailing time on routes between Asia and Europe.[161]

Four ports in the U.S.—the Port of Los Angeles (POLA), the Port of Long Beach (POLB), the Port of San Diego (POSD), and the Port of New York/New Jersey—have instituted voluntary speed reduction programs with the objective of reducing air emissions near these ports.[162] The programs of POLA and POLB were the first such programs in the U.S. At first, ships calling at POLA or POLB were asked to reduce their speed to 12 knots or less within 20 nautical miles of either port. Compliant vessel operators are provided the equivalent of a 15% discount of the first day of dockage, per vessel unit. In September 2009 the speed reduction area for POLA and POLB was expanded to 40 nm. Vessels that start slowing down to 12 knots from 40 nm receive a 30% reduction in dockage fees at POLA and a 25% reduction at POLB. Vessels attaining a 90% or better compliance rate with the voluntary vessel speed reduction program for a 12-month period are eligible to the incentives for 100% of the vessel calls in that year.[163]

In addition to the dockage fee discount, the POLB program (called the Green Flag program) gives a Green Flag Environmental Achievement award to individual vessels that attain a 90% or better compliance rate with the voluntary vessel speed reduction program.[164]

In 2008, POLB estimated that the program prevented 678 tonnes of NO_x, 453 tonnes of SOx, 60 tonnes of diesel PM, and more than 26,000 tonnes of CO_2 equivalent from being emitted. If only the NO_x reduction is considered, the cost of reducing vessel speed is equivalent to US$2,360 per tonne of avoided NO_x emissions, which was lower than the cost per tonne estimated for complying with the ECA.[165]

Furthermore, the California Air Resources Board (CARB) analyzed vessel speed reduction at 24 nm and 40 nm from Californian ports. If all ships were to reduce speeds to 12 knots within 40 nm of port, the emissions of PM, NO_x, SOx, and CO_2 would be reduced by an estimated 31%, 36%, 29%, and 29%, respectively (see Table 3).

Table 3: CARB-projected emission savings (tonnes per year) for different speed reduction scenarios (2008)[166]

	Without VSR* (24 nm)	With VSR all traffic** (24 nm)	With VSR port only (24 nm)	Without VSR (40 nm)	With VSR all traffic (40 nm)	With VSR all port only (40 nm)
PM	5.1	4.2 (–18%)	4.6 (–10%)	8.9	6.1 (–31%)	7.8 (–12%)
NO_x	53	42 (–21%)	48 (–9%)	98	63 (–36%)	83 (–15%)
SOx	45	39 (–13%)	42 (–7%)	73	52 (–29%)	64 (–12%)
CO_2	3,130	2,720 (–13%)	2,930 (–6%)	4,810	3,430 (–29%)	4,250 (–12%)

Source: CARB (2009)

* VSR = Vessel Speed Reduction; all scenarios assume speed reduced to 12 knots.

** All Traffic includes ships departing and arriving at ports as well as those transiting through the VSR zone.

4.7 EXTENSION OF THE FAIR WINDS CHARTER

The current Fair Winds Charter operating in Hong Kong could be extended to the ports of Shenzhen and Guangzhou. Many of the vessels calling at Hong Kong also call at one or both of these ports as well, either right before or after calling at a Hong Kong port or on a different vessel route. For instance, 10 of the 17 major ship lines that regularly call at Hong Kong ports and are signatories of the Fair Winds Charter are also major ship operators calling at Yantian Port. These shipping lines are Maersk, Evergreen, OOCL, APL, CMA CGM, COSCO, MOL, Hapag-Lloyd, NYK, and Hamburg Sud.[167] Also, 14 shipping lines operate at least one route that calls both at Hong Kong and at Guangzhou container terminals (COSCO, CSCL, CMA-CGM, Evergreen, Hanjin, Heung-A, K Line, KMTC, Maersk, Namsung, Pacific International, POS, Wanhai and Wuzhou).[168]

Shenzhen's Fuel Switching and Shore Power Subsidy Administration Measures offer incentives to OGVs switching to low-sulfur fuel at berth, and invited a number of ship operators to jointly signed the "Shenzhen Port Green Charter" (similar to extending the Fair Winds Charter to Shenzhen, see Section 3.2.2.2 for more details of the Shenzhen plan). To encourage vessels to register for an extended voluntary Fair Winds Charter that covers Guangzhou or other port regions like the YRD, it would be useful to look into the possibility of offering fuel switching incentives in these ports.

4.8 SUBSIDIES AND REBATES

In the EU, a number of incentive-based programs have encouraged early adoption of emission mitigation technologies on vessels, even though these programs were not initially designed for the purpose of promoting ECA compliance.

One example is the differentiated "fairway dues" program adopted in Sweden, in which major ports charge dues that vary according to a vessel's NO_x emission level and fuel sulfur content.[169] For instance, the port of Gothenburg applies environmentally differentiated port charges for vessels switching to low-sulfur fuel of 1,000 ppm (0.1%) or less and offers financial support to those converting to LNG or equivalent clean fuels. Vessels that run on fuel with a sulfur content higher than 5,000 ppm (0.5%) have to pay a surcharge, with the income generated from the sulfur surcharge being reinvested in vessels running on clean fuel.[170]

The Swedish program encouraged operators to switch to low-sulfur fuel even before the ECA for SOx was established, and it is believed to have enhanced compliance levels in the Baltic Sea ECA as well.[171] The program has also encouraged the use of NO_x reduction technologies on ships, such as SCR and humid air motor (HAM), even though the North Sea and Baltic Sea have not implemented an ECA for NO_x.[172]

4.9 EMISSION CONTROL AREAS

In order to reduce emissions from OGVs, a country (or group of countries) can call for an ECA under the IMO to be designated for SOx, PM and/or NO_x. In ECAs, emission standards for SOx and NO_x are more stringent than global standards. An ECA does not mandate the use of a specific technology. Rather, Regulation 4 of MARPOL Annex VI allows for vessels to use any effective "equivalent" mitigation method to meet the SOx/PM or NO_x requirement, so both the NO_x and SOx standards are technology neutral.

As noted in Section 3.1, all ships are currently required to use fuel with a maximum sulfur content of 10,000 ppm (1%) while within an ECA; this will be tightened in 2015 to 1,000 ppm (0.1%) maximum. Since the fuel sulfur standard applies to all ships, reductions in SOx and PM are seen from all vessels, new or old, while they operate inside an ECA. The much stricter NO_x emissions standard under ECA rules applies only to new ships; it will take time for fleet turnover to see substantial improvements.

Box 3: Introduction of Baltic Sea and North Sea ECAs

The world's first two ECAs were established in the Baltic Sea in 2006 and the North Sea in 2007.

They were set up as Sulfur Emission Control Areas (SECAs), and therefore they restrict only SOx and PM emissions from ships via fuel sulfur standards. Analysis of the costs and benefits of implementing the North Sea and Baltic Sea ECAs found that the health and environmental benefits (including reduced health risks, improved crop yield, and reduced damage to the built environment) far outweighed the costs of meeting ECA requirements.

The potential annual public health and environmental savings made through these two ECAs are estimated at [173]

- 8 billion to €16 billion in 2015
- 10 billion to €23 billion in 2020

…while costs are estimated to be:

- 0.6 billion to €3.7 billion in 2015
- 0.9 billion to €4.6 billion in 2020

If any part of China's waters is to be established as an ECA, an application for ECA designation will need to be submitted by the Chinese government to the IMO. An application for an ECA must contain, at a minimum, the following information:

- A clear delineation of the proposed ECA
- The emissions that are being proposed for control (i.e., SOx, PM, and/or NO_x)
- A description of the population and environmental areas at risk
- An assessment of ship contributions to ambient concentrations of air pollution or to adverse environmental impacts in the proposed ECA
- Meteorological conditions in the proposed ECA
- Patterns, density, and nature of the ship traffic in the proposed ECA
- A description of control measures addressing land-based sources of SOx, PM, and NO_x emissions that are in place and operating concurrent with any ECA measures to be adopted
- Analysis of the relative costs of reducing ship emissions compared with land-based controls and the economic impacts on shipping engaged in international trade

Discussions between authorities in Hong Kong and the PRD are ongoing, with a view toward having the entire PRD waters designated as an ECA in the long term.

Box 4: Introduction of the North American ECA[174]

The North American ECA–200 nautical miles from the coastline—is a full ECA, established in 2012, that restricts SOx, PM, and NO_x emissions.[175]

By 2020, emissions of NO_x, $PM_{2.5}$, and SOx from vessels operating in the ECA are anticipated to be 23%, 74%, and 86% lower, respectively, than the predicted levels without ECA. An estimated 5,500 to 14,000 premature deaths, 3,800 emergency room visits, and 4.9 million cases of acute respiratory symptoms will have been avoided by 2020 (and up to 31,000 premature deaths by 2030). Total health benefits are projected to be in the range of US$47 billion to $110 billion.

The overall cost of the North American ECA: an estimated US$3.2 billion by 2020.

4.10 ANTICIPATED IMPACT OF SELECTED MEASURES ON EMISSIONS IN CHINA

Building on the research for developing the Hong Kong 2007 marine emission inventory, Civic Exchange, HKUST, and HKU took the next step and assessed the impacts of emissions from OGVs operating in Hong Kong and the rest of the PRD region.[176] This study compared and analyzed four different ship emission control scenarios for Hong Kong and the PRD:

- Mandatory at-berth fuel switching to fuel with 5,000 ppm (0.5%) or less sulfur for OGVs
- Mandatory fuel switching to fuel with 1,000 ppm (0.1%) or less sulfur for OGVs operating in Hong Kong waters
- An ECA covering 100 nm from Hong Kong, hence including some part of the PRD waters
- Restricting vessel speeds to 12 knots in Hong Kong waters for OGVs

The following table summarizes the outcomes of this study. It shows that a low-cost measure such as reducing vessel speed to 12 knots in coastal waters could cut SO_2 from marine emissions by 1.4%, while establishing an ECA in PRD waters would bring the greatest emissions benefits, with a reduction of SO_2 estimated at 95%. Designating an ECA in PRD waters was therefore recommended by the study as the best long-term option for regulatory control of ship emissions in the PRD, and this recommendation was echoed in the Clean Air Plan for Hong Kong issued by the Hong Kong Environmental Bureau.[177] If this is the chosen course, the technology options for vessels discussed above could then be promoted within the larger regulatory framework of ECA.

Table 4: Emission reduction potential of four control measures in PRD waters, 2008[178]

Measures	Emission Reduction Potential	
	SO_2	PM
(a) Fuel switch at berth, 0.5% sulfur, OGVs	3.9%	2.9%
(b) Fuel switch in HK waters, 0.1% sulfur, OGVs	9.6%	8.3%
(c) ECA (100 nm from HK)	95%	85.3%
(d) Vessel speed reduction to 12 knots in HK waters, OGVs	1.4%	1.3%
Baseline emissions attributable to SO2 emissions from ships:	141,920 tonnes/year	16,433 tonnes/year

5. CONCLUSION

China is now the world's biggest manufacturing base and the second-largest consumer market. In parallel with robust growth in import/export trade is the rapid development of China's port system. Ships, trucks, and equipment that serve the ports likely contribute significantly to China's growing air pollution woes, as research conducted in Hong Kong suggests. Further, most of the Chinese container ports are located in or near highly populated cities. The high concentration of ship movement and maritime activities in these populated port cities may result in much greater health impacts in China than in other countries.

Mounting public pressure on the government to improve air quality has driven Hong Kong to become the first city in China to regulate shipping emissions. Other coastal cities are starting to look into the impacts of shipping and port emissions on air quality. And a few port cities and regions in mainland China, including Shenzhen, Qingdao, Guangdong, Jiangsu, and Shandong, have begun to introduce control measures for ship emissions, such as promoting fuel switching at berth or the use of shore power.

This paper has examined a variety of control strategies for shipping and port emissions that have been successfully adopted in the U.S. and the EU. They range from new technologies and fuel strategies (e.g., low-sulfur fuel, LNG, shore power, scrubbers, SCR, and EGR) to policy measures (e.g., ECA designation and incentive programs). While the plans announced by port cities and regions in China cover some of these strategies, regulators may face serious challenges in putting these measures into effect for the following reasons:

1. Research on mitigating port and shipping emissions is still at the inception stage in China, so there are only limited and preliminary data on shipping and port activities and the associated emissions levels, with the exception of the ports of Hong Kong and Shanghai. Many of the proposed measures entail considerable costs. Absent detailed data and analysis that could justify the costs and demonstrate benefits from the proposed control measures, governments will likely face opposition from the shipping industry, ports, and other stakeholders.
2. Efforts undertaken by major ports in the U.S. and EU have benefited from regularly updated emissions inventories, which enable ports and regulators to adjust and optimize emission control efforts and clean port plans. In China, detailed emissions inventories are available in Hong Kong and Shanghai but not yet in other Chinese ports. The lack of port-specific data may prevent port and regulatory agencies from tailoring mitigation measures to local conditions and regularly updating those measures to achieve the greatest environmental and health benefits.
3. The maritime transport industry is extremely competitive. As ports are a source of revenue and jobs for local governments, concerns over port competitiveness are, and will remain, a main obstacle for adopting clean shipping and port strategies that go beyond voluntary measures. Although this has not been documented to date, the shipping industry has expressed concern that if some ports decide to mandate control measures, the higher compliance costs may drive some ships away to ports with less stringent requirements, thereby undermining the effectiveness of programs that are already in place.

With the public highly concerned about air pollution and the associated serious health impacts, shipping and port-associated sources are expected to become a focus of clean air efforts in port regions. Efforts now under way to develop rough estimates of shipping and port-related emissions for key port regions, like the Pearl River Delta and the Yangtze River Delta, as well as the whole nation, will allow the government and relevant stakeholders to have a better grasp of the contribution of marine and port pollution, and their major sources.

Going forward, efforts to clean up ships, trucks, and port equipment could benefit substantially from studies targeting specific ports and regions, including detailed shipping and port emission inventories covering all sources of emissions, and analyses of the costs, benefits, and feasibility of adopting various emissions mitigation measures. Such analysis provides the scientific basis for key ports in the U.S. and EU to evaluate the effectiveness and feasibility of various emissions control measures. With a better understanding of the costs and benefits of each of the control measures, China's ports and regional governments could then chart a road map of clean air actions that gives ample time for the industry and related government agencies to prepare for the policy and/or technology choices. Local governments and ports in China could learn from the experiences of U.S. and EU ports by developing their own port clean air action plans that best suit their specific conditions and needs, and using these plans to communicate with—and solicit support from—the shipping industry and other stakeholders.

Furthermore, exchange of knowledge and experiences with international experts and regulators, particularly on advanced technologies like SCR, scrubbers, LNG, and shore power, will be valuable in helping China's policymakers better understand the opportunities and challenges in leveraging these advanced measures.

Looking ahead, joint regional and national efforts to control shipping emissions, such as establishing an ECA for major Chinese port regions or for the entire country, should be seriously considered as a way to address concerns over port competitiveness and to achieve the greatest environmental and health benefits in China. Establishing a consistent national regulatory framework is vital to discourage ships from evading their duties by switching to the least-regulated ports and to protect the economic interests of ports that opt for more stringent air quality improvement measures.

Finally, establishing an ECA could spur the adoption of advanced technologies and clean fuels on ships when they are operating within China waters, leading to substantial reductions in shipping emissions and contributing to the attainment of China's air quality goals.

APPENDIX: SUMMARY OF APPROACH—SHORE POWER ANALYSIS

1. INTRODUCTION

As part of a larger effort to develop emissions estimates for various freight pathways, Gladstein, Neandross & Associates (GNA) conducted an analysis of emissions from oceangoing vessels at berth.

In total, 12 scenarios were evaluated, including the use of shore power and traditional diesel auxiliary engines. A summary of the results of 8 scenarios are presented in section 4.2 of this report. Emissions estimates include direct vessel emissions and upstream emissions associated with fuel or electricity production and are reported on a per-visit basis. Upstream emissions are derived primarily from Argonne National Laboratory's GREET 1 2012 model. Vessel emissions and energy usage are based primarily on emissions inventories and data produced by the California Air Resources Board in support of their Ocean-Going Vessels rulemaking activities.[xxi] Assumptions regarding the mix of electrical grid generation technologies are based on guidance provided by NRDC.

2. SCENARIOS

The following tables summarize 8 of the 12 scenarios evaluated as part of the shore power emissions analysis. Of these 8 scenarios, 6 estimate lifecycle emissions from an OGV when it uses its auxiliary engines while at berth (the "Fuel Oil Scenarios"). The remaining 2 scenarios estimate lifecycle emissions from an OGV when it is connected to shore power, and the shore power is generated from two different energy mixes.[xxii]

Fuel Oil (HFO and MDO) Scenarios	
IMO engine NO_x emissions standard	**Fuel and sulfur content**
Tier 1	HFO, 2.5%
Tier 1	MDO, 0.5%
Tier 1	MDO, 0.1%
Tier 2	HFO, 2.5%
Tier 2	MDO, 0.5%
Tier 2	MDO, 0.1%

HFO: heavy fuel oil; MDO: marine distillate oil.

Shore Power Scenario	
Scenario Name	**Grid Mix**
2020 U.S. Grid	39% coal, 26% NG, 21% nuclear, 13.5% renewables, and the balance as residual oil
2020 Natural Gas: 100% NG	Uses the GREET default for natural gas power plants (not natural gas combined cycle plants) supplying 100% of transportation end use power

xxi Unless otherwise noted, vessel emissions factors and operational characteristics are derived from CARB's 2011 Emissions Estimation Methodology for Ocean-Going Vessels.

xxii The other four shore power scenarios considered in the GNA analysis, the results of which are not presented here, are: 1. U.S. coal-fired power plants supplying 100% of the transportation end use power (emissions control for meeting the Mercury and Air Toxics Standards [MATS] not included); 2. U.S coal-fired power plants supplying 100% of the transportation end use power, applies an 80% reduction in NO_x emissions and 90% reduction in PM_{10}, $PM_{2.5}$, and SOx emissions from the power plant; 3. estimated grid mix of Hong Kong (50% coal, 25% natural gas, 25% nuclear); and 4. estimated grid mix of Guangdong (48% coal, 29% petrol, 4% NG, 19% large hydro + nuclear).

Traditional diesel auxiliary engines—Emissions are estimated from Tier 1 and Tier 2 auxiliary marine engines operating on heavy fuel oil (HFO) and marine distillate oil (MDO). HFO is assumed to have a fuel sulfur content of 2.5%, and MDO is assumed to have a sulfur content of 0.5% or 0.1%.

Shore power—Vessels operating on shore power while in berth produce no direct emissions but have upstream emissions that depend strongly on the mix of technologies used to produce the electrical power. As noted above, in the GNA analysis, six different mixes of technology are considered, and the scenario using the average energy mix of the U.S. in 2020 and 100% natural gas are presented in this paper. For the 2020 U.S. Grid scenario, it is assumed that the U.S. has a grid mix of 39% coal, 26% NG, 21% nuclear, 13.5% renewables, and the balance as residual oil. Under the 100% natural gas scenario, shore power comes from 100% natural gas–generated electricity.

Note that in all cases only the grid mix associated with electricity for transportation end uses is modified. The grid mix for stationary end uses is left at the GREET default as stationary power emissions are included in fuel extraction and production processes for all fuels. The stationary grid mix factors into the overall fuel pathway emissions because stationary power is used in various aspects of production, processing, and transport of fuels. As an example, consider that some of the natural gas in the U.S. is moved through pipelines by electrically driven compressors, or that a gas processing plant requires some amount of electricity to power the facility. These are stationary end uses. Changing the assumed grid mix serving these end uses influences the fuel cycle energy inputs and emissions for natural gas (which, in turn, affects the grid mix and a host of other fuel pathways).

In the case of shore power, we are typically considering marginal grid mixes—electrical generation that is added to serve the shore power load. This implies that the broader national, baseline grid mix is not changing (at least not significantly). Consequently, the average grid mix serving stationary sources does not change under an analysis of marginal power demand for transportation end uses such as shore power. Using a constant assumption of grid mix for stationary end uses isolates the differences in emissions from shore power projects under different marginal grid mixes.

3. VESSEL CALL ASSUMPTIONS

Upstream and vessel emissions factors provide emissions estimates on an energy basis, either as grams/MMBTU or as grams/kWh. To calculate emissions per visit, the total fuel use or electrical energy consumed during a typical visit must be estimated. Consumption of HFO and MDO are based on fuel consumption rates provided by CARB for auxiliary engines. MDO has a slightly lower fuel consumption rate and lower carbon content per unit of fuel compared with HFO and results in MDO providing a GHG benefit relative to HFO. Electrical energy consumption rates are based on CARB estimates of average auxiliary engine size and load factor. CARB reports an average auxiliary engine size of 8,156 kW and a load factor of 18%. These figures are roughly representative of a container ship with 4,000-4,999 TEU capacity. The fuel and electricity consumption rates are converted to total consumption using an average vessel berth time of 40.1 hours, calculated as the weighted average of all vessel calls to the top six California ports in 2005.

Shore Power Vessel Call Assumptions	
Load Factor	18%
Engine Size (kW)	8,156
Hours/call	40.1
Energy/call (kWh)	58,877

4. VESSEL EMISSIONS FACTORS

CARB provides auxiliary engine emissions factors for uncontrolled (pre-Tier 1) engines. Tier 1 and Tier 2 emissions factors are estimated by applying NO_x emission control factors provided in CARB's Marine Emissions Model. Only NO_x emissions are assumed to differ between Tier 1 and Tier 2 engines.

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