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PREVENTION OF AIR POLLUTION FROM SHIPS

Opportunities for Reducing Greenhouse Gas Emissions from Ships

Submitted by the Friends of the Earth International (FOEI)

SUMMARY

Executive summary:	This document summarizes opportunities to reduce emissions of climate forcing agents from ships.
Strategic direction:	7.3
High-level action:	7.3.1
Planned output:	7.3.1.3
Action to be taken:	Paragraph 3
Related documents:	MEPC 58/4; GHG-WG 1/5; MEPC 57/4/10; MEPC 57/INF.15; MEPC 56/4/8 and MEPC 53/4/1

1 The annex to this document contains a recent summary and analysis of various approaches to reducing emissions of climate forcing agents from international shipping entitled "Opportunities for Reducing Greenhouse Gas Emissions from Ships". The report was authored by Erin H. Green, James J. Winebrake and James J. Corbett, and was commissioned by the Clean Air Task Force.

2 References to information in the report may be found online at: http://www.eerallc.com/public/IMO_GHG/.

Action requested of the Committee

3 The Committee is invited to note the information provided in the attached final report in its work on the reduction of greenhouse gas emissions from ships.

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ANNEX

OPPORTUNITIES FOR REDUCING GREENHOUSE GAS EMISSIONS FROM SHIPS

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1 Introduction

1.1 Purpose

This document presents a summary of opportunities for reducing several important greenhouse gas (GHG) and climate-forcing emissions from ships. These opportunities are grouped into five main categories: (1) technological; (2) operational; (3) fuel switching; (4) intermodal shifting; and, (5) demand management. For each category, emissions reduction options are presented, with associated costs, benefits, and limitations where available.

1.2 Select Climate-Forcing Emissions from Ships

1.2.1. Direct Impacts

Black carbon (BC). Black carbon is a component of particulate matter (PM) and is produced by marine vessels through the incomplete oxidation of diesel fuel. Black carbon has a positive climate-forcing effect since it absorbs sunlight; this effect is likely greater in the Arctic region and other snow- and ice-covered regions, because black carbon can reduce the snow's reflectivity and accelerate the melting process when deposited on snow or ice [1, 2]. The total warming effect of global BC emissions is estimated to be between 25% and 60% that of annual CO_2 emissions [3, 4]. International shipping emits between 71,000 and 160,000 metric tons of BC annually [5, 6].

Carbon dioxide (CO_2). Carbon dioxide is produced from marine vessels as a by-product of the oxidation of carbon in diesel fuel. International shipping emitted approximately 800 million metric tons (MMT) of CO_2 in 2000, contributing about 2.7% of global CO_2 emissions that year [7]. Current estimates (2007) report that ships emit about 1,000 $MMTCO_2$/yr, with the increases attributed to growth in international trade [8].

1.2.2. Indirect Impacts

Nitrogen Oxides (NO_x). Nitrogen oxides are produced in high temperature combustion in ship engines and act as precursors to tropospheric ozone (O_3), a potent GHG [9]. In 2000, ships emitted approximately 5 MMT of NO_x (as N), with registered fleet NO_x estimated in 2000 to range between 15% to 30% of global anthropogenic NO_x emissions [5, 7]. Recent estimates are on the order of 7.8 MMT of NO_x (as N) in 2007 [9]. Radiative forcing estimates for tropospheric O_3 due to shipping are in the range of 40% of annual CO_2 forcing from ships, although this does not consider the cumulative effects of CO_2 during its longer residence time in the atmosphere [10, 11]. NO_x emissions also can lead to increased nitrates in the atmosphere and methane (CH_4) scavenging, so overall climate forcing impacts may ultimately be neutral.

Carbon Monoxide (CO). Carbon monoxide is a precursor to tropospheric O_3 and CH_4, two potent GHGs, and is released during fuel combustion. In 2002, ocean-going ships emitted approximately 1.1 MMT of CO [5], or 0.1% of emissions from all fossil fuel sources [12].

2 Technological Options

2.1 Engine Optimization, Process Modification, and After-Treatment Technologies

Engine optimization and process modifications can be used to reduce emissions of NO_x and PM[1] (see Table 1) [13-17]. Engine Optimization (EOP) involves in-engine control (e.g., combustion time, compression ratio, valve timing) to optimize fuel economy and decrease emissions; these approaches in combination have been shown to reduce NO_x by up to 35% [18]. Engine process modifications involve changes to a ship's engine combustion process to reduce emissions. These modifications include: exhaust gas recirculation (EGR); addition of water, urea, or ammonia to combustion; and electronic valve control [18]. As shown in Table 1, EGR alone can achieve 50% reductions in NO_x, and 20% reductions in PM[2], but can increase CO emissions by 200% or more [18-20].

After-treatment technologies (ATT) are devices which control emissions in exhaust gases [13-15]. ATT devices used to reduce NO_x include Selective Catalytic Reduction (SCR), Selective Non-Catalytic Reduction (SNCR), Lean NO_x Trap (LNT), Diesel Oxidation Catalysts (DOC), and NO_x Absorber Catalyst. ATT devices used to remove PM include seawater scrubbing, DOC, Diesel Particulate Filters (DPF), and Catalyzed Exhaust Diesel Particulate Filters (CEDPF) [18, 19, 21-23]. DPF systems are particularly effective at controlling BC, reducing emissions by 95 to 99.9% by mass (with 70-95% reductions in total PM) [22].

SCR system effects on CO, PM and BC emissions are uncertain in both theoretical and empirical contexts, although some studies claim to reduce these pollutant emissions by various amounts [21]. Some particulate filters may also reduce CO emissions, and DOCs have been shown to reduce CO, NO_x, and hydrocarbons [23]. An option for ships at berth is Cloud Chamber Scrubbing combined with SCR, claimed to reduce PM by 95% [18].

ATTs do have some limitations. Many controls, including oxidation reactors, DPFs, CEDPFs, SCR, and NO_x Absorber Catalysts perform most effectively with low sulphur fuel oil [13-15, 18, 24 and 25]. DPFs may work best with newer engines operating at higher sustained temperatures [25]. Also, the most effective emissions control technologies (e.g., SCR, DPF) are often the most expensive [18, 25].

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1 Ships produce fewer CO emissions than other combustion sources, and technological measures to reduce CO alone are usually not cost-effective. Nevertheless, because CO emissions are closely tied to fuel consumption, any activities that either increase or decrease fuel consumption would also likely increase or decrease CO emissions, respectively.

2 Many studies only identify reductions of PM, without explicitly partitioning PM into its constituent components, such as BC. In some cases, we can assume that the level of PM reductions observed can also apply to BC, although this might not always be the case. Where specified in the literature, we identify whether a control option reduces BC in particular, or simply PM more generally.

Lastly, operation of ATTs may require additional energy inputs, and thus increased CO_2 emissions [13-15, 22, 26-28]. For example, Miller Cycle EOP, while decreasing NO_x, increases PM and increases fuel consumption by about 1% [18]. CEDPFs have been found to decrease emissions of CO and PM, with reported increases in fuel consumption of ~1%, and corresponding increases in emissions of CO_2 and NO_x [13-15, 29]. SNCR systems can lead to ammonia slippage or increased N_2O emissions [18, 30]. Finally, DOCs reduce CO and PM components, but do not reduce BC and may increase sulphates and total PM where sulphur is present in the fuel [23]. In the future, technological improvements may present exceptions to current limitations [18, 31].

2.2 Cold-Ironing (Shore-Side Electrification)

Cold-ironing involves the use of shore-based power to provide ships' electrical needs at port. Ships shut down their auxiliary engines while at port and connect to the local power source. Total fuel-cycle (TFC)[3] GHG emissions reductions of cold-ironing are highly variable, and are dependent on a number of factors such as the type of fuel displaced, and the source of on-shore electricity [24, 32, 33]. Because auxiliary engine use at port contributes only a small portion of total marine transport GHGs, cold-ironing would reduce total shipping-related GHGs by less than 0.5% given current electricity generation fuel mixes [34-36].

2.3 Vessel Design, Propellers, Maintenance, and Propulsion

Modifications to vessel and propeller design can reduce fuel consumption and therefore BC, CO_2, NO_x, and CO emissions (see Table 1). These modifications include: hull optimization (e.g., use of a stern flap which lengthens the bottom surface of a hull; replacement of flat bottom hull surface with air cavity system), propeller system improvements, propeller coatings, and a bulbous bow [26, 34-38]. Several propeller improvements were identified as best practices to reduce GHGs from marine freight transport [34-36]. Hull and propeller maintenance can also increase fuel efficiency [26].

Sails and kites can assist in ship propulsion, reducing fuel consumption while increasing speed. For instance, the Skysails system claims a 10% speed increase while decreasing fuel consumption by 10-35% on average—50% in optimal situations [38]. The WindShip concept (sail-assist for 50,000 DWT commercial carriers) could decrease fuel consumption by 10-27%, depending on speed and routeing [38].

3 Fuel Switching

Substituting residual oil (RO) with alternative fuels presents potential opportunities for reducing emissions GHG emissions from ships [24, 39]. Recent work examining the TFC emissions of fuel switching in the marine sector has indicated increases of some GHGs when using low sulphur fuels (e.g., marine gas oil or marine diesel oil) due to fuel processing emissions, but these increased emissions are mostly offset by fewer emissions during vessel operation [32, 33, 39, 40]. Fuel switching may also result in considerable reductions of PM (and likely BC), particularly when using non-fossil fuel based alternatives such as biodiesel [32, 33, 40].

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[3] Total Fuel-Cycle refers to total emissions generated in fuel production, transport, storage, and ultimate use in a vessel. While local/exhaust emissions are of concern for criteria pollutants (i.e. PM, SO_x, NO_x), total emissions are important when examining GHGs [33].

Switching from RO to marine diesel oil (MDO) would reduce PM by 63% and NO_x by about 5% [39]. Due to the higher energy content of MDO less fuel would be required, reducing CO_2 exhaust emissions by about 3%. TFC CO_2 emissions would increase (slightly less than 1%) with a switch from RO to MDO or marine gas oil (MGO) due to increases primarily at refineries; however stationary emissions could be addressed with offsets or controls [32, 40].

Compared to RO, 20% biodiesel (B20) can significantly reduce exhaust and TFC emissions of PM and SO_x [33]. B20 was found to increase CO_2, N_2O, NO_x and CO emissions in a recent case study of a containership and tanker, for a 2% increase in TFC GHG emissions (considering only CO_2, N_2O, and CH_4) [33]. However, the study estimated a 68% TFC decrease in PM so net climate forcing impacts are uncertain. Another recent study examining the use of B20 to replace MGO in ships found that B20 had lower TFC GHG emissions [34-36]. (Note that the overall (TFC) emissions effects of biodiesel are largely dependent on how the biofuel component of the biodiesel is farmed, harvested, and processed).

4 Operational Measures

4.1 Speed Reductions

Speed reductions can result in considerable fuel savings, leading to proportional reductions in GHG emissions. If operating at a few knots below design speeds, vessels can substantially reduce fuel use [41]. Fuel consumption increases with a power function of speed (approximating a cubic function in large cargo ships), so a 10% reduction in speed of a vessel may result in ~23% reduction in GHG emissions [26]. One case study found that a speed reduction of about 20%, coupled with a similar 20% increase in the number of vessels can produce 44% fewer GHGs with equal transport capacity; another case study found that a 34% speed reduction, coupled with a 40% increase in the number of vessels, can produce 57% fewer emissions [42].

4.2 Ship Routeing and Logistics

Measures to improve ship routeing and logistics can have impacts on fuel consumption and emissions. Such measures include: planning to better utilize existing fleets; weather routeing to exploit favourable weather and currents; just-in-time routeing; reduced time at port through optimal cargo handling, berthing, mooring and anchoring; and, improved terminal operations to reduce delays (see Table 1) [26].

5 Intermodal Shifting

Modes of transportation differ considerably in energy- and carbon-intensity per unit of service, so total transportation emissions can be reduced by shifting to lower energy- and emissions-intensity modes when possible. Marine transportation performs well against air and truck transportation, and is comparable to rail on a per ton-kilometre (tkm) basis [34, 43]. The amount of reductions of such mode-shifting is a function of the type of vessel being operated and route selection, as well as the emissions characteristics of the alternative shipping mode.

6 Demand Management

Demand management of marine transport activity (measured in tkm) is a central factor in controlling all of the emissions presented above [41]. As shipping is anticipated to grow approximately 2.5% to 4% annually in the coming decades [5, 26], short-term emissions reduction efforts could easily be offset by increased shipping activity within one to two decades [5]. Although technological advances have been made to improve fuel efficiency and reduce emissions, growth in activity has overwhelmed savings, and future advances in technology may not overcome anticipated emissions increases [5, 9, 26, 44].

A challenge with demand management is that freight transport is linked with economic growth, so efforts to reduce tkm may be seen as a constraint on growth [8, 41]. However as the current trade system emphasizing just-in-time logistics has resulted in decreased shipment density and increased frequency [44], there may exist many opportunities for efficiencies which would not equate to loss of transport service. There are indications, for instance, that Germany and Japan have had success at decoupling transport emissions and economic activity [41].

7 Conclusion

A survey of the available studies and peer-reviewed literature shows potential for ships to achieve reductions of NO_x, BC, CO, and CO_2. Individually, each option offers potential for measurable emissions reductions (see Table 1). However, combining strategies can produce considerable reductions; for example, efficiency improvements, fuel switching, and speed reduction could in combination result in over 50% GHG reductions by 2020 [26].

Table 1: Shipping GHG Reductions by Category, Option and Pollutant

Technology/Strategy	NO_x	N_2O	PM	CO	CO_2	Fuel
	% Change[a]					
Technology						
EOP, EPM & ATP						
SCR System	90%			(-)	**(+)**	
SNCR	(-)	**(+)**				
Seawater Scrubbing	75%		25-30%			
DPF			70-95%			
CEDPF			(-)	(-)		
Cloud Chamber Scrubbing (with LSF)			95%			
EGR	35 - 50%		20% - 63%	**200% (+)**	**(+)**	**(+)**
Humid Air Motors	70%				**(+)**	
Direct Water Injection	50%				**(+)**	
Diesel Oxidation Reactor	(-)		(+/-)	(-)		
Fuel Injection (Old)*		1 – 2%	1 – 2%	1 – 2%	1 – 2%	1 – 2%
Miller Cycle EOP	35%		**(+)**			**1% (+)**
IP Hercules	30 – 60%		20 – 40%	3 – 5%	3 – 5 %	3 – 5 %
Retarded Timing	10%				**10% (+)**	
Efficiency Optimized*		10 - 12%	10 - 12%	10 - 12%	10 - 12%	10 - 12%
Vessel, Propeller, Maintenance, and Propulsion±						
Hull Shape (New)*	5 - 20%	5 - 20%	5 - 20%	5 - 20%	5 - 20%	5 - 20%
Propeller Choice (New)*	5 - 10%	5 - 10%	5 - 10%	5 - 10%	5 - 10%	5 - 10%
Off-Centre Propeller (New)*	1.5 - 3%	1.5 - 3%	1.5 - 3%	1.5 - 3%	1.5 - 3%	1.5 - 3%
Propeller Boss Cap Fins*	2 – 5%	2 – 5%	2 – 5%	2 – 5%	2 – 5%	2 – 5%
Propeller Auxiliary Rotating Device*	3 – 6%	3 – 6%	3 – 6%	3 – 6%	3 – 6%	3 – 6%
Optimal Hull Maintenance*	3 – 5%	3 – 5%	3 – 5%	3 – 5%	3 – 5%	3 – 5%
Propeller Maintenance*	1 – 3%	1 – 3%	1 – 3%	1 – 3%	1 – 3%	1 – 3%
Propeller Coating[b]*	4 – 5%	4 – 5%	4 – 5%	4 – 5%	4 – 5%	4 – 5%
Stern Flap[b]*	6 – 7.5%	6 – 7.5%	6 – 7.5%	6 – 7.5%	6 – 7.5%	6 – 7.5%
Air Cavity System*	15%	15%	15%	15%	15%	15%
Bulbous Bow*	4 – 5%	4 – 5%	4 – 5%	4 – 5%	4 – 5%	4 – 5%
Cold-ironing					0.2%	0.2%
Propulsion: Skysails*	10 - 35%	10 - 35%	10 - 35%	10 - 35%	10 - 35%	10 - 35%
Propulsion: WindShip*	10 - 27%	10 - 27%	10 - 27%	10 - 27%	10 - 27%	10 - 27%
Fuel Switching (Compared to RO)						
MDO (Exhaust/TFC)	5%/(-)	91%/(-)	63%/(-)	(?)/**(+)**	5% / **(+1%)**	**(+/-)**
B20 (Exhaust/TFC)	**(+)/(+)**	**(-)/(-)**	**(-)/(+)**	**(-)/(+)**	**(+/-)/(+/-)**	**(+/-)**
Operational±						
Speed (10%)*	23%	23%	23%	23%	23%	23%
Speed (21%)[b]*	44%	44%	44%	44%	44%	44%
Speed (34%)[b]*	57%	57%	57%	57%	57%	57%
Fleet Planning*	5 - 40%	5 - 40%	5 - 40%	5 - 40%	5 - 40%	5 - 40%
Weather Routeing*	2 - 4%	2 - 4%	2 - 4%	2 - 4%	2 - 4%	2 - 4%
Just-in-time routeing*	1 – 5 %	1 – 5 %	1 – 5 %	1 – 5 %	1 – 5 %	1 – 5 %
Optimal cargo handling*	1 – 5 %	1 – 5 %	1 – 5 %	1 – 5 %	1 – 5 %	1 – 5 %
Optimal berthing, mooring, and anchoring*	1 – 2 %	1 – 2 %	1 – 2 %	1 – 2 %	1 – 2 %	1 – 2 %

± Reductions resulting from increased fuel efficiency.
[a] When % reduction estimates are not available, (-) denotes reduction and (+) denotes an increase in emissions.
[b] Estimated from case study – does not necessarily apply to worldwide fleet.
* Assumes proportional emissions reductions due to reduced fuel consumption.
Estimates obtained from various sources including: [18, 19, 21-23, 26, 32-34, 37, 40, 42].

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