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PREVENTION OF AIR POLLUTION FROM SHIPS

Reducing Shipping Emissions of Air Pollution — Feasible and Cost-effective Options

Submitted by Friends of the Earth International

SUMMARY	
Executive summary:	The annex to this document presents the paper "Reducing Shipping Emissions of Air Pollution – feasible and cost-effective options" that has been produced by a coalition of NGO's
Action to be taken:	Paragraph 4
Related documents:	

Introduction

1 Air pollution from shipping is a growing problem that is drawing increased attention, internationally as well as nationally in such places as Europe and the United States. Although the implementation of Annex VI is a beginning, the problem is far from solved. The attached paper "Reducing Shipping Emissions of Air Pollution – Feasible and Cost-effective Options," produced by a coalition of NGO's,[1] summarizes inventories of shipping emissions worldwide as well as those from United States and European waters, summarizes some of the effects of air emissions from ships on human health and the environment, and discusses some of the approaches that are available over the near term to reduce these emissions in a cost-effective manner.

2 Emissions from shipping are significant and are projected to continue to grow, constituting a larger share of total emissions, especially as Europe and the United States continue to reduce emissions from land-based sources. Health and environmental impacts from shipping emissions include premature death, various health and lung impacts, as well as acid rain, eutrophication of coastal ecosystems and climate change.

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[1] Clean Air Task Force, Bluewater Network, European Environmental Bureau, North Sea Foundation, Seas at Risk, the European Federation for Transport and Environment and the Swedish NGO Secretariat on Acid Rain.

3 There are, however, feasible and cost-effective methods of substantially reducing air emissions from ships. These include reducing the sulphur content in marine fuel and potentially seawater scrubbing for sulphur dioxide; internal engine modifications, water/fuel emulsions, introduction of water or water vapour into the combustion process and selective catalytic reduction for nitrogen oxides; and sulphur reduction measures as well as oxidation catalysts and particulate filters for particulate matter. Most of these emission control measures are not only feasible and cost-effective, but are more cost-effective than additional reductions of emissions from many land-based sources, and will produce benefits far in excess of their costs.

Action requested of the Committee

4 The Committee is invited to take note of the information provided and to take action as appropriate.

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ANNEX

**Reducing Shipping Emissions of Air Pollution —
Feasible and Cost-effective Options**

**A Background Paper
by
Clean Air Task Force
Bluewater Network
European Environmental Bureau
North Sea Foundation
Seas at Risk
European Federation for Transport and Environment
Swedish NGO Secretariat on Acid Rain**

The international shipping trade is an important part of the global economy. Ships are also an efficient means of transporting goods. However, until recently, air pollution from ships went largely unregulated, with regulatory and advocacy focus on more visible land-based sources. Over the past several decades, regulators in both the United States and Europe have required significant emission reductions from nearly all types of mobile land-based emission sources. As a result, emissions from diesel marine engines have come to represent an increasingly large share of air pollution. Moreover, recent studies show that most shipping emissions occur near the coast where they can be transported over land. This belies the outdated notion that because shipping emissions originate at sea, their impact on human health and the environment is minimal. Given the increasing pace of shipping activity,[2] without stringent controls, shipping emissions are likely to become an even larger environmental problem in the coming years.

Fortunately, there are measures to reduce substantially shipping emissions that are technically and economically feasible, and in many instances are more cost-effective than available options to reduce remaining land-based emissions.

World–wide shipping emission inventories.

Significant progress in estimating international shipping emissions has been made in recent years. In 1999, an initial study of nitrogen and sulphur emissions from ocean-going shipping estimated that ships were responsible (in 1993) for over 14% of total nitrogen emissions from combustion sources and about 5% of total sulphur emissions from such sources.[3] Other findings from this and similar studies include:

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2 For example, according to statistics compiled by the American Association of Port Administrators, container traffic in US and Canadian ports almost doubled from 1993 to 2003. *See:* http://www.aapa-ports.org/industryinfo/statistics.htm. In addition, the North American passenger cruise industry has grown an average of 8.4% over the last decade, and is expected to continue to grow, with port calls estimated to increase almost 4-fold from 2003 to 2010. *See, e.g.*, http://www.aapa-ports.org/pdf/The%20Impact%20of%20FIS%20Facilities%20at%20Cruise%20Terminals.pdf.

3 Corbett, J, Fischbeck, P. and Pandis, S. (1999), "Global nitrogen and sulphur inventories for oceangoing ships," *J. of Geophysical Research*, Vol. 104, No. D3 (February 20, 1999), p.3457. Due to the dramatic increase in shipping traffic since 1993, shipping emissions are likely today to be much higher and to represent a larger portion of air pollution.

- About 85% of shipping emissions occur within the northern hemisphere.[4]
- On a summer day, ships' contribution to projected ambient sulphur dioxide (SO_2) levels in the north Atlantic exceeds 60%, and in January can rise to around 90%.[5]
- Almost 70% of global ship emissions occur within 400km (~250 miles) of land, within potential transport distance of land.[6] Thus, diesel engines from commercial ships contribute more than 5% and up to as much as 30% of modelled SO_2 concentrations in many coastal regions.[7]
- Ships are responsible for roughly 2% of global carbon dioxide (CO_2) emissions.[8]

Furthermore, an updated study of ship emissions using more accurate fuel consumption statistics estimates global shipping emissions of nitrogen oxides (NOx) and CO_2 at twice the earlier estimates, and SO_2 at about 50% higher.[9] This would imply that ship emissions represent an even larger part of global emissions of NOx, SO_2 and CO_2 than earlier estimated.

European and United States Emission Inventories

Emissions from shipping in the waters near Europe and certain areas of the United States make up a significantly greater share of total emissions. Shipping emissions in the sea areas surrounding Europe, *i.e.,* the Baltic Sea, North Sea, the northeast Atlantic and the Mediterranean, have been estimated at about 2.6 million tons[10] SO_2 and 3.6 million tons NOx in 2000.[11] This was then equal to approximately 45% of the total land-based SO_2 emissions in the EU's then 15 member states and about 37% of total land-based NOx emissions. Ship emissions contribute an estimated 20-30% to secondary inorganic particle concentrations in most European coastal areas.[12] While European land-based emissions are gradually being reduced, those from shipping are expected to continue to increase. Even assuming implementation of MARPOL Annex VI[13] and sulphur emission control areas (SECAs) in the North Sea, Baltic Sea and English Channel, international shipping emissions of SO_2 are expected increase by more than 42% by 2020, and those of NOx by

4 Corbett, et al (1999), at p.3461.
5 Capaldo, K., Corbett, J., Kasibhatla, P., Fischbeck, P. and Pandis, S. (1999), "Effects of ship emissions on sulphur cycling and radiative climate forcing over the ocean," *Nature*, Vol. 400 (August 19, 1999), p. 743, at p.744.
6 Corbett, et al (1999), at pp.3465, 3469.
7 Capaldo, et al (1999), at p.745.
8 Corbett, et al (1999), at p.3465.
9 Corbett, J. and Koehler, H. (2003), "Updated Emissions from Ocean Shipping," *J. of Geophysical Research*, Vol. 108, No. D20, 4650, doi:10.1029/2003/D003751 (October 29, 2003).
10 Note that in this paper "tons" of European emissions is expressed in metric tonnes, while US emissions are expressed in short tons (1 metric tonne is equal to 1.1023 short ton).
11 Entec (2002). "Quantification of emissions from ships associated with ship movements between ports in the European Community" (2002) (Study produced for the European Commission), available on the internet at www.europa.eu.int/comm/environment/air/background.htm#transport.
12 European Commission, "Proposal for a directive of the European Parliament and of the Council amending Directive 1999/32EC as regards the sulphur content of marine fuels," COM (2002) 595 final, 2002/0259 (COD), Vol. II. Brussels, Belgium, available on the internet at www.europa.eu.int/acomm/environment/air/transport.htm#3.
13 Annex VI to the International Convention of the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 Relating thereto (more commonly referred to as MARPOL or MARPOL 73/78).

two-thirds.[14] By 2020, projected international shipping emissions in European sea areas will exceed total land-based emissions in the EU25 countries.[15]

In the United States, marine diesel engines presently account for about 7% of NOx emissions and 6% of fine particulate matter ($PM_{2.5}$) emissions from mobile sources.[16] The United States Environmental Protection Agency (EPA) expects shipping emissions to grow by 2030 to about 28% of mobile source NOx emissions[17] and 10% of mobile source PM emissions.[18] Given current regulations (including MARPOL Annex VI), NOx emissions from ocean-going (C3) ships[19] in United States waters in 2030 are projected by the United States EPA to increase by almost 300% from 1996 levels.[20]

These emissions are even more significant in the most severely impacted United States ports.[21] By 2020, EPA estimates that annual emissions from large ocean-going ships alone in certain port areas will approach 20% of all NOx emissions and 20% of all PM emissions.[22] And in Santa Barbara County, California (which has a long coastline, but no ports), NOx emissions from marine vessels were estimated to be more than 1/3 of the total NOx emissions inventory in 1999, and projected to comprise more than 60% of total NOx by 2015.[23]

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14 *See, e.g.*, "Air pollution from ships," a briefing document published by the European Environmental Bureau, the European Federation for Transport and Environment, the North Sea Foundation, Seas at Risk and the Swedish NGO Secretariat on Acid Rain (November 2004), available on the internet at www.acidrain.org. (hereinafter "NGO Ship Briefing"), at p2 and IIASA data cited therein.

15 NGO Ship Briefing, at p.2.

16 US EPA (2003), "Final Regulatory Support Document: Control of Emissions from New Marine Compression – Ignition Engines at or Above 30 liters per Cylinder," January 2003, EPA420-R-03-004, at pp. 2-5 (hereinafter "C3 RIA"). Commercial ships of all sizes emit annually in the US about 1 million tons of NOx, 40,000 tons of $PM_{2.5}$ and 160,000 tons of SO_2. *See also*, US EPA (2003), "Control of Emissions from New Marine Compression-Ignition Engines at or above 30 liters per Cylinder; Final Rule," 68 Fed. Reg. 9746 (February 28, 2003), at pp.9755-56 (hereinafter "EPA C3 Rule").

17 US EPA (2004), "Control of Emissions of Air Pollution from New Locomotive Engines and New Marine Compression-Ignition Engines Less than 30 liters per Cylinder; Proposed Rule," 69 Fed. Reg. 39276 (June 29, 2004), at p.39286 (hereinafter "EPA 2004 Marine ANPR").

18 C3 RIA at p.2-6. By 2030 in the US, large, oceangoing ships will account for almost half of shipping emissions of NOx, and about ¾ of PM shipping emissions.

19 EPA divides the universe of commercial marine diesel engines into three sizes, Categories 1, 2 and 3. Category 3 (C3) are the largest engines, greater than 30 liters per cylinder in size, used primarily for propulsion power on ocean-going vessels such as container ships, tankers, bulk carriers, and cruise ships. C3 engines have no land-based mobile source counterpart, although they are similar to engines used to generate electricity in municipal power plants. C2 and C1 engines have a displacement per cylinder of up to 30 liters, with a power rating of over 37 kw; they include the largest propulsion engines widely used in harbor and coastal vessels such as tug boats, as well as propulsion engines on smaller commercial vessels such as fishing boats and crew boats, and auxiliary engines on large vessels. Locomotives are the land-based counterpart to C2 marine engines, while C1 engines are similar to many non-road land-based engines in size and configuration. *See, e.g.*, EPA C3 Rule, 68 Fed. Reg. at 9758.

20 C3 RIA at p.4-14.

21 EPA estimates US shipping emissions based on ships operating within 175 miles of the US coast; port emissions are based on ships operating within 25 miles of the port. C3 RIA at p.2-1.

22 C3 RIA at pp.2-8, 2-9.

23 Murphy, T., McCaffrey, R., Patton, K., and Allard, D. (2003), "The Need to Reduce Marine Shipping Emissions: A Santa Barbara County Case Study," Santa Barbara County APCD Paper #70055, at pp.1, 8-10, available on the internet at http://www.sbcapcd.org/itg/download/awma03finalpaper.pdf.

Furthermore, shipping emissions can travel substantial distances. One study in the North Atlantic found that ship emissions spread at least 400 km (with a mean of 900 km and a maximum of 1700 km).[24] And both ozone and fine aerosol particles, produced as secondary products of shipping emissions, can be transported long distances (thousands of kilometres) in the atmosphere—from sea to land, and even from one continent to another.[25]

Emissions Rates from Ships and Land-Based Mobile Sources

Reflecting the lack of meaningful regulation, the permitted *rates* of SO_2, NOx and PM emissions from diesel marine engines are much greater than that from almost any other category of mobile sources. The United States EPA's current regulations permit new coastal and harbour craft diesel marine engines to emit NOx and PM at rates between 2 and 27 times higher than new nonroad land-based heavy-duty diesels, as shown in the Tables 1 and 2 below. Furthermore, emissions rates for larger ocean-going (C3) ships are higher still, up to 43 times higher for NOx, and infinitely higher for PM, as there are *no* PM standards at all for these large marine diesels.[26]

Table 1. United States Nonroad Tier 3 Standards versus United States Commercial Marine Engine Emission Standards[27]

Engines Covered	Effective Year	Emission Standards		Ratio to Tier 3 Nonroad Standards	
		NMHC + NO_x (g/bhp-hr)	PM (g/bhp-hr) (Tier 2)	NMHC + NO_x	PM
Nonroad Land-Based Heavy Duty Diesel Tier 3 Engines					
175-750 horsepower	2006	3.0	0.15	1.0	1.0
Over 750 horsepower (Tier 2)	2006	4.8	0.15	1.0	1.0

24 Benkovitz, C.M., C.M. Berkowitz, and others (1994), "Sulfate over the North Atlantic and Adjacent Continental Regions: Evaluation for October and November 1986 Using a Three-Dimensional Model Driven by Observation-Derived Meteorology," Journal of Geophysical Research 99 (D10): 20,725—20,756.

25 *See e.g.,* Qinbin Li, D. Jacob, I. Bey, P. Palmer, B. Duncan, B. Field, R. Martin, A. Fiore, R. Yantosca, D. Parrish, P. Simmonds, and S. Oltmans (2002), "Transatlantic transport of pollution and its effects on surface ozone in Europe and North America," Journal of Geophysical Research Vol. 107, "NO. D13, 10.1029/2001JD001422; Derwent, R.G., Stevenson, D.S., Collins, W.J., Johnson, C.E.(2004), "Intercontinental transport and the origins of the ozone observed at surface sites in Europe," Atmos. Environ 38:1891; and Jaffe, Dan, I. McKendry, T. Anderson, H. Price (2003), "Six 'new' episodes of trans-Pacific transport of air pollutants," Atmospheric Environment 37:391–404.

26 EPA is committed to considering new emission limits for C3 ships by 2007. EPA C3 Rule, 68 Fed. Reg. at pp.9750, 9763-69.

27 Sources for Table 1 are: US EPA (1998), "Control of Emissions of Air Pollution from Nonroad Diesel Engines; Final Rule," 63 Fed. Reg. 56968 (October 23, 1998), at p.56970; US EPA (1999), "Control of Emissions of Air Pollution from New Marine Compression-Ignition Engines at or above 37 kW; Final Rule," 64 Fed. Reg. 73300 (December 29, 1999), at p.73307 (hereinafter "EPA 1999 C1-C2 Marine Rule"); EPA C3 Rule, 68 Fed. Reg. at 9761.

Medium and Large (C2 and C3) Commercial Marine Engines[a]					
5.0-14.9 litres/cylinder	2007	5.8	0.20	1.2 to 1.9	1.3
15.0-19.9 litres/cylinder, <4425 hp	2007	6.5	0.37	1.4 to 2.2	2.5
15.0-19.9 litres/cylinder, ≥4425 hp	2007	7.3	0.37	1.5 to 2.4	2.5
20.0-24.9 litres/cylinder	2007	7.3	0.37	1.5 to 2.4	2.5
25.0-29.9 litres/cylinder	2007	8.2	0.37	1.7 to 2.7	2.5
30 litres/cylinder and above (C3)	2004	7.35 to 12.75	NONE	**1.5 to 4.2**	**~ (NO PM C3 marine std.)**

[a] Commercial marine engine standards are THC + NO_x (as opposed to NMHC + NO_x). However, since HC emissions are low compared to NO_x, it is not expected that this difference is significant for purposes of this comparison. Also, commercial marine standards are expressed in g/kW-hr; the conversion rate to g/bhp-hr is 0.7457.

Table 2. United States Nonroad Tier 4 Standards Versus United States Commercial Marine Engine Emission Standards[28]

Engines Covered	Effective Year	Emission Standards		Ratio to Tier 4 Nonroad Standards	
		NMHC + NO_x (g/bhp-hr)	PM (g/bhp-hr)	NMHC + NO_x[b]	PM
Nonroad Land-based Heavy Duty Diesel Tier 4 Engines					
75-750 horsepower	2011-2014	0.30[b]	0.01	1.0	1.0
Over 750 horsepower	2011-15	0.50 to 2.6[b]	0.02-0.03	1.0	1.0
Medium and Large (C2 and C3) Commercial Marine Engines[a]					
5.0-14.9 litres/cylinder	2007	5.8	0.20	2.2 to 19	7 to 10
15.0-19.9 litres/cylinder, <4425 hp	2007	6.5	0.37	2.5 to22	12 to 19
15.0-19.9 litres/cylinder, ≥4425 hp	2007	7.3	0.37	2.8 to 24	12 to 19
20.0-24.9 litres/cylinder	2007	7.3	0.37	2.8 to 24	12 to 19
25.0-29.9 litres/cylinder	2007	8.2	0.37	3.2 to 27	12 to 19
30 litres/cylinder and above (C3)	2004	7.35 to 12.75	NONE	**2.8 to 43**	**~ (NO PM C3 marine std.)**

[28] Sources for Table 2 are US EPA (2004), "Control of Emissions of Air Pollution from Nonroad Diesel Engines and Fuel; Final Rule," 69 Fed. Reg. 38958 (June 29, 2004), at pp. 38971 and 38980 (hereafter "EPA 2004 Nonroad Rule"); and EPA1999 C1-C2 Marine Rule, 64 Fed. Reg. at 73307; EPA C3 Rule, 68 Fed. Reg. at 9761.

[a] Commercial marine engine standards are THC + NO_x (as opposed to NMHC + NO_x). However, since HC emissions are low compared to NO_x, it is not expected that this difference is significant for purposes of this comparison. Also, commercial marine standards are expressed in g/kW-hr; the conversion rate to g/bhp-hr is 0.7457.

[b] Tier 4 land-based standard is NOx only (as opposed to NMHC + NO_x). However, since diesel HC emissions are low compared to NO_x, it is not expected that this difference is significant for purposes of this comparison. For instance, EPA assumes that the proposed nonroad standard for 25-75 hp engines, 3.5g/bhp-hr NOx+NMHC, is equivalent to 3.3g/bhp-hr NOx.[29]

In Europe, as of the end of 2004, cargo vessel emissions exceeded heavy truck emissions of PM by 4-6 times, SO_2 by about 30-50 times, and NOx emissions by about 2 times (comparing emissions expressed in term of units per ton-kilometre). These disparities will grow greater in 2005 when the sulphur content of road-vehicle diesel fuel will be reduced from 350 ppm to 50 ppm, and in 2005 and 2008 when NOx emission standards for trucks are tightened.[30]

Table 3: Comparison of emissions[a] from trucks on long hauls with different EU standards for emissions and cargo vessels of various sizes. Figures in grams per ton-kilometre.

	CO_2	PM	SO_2	NOx	VOCs
Heavy truck with trailer:					
Before 1990	50	0.058	0.0093	1.00	0.120
Euro 0 (1990)	50	0.019	0.0093	0.85	0.040
Euro 1 (1993)	50	0.010	0.0093	0.52	0.035
Euro 2 (1996)	50	0.007	0.0093	0.44	0.025
Euro 3 (2000)	50	0.005	0.0093	0.31	0.025
Cargo vessel:					
large (>8000 dwt)	15	0.02	0.26	0.43	0.017
medium size (2000-8000 dwt)	21	0.02	0.36	0.54	0.015
small (<2000 dwt)	30	0.02	0.51	0.72	0.016
RoRo (2-30 dwt)	24	0.03	0.042	0.66	0.029

[a] Emissions are average in each case. **Trucks:** maximum overall weight 40 tons, loading 70 per cent, operating on diesel with a sulphur content of 300 ppm. **Cargo vessels**: bunker oil with an average sulphur content of 2.6 per cent. *Source: www.ntm.a.se (November 2002)*

No justification for the continuation of such large disparities between diesel emissions at sea and on land is apparent.

Impacts of Shipping Emissions

Human Health Impacts

Diesel combustion from ships is a significant source of primary (directly emitted) fine particulate matter ($PM_{2.5}$), as well as NOx and SO_2. These latter two pollutants also can be converted into sulphate and nitrate aerosols, among the more common forms of fine particulates.

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[29] US EPA (2004), "Regulatory Impact Analysis: Control of Emissions from Nonroad Diesel Engines," EPA 420-R-04-007, May 2004 (hereinafter "Nonroad RIA"), at p.12-5.

[30] NGO Ship Briefing, at p.4.

Fine particles have been associated in numerous studies with serious human health impacts, including premature cardiovascular mortality and lung cancer death, as well as a host of respiratory and cardiovascular problems, such as heart attacks, abnormal heart rhythms, atherosclerosis, stroke and permanent respiratory damage.[31] The World Health Organization has estimated that exposure to fine particulate matter leads to about 100,000 premature deaths (and 725,000 years of life lost) annually in Europe, and that the average reduction in European life expectancy is about one to two years.[32] A more recent study for the European Commission's Clean Air for Europe (CAFE) programme has preliminary estimated that due to PM concentrations in the year 2000, some 3 million life years have been lost in the EU25, which is equivalent to about 288,000 premature deaths.[33]

A recent report by the Clean Air Task Force estimates that diesel particulate emissions cause 21,000 premature deaths in the United States.[34]

NOx emissions also contribute to the formation of ground-level ozone, another damaging air pollutant. Short-term exposure to ozone smog can cause a myriad of harmful human upper and lower respiratory system effects, including chest pain, coughing, shortness of breath, reduced lung function, inflammation and other changes of lung tissue, increased hospital admissions and emergency room visits, impaired immune systems, and exacerbation of asthma-related symptoms.[35] Effects of longer term ozone exposure described by the United States EPA include transient pulmonary function responses, transient respiratory symptoms, effects on exercise performance, increased airway responsiveness, increased susceptibility to respiratory infection, increased hospital and emergency room visits and transient pulmonary respiratory inflammation.[36] And some recent studies have suggested that ozone may be associated with premature mortality in adults.[37]

The exhaust from ships and other diesel engines is also highly toxic, containing a plethora of harmful particulate and gaseous substances. Among some of the most toxic substances emitted from diesels are hundreds of organic carbon compounds such as formaldehyde and polyaromatic

[31] *See, e.g.,* US EPA (2004), Air Quality Criteria for Particulate Matter, Vols. I and II., available on the internet at http://cfpub.epa.gov/ncea/cfm/partmatt.cfm; and EPA 2004 Nonroad Rule, 69 Fed. Reg. at pp.38965-67. *See also* Clean Air Task Force (2005), Fact Sheet—"Diesel Engines: Health and Environmental Impacts," pp.2-3, and sources cited therein, available on the internet at www.catf.us. *See also*, C3 RIA at pp. 2-19 to 2-24.

[32] World Health Organization (2002), "World health report 2002," Geneva Switzerland.; and World Health Organization (2003), "Health aspects of air pollution with particulate matter, ozone and nitrogen dioxide," Report on a WHO Working Group, January 2003, WHO Regional Office for Europe, Copenhagen, Denmark.

[33] CAFE CBA Baseline Analysis 2000 to 2020 (January 2005) AEA Technology, Inc., UK.

[34] Clean Air Task Force (2005), "Diesel and Health in America: The Lingering Threat," available on the internet at www.catf.us/goto/diesel report.

[35] *See, e.g.,* US EPA (2001), "Control of Air Pollution from New Motor Vehicle: Heavy-duty Engine and Vehicle Standards and Highway Diesel Sulfur Control Requirements," 66 Fed. Reg. 5002 (January 18, 2001) (hereinafter "EPA 2001 On-Road Rule"), at pp.5012-13; and EPA 2004 Nonroad Rule, 69 Fed. Reg. at p.38967. *See also*, C3 RIA at pp. 2-13 to 2-17.

[36] *See* EPA 2001 On-Road Rule, 66 Fed. Reg. at 5017.

[37] Thurston, G.D. and Ito, K. (2000), "Epidemiological Studies of ozone exposure effects," in Air Pollution and Health, S.T. Holgate Ed. Academic Press.

hydrocarbons, many of which are carcinogens. The relationship between diesel exhaust and cancer has been well established in numerous epidemiological studies.[38]

Environmental Impacts

Furthermore, ship emissions contribute to numerous adverse environmental impacts. These include acidification, eutrophication of terrestrial and coastal ecosystems, damage to vegetation from ozone, increased corrosion to buildings and materials, deposition of toxic polycyclic organic matter and visibility impairment and regional haze.[39] And although much of international shipping emissions of SO_2 and NOx are deposited over the oceans, shipping is the single largest sources of acidifying and eutrophying emission deposition over many countries in Europe.[40]

Ozone is also associated with climate change, as is black carbon, one of the constituents of PM emitted by ships.[41] Of course, ship emissions of CO_2 also contribute to climate change.

Approaches to Reducing Shipping Emissions

Like power plants, large marine engines can have very long lives (20-30+ years),[42] so it will take a long time for the effect of emission reductions from new marine engines to be fully realized throughout the fleet. Therefore, in order to reduce the environmental impact from shipping, it will be necessary to reduce emissions from existing ships through a combination of cleaner fuel, engine modifications, add-on retrofits and other measures. At the same time, it is important to begin to reduce emissions from new engines as soon as possible.

Fortunately, there are feasible, cost-effective measures available now or within the next few years that can substantially reduce emissions from ships. Below is a survey of the most promising emission control measures for ships.

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38 *See, e.g.*, EPA 2004 Nonroad Rule, 69 Fed. Reg. at pp.38965-67; US EPA (2002), *Health Assessment Document for Diesel Engine Exhaust*,. U.S. EPA, Office of Research and Development, National Center for Environmental Assessment, Washington Office, Washington, DC, EPA/600/8-90/057F (2002), available online at http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=29060 (hereinafter "EPA Diesel HAD"); *9th Report on Carcinogens* (2000), U.S. Department of Health and Human Services, Research Triangle Park, NC.

39 *See, e.g.*, C3 RIA at pp.2-18 to 2-19, 2-22, and 2-26 to 2-28; EPA 2004 Nonroad Rule, 69 Fed. Reg. at 38967.

40 EMEP (2003), Tarrason, L. et.al., "Transboundary acidification, eutrophication and ground-level ozone in Europe," Status Report 1/2003, Part III. Oslo, Norway, available on the internet at www.emep.int. *See also,* NGO 2004 Briefing, at p.3.

41 *See, e.g., Report of the Intergovernmental Panel on Climate Change (2001), The Scientific Basis*. Contribution of the Working Group I to the Third Assessment Report; Hansen, J.E., and Mki. Sato (2001), "Trends of measured climate forcing agents," Proc. Natl. Acad. Sci. 98, 14778-14783, doi:10.1073/pnas.261553698. Bond, Tami C., D. Streets, K. Yarber, S. Nelson, J. Woo, Z. Klimont (2004), "A Technology-Based Global Inventory of Black and Organic Carbon Emissions from Combustion," Journal of Geophysical Research, 109, D14203, doi: 10.1029/2003JD003697 and Rypdal, Kristin, T. Bernsten, J. Fuglestvedt, K. Aunan, A. Torvanger, F. Stordal, J. Pacyna, L. Nygaard, (2005), "Tropospheric ozone and aerosols in climate agreements: scientific and political challenges," Environmental Science and Policy, 8: 29-43.

42 EPA noted that the "average age of the world fleet was 19 years at the end of 2000." C3 RIA at p.3-46.

Lower Sulphur Content in Fuel

The most common classes of marine fuels are heavy fuel oil, sometimes called bunker fuel, or residual or heavy fuel oil (HFO), and the lighter marine distillates. HFO is most often used to fuel the main engines of large ocean-going vessels, while distillates are used to fuel smaller coastal vessels and harborcraft, as well as the auxiliary engines of ocean-going vessels that are typically operated when manoeuvring or lying in port.[43] The global average sulphur content of HFO is about 2.7%,[44] while distillate fuels used by ocean-going ships generally exceed 1% sulphur.[45]

One of the most important initial actions that can be immediately taken to reduce shipping emissions is to lower substantially the sulphur level in marine fuels. Because SO_2 emissions are directly proportional to the sulphur content of the fuel combusted, reducing the sulphur content of fuel will produce immediate reductions of SO_2. For instance, reducing the sulphur level of marine fuel used by ocean-going ships from the current average of 2.7% to 0.5% would reduce SO_2 emissions from those ships by about 80%. The highest portion of PM from large marine diesels operating on HFO is from ash, metals, oxides and sulphates (about 65% on a medium-speed engine).[46] As a result, sulphur fuel reductions will also reduce sulphate formation and therefore PM emissions (by about 40%).[47] Finally, deep cuts in sulphur fuel content will permit additional and dramatic reductions of NOx and PM from *both new and existing* engines using certain after-treatment emission control devices that do not work as effectively in the presence of high sulphur levels.

There are no significant technical impediments to more widespread use of low sulphur fuel in ships. Generally, no engine modification is required. In fact, because low sulphur fuel is cleaner and of higher quality, its use results in reduced engine wear, maintenance, and lubricating oil use, thereby increasing engine performance and reducing the risk of operating problems.[48] These quality advantages can partially offset the higher cost of lower sulphur fuel.

There are two primary ways that the global shipping fuel market could meet increased demand for low sulphur fuels. Both involve some increase in fuel cost. In conjunction with several proposals in Europe to reduce the sulphur content of marine fuel down to 1.5% and/or 0.5%, several studies have been conducted to estimate the cost of reducing the maximum allowed sulphur content for shipping in European waters to these levels.[49] The first approach involves the processing of

[43] See, e.g., NGO Ship Briefing, at p.6.
[44] *See* C3 RIA at 1-9.
[45] *See* C3 RIA at 5-10.
[46] C3 RIA at pp.4-1 to 4-2.
[47] *See, e.g.,* US EPA (2002), "Control of Emissions from New Marine Compression-Ignition Engines at or above 30 litres per Cylinder; Proposed Rule," 67 Fed. Reg. 37548 (May 29, 2002), at pp.37586—88. As part of its C3 rule proposal, EPA evaluated a reduction in sulphur fuel content: EPA estimated that a reduction of sulphur in marine fuel from 2.7% to 1.5% will produce an 18% PM reduction based solely on the 44% reduction in sulphur content; EPA also estimated that a switch to 0.3% *distillate* fuel would produce a 63% PM reduction, but this reduction was attributed not only to the sulphur reduction, but also to the lower ash content and lower density of distillate fuel.
[48] Kageson, P. (1999), "Economic instruments for reducing emissions from sea transport," Air Pollution and Climate series No. 11, The Swedish NGO Secretariat on Acid Rain, Goteborg, Sweden, available on the internet at www.acidrain.org.
[49] *See generally,* Agren, C. (2005), "Cost-benefit analysis of using 0.5% marine heavy fuel oil in European sea areas," January 2005, The Swedish NGO Secretariat on Acid Rain, Goteborg, Sweden, available on the internet at www.acidrain.org (hereafter "Agren CBA").

lower-sulphur crude oils. This has an estimated incremental cost of 40-45 euro per ton of fuel.[50] A second approach would be to desulphurize the residual HFO. This would cost more (estimated at between 50 and 90 euro per ton) and is a more difficult process.[51] A third, lower-cost option is re-blending, but this is expected to be capable of delivering less significant quantities of lower sulphur fuel.[52]

The European Commission has assumed a price premium of 50 euro per ton of fuel for lowering the sulphur content of marine HFO to 1.5% and 65 euro/ton for 0.5%.[53] The RAINS computer model developed by IIASA (which supports the work of the Convention on Long-Range Transboundary Air Pollution and the EU's National Emissions Ceiling Directive) has utilized a cost effectiveness estimate of about 500 euro per ton of SO_2 removed for the reduction of sulphur in marine fuel in European waters to the 0.5-0.6% level.[54]

This cost-effectiveness range compares favourably with the cost-effectiveness of land-based emission reductions. For example, the United States EPA recently found that average costs for annual SO_2 reductions from United States power plants and other land-based sources ranged between \$400 and \$3,400 per ton of SO_2 removed.[55] In Europe, the cost –effectiveness of retrofitting land-based sources with flue-gas desulphurization ranges from 400 and 800 euro per ton of SO_2 removed for coal-fired large combustion plants, and from 1500-2000 euro per ton for smaller boilers.[56]

Furthermore, the cost of reducing fuel sulphur content to 0.5% is far outweighed by an even conservative measure of the benefits. A recent study by the Swedish NGO Secretariat on Acid Rain found that the benefits solely from reduced damage to human health of lowering the sulphur content of marine HFO from 2.7% to 0.5% would exceed costs in 2020 by between 2.2 and 7.5 times.[57]

Other SO_2 Reduction Measures

Another possible means of reducing shipping emissions of SO_2 is seawater scrubbing. This is essentially the marine equivalent of flue-gas desulphurization, a well-established, reliable and

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50 Beicip-Franlab (2003), "Advice on Marine Fuels; Potential price premium for 0.5% marine fuels," Final Report, European Commission Study C1/3/2003, Contract ENV.C1/SER/2001/0063, at pp.12-13, available on the internet at www.europa.eu.int/comm/environment/air/background.htm#transport. *See also* NGO Ship Briefing, at p.6.

51 Beicip-Franlab (2003), at pp.12-13.

52 Beicip-Franlab (2003), at pp.12-13.

53 *See, e.g.,* NGO Ship Briefing, at p.8; (note that the figure of 65 euro per ton fuel is not mentioned in the NGO report, but it is the figure now used by IIASA, and thus it is based on recommendation from the European Commission).

54 NGO Ship Briefing, at p.8. Others have used higher cost estimates. For example, assuming a price premium of 52-93 euro/ton to move to 0.5%, would produce an estimate of cost-effectiveness of between 1,100 and 1,900 euro per ton SO_2 removed. *Id.* It is important to note that these estimates attribute the incremental fuel costs solely to SO_2 reductions. In reality, as discussed earlier, reducing sulphur in fuel will also produce valuable reductions of particulate matter; considering those reductions together would improve the cost effectiveness of low sulphur fuel substantially.

55 US EPA, "Rule to Reduce Interstate Transport of Fine Particulate Matter and Ozone (Clean Air Interstate Rule); Revisions of Acid Rain Program; Revision to the NOx SIP Call," March 10, 2005 (hereinafter CAIR), at pp. 217-219, Table IV-3, prepublication version available on the internet at http://www.epa.gov/air/interstateairquality/rule.html.

56 NGO Ship Briefing, at p.8.

57 Agren CBA, at pp.3, 7.

cost-effective control methodology for power plants and other large land-based combustion sources. Trials using this technology indicated that it can achieve a sustainable SO_2 removal level of 74% to 80%. Potential emission reductions of up to 95% for SO_2 and 80% for PM have been claimed, but still remain to be verified in practical use.[58] The developer asserts that sea scrubbing is more a more cost-effective means of reducing sulphur than the use of 1.5% sulphur fuel.[59]

Widespread adoption of seawater scrubbing will likely be dependent upon satisfactory resolution of the issue of the impact of seawater scrubbing on water quality. The spent effluent from the scrubber contains particulates and other pollutants, as well as sulphur compounds. Although the effluent can be treated prior to discharge to remove many of the contaminants, the treated discharge typically will contain sulphur and be more acidic than seawater. The potential water quality impacts of this discharge are presently under review.

NOx Reduction Measures

For various reasons, there are a larger variety of NOx reduction measures available. These measures may be classified as engine modifications, pre-engine technologies and after-treatment technologies.

Engines modifications such as engine derating, injection timing retard, fuel injector upgrades, etc., have been reported to reduce NOx by ~15-20%, but may have the disadvantage of increasing PM emissions and fuel consumption somewhat.[60] More advanced combinations of internal engine modifications are under development, and these are projected to be able to reduce NOx emissions to levels that are at least 30-40% below the MARPOL Annex VI standard.[61]

Pre-engine approaches generally involve the reduction of combustion temperature by the addition of water to the combustion process.[62] Water can be injected into the combustion chamber, reducing NOx by almost 30%,[63] with higher reductions reported.[64] However, this approach has been reported to result in increased PM emissions when HFO is used as the fuel.[65] A variation of this approach is the addition of water vapour to the combustion air (called "humid air motor" or "HAM"),

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58 *See* NGO Ship Briefing, at p. 7. *See also*, "System Trial Results, EcoSilencer, August 2003 to December 2004," Marine Exhaust Solutions, Inc., at pp.2, 9, available on the internet at www.marineexhaustsolutions.com (hereafter "MES Paper"); and Shipping Emissions Abatement and Trading (SEAaT) Group (2005), "Emission Control, An Overview of the Technologies," at p.9, available on the internet at www.seaat.org/media/emission controlv053.doc.

59 MES Paper, at p.2, 11.

60 *See, e.g.*, Corbett, J. and Fischbeck, P. (2001), "International Technology Policy, Challenges in Regulating Ship Emissions," in "Improving Regulation, cases in environment, health and safety," p. 288. Fischbeck, P. and Farrow, S, editors, Resources for the Future. *See also*, Corbett, J. and Fischbeck, P. (2002), "Commercial Marine Emissions and Life-Cycle Analysis of Retrofit Controls in a Changing Science and Policy Environment," Naval Engineers Journal, p. 93 (Winter 2002).

61 Based on advice from the European Commission, IIASA is currently assuming that internal engine modifications can reduce NOx by about 30 %.

62 *See, e.g.*, C3 RIA, at pp. 5-1—5-3.

63 Diesel NOx reductions of up to 70% have been reported. *See, e.g.,* C3 RIA, at pp. 5-1—5-3.

64 Corbett, J. and Fischbeck, P. (2002), at p. 96.

65 *See* Radloff, E. (2004), "Marine Vessel Emissions Reduction," at pp. 15, 16. Presentation of Transport Canada at MARAD Shipboard Energy Technologies Workshop, Sacramento, CA, (April 2004). See also, Corbett and Fischbeck (2002), at p.96.

which has been reported to reduce NOx by an average of 28%, with a range from 5 to 60%.[66] However, the retrofit of a Scandinavian ferry (the MS Mariella) for HAM in 1999 was reported to reduce NOx emissions by 80-85%.[67]

Mixing water with the fuel to create a stable emulsion is an approach particularly suited for ships using residual fuel, which may contain emulsified water in any event (standard engine design permits about a 20% water mixture).[68] This technology is reported to reduce NOx emissions by up to about 40% or more, and PM by about 15% or more.[69]

Deeper NOx reductions may be obtained with selective catalytic reduction (SCR), which involves treatment of the exhaust gases with ammonia or urea in the presence of a catalyst.[70] SCR has been effectively used in both marine and land-based applications, producing mobile source emission reductions of NOx ranging from 65-99%, with an average of about 80%.[71] PM reductions in the range of 30-40% have also been reported.[72] Because the size of SCR installations can be an issue is marine applications, a compact form of SCR has been developed for ships. Compact SCR systems using an upstream oxidation catalyst have been demonstrated to reduce NOx by 85-95% from ocean-going ships burning fuel with sulphur contents ranging up to 1%.[73] Very high levels of sulphur may reduce the efficiency of these compact marine SCR systems. The United States EPA indicates that SCR systems typically operate at sulphur levels ranging from 500 ppm to 10,000 ppm (1.0%).[74]

All of the above NOx reduction technologies are feasible and cost-effective.[75] For example, the cost–effectiveness of global or regional application to existing ships of several NOx reduction technologies has been estimated as follows:[76]

NOx Control Technology	Average NOx Reduction	Cost-effectiveness ($/ton NOx removed)
Water in combustion air	28%	$470-560
Water/fuel emulsion	42%	$280-340
Selective catalytic reduction	81%	$230-300

66 Farrell, A., Corbett, J. and Winebrake, J. (2002), "Controlling Air Pollution from Passenger Ferries: Cost Effectiveness of Seven Technological Options," Journal of the Air & Waste Management Ass'n, Vol. 52, p. 1399, 1403 (Dec. 2002). See also, C3 RIA, at pp. 5-2—5-3; and CALSTART (2003), "Passenger Ferries, Air Quality and Greenhouse Gases," at p. 30, available on the internet at http://www.calstart.org/info/publications/ferryreport/ferryreport.pdf.

67 *See* http://www.vikingline.aland.fi/foretagsinfo/miljo.asp.

68 Corbett and Fischbeck (2001), at p.287. See also Corbett and Fischbeck (2002), at pp.95-96.

69 Corbett and Fischbeck (2001), at p.288; and Farrell, Corbett and Winebrake (2002), at pp. 1403, 1404. *See also* Corbett. and Fischbeck (2002), at p.96.

70 Corbett and Fischbeck (2001), at p.287.

71 Corbett and Fischbeck (2001), at p.288; Corbett, and Fischbeck (2002), at pp.96-97; and Farrell, Corbett, and Winebrake (2002), at p. 1403. See also, C3 RIA, at pp. 5-3—5-7; CALSTART (2003), at pp. 31-32.

72 Farrell, Corbettand Winebrake (2002), at pp.1403, 1404; CALSTART (2003), at p.32.

73 C3 RIA, at pp. 5-4—5-6.

74 C3 RIA, at pp. 5-5—5-6.

75 *See generally*, Corbett and Fischbeck's in-depth study of NOx controls for ships, (Corbett and Fischbeck 2001), at p.291—302; and Corbett and Fischbeck (2002), at pp. 93-105.

76 Corbett and Fischbeck (2001), at p.302

It is noted that because SCR is very capital intensive, the estimation of its cost is most sensitive to the size of the installation, the assumed life of the retrofit, and the discount rate used to calculate net present value. Thus, an analysis of using SCR on passenger ferries found cost-effectiveness in the range of $1500 to 1800 per ton of NOx removed.[77]

The cost effectiveness of these marine NOx reduction technologies compares very favourably with NOx reductions from land-based sources. In other words, it is less expensive—in some cases, dramatically less expensive—to obtain needed NOx reductions from marine engines rather than additional reductions from land-based sources. For instance, several years ago the United States EPA discussed a variety of NOx control measures in connection with its 1998 regional transport rule to reduce NOx emissions in the eastern half of the United States.[78] EPA found that measures to reduce NOx with costs of less than $2500 per ton (1999$), were "highly cost-effective."[79] EPA included an updated summary of average annual NOx costs in a recently announced second interstate transport rule.[80] Those costs ranged from a low of $200/ton NOx (for marine diesel engines) to a high of $12,700 per ton (NOx reductions via the Texas Emission Reduction Program); most local mobile source programs to reduce NOx cost over $2,000 per ton.[81] And in California, public funds are being used to pay for NOx reductions with a cost-effectiveness of up to $13,600/ton.[82] The average cost-effectiveness during the first four years of the California program was approximately $3,000 per ton of NOx reduced.[83]

It is clear from the foregoing that the cost of reducing NOx from ocean-going ships using either water in combustion air, water/fuel emulsions, or SCR would be substantially more cost effective than requiring those reductions to be achieved from land-based sources in the United States. It is also more cost effective to reduce shipping emissions than to obtain additional land-based emission reductions in Europe. As reported in the NGO Ship Briefing:

The cost-effectiveness of abatements at sea was studied by IIASA, while examining the EU strategy for combating acidification (CEC, 1997). The analysis showed that if the interim target for environmental quality proposed for the EU were to be obtained solely by use of technical measures on land, the annual cost by 2010 would be around 7 billion euro. The overall cost could be brought down by 2.1 billion euro, or about 30%, if cost-effective measures to limit the emissions of SO_2 and NOx from ships [such as low sulphur fuel and SCR] were applied in the Baltic, North Sea

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77 Farrell, Corbett and Winebrake (2002), at p. 1409.

78 US EPA, "Finding of Significant Contribution and Rulemaking for Certain States in the Ozone Transport Assessment Group Region for Purposes of Reducing Regional Transport of Ozone," 63 Fed. Reg. 57356, 57400 (October 27, 1998) (hereafter the "NOx SIP Call").

79 Id.

80 US EPA, "Rule to Reduce Interstate Transport of Fine Particulate Matter and Ozone (Clean Air Interstate Rule); Revisions of Acid Rain Program; Revision to the NOx SIP Call," March 10, 2005 (hereinafter "CAIR"), prepublication version available on the internet at http://www.epa.gov/air/interstateairquality/rule.html.

81 CAIR, at pp. 248-250 (Tables IV-6 through IV-8).

82 California Air Resources Board (CARB) (2005), Carl Moyer Program Advisory: 05-001, "Revised Cost-effectiveness Calculation and Minimum Project Life," available on the internet at http://www.arb.ca.gov/msprog/moyer/advisories_005/05-001_cost_effectiveness.doc. Until this year, this cost-effectiveness limit covered only NOx emissions; now it is applicable to reactive organic gases and PM as well as NOx.

83 CARB (2004), Carl Moyer Status Report, February 2004, at p. iii, available on the internet at http://www.arb.ca.gov/msprog/moyer/moyer_2004_report.pdf.

and waters of the north-east Atlantic. (No account was at that time taken of emissions in the Mediterranean).[84]

In addition to those NOx reduction measures available presently, other control measures are being developed but not yet available commercially. One highly effective catalyst–based control technology projected by EPA to be available over the next decade is the NOx absorber, which is capable of reducing NOx emissions by over 90%.[85] This control technology will be effective only with engines that use ultra-low sulphur fuel (~15 ppm), which will be available in the United States for coastal and inland marine diesel engines by 2012.[86]

PM Reduction Measures

Advanced PM reduction techniques such as particulate filters and diesel oxidation catalysts have been used for years in many land-based diesel applications.[87] Advanced diesel oxidation catalysts can reduce PM by between about 20 and 50%, given low sulphur fuel ~500-2000 ppm).[88] Catalyzed diesel particulate filters are much more effective, achieving removal efficiencies of up to 99%, given ultra-low sulphur fuel (~15ppm).[89] The United States EPA has recently stated that "PM filters and NOx absorbers can be applied to marine diesel engines for emission reductions of 90% or more."[90] Although these technologies are not yet as fully developed for application to the largest marine diesel engines, EPA [91]believes that within a decade or so, issues relating to the very large filter sizes required for these larger diesel engines should be resolved, and thus last year EPA established emission standards for the largest land-based nonroad engines that are predicated on filter-based emission control technologies.[92]

In the meantime, there are feasible and cost-effective options to reduce PM in the near term. As mentioned earlier, the reduction of SO_2 in fuel will also reduce particulate matter to some degree. Seawater scrubbing also will reduce PM, and has been reported to be a more effective means of reducing PM that lowering the sulphur content of marine fuel.

Due largely to the severe impacts that fine PM has on human health, the benefits of reducing PM shipping emissions will almost certainly overwhelm the costs. For example, EPA estimated that the emission reductions expected from its land-based 2004 Nonroad Rule will produce benefits that can be monetized about 40 times as great as the costs.

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84 NGO Ship Briefing, at pp.8-9.
85 EPA 2004 Marine ANPR, 69 Fed. Reg. at 39284.; Nonroad RIA, at pp.4-21 to 4-68.
86 EPA 2004 Nonroad Rule.
87 *See, e.g.,* Nonroad RIA, at pp.4-5 to 4-19.
88 *See, e.g.,* Nonroad RIA, at pp.4-5 to 4-6.
89 *See, e.g.,* Nonroad RIA, at pp.4-6 to 4-6.
90 EPA 2004 Marine ANPR, 69 Fed. Reg. at 39284.
91 EPA 2004 Nonroad Rule, 69 Fed. Reg. at pp.39133-39. This ratio only included only benefits that can be quantified in monetary terms; many other real health and environmental benefits that EPA could not then quantify or monetize were not included in this measure of benefits.
92 EPA expects that these largest engines will employ a wire or fiber mesh depth filter than a ceramic wall flow filter; the wire mesh filters are capable of reducing PM by about 70%. EPA 2004 Nonroad Rule, 69 Fed. Reg. at pp.38989-90.

Alternative Power Sources

A different approach to reducing air pollution form shipping is to use a different fuel or power source for the ship's engines. Natural gas engines are commercially available and have been used on ships for more than a decade.[93] Although emissions data for marine natural gas ships is not voluminous, emissions of NOx and PM from their land-based counterparts are extremely low.[94] Presently, cost and the lack of a marine fueling infrastructure appear to be the primary barriers to the more widespread use of this approach. Ships powered by fuel cells are even cleaner.[95] Although this technology is not yet commercially available, it has the potential in the future of powering a clean and efficient fleet of marine vessels.

A further opportunity exists to reduce emissions from ships at berth. Ships at dock operate either their auxiliary or main engines to meet their electrical "hotel" power needs. These hotelling emissions can be substantial, even if they are produced by auxiliary engines running on cleaner distillate fuel (rather than HFO). For instance, in southern California, auxiliary engine hotelling emissions are estimated to account for 37% of all ship NOx emissions, and 27% of all ship PM emissions.[96] In NY Harbour, 33% of NOx shipping emissions and 18% of PM emissions were from ships at dock.[97] These emissions can be reduced through the use of shore-side electrical power, often called "cold ironing." In areas such as California, where the local shore side power is generated by relatively clean sources, cold ironing can reduce emissions by up to 90% or more.[98] The California Air Resources Board is in the process of evaluating the feasibility of cold ironing, and is expected to release its findings this year.[99]

Conclusion

Shipping emissions of air pollution are substantial and growing. They are also largely unregulated, and are substantially less regulated than their land-based counterparts. These emissions produce considerable human health and environmental impacts. Furthermore, certain of these pollutants or there secondary products are important greenhouse gases.

No reason for the continued lax regulation of shipping emissions is apparent. This is especially true given the availability of feasible and cost-effective means of reducing those emissions. While different engine types and configurations will definitely result in a variety of appropriate control measures being applied, in general, the most promising appear to be:

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93 *See, e.g.,* CALSTART (2003) at pp. 32-3; Farrell, et. al (2002), at pp.1403-04.
94 *See, e.g.,* CALSTART (2003) at p.34; Farrell, et. al (2002), at p.1404.
95 C3 RIA, at 5-7, and references cited therein.
96 CARB Marine Air Quality Technical Working Group (2004), "Proposal to Reduce Emissions from Oceangoing Ship Auxiliary Engines," CARB Presentation, April 8, 2004, Sacramento, CA, available on the internet at http://www.arb.ca.gov/msprog/offroad/marinevess/presentations/040804/carbproposal.pdf.
97 M.J. Bradley & Associates (2004), "Port Electrification Opportunities," March 2004, at p.3, available from CATF.
98 Bluewater Network et al (2004), "Shoreside Power for Marine Vessels—Environmental Perspective," available of the internet at http://www.arb.ca.gov/msprog/offroad/marinevess/presentations/110904/shore.pdf.
99 *See* presentations from CARB's November 10, 2004 "Shore-Based Power for Ships Meeting," collected at http://www.arb.ca.gov/msprog/offroad/marinevess/presentations.htm.

- For SO_2 reduction, lower sulphur content in fuel, and once water quality issues can be resolved, seawater scrubbing;
- For NOx reduction, internal engine modifications, water/fuel emulsions, water or water vapor introduced into the combustion process, and SCR;
- For PM reduction, SO_2 reduction measures, as well as advanced diesel oxidation catalysts and particulate filters.

We also expect that a variety of new and efficient control technologies will become available in the future as air pollution from ships becomes an increasingly pressing issue. Experience from other sectors teaches that the tightening of shipping emission limits will likely spur and hasten the development of these control technologies.[100]

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[100] *See, e.g.,* Farrell, et al (2002), at p.1408, who summarize this point by stating: "The invention and use of environmental control technologies generally follow regulation—they do not precede it[citations omitted]."