Controlling PM by proxy? International regulation of sulphur and PM emissions from shipping

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PM by proxy? Regulation of sulphur and PM emissions from shipping

Abstract

Ships are major contributors to global emissions of air pollutants, with their health and environmental effects being of particular concern in port cities and heavily populated coastal areas adjacent to major shipping lanes. This paper outlines the international regulations tackling two such ship pollutants, being sulphur dioxide (SOx) and particulate matter (PM). In order to understand the current regulatory strategy, it reviews the health and environmental impact of these emissions. The paper then addresses the 2020 sulphur cap on marine fuel imposed by MARPOL and its potential efficacy in reducing the health and environmental effects of shipping emissions. Examples of differing regional and national regulation of sulphur and PM are presented and discussed. The paper questions whether the current international regulatory framework directed at reducing sulphur emissions from ships is an appropriate means to reduce PM emissions.

1 Introduction

This paper concerns the regulation of sulphur and particulate matter (PM) emissions from international shipping. Shipping is a highly efficient means of transport essential for world trade. Ships have traditionally used degraded residual heavy fuel oil (HFO).[1] HFO has a sulphur content which is higher than other shipping fuels, and orders of magnitude higher than road vehicle fuels, and similarly contains metals and other non-combusted contaminants in greater concentrations than other petroleum products.[2]

Shipping emissions of SO_x and Particulate Matter (PM) contribute to local and regional air pollution and have profound consequences for human health and environment. Port communities and coastal populations near busy shipping routes are especially affected by airborne fine and ultrafine PM emitted by ships. Cruise ships tend to be a focus point for residents of port cities[3] because they are highly visible visitors with large energy needs whilst in port; and the cruise ship industry is enjoying significant growth. However the sheer number of ships of all types visiting a port is also a

[1] Bin Lin, Chrng-Yuan Lin 'Compliance with International Emission Regulations: Reducing the Air Pollution from Merchant Vessels' (2006) 30 *Marine Policy* 220, 220.

[2] S. Oeder et al, 'Particulate Matter from Both Heavy Fuel Oil and Diesel Fuel Shipping Emissions Show Strong Biological Effects on Human Lung Cells at Realistic and Comparable In Vitro Exposure Conditions.' (2015) 10(6) *PLoS ONE*: e0126536. doi.org/10.1371/journal.pone.0126536. *[note to ed; this is an electronic journal that does not include a starting page.]*

[3] See The Danish Ecological Council *Cleaner Shipping- Focus on air pollution, technical solutions and regulation* 2nd ed (2018) 9, showing particles per cm both near and downwind from the cruise ship Ocean Kaj in the port of Copenhagen.

major factor. In fjords and arctic environments, black carbon (a component of PM), is of concern not only for its detrimental effects on health but also for its climate forcing quality.[4]

The *International Convention for the Prevention of Pollution from Ships 1973 as modified by the 1978 and 1997 Protocols* (*MARPOL*) governs ship based marine pollution control and prevention. The IMO's Marine Environment Protection Committee (MEPC) is the Committee responsible for MARPOL. The 1997 Protocol introduced Annex VI, which dealt with air pollution from ships, came into force in 2005.[5] Regulation 14 included a cap on the sulphur content of marine fuel at 4.5% m/m sulphur. [6]

In 2008, MEPC58 resolved to step down the sulphur content of marine fuel towards a 0.5% m/m cap effective 1 January 2020 (2020 sulphur cap). The 2020 sulphur cap was subject to a review as to whether there would be sufficient availability of compliant fuel, to be completed by 2018.[7] In 2016, MEPC decided to proceed with the introduction of the 2020 cap.[8] In 2018, with a view to consistent implementation of the 2020 sulphur cap, MEPC resolved to introduce a ban on the carriage of non-compliant fuel oil.[9]

The decisions of MEPC not to defer the 2020 implementation date and to introduce the carriage ban understandably attracted significant global interest. The various stakeholders have been working hard to prepare the industry for compliance; including the State parties to MARPOL Annex VI, who will need to enforce compliance with the 2020 sulphur cap.

While MARPOL Annex VI explicitly regulates the sulphur content of fuel, control of PM emissions has only ever been managed by proxy with the expectation that combustion of lower sulphur fuel will result in reduced emissions of PM.[10] Some studies have found that reduced sulphur concentration in fuel correlates with reduced particle emissions by both mass and number concentrations.[11] However, it has also been suggested that HFO with 0.5% S may, depending on engine type and operating conditions, emit greater numbers of particles than more sulphurous HFO, leading the authors to question the suitability of fuel sulphur content as a proxy for PM emission factors.[12]

As well as international regulation of SO_x and PM emissions from ships via MARPOL, regulations exist at a regional (notably, EU), national and port level. Some simply adopt a lower sulphur content than would otherwise apply under MARPOL; others may impose particular restrictions on to a certain

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[4] *Investigation of Appropriate Control Measures (Abatement Technologies) to Reduce Black Carbon Emissions from International Shipping* (IMO, 2015), 1.3. For reasons of space we will not deal with issues posed BC in this paper.
[5] MP/Conf. 3/34.
[6] Regulation 14.1. 'm/m' means mass by mass.
[7] MEPC.176(58) adopted 10 October 2008. See below at 3.1.3.
[8] Resolution MEPC.280(70). MEPC decided not to defer until 2025. MARPOL Annex VI Regulation 14.8 -14.10 contained a review provision permitting deferral of the 0.5% limit if there were concerns that ships would not be able to comply based on the availability of compliant fuel.
[9] Resolution MEPC.305(73).Ships with scrubbers are excepted from the carriage ban. This is discussed further below.
[10] See 3.1 below.
[11] Sergey Ushakov et al, 'Effects of high sulphur content in marine fuels on particulate matter emission characteristics'(2013) 12 *Journal of Marine Engineering & Technology*, 30. doi.org/10.1080/20464177.2013.11020283; B. Alföldy et al, 'Measurements of air pollution emission factors for marine transportation in SECA' (2013) 6 *Atmospheric Measurement Techniques* 1777 doi:10.5194/amt-6-1777-2013.
[12] Hulda Winnes et al, 'On-board measurements of particle emissions from marine engines using fuels with different sulphur content' (2016) 230(1) *Journal of Engineering for the Maritime Environment* 45.

type of ship (such as passenger ships). The EU, China, and some states of the US are amongst those who have introduced additional regulations.

The 2020 sulphur cap is one of the measures taken by the IMO to reduce the shipping industry's contribution to air pollutants. The IMO is also at the vanguard of the development of measures to reduce greenhouse gases (GHGs) from shipping.[13] GHGs have a global impact on climate. As will be discussed, measures to reduce air pollution may not necessarily help efforts to reduce GHGs.

In this paper we consider the means by which MARPOL seeks to reduce the sulphur and PM emissions from ships. First, we outline the health and environmental impact of ship emissions, with a focus on SO_x and PM emissions. We explore the international regulation of ship sourced sulphur and PM emissions with particular focus on the 2020 sulphur cap and its potential effect on PM; then consider the relationship between sulphur regulations and the IMO's intended reductions in GHG emissions from shipping. We also outline the challenges of compliance and enforcement of the 2020 sulphur cap; and illustrate this with examples of differing national and port regulation of sulphur and PM emissions. To conclude, we ask whether the current international regulations to reduce sulphur content from ship emissions are an appropriate means to reduce PM emissions.

2 Background – effects of emissions from shipping

2.1 Gaseous Emissions

The pollutant effects of the by-products of fossil fuels in combustion engines have been identified in many official health reports and scientific papers. The combustion of diesel produces gases including oxides of nitrogen (NO_x), which derive predominantly from the reaction between nitrogen and oxygen in the air in the high temperature of the combustion mix,[14] and oxides of sulphur (SO_x) and carbon dioxide (CO_2), which derive from the reaction between oxygen in the air and sulphur and carbon found in the fuel. Both NO_x and SO_x contribute to acid rain and ocean acidification which may affect, for example, coral and mollusc formation, and krill, which forms the mainstay of the global food chain.[15] Both NO_x and SO_x have been associated with adverse effects on health.[16] NO_x contributes to the formation of photochemical smog, leading to elevated levels of ozone (O_3) and a production of hazardous organic compounds.[17] The increase in CO_2 in the atmosphere is leading to a change to the carbon chemistry of the ocean which impedes calcification processes of many marine

[13] See 3.3 below.

[14] Emissions of NO_x are more dependent on engine load than fuel type. Hulda Winnes & Erik Fridell, 'Particle Emissions from Ships: Dependence on Fuel Type, (2009) 59:12 *Journal of the Air & Waste Management Association*, 1391. doi: 10.3155/1047-3289.59.12.1391.

[15] VJ Fabry et al, 'Impacts of ocean acidification on marine fauna and ecosystem processes' (2008) 65 *ICES Journal of Marine Science* 414.

[16] Brunekreef B & Holgate ST, 'Air pollution and health' (2002) 360 (9341) *Lancet* 1233 – 1242; UK Committee on the Medical Effects of Air Pollution, *Associations of long-term average concentrations of nitrogen dioxide with mortality* (2018) found at https://www.gov.uk/government/publications/nitrogen-dioxide-effects-on-mortality.

[17] While NO_x emissions are not the primary focus of this paper, passing reference will be made to the NO_x requirements because the efficiencies introduced to control NO_x also have a beneficial effect on sulphur – and indeed, GHG – emissions.

organisms and ecosystems.[18] O_3 is hazardous to human health as well as being a greenhouse gas (GHG). [19] Other byproducts of combustion engines include Volatile Organic Compounds (VOCs) and methane (also a GHG, more harmful than CO_2 although shortlived).

The amount of SO_x emitted by a combustion engine depends on the sulphur content of the fuel, and can be reduced by decreasing the percentage sulphur in the fuel. Conversely, reduction in NO_x emissions may be achieved by engine modifications or, most effectively, selective catalytic reduction.

2.2 Particulate Emissions

2.2.1 Particulate Matter

Airborne particulates may be solid or liquid, and derive from anthropogenic (man-made) sources such as fossil fuel combustion and industrial emissions, and non-anthropogenic sources such as soil erosion and sea salt.

Particulate matter is usually described using the initials "PM" followed by a number indicating the median aerodynamic diameter of the particles, in microns, such as PM_{10} (<10 µM) or $PM_{2.5}$ (<2.5 µM).[20] Alternatively, the terms "coarse" and "fine" may be used to describe PM 2.5-10 µm and <2.5 µm in diameter, respectively. It is now recognised that smaller particulates, such as $PM_{0.1}$, also termed "ultrafine", may be especially harmful.[21] Ultrafine particulates have an extremely large surface area:volume ratio, meaning that they are more able to interact with their surrounding environment following inhalation, and their size means they are able to penetrate down to, and almost certainly across, the gas exchange surfaces of the lung, thus entering the circulation and potentially reaching other organs including the heart and brain.[22] Of significance to understanding the relevance of legislation to health protection, it is noteworthy that $PM_{0.1}$ comprises only a small percentage of the total mass of airborne PM_{10}, but that by number of particles, the great majority of airborne particles are in the $PM_{0.1}$ category.[23] Given that mass concentration (i.e. micrograms per cubic metre) is the standard metric for monitoring air pollution, it may be that legislation is targeting

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[18] Meredith Simons & Tim Stephens 'Ocean Acidification: Addressing the other CO_2 Problem' (2009) 12 *Asia Pacific Journal of Environmental Law* 1, 3.

[19] https://unearthed.greenpeace.org/2018/07/18/china-ozone-air-pollution-is-getting-really-bad/amp/

[20] Namely particulates with an aerodynamic diameter equal to or less than 10 microns (PM_{10}) which includes those with an aerodynamic diameter equal to or less than 2.5 microns ($PM_{2.5}$).

[21] Research is increasingly being done on the effects of ultrafine PM: eg Stölzel et al; 'Daily mortality and particulate matter in different size classes in Erfurt, Germany' (2007) 17 *Journal of Exposure Science and Environmental Epidemiology* 458; George S Downward et al, 'Long-Term Exposure to Ultrafine Particles and Incidence of Cardiovascular and Cerebrovascular Disease in a Prospective Study of a Dutch Cohort (2018) 126 (12) *Environmental Health Perspectives* doi.org/10.1289/EHP3047 [ed: this is an online journal and has no starting page number.]

[22] "The negative health effects of ambient fine particulate matter air pollution ($PM_{2.5}$) are well established in the epidemiological, clinical and toxicological literature" (US EPA 2009, WHO, 2013b); Broome et al 'The mortality effect of ship related fine particulate matter in the Sydney greater metropolitan region of NSW, Australia.' (2016) 87 *Environment International* 85, 93. See also Mark R. Miller et al, 'Inhaled Nanoparticles Accumulate at Sites of Vascular Disease' (2017)11 (5) *ACS Nano* 4542; Frank J Kelly & Julia C Fussell, 'Size, source and chemical composition as determinants of toxicity attributable to ambient particulate matter' (2012) 60 *Atmospheric Environment* 504.

[23] Prashant Kumar et al, 'Ultrafine particles in cities' (2014) 66 *Environment International* 1. Stephen Thomas et al, 'The modality of particle size distributions of environmental aerosols' (1999) 33 (27) *Atmospheric Environment* 4401.

the wrong metric. Furthermore, of great relevance to shipping, is the fact that combustion engines tend to emit extremely high number concentrations (i.e. number of particles per cubic metre) of primary PM (PM emitted from source) and secondary PM precursors (gaseous emissions which later react to form PM),[24] and these very smallest particles may be relatively little affected by existing emissions control technologies deployed on board ships, such as exhaust gas cleaning systems (scrubbers).[25] Although newer electrostatic scrubbers offer improved efficiency for removal of submicron diameter particles,[26] they do not yet appear to be in widespread use. Scrubbers are not commonly fitted with particulate filters; these too may improve PM removal.[27] Indeed, technology for removal of PM from ship exhaust is not as advanced as might be hoped.[28] As discussed below, in the current regulatory environment ships do not need to install scrubbers that are highly efficient at removing PM.

Particulates produced by combustion engines show different size distributions and compositional profiles depending on the fuel used. Traditionally, ships burnt HFO, a thick viscous product of the oil refining process, which distils just above bitumen in the fractionating process. HFO contains metals and other non-combusted contaminants in greater concentrations than other petroleum products, with this being apparent in HFO PM emissions.[29] PM emissions have a recognisable chemical ratio which indicate their source, such as HFO, or diesel used in road transport.[30] As one would expect, the PM produced by the burning of marine HFO with a 3.5% sulphur content contains much more sulphur than diesel and petrol used in road traffic.[31]

2.2.2 Health impacts of PM

[24] Robert Healy et al, 'Characterisation of single particles from in-port ship emissions' (2009) 43 (40) *Atmospheric Environment* 6408 doi.org/10.1016/j.atmosenv.2009.07.039; J. Moldanová et al, 'Physical and chemical characterisation of PM emissions from two ships operating in European Emission Control Areas' (2013) 6(12) *Atmospheric Measurement Techniques* 3577 doi:10.5194/amt-6-3577-2013; Yenny González et al, 'Ultrafine particles pollution in urban coastal air due to ship emissions' (2011) 45(28) *Atmospheric Environment* 4907 doi.org/10.1016/j.atmosenv.2011.06.002.
[25] C. Carotenuto et al, 'Wet Electrostatic scrubbers for the abatement of submicronic particulate' (2010) 165 *Chemical Engineering Journal* 35. Scrubbers are discussed below at 3.2.2.
[26] Di Natale et al, 'Capture of fine and ultrafine particles in a wet electrostatic scrubber' (2015) 3(1) J*ournal of Environmental Chemical Engineering* 349.
[27] See Sapcariu et al, n 68 below.
[28] Mingyu Guo et al, 'A short review of treatment methods of marine diesel engine exhaust gases' (2015) 121 *Procedia Engineering* 938.
[29] Thorsten Streibel et al, 'Aerosol emissions of a ship diesel engine operated with diesel fuel or heavy fuel oil' (2017) 24 *Environmental Science and Pollution Research* 10976. DOI 10.1007/s11356-016-6724-z.
[30] For example, the ratio of the concentration of vanadium to nickel, lying between 2.5 and 3, may be used to mark emissions from heavy oil combustion, although this may derive from non-ship combustion of heavy oil, and so may also act as a fingerprint for emissions from oil refining. Mar Viana et al, 'Chemical Tracers of Particulate Emissions from Commercial Shipping' (2009) 43(19) *Environmental Science and Technology* 7472; Marco Pandolfi et al, 'Source apportionment of PM_{10} and $PM_{2.5}$ at multiple sites in the strait of Gibraltar by PMF: impact of shipping emissions' (2011) 18 *Environmental Science and Pollution Research* 260.
[31] There are much lower limits of sulphur in fuel for road transport. The 'cleaner' fuel ships are required to use in ECAs, has a maximum sulphur content m/m of 0.1% (in 1000 mg/kg S). This compares to 0.001% S (i.e. 10 mg/kg S) for road vehicles in Europe. See Directive 2009/30/EC of the European Parliament and European Council (23 April 2009).

Significantly, the PM of HFO also contains metals, including the toxic heavy metals nickel and vanadium which are both strongly associated with cardiovascular disease.[32] There are risks associated with human exposure to PM both through acute (i.e. a brief spike) and chronic (i.e. prolonged over months or years) exposure. Acute exposure is associated with increased rates of medication use and hospitalisation for underlying diseases and their exacerbations, including asthma and cardiovascular disease (e.g. myocardial infarction, stroke). Chronic exposure to PM is associated with increased incidence of diseases including lung cancer, asthma, and chronic obstructive pulmonary disease (COPD).[33] Both are associated with increased mortality rates. Epidemiological studies which uncover such associations are generally unable to determine causality, and are usually not powered to identify the specific individual pollutants responsible for the associations, given the strong correlation between multiple pollutants.[34] Nonetheless, epidemiological evidence, combined with intervention and exposure studies, means there is now little doubt that the air pollution mix, of which $PM_{2.5}$ plays a part, has a causal effect on mortality.[35]

There is a general upward trend in the estimated mortality burden of exposure to outdoor $PM_{2.5}$, mainly due to methodological improvements. This was most recently calculated at 8.9 million premature deaths per annum, in a study which suggested that 30% of modelled premature deaths were not accounted for by the most commonly associated causes – ischaemic heart disease, stroke, lung cancer, COPD, and lower respiratory tract infection. Notably, recent studies have suggested associations between $PM_{2.5}$ and type 2 diabetes[36], Alzheimer's disease, and impaired cognitive function.[37]As larger datasets become available, alongside improved understanding of pollution exposure and better quantification of the excess risk posed per unit exposure to $PM_{2.5}$, it is likely that new health effects will be identified, and that the burden of exposure will be further refined. The UK Committee on the Medical Effects of Air Pollution (COMEAP) reports that in the UK, outdoor air pollution at current 2018 levels poses a greater burden on mortality than environmental tobacco smoke or road traffic accidents.[38]

Multiple national and international organisations have developed guidelines for airborne PM_{10} and $PM_{2.5}$ concentrations,[30] some legally enforced, others (including those from the WHO) merely advisory. Legal limits tend to be set pragmatically, to reduce airborne PM concentrations and their

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[32]Michelle L. Bell et al, 'Hospital Admissions and Chemical Composition of Fine Particle Air Pollution' (2009) 179(12) *American Journal of Respiratory and Critical Care Medicine* 1115 doi: 10.1164/rccm.200808-1240OC; Linwei Tian et al, 'Shipping emissions associated with increased cardiovascular hospitalizations' (2013) 74 *Atmospheric Environment* 320. Morton Lippmann, 'Toxicological and epidemiological studies of cardiovascular effects of ambient air fine particulate matter (PM2.5) and its chemical components: Coherence and public health implications' (2014) 44 *Critical Reviews in Toxicology* 299 doi: 10.3109/10408444.2013.861796

[33] Broome et al, above n22, 85.

[34] See, for example, COMEAP *Associations of long-term average concentrations of nitrogen dioxide with mortality* (2018) Page viii. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/734799/COMEAP_NO2_Report.pdf

[35] Ibid, COMEAP *Associations of long-term average concentrations of nitrogen dioxide with mortality* (2018), ix, referring to COMEAP 2009a.

[36] John F. Pearson et al, 'Association between Fine Particulate Matter and Diabetes Prevalence in the U.S.' (2010) 33(10) *Diabetes Care* 2196. doi.org/10.2337/dc10-0698.

[37] Zhang X, Chen X, Zhang XB., 'The impact of exposure to air pollution on cognitive performance' (2018) 115 (37) *Proceedings of the National Academy of Sciences U S A* 9193-7; Ulrich Ranft et al, 'Long-term exposure to traffic-related particulate matter impairs cognitive function in the elderly' (2009) 109 (8) *Environmental Research* 1004 doi.org/10.1016/j.envres.2009.08.003

[38] COMEAP *The Mortality Effects of Long Term Exposure to Particulate Air Pollution in the United Kingdom*. (22 August 2018) par 25.

health consequences to the lowest level practicable in the context of the country's logistics and development. As such, legal limits in some countries may be significantly higher than those elsewhere. Conversely, WHO guidelines are based on the concentrations at which there is clear evidence that air pollution harms health. However, it does not follow that concentrations of PM below WHO guidelines are safe – there is evidence to the contrary.[39] Although difficulties in measuring or modelling lower concentrations, along with noise in the data, mean that there is less statistical significance for associations at lower PM concentrations, there is no lower concentration of PM which has been demonstrated to have no health effect, and thus reducing pollution concentrations is expected to reduce health risks.[40]

Potential ineffectiveness of such guidelines also derives from their focus on particle mass concentration, thus neglecting the particle number concentration driven by the ultrafine fraction (as discussed above) and also their lack of consideration of particle composition.[41] Although there is little evidence for specific elemental components of PM driving toxicity, there is good evidence that certain classes of PM components, including transition metals and polyaromatic hydrocarbons (PAHs), are important in mediating PM toxicity.[42] Furthermore, certain sources of PM, identified by compositional fingerprints, have also been shown to be especially associated with the health effects of PM, including shipping.[43] Whether or how certain individual elemental components interact to drive these effects is less understood.

In summary, $PM_{2.5}$ 'has adverse impacts on human health, visibility, ecosystems and climate change[44] and the UN Economic Commission for Europe named high PM concentrations as one of the most pressing challenges facing the region.[45]

2.2.3 PM emissions from ships

International shipping has been estimated to contribute around 1.5 million tonnes of PM_{10} to the global PM burden, the great majority of which is $PM_{2.5}$.[46] This PM_{10} contribution compares to the

[39] Qian Di et al, 'Air Pollution and Mortality in the Medicare Population' (2017) 376 *The New England Journal of Medicine* 2513 doi: 10.1056/NEJMoa1702747

[40] *1999 Protocol to Abate Acidification, Eutrophication and Ground-level Ozone to the Convention on Long-range Transboundary Air Pollution*, as amended on 4 May 2012, Annex I VIA 11.

[41] M Loxham, 'Harmful effects of particulate air pollution: identifying the culprits' (2015) 20 *Respirology* 73 https://doi.org/10.1111/resp.12432; DM Cooper & M Loxham 'Particulate Matter and the Airway Epithelium – The Special Case of the Underground?' (2019) *European Respiratory Review* (in press – ed, pg number should be available prior to print).

[42] Athanasios Valavanidis et al, 'Airborne Particulate Matter and Human Health: Toxicological Assessment and Importance of Size and Composition of Particles for Oxidative Damage and Carcinogenic Mechanisms' (2008) (26) *Journal of Environmental Science and Health*, Part C 339 — 362 doi:10.3109/10408444.2013.861796

[43] Morton Lippmann, above, n 32.

[44] Zhen Cheng et al, "Status and characteristics of ambient PM 2.5 pollution in global megacities" (2016) 89- 90 *Environment International*, 212 – 221.

[45] Discussing the *Convention on Long range Transboundary Air Pollution* 1979 (CLRTAP) and its strategy for the upcoming 10 years. ECE Decision 2010/18 *Long-term strategy for the Convention on Long-Range Transboundary Air Pollution and Action Plan for its Implementation* [13]. https://www.unece.org/fileadmin/DAM/env/lrtap/ExecutiveBody/Decision_2010.18.pdf accessed 3 September 2018.

[46] Sofiev et al, 'Cleaner fuels for ships provide public health benefits with climate tradeoffs' (2018) 9 *Nature Communications* 1.

non-shipping load of 17.3 million tonnes,[47] meaning that shipping is the source of approximately 8% of global airborne PM_{10}. However, in terms of population exposure to $PM_{0.1}$, it is likely that, in coastal areas at least, the contribution of shipping may be much higher. Indeed, around 70% of emissions from ships are released within 400 km of the coastline.[48] Ships are an important source of particle numbers, as illustrated by several studies. 65-70% of the particle number concentration (PNC) of up to 50,000 particles/cm^3 were attributed to ship emissions in Tenerife when the wind was blowing towards the coast,[49] contributing especially to spikes in PNC against the road vehicle background[50] A similar predominance of the ultrafine fraction in ship emissions, (up to 212,000 particles/cm^3) was found in the Port of Cork, Ireland.[51] Conversely, a lower contribution of shipping emissions to ultrafine PM load was found in in 2008 study in the Los Angeles and Long Beach area, perhaps partly due to an increased burden of road traffic.[52] Interestingly, a 2018 study in the same area found that, near the port, port sources (ships, and port-based trains, cargo haulage equipment and HGVs) contributed 11 times more PM mass and 38 times more particle number than did local roads, although in Los Angeles as a whole, emissions rates were 2-5 times higher for road vehicles than port sources.[53] Of relevance to health, in areas adjacent to the Port of Long Beach, port emissions of $PM_{0.25}$ accounted for 16% of the oxidative potential of total $PM_{0.25}$,[54] with oxidative potential thought to be a good marker of potential effects on health.[55] In general, it is not surprising that, as distance to the port decreases, contribution of shipping to PNC increases – at a site 50 m from hotelling ships, almost 50% of the PNC was determined to originate from manoeuvring and hotelling ships, a greater proportion than for larger PM fractions, leading the authors to suggest that PNC may be a more suitable metric than mass concentration for investigating the contribution of shipping emissions,[56] the latter often underestimating the contribution of shipping compared to the former.[57] Nonetheless, there is also good evidence for longer range transport of ship-emitted ultrafine PM, which was seen to contribute up to 19% of PNC

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[47] Janssens-Manehout et al (2015) *Atmospheric Chemistry and Physics* 15.
[48] James J Corbett et al, 'Global nitrogen and sulphur inventories for oceangoing ships' (1999) 104 *Journal of Geophysical Research* 3457.
[49] Yenny González et al,'Ultrafine particles pollution in urban coastal air due to ship emissions' above n 24.
[50] Yenny González & Sergio Rodríguez, 'A comparative study on the ultrafine particle episodes induced by vehicle exhaust: A crude oil refinery and ship emissions' (2013) 120-121 *Atmospheric Research* 43. doi.org/10.1016/j.atmosres.2012.08.001
[51] Robert Healy et al, above n 24.
[52] María Cruz Minguillón et al, 'Seasonal and spatial variations of sources of fine and quasi-ultrafine particulate matter in neighborhoods near the Los Angeles–Long Beach harbor' (2008) 42(32) *Atmospheric Environment* 7317 doi.org/10.1016/j.atmosenv.2008.07.036.
[53]Amirhosein Mousavi et al, 'Impact of particulate matter (PM) emissions from ships, locomotives, and freeways in the communities near the ports of Los Angeles (POLA) and Long Beach (POLB) on the air quality in the Los Angeles county' (2018) 195 *Atmospheric Environment* 159. doi.org/10.1016/j.atmosenv.2018.09.044.
[54] Amirhosein Mousavi et al, 'Impact of emissions from the Ports of Los Angeles and Long Beach on the oxidative potential of ambient PM0.25 measured across the Los Angeles County' (2019) 651 *Science of the Total Environment* 638 doi.org/10.1016/j.scitotenv.2018.09.155.
[55] Frank J. Kelly and Julia C. Fussell, 'Linking ambient particulate matter pollution effects with oxidative biology and immune responses' (2015) 1340 (1) *Annals of the New York Academy of Sciences* 84.
[56] E. Merico et al, 'Influence of in-port ships emissions to gaseous atmospheric pollutants and to particulate matter of different sizes in a Mediterranean harbour in Italy' (2016) 139 *Atmospheric Environment* 1. doi.org/10.1016/j.atmosenv.2016.05.024.
[57] Daniele Contini et al 'Inter-annual trend of the primary contribution of ship emissions to PM2.5 concentrations in Venice (Italy): Efficiency of emissions mitigation strategies' (2015) 105 *Atmospheric Environmen*t 183. doi.org/10.1016/j.atmosenv.2014.11.065.

in Denmark, 25-60 km from a shipping lane,[58] while 20 km from Calais harbour, PNC rose from 2,000 to 20,000 particles/cm^3 under the influence of ship emissions.[59]

In terms of the health effects from PM shipping emissions, it has been claimed that a reduction in fuel sulphur will lead to a reduction in the health burden of shipping emissions through reduced PM emissions. However, this is based simply on mass of PM emitted, and assumes that shipping emissions are, mass for mass, toxicologically equivalent to ambient urban PM. As we illustrate below, the evidence base does not uniformly support this.

There are three specific factors of concern regarding shipping PM emissions: PM metals, PM organic carbon, and particle number. Switching of fuel from HFO to lower sulphur diesel has been seen to result in significant reduction in PM concentration of metals including vanadium and iron.[60] A key mechanism through which PM is thought to exert its effects is by the generation of highly reactive oxygen-containing molecules known as reactive oxygen species, resulting in oxidative stress on cells.[61] Notably, transition metals such as vanadium and iron are especially potent in this regard.[62] HFO-derived PM has been seen to be more potent in eliciting oxidative stress and cell death in exposed lung-lining cells than has lower-sulphur diesel-derived PM.[63] However, the latter may still more damaging to cells than ambient outdoor PM, suggesting that switching to lower sulphur diesel is not a complete solution.

The same study[64] also found a decreased risk of cancer through calculating the carcinogenic potency of PAHs in the collected PM. 16 individual PAHs are regulated by the US EPA as carcinogenic [65] due to their ability to damage and mutate DNA.[66] Therefore a reduction in their concentration in shipping PM may have beneficial health effects, with reduced DNA damage seen in cells exposed to HFO PM if the particles have been thermally stripped of these PAHs,[67] although PAHs in the gas phase of HFO emissions may also have inflammatory effects on exposed cells.[68] Larger polyaromatic molecules tend to exhibit greater carcinogenic potential, and have been noted to be reduced in emissions by burning lower sulphur fuel. A reduction in PAH emissions has also been noted by other

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[58] N. Kivekäs et al, 'Contribution of ship traffic to aerosol particle concentrations downwind of a major shipping lane' (2014) 14 *Atmospheric Chemistry and Physics* 8255. doi:10.5194/acp-14-8255-2014.
[59] Frédéric Ledoux et al, 'Influence of ship emissions on NO_x, SO2, O3 and PM concentrations in a North-Sea harbor in France' (2018) 71 *Journal of Environmental Sciences* 56.
[60] Di Wu et al, 'Primary Particulate Matter Emitted from Heavy Fuel and Diesel Oil Combustion in a Typical Container Ship: Characteristics and Toxicity' (2018) 52 *Environmental Science & Technology* 12943 doi.org/10.1021/acs.est.8b04471
[61] Frank J Kelly et al, 'Linking ambient particulate matter pollution effects with oxidative biology and immune responses' (2015) 1340 *Cellular and Environmental Stressors in Biology and Medicine* 84 doi:10.1111/nyas.12720
[62] Athanasios Valavanidis et al, above n 42.
[63] Di Wu et al, above n 60.
[64] Ibid.
[65] Lawrence H. Keith, 'The Source of U.S. EPA's Sixteen PAH Priority Pollutants' (2015) 35 *Polycyclic Aromatic Compounds* 147 doi:10.1080/10406638.2014.892886.
[66] Bhagavatula Moorthy et al, 'Polycyclic Aromatic Hydrocarbons: From Metabolism to Lung Cancer' (2015) 145 *Toxicological Sciences* 5.
[67] Tamara Kanashova et al, 'Differential proteomic analysis of mouse macrophages exposed to adsorbate-loaded heavy fuel oil derived combustion particles using an automated sample-preparation workflow' (2015) 407 *Analytical and Bioanalytical Chemistry* 5965 doi: 10.1007/s00216-015-8595-4.
[68] Sean Sapcariu et al, 'Metabolic Profiling as Well as Stable Isotope Assisted Metabolic and Proteomic Analysis of RAW 264.7 Macrophages Exposed to Ship Engine Aerosol Emissions: Different Effects of Heavy Fuel Oil and Refined Diesel Fuel' (2016) 11(6) PLoS ONE https://doi.org/10.1371/journal.pone.0157964.

researchers, who found that, in contrast, there may be little change[69] or even an increase in elemental carbon (soot) release with diesel fuel compared to HFO,[70] and also in the similar measure of black carbon.[71] Indeed, an increase in elemental carbon emissions from diesel fuel rather than HFO combustion has been associated with the former having more pronounced effects on fundamental cellular processes such as cellular metabolism[72] in exposed human lung lining cells. Furthermore, diesel fuel particles may be more cytotoxic to lung macrophages, cells responsible for clearing inhaled PM from the lungs, compared to HFO PM, with a broader spectrum of effects.[73] However, relative elemental carbon emissions are not consistent across studies,[74] and there is evidence that non-fuel factors, such as the air-fuel mixing ratio and engine load may play an important role in determining emissions characteristics,[75] suggesting that targeting fuel sulphur alone may not have maximal effect. Furthermore, the chemical differences in PM between fuel types may be less than anticipated based on analysis of liquid fuel alone, potentially because of the influence of lubrication oil in the fuel, of which there is a paucity of knowledge regarding contribution to emissions and resultant health effects.[76]

Therefore, the balance of evidence suggests that using lower sulphur fuel may reduce concentrations of toxic metal and organic carbon species in ship emissions, although other factors such as engine load may also play an important role as well. Furthermore, the evidence suggests that emissions of elemental carbon and black carbon may not be decreased, and indeed may be increased, by using lower sulphur fuel, with possible negative health consequences.

Finally, it cannot be said with any certainty that switching to lower sulphur fuel will lead to a reduction in the numbers of particles emitted. There is evidence that the emitted particle number concentration (PNC) may be greater from lower sulphur fuel compared to HFO[77] especially with decreasing engine load.[78] Conversely, at full-speed load, the PNC is greater with HFO. However, if only particles <1.6 µm diameter are considered, the emitted PNC may be greater with lower sulphur fuel even at full speed conditions. This effect of engine load in particular may have significant implications for understanding emissions from auxiliary engines, rather than full-speed sailing away

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[69] Rüger CP et al, 'Comprehensive chemical comparison of fuel composition and aerosol particles emitted from a ship diesel engine by gas chromatography atmospheric pressure chemical ionisation ultra-high resolution mass spectrometry with improved data processing routines' (2017) 23 *European Journal of Mass Spectrometry* 28. doi: 10.1177/1469066717694286

[70] O. Sippula et al, 'Particle Emissions from a Marine Engine: Chemical Composition and Aromatic Emission Profiles under Various Operating Conditions' (2014) 48 *Environmental Science and Technology* 11721 dx.doi.org/10.1021/es502484z

[71] Thorsten Streibel et al, above, n 29.

[72] Oeder S, et al, above, n 2.

[73] Sapcariu SC, et al, above n 68.

[74] Daniel A. Lack et al, 'Impact of Fuel Quality Regulation and Speed Reductions on Shipping Emissions: Implications for Climate and Air Quality' (2011) 45 *Environmental Science and Technology* 9052 doi: 10.1021/es2013424.

[75] Laarnie Mueller et al, 'Characteristics and temporal evolution of particulate emissions from a ship diesel engine'(2015) 155 *Applied Energy* 204.

[76] CP Rüger et al, above, n 68; Philipp Eichler et al, 'Lubricating Oil as a Major Constituent of Ship Exhaust Particles' (2017) *Environmental Science and Technology Letters* 54 https://doi.org/10.1021/acs.estlett.6b00488.

[77] Daniel A. Lack et al, above, n 74.

[78] A. Petzold, 'Physical Properties, Chemical Composition, and Cloud Forming Potential of Particulate Emissions from a Marine Diesel Engine at Various Load Conditions' (2010) 44 *Environmental Science and Technology* 3800 doi: 10.1021/es903681z.

from land.[79] Similarly, PNC emissions from a large cargo ship at berth have been seen to be considerably greater than from the same ship when cruising, with potential implications for port city residents.[80]

In contrast to GHG emissions (which have a more global effect), PM emissions have a health impact on the populations near where they are emitted. Therefore the health effects of shipping emissions are most likely to be found in heavily populated coastal areas adjacent to busy ports and shipping lanes.[81] It likely that shipping emissions will contribute significantly to the total environmental exposure (termed the 'exposome')[82] of those living in such areas. Seafarers and ship passengers are also populations exposed to PM emissions whilst on board, and such exposures may, in some circumstances, exceed those which would be experienced in urban environments.[83]

Although it is not within the aim or scope of this review to discuss the climate effects of fuel sulphur regulation, the evidence appears as conflicting as it does for health effects. Research suggests that, on a global scale, ship emissions have a net cooling effect, due to the cooling effect of SO_2 and organic carbon emissions outweighing the warming effect of emissions such as black carbon and CO_2. Using lower sulphur fuel would especially reduce emissions of the cooling species, with a comparatively lesser effect on emissions responsible for warming,[84] while also potentially increasing greenhouse gas emissions from refineries.[85] As such, and with exceptions for Arctic areas where the warming/cooling effect may be different, it may be that the optimal solution is the burning of clean or ultra-low sulphur fuel in areas where health impacts are likely, and highly sulphurous fuels on the open seas, although it should be noted that this does not account for potential effects on marine ecosystems.

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[79] Hulda Winnes & Erik Fridell, 'Particle Emissions from Ships: Dependence on Fuel Type' above, n14.

[80] Thuy Chu-Van et al,' On-board measurements of particle and gaseous emissions from a large cargo vessel at different operating conditions' (2018) 237 *Environmental Pollution* 832.

[81] Sofiev et al, above n 46. There is a decline in ship related PM 2.5 concentration with distance from a port or coast. R. Broome et al, above n 22, 90.

[82] Being the life-course environmental exposures from the prenatal period onwards: Christopher Wild "Complementing the Genome with an "Exposome": the Outstanding Challenge of Environmental Exposure Measurement in Molecular Epidemiology' (2005) 14(8) *Cancer Epidemiology Biomarkers & Prevention* 1847, 1848.

[83] Ryan D Kennedy, 'An investigation of air pollution on the decks of 4 cruise ships' A report for Stand.earth 24 January 2019. Available at: https://www.researchgate.net/publication/330666991. An_investigation_of_air_pollution_on_the_decks_of_4_cruise_ships (accessed 6 March 2019). See also Will Coldwell, 'Air on board cruise ships 'is twice as bad as at Piccadilly Circus'' *The Guardian* 4 July 2017, available at: https://www.theguardian.com/travel/2017/jul/03/air-on-board-cruise-ships-is-twice-as-bad-as-at-piccadilly-circus. Note – these studies are not published in the peer-reviewed literature, but have been conducted using equipment in regular use in scientific research, and advised by/carried out by air pollution scientists.

[84] Haakon Lindstad et al, 'Maritime shipping and emissions: a three-layered, damage based approach' (2015) 110B *Ocean Engineering 94.* doi: 10.1016/j.oceaneng.2015.09.029. See also Sofiev et al, above n 46.

[85] Thuy Chu Van et al, 'Global impacts of recent IMO regulations on marine fuel oil refining processes and ship emissions' (2019) 70 *Transportation Research Part D: Transport and Environment* 123 DOI: 10.1016/j.trd.2019.04.001

3 International regulation of sulphur and PM emissions from ships

Under the *United Nations Convention on the Law of the Sea 1982* (UNCLOS), parties are obliged to protect the marine environment; ensure their activities do not affect other parties; and prevent, reduce and control pollution of the marine environment from or through the atmosphere applicable to the airspace under their sovereignty.[86] Party States must endeavour to establish global and regional rules, standards, practices and procedures to prevent, reduce and control atmospheric pollution.[87] States are required to enforce their laws and regulations and take measures necessary to implement the applicable international rules and standards through the IMO or diplomatic conferences to prevent, reduce and control pollution of the marine environment from or though the atmosphere.[88] Concerns that UNCLOS may not extend beyond the *marine* environment to deal with air emissions in Annex VI have been allayed by Regulation 11(6) which 'specifically ties the Annex to the jurisdictional regime for ship sourced pollution'.[89]

Under UNCLOS, the International Maritime Organisation (IMO) is charged with responsibility for ships and their effect on the environment.[90] The IMO Committee Maritime Environment Protection Committee is responsible for environmental issues including MARPOL.[91]

3.1 MARPOL Annex VI – regulation of air emissions from ships

3.1.1 History

The original MARPOL 1973/1978 Convention contained five annexes with broad scope, dealing with not only oil spills but disposal/discharge of waste, sewage and noxious liquids from ships.[92] Emissions affecting air quality had been discussed at the time of the original MARPOL in 1973, but were not included. By contrast, around that time, regulation of land-based emissions of airborne pollutants - including SO_x, NOx and PM - were the subject of negotiations leading to the *Convention on Long Range Transboundary Air Pollution* 1979 (CLRTAP) which entered into force in 1983.[93] Its coverage extends across most of the northern hemisphere.[94]

[86] UNCLOS Art 212. Pollution of the marine environment is defined in UNCLOS Art 1.1(4) as 'the introduction by man, directly or indirectly, of substances or energy into the marine environment, including estuaries, which results or is likely to result in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for use of sea water and reduction of amenities.'
[87] UNCLOS Art 212 Rule 3.
[88] UNCLOS Article 222.
[89] Henrik Ringbom, 'Enforcement of the Sulphur in Fuel Requirements: Same, Same but Different' (2016) SIMPLY Yearbook 9.
[90] UNCLOS, Art 59.
[91] MEPC has divides its consideration of air emissions matters into three separate agenda items: air pollution and energy efficiency; technical measures to enhance efficiency, and reduction of greenhouse gas (GHG) emissions from ships. Pollution by SO_x and PM generally falls in the first of these.
[92] It also deals with the carriage of harmful substances as cargo. See Annex III.
[93] *1999 Protocol to Abate Acidification, Eutrophication and Ground-level Ozone to the Convention on Long-range Transboundary Air Pollution (Gothenburg Protocol)*, as amended on 4 May 2012, 11bis. The parties to COLTAP agreed to reduce their emissions levels to a percentage of their 2005 levels by 2020, by varying amounts per state but ranging between 10 and 46% (Annex II). EU as a whole is aiming to reduce its emissions of PM 2.5 by 22%.
[94] ECE/EB.AIR/106/Add.1, page 2. For signatories see https://treaties.un.org/Pages/showDetails.aspx?objid=0800000280020aa6&clang=_en

Some 15 years after CLRTAP, air emissions from ships were first addressed in the *1997 Protocol* to MARPOL (1997 Protocol).[95] The 1997 Protocol added *Regulations for the Prevention of Air Pollution from Ships (Annex VI)*.One hundred and fifty seven states have signed the original 1973/78 Convention but fewer - only 95 States - are signatories to Annex VI.[96] The 1997 Protocol came into force on 19 May 2005.[97] Signatories to Annex VI include all littoral European countries and Australia, China, Indonesia, Japan, Malaysia, Philippines, Russia, Singapore, and USA amongst others. Non-party States at the time of writing include Iraq, Israel, Fiji, New Zealand, Papua New Guinea, Pakistan, Qatar, Sri Lanka and Thailand.[98]

Since coming into force, Annex VI has been steadily expanding in scope.[99] In 2011, MEPC60 introduced technical and operational measures to increase ship efficiency thereby reducing all ship emissions into the air, with a particular emphasis on NOx and GHG. Those measures consist of the energy efficiency design index (EEDI) (applicable to new builds of certain ship types) and the ship energy efficiency plans (SEEMP) (required to be in place for all ships). These requirements entered into force on 1 January 2013 and are regularly updated and improved. 'The EEDI is a non-prescriptive, performance-based mechanism that leaves the choice of technologies to use in a specific ship design to the industry. As long as the required energy-efficiency level is attained, ship designers and builders are free to use the most cost-efficient solutions in complying with the regulations.'[100] The EEDI becomes increasingly strict. Because the EEDI/SEEMP measures aim to reduce fossil fuel consumption, [101] they should also improve PM emissions from those ships to which they apply.

3.1.2 Regulation of SO_x and PM in Annex VI

The original Annex VI adopted by the IMO Conference of Parties to the 1997 Protocol to MARPOL[102] dealt with various emissions, notably NO_x, SO_x and O_3 limits.[103] It came into force in 2005.

The original Annex VI:

- imposed a cap on sulphur content of fuel oil of 4.5% m/m.[104]
- stipulated that within designated Emission Control Areas (ECAs) ships were to use fuel with a sulphur content no more than 1.5% m/m; or an approved exhaust gas cleaning system

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[95] *The Protocol of 1997 to amend the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto*.
[96] IMO Status of Treaties, as at 5 August 2019, accessed 15 August 2019: http://www.imo.org/en/About/Conventions/StatusOfConventions/Documents/StatusOfTreaties.pdf In percentage terms, 99.01% of world tonnage is flagged in a State Party to MARPOL 73/78, as opposed to 96.71% in a State Party to 1997 Protocol.
[97] http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/The-Protocol-of-1997-(MARPOL-Annex-VI).aspx
[98] http://www.imo.org/en/About/Conventions/StatusOfConventions/Pages/Default.aspx as at 5 August 2019. The New Zealand Government is currently considering whether to accede to Annex VI: Ministry of Transport, *New Zealand's potential accession to International Maritime Organization treaty: MARPOL Annex VI: Prevention of Air Pollution from Ships* (Discussion Document, November 2018).
[99] It now also contains the IMO approaches to reducing GHGs. See 3.3 below.
[100] IMO Leg/MISC.8, 81.
[101] Complex technical calculations and assumptions are involved in assessing the EEDI for each type of ship.
[102] MP/Conf. 3/34.
[103] But also VOC from tankers (regulation 15) and shipboard incineration (reg 16). Neither of those will be covered in this paper.
[104] Annex VI, Regulation 14(1).

('scrubber'); or some other verified and approved technological method to control emissions.[105]

- Required that ships built after 1 January 2000 were to have NOx emissions below a certain limit.[106]
- Introduced the requirement for all ships to be surveyed and hold an International Air Pollution Protection Certificate issued by or on behalf of the flag state, by which compliance with Annex VI would be established.[107]
- Required parties to make port facilities available for reception of residues.
- Contained enforcement measures such as requiring flag state certification and port state inspection of ships and prosecution of violations; the certification and sampling of bunkers as supplied; and state party regulation of local suppliers of bunker fuel.[108]

The 4.5% m/m[109] figure was a compromise between competing interests.[110]

The original Annex VI did not mention PM.

3.1.3 2008 Revisions to Regulation 14 - reducing Sulphur limits for fuel oil used in shipping

In 2008 Annex VI was revised by MEPC58.[111] The title of Regulation 14 was amended to refer to both SO_x and PM. During negotiations, specific limits on PM had been suggested by some countries. [112] Ultimately the revision to Regulation 14 set no specific limits or targets for PM; probably because PM emissions are hard to measure and any limits would be difficult to enforce. Furthermore, given that, depending on particle size, PM may travel large distances before reaching the "receptor" (i.e. the individual inhaling the PM[113]), measurements at source may yield incomplete information about the potential risks to health. (However, this is less likely to be a confounding issue in port cities, where the source and exposed population are in close proximity.) Rather, MEPC decided that PM

[105] Regulation 14(4). This clause was subsequently deleted; Regulation 4 permits the flag state to approve alternative compliance methods. Annex VI Regulation 3 provides very limited exceptions and an exemption for ships conducting trials of reduction technologies. A permit is required.
[106] Annex VI, Regulation 13 (1)(a), Regulation 13(3).
[107] Chapter II.
[108] Regulations 9, 10, 11, 18 (7). Fuel suppliers must document the sulphur content in the bunker delivery note which is to be retained for 3 years and made available for inspection by competent authorities of party States. Suppliers must also supply a representative sample of the oil delivered, to be sealed and signed by the supplier's representative and the ship officer in charge of bunkering. The sample is to be kept for at least 12 months and made available for testing if required.[108] A failure to comply will lead to penalties according to the applicable domestic legislation giving effect to Annex VI.
[109] Regulation 14 (1).
[110] Alan Khee-Jin Tan, *Vessel-Source Marine Pollution: the Law and Politics of International Regulation* (Cambridge University Press, 2005) 160.
[111] Resolution MEPC.176 (58).
[112] BLG11/5/15 (USA).
[113] Kristina M Wagstrom & Spyros N Pandis, 'Source–receptor relationships for fine particulate matter concentrations in the Eastern United States' (2011) 45(2), A*tmospheric Environment* 347 doi.org/10.1016/j.atmosenv.2010.10.019; World Health Organization *Health risks of particulate matter from long-range transboundary air pollution* Regional Office for Europe & Joint WHO/Convention Task Force on the Health Aspects of Air Pollution. (2006) Copenhagen found at < http://www.who.int/iris/handle/10665/107691>.

emissions would be reduced as a function of reducing sulphur;[114] therefore a cap on the sulphur content of fuel was one of the most direct means of reducing PM.[115]

INTERTANKO initially proposed a shift to distillate fuels with a stipulated maximum sulphur content of 1% from 2010.[116] Ultimately, the 2008 revisions accepted by MEPC involved a much more modest proposition: a gradual stepdown in sulphur content of fuel oil over the course of the ensuing 12 years. The final limit envisaged by Annex VI is the 0.5%m/m (0.5%) sulphur cap, which came into effect on 1 January 2020.

Permissible sulphur content in marine fuel outside ECAs under the Amended Annex VI[117]
Prior to 1 January 2012 - 4.50% m/m
On and after 1 January 2012 - 3.50% m/m
On and after 1 January 2020 (possibility to defer to 2025) - 0.5% m/m

Under the 2008 revisions flag states could approve alternative technologies, such as scrubbers, so long as that alternative was at least as effective in terms of emissions reduction.[118] However, as there was no explicit reduction required for PM, the 'alternative technology' did not have to meet a specific PM reduction target.

The 2008 revisions included a review date at which time the IMO would consider the availability of fuel oil and trends in supply and demand before determining whether to implement the sulphur limit in 2020 or defer to 2025.[119] In October 2016, MEPC decided to retain the 2020 implementation date.[120]

3.1.4 SO_x and PM limits within Emission Control Areas

The original Annex VI permitted the designation of SO_x Emission Control Areas pursuant to Appendix III. Within these ECAs, the sulphur content was capped at 1.5% m/m, once Annex VI came into effect in 2005. Since January 2015 the sulphur content of fuel in use in ECAs has been set at 0.1% m/m. The 2020 sulphur cap will have zero effect in ECAs.

There are now four ECAs: the Baltic Sea, the North Sea, North America, and the US/Caribbean Sea. Currently the east coast of the United Kingdom fall within an ECA, but the west coast does not.[121]

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[114] See BLG12/6, 5.32. There has been much scientific debate about how best to measure PM.. See discussion of 'bottom up' and 'top down' methodology in L Goldsworthy, B Goldsworthy *Modelling of ship engine exhaust emissions in ports and extensive coastal waters based on terrestrial AIS data – an Australian case study* (2015) 63 Environmental Modelling &Software 45, 46-48. Also, see Finland's submission to the IMO Sub-Committee on Bulk Liquids and Gases concerning differing ISO standards and outcomes: BLG 12/6/14.
[115] See IMO Sub-Committee on Bulk Liquids and Gases BLG10/19 (30 May 2006), 14.21. The expectation at this time was that distillates would be used to meet the cap; Sweden submitted that when a commercial car carrier was operated on Marine Diesel Oil, the rate of PM fell to unmeasurable levels: BLG 11/5/19, 11.
[116] BLG-WGAP 1/2/5 (Intertanko); summarised in BLG 11/5/19, 2. (Sweden).
[117] Annex VI amended 2008, Regulation 14(1).
[118] Annex VI amended 2008, Regulation 4. Scrubbers are discussed at 3.2.2 and 5.2.6 below.
[119] Annex VI Regulation 14 (8) - (10).
[120] Resolution MEPC.280(70).
[121] The south western most point of the Baltic ECA lies just east of Falmouth. However, the EU Sulphur Directive does currently apply to these ports. See 5.1 below.

There are plans to put forward the Mediterranean Sea as an ECA.[122] ECA areas under MARPOL cover only a small fraction of the oceans and by no means cover all congested shipping lanes or coastal routes. Notably, there are no MARPOL designated Annex VI ECAs in Asia despite it having some of the world's busiest shipping lanes and significant air pollution problems.

NOx controls are being added to the ECAs. A vessel operating within a NOx ECA constructed after 1 January 2016 must comply with the most stringent Tier III NOx controls. Currently only the US ECAs are NOx ECAs[123] but the North Sea and Baltic Sea ECAs will adopt the NOx provisions as from 1 January 2019, effective January 2021. Ships built on or after 1 January 2021 will need to be Tier III compliant if they are to be deployed in an ECA.[124]

For sulphur controls, the stepdown in permitted sulphur content of fuels within the ECA areas has been steeper than the general sulphur content stepdown - to much lower absolute figures, and in a shorter timeframe.

Permissible sulphur content in marine fuel in ECAs under the Amended Annex VI[125]
Prior to 1 July 2010 – 1.5%m/m
On and after 1 July 2010 – 1.0% m/m
On and after 1 January 2015 - 0.1% m/m

The IMO relies on flag and port States to ensure ships comply with Regulation 14. Party States are authorised to conduct audits, detain ships and create offences under domestic law to enforce breaches.[126] State parties' actions will themselves be audited by the IMO, under Chapter 5 of Annex VI. Enforcement is discussed further below.

3.1.5 Ban on carriage of non-compliant fuel for use on board a ship – effective March 2020

In April 2018, MEPC72 proposed amending Regulation 14 to include a ban on the carriage of non-compliant fuel for use on board the ship, unless the ship was fitted with approved scrubbers (the carriage ban).[127] The proposed carriage ban was passed at MEPC73,[128] and comes into force on 1 March 2020.

The amended Regulation 14.1 reads:

> 14.1 The sulphur content of fuel oil used or carried for use on board a ship shall not exceed 0.50% m/m. (Underlining added)

[122] MEPC73. There would be a gap between the North Sea ECA and the Mediterranean ECA: falling outside it would be the coastlines along the Bay of Biscay and the European (Portuguese and Spanish) coasts abutting the North Atlantic. (The EU imposes its own sulphur cap for ships visiting ports in the Mediterranean: see 5.1 below).
[123] MARPOL, Regulation 13, 5.1
[124] http://www.imo.org/en/OurWork/Environment/SpecialAreasUnderMARPOL/Pages/Default.aspx sets out the critical dates.
[125] Revised Annex VI (2008), Regulation 14.4.
[126] See *2009 Guidelines for port State control under the revised MARPOL Annex VI* (Resolution MEPC.181(59).
[127] Resolution MEPC 280(70).
[128] Resolution MEPC.305(73).

The addition of the underlined words is intended to make it easier for port and flag states to enforce compliance, as they only need to prove that the oil is on board and intended for use on board rather than the actual use of non-compliant fuel. Carriage of non-compliant fuel as cargo is not affected.

MEPC74, in May 2019, was the final meeting before the 2020 cap came into force. MEPC74 approved various guiding documents, including *2019 Guidelines for consistent implementation of the 0.50% sulphur limit,* [129] *Guidance for port State control on contingency measures for addressing non compliant fuel oil,*[130] *and Guidance for best practice for member States/coastal States* to aid the implementation and enforcement of Annex VI.[131]

3.2 Compliance with 2020 cap and the potential impact on PM emissions

The 2020 sulphur cap has just come into force. The main means of compliance are briefly dealt with here.

3.2.1 Meet the sulphur cap by using low sulphur fuel

It is estimated that the reduction in sulphur content from 3.5% to 0.5% will reduce a ship's SO_x emissions by more than 97%[132] and PM emissions by about 50%.[133] It is difficult to predict the likely cost of compliant fuel, however the increase is expected to be significant. Bunker fuel costs are generally about half of the overall operating costs of a ship.[134] There have been predictions that some smaller ship operators will go out of business; and that, inevitably, the cost of shipping goods will go up. (Ironically, a reduction in the shipping trade would lead to a reduction in all emissions, which would assist the IMO in reaching its GHG emissions targets (discussed below)).[135]

Aside from increased cost of low sulphur fuel, there have been numerous other concerns expressed by industry about its readiness to meet the 2020 implementation date. One is whether sufficient compliant fuel can be produced to meet demand. Only 1.6% of residual fuel oil (HFO) in use in the three years to 2017 would have complied with the 0.5% cap.[136] Other than the rare, compliant HFO, different fuel types will need to be used, such as a blend of low and high sulphur fuel, or distillates.[137] The 0.1% limit cannot be achieved with a blend.[138] It is unclear whether compliant fuel will be available at any given port, although bunker suppliers and refineries are working to ensure

[129] Resolution MEPC 320(74).
[130] MEPC.1/Circl.881 (21 May 2019).
[131] MEPC.1/Circ.884 (21 May 2019).
[132] Zheng Wan et al, 'Three steps to a green shipping industry' (2016) 530 *Nature* 277.
[133]R. Broome et al, above n 22, 91.
[134] Libby George, Ahmad Ghaddar,'New rules on ship emissions herald sea change for oil market', *Reuters* (online, 17 May 2018) <https://www.reuters.com/article/us-shipping-fuel-sulphur/new-rules-on-ship-emissions-herald-sea-change-for-oil-market-idUSKCN1II0PP>.
[135] Economic and other consequences are outside the scope of this paper.
[136] MEPC72-17, 5.23 (comments by Russia).
[137]GHG Study 2014, 284. Airlines are also concerned that there will be a dip in availability of jet fuel as refineries seek to meet increased demand for low sulphur fuel. Alex Longley 'Airline are Stepping Up Oil Hedges before 2020 Shipping Rule Bites' (Bloomberg, 6 September 2018). https://www.bloomberg.com/news/articles/2018-09-06/airlines-stepping-up-oil-hedges-before-2020-shipping-rule-bites accessed 19 November 2018.
[138] GHG Study 2014, 284.

availability by 1 January 2020. In any event, the Annex permits the use of higher sulphur fuel when compliant fuel is not available, subject to provision of evidence of unavailability.[139]

Technically, transition to the lighter sulphur fuel is not straightforward for engines that are designed to operate on heavy fuel oil.[140] There has been some apprehension that the qualities of such a blend will not be apparent: viscosity, flashpoint etc.[141] Nonetheless, in October 2018 MEPC73 resisted introducing an 'experience building phase' to the sulphur cap,[142] a proposal seen by some attendees as an attempt to delay the 2020 implementation of the cap.

As is currently the case, ships that enter ECAs (whether IMO designated or State imposed) may need to carry two different fuel oils (0.5% and 0.1%) and changeover fuel upon entering and leaving an ECA. Regulation 14 requires ships to carry a written procedure for doing so, and to record each changeover.[143] However, emissions do not change immediately following the changeover; it may take over an hour to reach a steady state representative of the new fuel.[144]

As already noted, reduction in sulphur content in fuels has been regarded as a proxy for reduction in PM. However, PM is still produced from lower sulphur fuels, which are nonetheless much more sulphurous (often by orders of magnitude) than road diesel. Lower engine loads can result in a higher degree of soot formation.[145] PM will be produced, therefore, whilst a ship is in port or whilst navigating at slow speed: such as close to coastal areas or in fjords. Importantly for understanding effects on health, while combustion of lower sulphur fuels may be expected to result in a reduced emission of PM mass, there may be an increase in the number of ultrafine particles emitted.[146]

Therefore even with lower sulphur fuels, increased numbers of ultrafine PM may be generated in the very surroundings where that PM is likely to cause the most health problems due to a concentration of population.[147] In congested shipping lanes and ports, States (or regions) may be tempted to regulate to reduce the sulphur content of fuel even further, in order to control emissions; this is the path taken by the EU. As we shall see, the EU has imposed stricter limit of 0.1% sulphur content for use by ships at berth in EU ports:[148] however, the studies suggest that the lower sulphur fuel may produce increased numbers of ultrafine particles, which may be especially harmful to human health.[149]

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[139] Regulation 18; and see *2019 Guidelines for the Consistent Implementation of the 0.50% Sulphur Limit under MARPOL Annex VI* (Res MEPC 320.74) which deals with fuel unavailability and annexes the Fuel Non-Availability Report (FONAR) to be completed by the ship.
[140] See the American Bureau of Shipping *Marine Oil Advisory 2018* found at https://ww2.eagle.org/content/dam/eagle/advisories-and-debriefs/marine-fuel-oil-advisory.pdf
[141] MEPC73/5/14 (submitted by Bahamas, Liberia, Marshall Islands, Panama, BIMCO, INTERTANKO and INTERCARGO).
[142] See Submissions MEPC 73/5/14 and 73/5/17.
[143] Regulation 14.6.
[144] M. Yusuf Khan et al, 'Benefits of Two Mitigation Strategies for Container Vessels: Cleaner Engines and Cleaner Fuels' (2012) 46 *Environmental Science & Technology* 5049 doi:10.1021/es2043646.
[145] DNV-GL *The effect of reducing cruise ship speed in the World Heritage fjords* (Report to the Norwegian Maritime Authority) 13 February 2018. More NO_x is also produced at slow speeds. Hulda Winnes & Erik Fridell, 'Emissions of NO_x and particles from manoeuvring ships' (2010) *Transportation Research Part D* 204. See Mueller, above n75.
[146] Wu et al, above n60. See discussion at 2.2 above.
[147] See discussion about Norway's electric ferries in 5.2.5 below.
[148] Directive (EU) 2016/802, Art 7.
[149] See discussion at 2.2.3 above.

There are other options to reduce PM from low sulphur fuel, such as particulate filters – similar to those used in diesel cars.[150] Such filters have been shown to remove upwards of 90% of fine and ultrafine PM.[151] The concern is that with no explicit PM reduction target contained in Annex VI, there is currently no imperative or incentive to explore their capabilities.

3.2.2 Meet the cap by using HFO coupled with a scrubber

Some shipowners have calculated they are better off taking advantage of the exemption from the 0.5% sulphur limit for ships fitted with scrubbers; at least for part of their fleet. Ships with scrubbers may continue to use fuel with a sulphur content of not more than 3.5%[152] if the effect is at least equivalent to the emissions reductions required by the Annex and the scrubber is approved by the flag State.[153] The Clean Shipping Alliance, a stakeholder group of shipowners committed to scrubbers, assert that when used with HFO, scrubbers reportedly reduce up to 98% of SO_x and between 60 - 90% of PM.[154] The manufacturers understandably emphasise the sulphur reduction capabilities of their scrubbers to establish compliance with the Regulation. Because scrubbers are not required to measurably reduce PM,[155] the extent to which they reduce fine and ultrafine PMs emissions is rarely mentioned.

Supporters of scrubber technology point out that using scrubbers creates a market for HFO which would otherwise constitute waste or require refining with consequent GHG emissions and investments in additional refining capability.[156] Ships fitted with scrubbers will be the only ships permitted to carry HFO for use as fuel.

In June 2018, Shell estimated that fewer than 2000 ships would have scrubbers fitted by the deadline.[157] In October, 2018, DNV GL claimed that 1700 vessels had scrubbers installed or orders for installation.[158] Others predict that as many as 25% of newbuilds may use that technology.[159] More than 43% of cruise ships will be retrofitted with scrubbers, and 48% of cruise ship newbuilds

[150] They are only effective when so combined: when used with high sulphur fuel the filters become ineffective or may actually produce PM: *Investigation of Appropriate Control Measures (abatement technologies) to reduce Black Carbon emissions from International Shipping* IMO, Air Pollution and Energy Efficiency Studies (2015) 3.8.2. However particulate filters may be effectively used with scrubbers. See the next section.
[151] The Danish Ecological Council *Cleaner shipping – focus on air pollution, technical solutions and regulation* (2edn, 2018) 19.
[152] ISO 8217 specifies the maximum sulphur content of high sulphur fuel oils as 3.5%.
[153] See Annex VI, Regulation 4. See 2015 guidelines for exhaust gas cleaning systems, adopted by MEPC in 2015 (MEPC.259(68). The Guidelines stipulate that EGCS compliance is determined by the measured SO_2/CO_2 concentration ratio (Table 3). There is no target for PM reduction.
[154] Clean Shipping Alliance 2020 press statement 'Ten Scrubber Questions Answered' 20 October 2018 Maritime Executive: https://www.maritime-executive.com/article/ten-scrubber-questions-answered.
[155] See *2015 Guidelines for exhaust gas cleaning systems* (MEPC.259(68)). Emissions measurements do not include PM.
[156] Clean Shipping Alliance (ibid).
[157] Sara Lawrence (Global Technical Manager, Shell Marine) 'Lubricant Options for a post 2020 world' Safety4sea.com 19 June 2018, accessed 19 November 2018. https://safety4sea.com/lubricant-options-for-a-post-2020-world/
[158] 'Installation of exhaust gas cleaning systems (SO_x Scrubbers) some practical recommendations' 8 October 2018 https://www.dnvgl.com/news/installation-of-exhaust-gas-cleaning-systems-sox-scrubbers-some-practical-recommendations-131328 accessed 6 December 2018.
[159] 'Clarksons: A Quarter of Ships on Order to be Fitted with Scrubbers' *World Maritime News* 30 August 2018.

will have scrubbers.[160] However, overall it appears only a small fraction of the world fleet of around 60,000 ships will be fitted with scrubbers.

Undoubtedly scrubbers are a pragmatic solution – perhaps, a halfway house – because they do allow ships to operate within IMO limits by continuing to use HFO rather than purchasing lower sulphur fuel. Some bemoan the fact that MARPOL permits scrubbers at all.[161] There are drawbacks: most importantly for our purposes, they tend to be effective at removing SO_x but less effective at removing the ultrafine $PM_{0.1}$ - the most dangerous PM. (This is not reflected by measure of PM removal efficiency, since ultrafine PM represents the major component of emitted PM by particle number, but only a small percentage of the PM mass – it is the latter on which scrubber efficiency is based.) Nor does there appear to be any incentive to improve – or even promote - the rate of PM removal by scrubbers, as the explicit target in Regulation 14 relates only to sulphur.

Secondly, scrubbers do not reduce CO_2 emissions; so their use does not contribute to a transition to low sulphur/no sulphur fuels. Thirdly, while many newbuilds will have to eschew scrubbers to comply with tightening EEDI requirements, those ships with no current EEDI rules – such as cruise ships – can still plan to install scrubbers on new builds; these ships could remain in operation for 25 or more years.[162] Fourthly, if scrubbers can be switched off, that allows operators to walk a tightrope of compliance by not using scrubbers (whilst burning HFO) on the high seas or when in the waters of a State not party to Annex VI.[163] Fifth, scrubbers add an extra layer of bureaucracy under Annex VI as they require approval by the flag state and monitoring under port state control. Finally, there is significant concern about the washwater from scrubbers;[164] some States have banned the operation of open loop scrubbers in their waters. This is briefly discussed below.

There is also a sense of a lost opportunity when it comes to scrubbers and PM. There would have been significant health benefits had regulations permitting scrubbers focussed on reduction of PM as well as SOx,[165] given than conventional wet scrubbers appear to be relatively ineffective in removing the submicron fraction of PM. Furthermore, recent research has suggested that PM-filtered gaseous emissions may be more toxic from HFO-fuelled ship engines than from DF-fuelled engines on account of the chemical species carried within the gas phase of HFO emissions.[166] This suggests that using lower sulphur fuel coupled with PM scrubbing mechanisms that efficiently reduce both the mass and number of emitted particles would potentially offer improved health

[160] MEPC 73/3/2 (30 August 2018) submission by CLIA.
[161] Dagfinn Lunde, former head of Intertanko. '2019 predictions and beyond' https://splash247.com/2019-predictions-and-beyond/ accessed 19 November 2018.
[162] Note that the cruise industry peak body, Cruise Lines Industry Association (CLIA) has announced its members will seek to reduce the rate of carbon emissions across the industry fleet by 40% by 2030: 'Cruise Industry Commits to Reduce the Rate of Carbon Emissions Globally by 40% by 2030' (Press Release, 18 December 2018). However, green groups have claimed the reductions are reductions in intensity rather than absolute emissions: 'CLIA Sets 2030 Carbon Emissions Target' *The Maritime Executive* (19.12.2018). Cruise passenger ships pose a challenge to EEDI because of the need to determine a proxy for 'transport work': see CLIA submission MEPC 74/6/1.
[163] Port of Auckland, *Cruise Vessel Emission Reduction Technologies Feasibility Study* (3 August 2017), 4.2.1: 'Anecdotally, vessels that have scrubbers currently do not operate these when berthed at Auckland. There is an operating cost associated with the scrubbers and it is fair to expect that lines would not self-impose those costs unless there was an incentive based scheme available or a mandatory requirement to do so.' https://www.poal.co.nz/sustain/Documents/Cruise%20Vessel%20Emission%20Reduction%20Technologies.pdf
[164] Washwater waste is a byproduct of open loop scrubbers; it contains PM and sulphur removed from the exhaust. Open loop systems release that washwater back into the sea.
[165] See Scapcariu et al, above, n 68.
[166] Ibid.

benefits over simply using one or the other mitigation strategy. Wet electrostatic scrubbers are also showing promise. The absence of regulations targeting PM means there is little incentive for shipowners to consider and adopt this technology.

3.2.3 Alternative fuels

Ships may also meet the sulphur cap by using alternative, cleaner fuels, or other means of propulsion such as electricity. LNG is the most developed alternative. LNG emits virtually no SO_x and less than 20% of PM of HFO,[167] but it can emit unburnt methane (termed "slip"), a GHG more potent than CO_2. The LNG production process is an intensive emitter of GHGs.

There are already ships in service with dual fuel engines to permit the use of LNG fuel by the main engine in areas where very low sulphur caps are in force, such as ECAs or EU ports. LNG retrofitting is expensive and the availability of bunkering facilities is still patchy.[168] Longer term, alternative sources of power such as methanol, hydrogen, electric, and biofuels may all come into play. The imperative for developing such alternative fuels comes from the push to reduce GHG emissions from ships, discussed in the next section.

3.3 Link between SO_x, NO_x and GHG measures

The background to the IMO regulation of GHG emissions is not the focus of this paper,[169] but as it is part of the broader context, and the solutions to both types of emissions overlap it is outlined here.

3.3.1 IMO measures to reduce GHGs

Combustion engines powered by fossil fuels also emit GHGs. The IMO control of air pollutants such as SO_x, NO_x and particulates predated the more recent concerns about GHG emissions from ships. MARPOL Annex VI, originally a means by which to control air pollutants such as SO_x, NO_x and particulates, has expanded to encompass GHG measures as well. GHG and air pollution are governed by separate Regulations in Annex VI and are two separate items on the MEPC agenda.

The sulphur cap will not *directly* assist with a reduction of GHG emissions such as CO_2. MARPOL Annex VI Regulation 14, and its control of the SO_x content of marine fuel oil, will reduce SO_x and overall PM emissions significantly. But ships that comply with the cap through the use of lower sulphur fuel are still running on carbon-based fuel; because the ships continue to burn fossil fuel, the sulphur cap does not of itself reduce GHG emissions nor NO_x emissions.[170] Nor will there be an improvement in GHG emissions from the ships who are permitted to continue to burn HFO using scrubbers.

The IMO has been exploring the need to reduce GHG emissions for more than two decades. [171] The IMO has been caught between an industry heavily reliant on high GHG emitting cheap fossil fuel and a world community increasingly expecting a move away from it –whilst, ironically, highly dependent

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[167] Laurie Goldsworthy, *Exhaust Emissions from Ship Engines* (2010) 24 ANZ Mar LJ 21, 25.
[168] *Investigation of Appropriate Control Measures (abatement technologies) to reduce Black Carbon emissions from International Shipping* IMO, Air Pollution and Energy Efficiency Studies (2015) 6.4.3.
[169] See K. Goddard, 'Is it time to reconsider sails?' (2010) *Lloyd's Maritime and Commercial Law Quarterly* 453, 465.
[170] It does however incentivise the investigation of alternative fuels, discussed below.
[171] The 1997 MARPOL Conference invited MEPC to undertake a study of CO_2 emissions from ships (Resolution 8).

on the transport work efficiency that fossil fuel provides. Over the years, the pace by which IMO has been addressing the GHG problem has been criticised, particularly by the EU, given its own efforts to reduce carbon emissions from industry and transport. The EU announced it would propose legislation on GHG emissions from ships if the IMO had not made significant progress by the end of 2011.[172] After a voluntary trial, in 2011 the IMO introduced compulsory EEDI and SEEMP measures via amendments to Annex VI to assist in curbing both NO_x and GHG. Those amendments, discussed in 3.1.1 above, came into force on 1 January 2013.[173] The IMO claimed that the 2011 amendments constituted the first legally binding climate deal with global coverage since the *Kyoto Protocol*.[174]

Compellingly, the IMO's third GHG Study (published in 2015) projected that if the international shipping industry's GHG emissions were unchecked, by 2050 they could have increased between 50 and 250%, and amount to up to 17% of the total global emissions.[175] Further, that Study showed that whilst efficiency improvements are important in mitigating emissions, efficiency improvements alone will not be sufficient to yield a downward trend in GHG emissions as world trade increases.[176]

The IMO was criticised for not going far enough. Discussions at IMO concerning a market based mechanism, tax or levy for shipping[177] came to naught.[178] In 2015 the EU adopted Regulation 2015/757 setting out a monitoring, reporting and verification scheme for maritime emissions, as a first step towards an EU market based measure for reduction of GHGs. Ships must collect data for voyages to and from EU ports (including the parts of the voyage beyond EU territory.)[179] In 2016, MEPC amended Annex VI to include its own data collection system for fuel consumption of ships, starting 1 January 2019.[180] In 2017, the EU Parliament warned that unless the IMO delivered 'the required level of ambition', maritime transport emissions would be included in the EUs emissions trading scheme from 2023.[181]

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[172] SEC (2009) 1343, p. 35. See Henrik Ringbom, 'Global Problem – Regional Solution? International Law Reflections on an EU CO_2 Emissions Trading Scheme for Ships' (2011) 26 *The International Journal of Marine and Coastal Law* 613.

[173] (Some 16 years after the original IMO resolution on CO_2 emissions from ships in 1997: MP/CONF.3/35, 1997)

[174] See MEPC 72/17 *Initial IMO Strategy on Reduction of GHG Emissions from Ships,* 1.3.

[175] *Third IMO Greenhouse Gas Study 2014 Executive Study and Final Report* (IMO, 2015). BIMCO claims the IMO has used unrealistically high GDP growth projections. 'BIMCO demands 4th IMO GHG Study based on realistic economic growth' *BIMCO News* 13 February 2019 https://www.bimco.org/news/priority-news/20190213-fourth-imo-ghg-study. The terms of reference for the Fourth GHG Study were approved at MEPC74 . That Study is due to be submitted to MEPC76 in late 2020 (MEPC74/18, Section 7 and Annex 18).

[176] Ibid, 5.3.

[177] See Md Saiful Karim & Felicity Deane, (2014) *Lloyd's Maritime and Commercial Law Quarterly* 370.

[178] MEPC62 (July 2011), resolution MEPC.203 (62) *Inclusion of regulations on energy efficiency for ships in MARPOL Annex VI.*

[179] *Regulation (EU) 2015/757 on the monitoring, reporting and verification of carbon dioxide emissions from maritime transport, amending Directive 2009/16/EC*. The EU's ability to impose such requirements has been the subject of legal commentary: see articles at n 218 below.

[180] MEPC 278(70).

[181] 'EU Parliament, Council Reach Deal on EU ETS (World Maritime News, 9 November 2017). See discussion of WTO implications: Md Saiful Karim & Felicity Deane,above, n 177; also Dobson & Ryngaert, below n 218; Henrik Ringbom, 'Global Problem – Regional Solution?' above n 172.

In a watershed decision, in April 2018 the IMO Marine Environment Protection Committee (MEPC72) adopted the *Initial IMO Strategy on reduction of GHG emissions from ships*.[182] This contains 'levels of ambition': (inter alia)

- aiming for a reduction in CO_2 emissions per transport work, at an average across international shipping, by at least 40% by 2030, pursuing efforts towards 70% by 2050, compared to 2008; and
- to peak GHG emissions from international shipping as soon as possible and to reduce the total annual GHG emissions by at least 50% by 2050 compared to 2008 whilst pursing efforts towards phasing them out.[183]

There is still much work to be done. The IMO's work on GHG emissions proceeds alongside the separate work items of air pollution and energy efficiency, and black carbon, on the agenda of MEPC.

3.3.2 Convergence

As already noted, the 2020 sulphur cap will not *directly* reduce GHG emissions. Lower sulphur fuel is still a fossil fuel; and scrubbers do not reduce CO_2 emissions. Furthermore, any reduction in PM emissions may have unintended detrimental consequences for the environment, including loss of the cooling effect of emitted PM.[184] However the obligation to comply with the sulphur cap, together with NO_x limits, EEDI requirements and SEEMP as set out in Annex VI combine to create the imperative (as well as financial incentive) for shipowners to find different ways to ensure full compliance with IMO requirements. This is spawning a myriad of research and development into technical and operational measures.[185] Those include:

- engines that use currently available alternative fuel types such as LNG[186] and electric batteries;[187]
- much more efficient ship design, including engines, keel and propeller design such that, although burning fossil fuels, require less fuel to perform the transport work;[188]
- management practices aimed at optimising fuel economy, such as slow steaming, weather routing, 'just in time' arrivals, and hull maintenance;[189]
- encouraging R&D into the alternative fuels and methods of propulsion of the future such as electric engines, hydrogen, methane, solar power, Fletner rotors, kites or sails.

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[182] MEPC.304 (72): http://www.imo.org/en/KnowledgeCentre/IndexofIMOResolutions/Marine-Environment-Protection-Committee-%28MEPC%29/Documents/MEPC.304%2872%29.pdf
[183] MEPC 72/17/Add.1, 3.1.
[184] Sofiev et al, above n 46.
[185] See Andreas Chrisostomou and Eivind S Vågslid, 'Climate Change – A challenge for IMO too' in Regina Asariotis and Hassiba Benamara (eds) *Maritime Transport and the Climate Change Challenge* (Earthscan Routledge, 2012), 94.
[186] See 3.2.3 above.
[187] Concerns over the mining and disposal of metals required in the production of batteries are outside the scope of this paper.
[188] Although vessels must have sufficient power to maintain manoeuvrability in adverse conditions, about which MEPC has issued Guidelines: (resolution MEPC.232(65) as amended.
[189] See *2016 Guidelines for the development of Ship Energy Efficiency Management Plan* (MEPC.282 (70)); Notably, slow steaming can decrease fuel consumption by about 20%: IMO, *Study on the Optimisation of Energy Consumption as part of Implementation of a Ship Energy Efficiency Management Plan* (2016), 2.2.2, but slow steaming may lead to an increase in PM.

So how will all of these international measures aimed at GHG reduction affect the rate of sulphur and particulate emissions? As a general rule, reducing fuel consumption and reliance on fossil fuels will reduce the 'per ship' emission of sulphur and particulates. Clearly, this is very welcome.

While fossil fuels are in use, even with efficiency measures, an increase in world trade/shipping traffic will also increase emissions. A growth in trade means more ships, more voyages and more port movements. Thus, the move to low carbon and eventually carbon free fuels anticipated by the IMO's GHG initial strategy is necessary, and will bring the additional – and significant- benefit of a reduction in SO_x and PM emissions as well as minimising GHG emissions.

4 Regulation 14: Enforcing Compliance with 2020 sulphur cap

Annexe VI imposes obligations on the flag state, port state and bunker suppliers to enforce Regulation 14 and Regulation 18, which deals with fuel oil availability and quality.

4.1.1.1 Obligations on State parties – fuel availability

State parties must take reasonable steps to ensure that compliant fuel oils are available in their jurisdiction.[190] As regards suppliers, Regulation 18.9 requires each State party to:

- maintain a register of local suppliers,
- require suppliers to provide a compliant bunker delivery note (BDN)[191] and provide a sample of fuel supplied, sealed and signed by both supplier and the ship officer in charge of bunkering.,
- require suppliers to keep a copy of each BDN for 3 years, and the oil sample for at least 12 months;
- take action against suppliers found to have delivered oil not complying with the standard stated on the BDN; as well as informing the affected flag state, and the IMO.

Where ships trade into ECAs and use separate fuel oils for the ECA, there must be a written procedure for the changeover, and each changeover must be documented and logged in accordance with the Regulation.[192]

If a ship finds itself unable to obtain compliant fuel it must document and evidence its attempts: a ship is not required to deviate from its intended voyage or delay unduly the voyage in order to achieve compliance.[193] The International Energy Agency anticipates that about 16% of the global fleet will be non-compliant in 2020, mainly due to non-availability of fuel, but that availability will spread within a few years.[194]

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[190] Regulation 18.

[191] Regulation 18.5. Bunker delivery notes must contain at least the information specified in appendix V to the Annex.

[192] Regulation 14.6.

[193] Regulation 18.2. (Regulation 18.2.2). It must inform the port state and its flag state of the inability to locate compliant oil. (Regulation 18.2.4.) *2019 Guidelines for the Consistent Implementation of the 0.50% Sulphur Limit under MARPOL Annex VI* (Res MEPC 320.74) deal with fuel unavailability and annexes the Fuel Non-Availability Report (FONAR) to be completed by the ship.

[194] Anastassios Adamopoulos, 'Marine gasoil demand to double on IMO rules, say IEA' (Lloyd's List, 11 March 2019) reporting on the release of International Energy Agency, *Oil 2019 Analysis and forecast to 2024.* <https://lloydslist.maritimeintelligence.informa.com/LL1126567/Marine-gasoil-demand-to-double-on-IMO-

4.1.1.2 Obligations on flag states

Flag States are expected to ensure the ships on their register comply with Annex VI. They certify as much by issuing each ship an Air Pollution Prevention Certificate.[195]

As we have already seen, Annex VI Regulation 4 permits party flag States to accept the fitting of a scrubber, and ongoing use of HFO so long as the scrubber is at least as effective in terms of emissions reductions as the use of compliant fuel.[196] In determining what scrubbers will be acceptable, flag States are to take into account relevant guidelines issued by the IMO as to permitted equivalents.[197]

4.1.1.3 Obligations on State parties – port State control

MEPC has issued Guidelines for port State control regarding MARPOL Annex VI.[198] Port States are entitled to carry out inspections on visiting ships to verify operational compliance with Annex VI requirements[199] and to verify whether the ship has emitted any of the substances covered by the Annex in violation of its provisions.[200] Information about any violation is to be passed to the flag State.[201] In the event of non-compliance, Port State Control Officers may detain the vessel.[202] Whilst carrying out inspections for general compliance with IMO regulations including MARPOL, inspectors will check fuel already on board for compliance with the sulphur limit.[203] The inspectors can also check scrubbers.[204]

Each State is obliged to put laws in place setting out requirements, facilitating inspections, and creating offences and appropriate penalties for their breach.[205] By rights, given that sulphur caps have existed since 2005, these should already be in place. If there is evidence that an offence has been committed, then the flag state or the port state will prosecute under domestic law enacted in pursuit of that State's obligations under Annex VI. The penalties are to be determined by domestic law. Undoubtedly there will be differences between States in terms of rates of inspection,[206] as well

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rules-says-IEA> [note to ed: i am relaxed if you do not wish to include the link for this and others, but included them out of abundance of caution.]

[195] Regulation 9.

[196] The flag State must communicate their decision to IMO for distribution amongst parties. There is also an exception for shipowners trialling new technologies: Annex VI, Regulation 3.2.

[197] In 2015 MEPC released *Guidelines for Exhaust Gas Cleaning Systems:* Res. MEPC.259(68) (2015 Guidelines). The guidelines specify the requirements for the testing, survey certification and verification of EGC systems by flag States. Scrubbers produce waste, which is to be dealt with in accordance with the 2015 Guidelines: see 10.4.

[198] See *2009 Guidelines for Port State Control under the revised MARPOL Annex VI* (res. MEPC.181(59), and *2019 Guidelines for Port State Control Annex VI Chapter 3* (res. MEPC.321(74).

[199] Regulation 10.

[200] Regulation 11.

[201] Regulation 11.2.

[202] Regulation 10.1 and 10.2; see also *2019 Guidelines for Port State Control Annex VI Chapter 3* (res. MEPC.321(74), 2.7.2.)

[203] See *2009 Guidelines for port State control under the revised MARPOL Annex VI* (res. MEPC.181(59).

[204] MARPOL Annex VI regulation 10; 2015 *Guidelines for Exhaust Gas Cleaning Systems*, 4.2.3.2; 5.3.2. *2019 Guidelines for Port State Control Annex VI Chapter 3* (res. MEPC.321(74), 2.2.

[205] IMO has produced guides to assist countries incorporate Annex VI into national law: *Ship Emissions Toolkit, Guide no 2: Incorporation of MARPOL Annex VI into national law* (2018).

[206] Although one of the benefits of a MOU is that members settle on agreed rates of inspection.

as the penalties for offences and other consequences for non-compliance.[207] They may include detention of the vessel or offloading of the offending fuel.

The extra expense of complying with the cap may tempt some operators to use non-compliant fuel and/or falsify the documents and samples. Industry intelligence agencies analyse inspection rates and penalties accruing in each jurisdiction, giving operators the tools to take calculated risks.[208] Unscrupulous operators may attempt to play the odds, by frequenting ports known to have a low inspection rate, or those with low penalties. Such a course of action is tempting, given that Panamax operator may save US$10,000 a day by using HFO rather than compliant fuel.[209] Further, not all States are parties to MARPOL Annex VI, and non-party states will not be inspecting for compliance with Annex VI standards.

Port States might struggle to collect evidence of non-compliance occurring outside their waters. The carriage ban approved at MEPC73 will allow port States to impose sanctions for the carriage of non-compliant fuel oil even if it had not been used for combustion in that port's jurisdiction.[210] The port State will be assisted by the reporting requirements and the availability of bunker samples – held by both ship and supplier. Further, new technological developments have the ability to test ship emissions; for example, a port may use 'sniffer drones' that might be sent out to greet the vessel; and bridge mounted sensors can sample emissions as the ship approaches port. [211]

Regional MOUs on port State control are important to minimise avoidance and the consequent distortion of competition. Whilst not legally binding, the parties to MOUs nonetheless commit to establishing and maintaining an effective system of port state control, aiming to attain an annual inspection rate of a percentage of all ships operating in the region. Ships are selected for inspection based on an agreed order of priority. Several MOUs have conducted Concentrated Inspection Campaigns (CICs) on Annex VI requirements during 2018. The aim was to establish the level of compliance, create awareness amongst ships' crew and owners about the importance of compliance; send a signal to the industry that prevention of pollution and enforcement of compliance is high on the agenda of MOU member states, and underline the importance of the Port State Control to harmonised enforcement.

There have been few reported examples of prosecutions for breach of the 3.5% sulphur cap in force prior to 2020. With the global average HFO sulphur content being around 2.7%, it was relatively easy to comply with that limit.[212]

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[207] For example, in the EU, port state control has evolved from a two step (inspection and detention) model to allow greater use of mandatory inspections of certain ships, automatic detention for some deficiencies, and public blacklisting for non-compliant ships and operators: see Henrik Ringbom, 'Regulatory Layers in Shipping' in Vidas, Davore, and Peter Johan Schei *The World Ocean in Globalisation: Climate Change, Sustainable Fisheries, Biodiversity, Shipping, Regional Issues* (BRILL 2011) 345 357 (Ringbom, Layers).

[208] Mike Wackett, 'Fines for breaking new ECA zone sulphur won't match the higher fuel cost' *The Loadstar* 23 March 2014 https://theloadstar.co.uk/confusion-policing-penalties-contravening-new-eca-zone-restrictions/ .

[209] As quoted before the IMO by Cook Islands & Norway (PPR5/13/2, (30 November 2017) par. 5), which proposed a ban on carriage of non-compliant fuel by a ship not entitled to use it (ie a ship without scrubbers).

[210] Ibid, Cook Islands & Norway par 7.

[211] As to coastal states and the UNCLOS provisions relating to marine pollution, see Henrik Ringbom, 'Enforcement of the sulphur in fuel requirements: the same, only different.' 2017 (482) *MarIus* 45 - 110.

[212] There have been prosecutions under the EU regulations: See 5.1 below.

The penalties for non-compliance need to be set at a level that poses a true disincentive. Further, the regulations will be toothless if not coupled with requisite resources to set up systems, gather information and enable inspections and prosecution.

As Henrik Ringbom sagely observed:

> [T]he introduction of new rules, without proper implementation, tends to benefit those who were targeted in the first place. Ship operators who routinely flout the required standards will obtain a competitive advantage from rules that are not properly enforced, as many of their more scrupulous competitors are likely to go through the often burdensome implementation process anyway. In this sense new rules, at any level, might only widen the gap between those 'good' operators who do their best to comply and the 'bad' ones who do not- and are usually the main target of regulators.[213]

Even within the highly motivated and well-funded auspices of the EU, the practical challenges of enforcing sulphur limits have been known to be a challenge.[214] Clearly they would be multiplied for a country without the resources and means to properly enforce their port state responsibilities: ports in danger of becoming 'ports of convenience'.[215] It would be unfortunate if less efficient ships, using non-compliant fuel, find a haven in countries who have weak enforcement of the requirements of MARPOL VI: particularly as a failure to enforce Annex VI *will* lead to poorer air quality for its population.

The IMO recognises that consistency of implementation and enforcement of the sulphur limit is critical to ensure that commercial distortion is minimised,[216] Annex VI permits the IMO to audit states for compliance with their obligations. However, ultimately it is for flag and port States to ensure their houses are in order.[217]

5 Regional, national and port based regulation

As already discussed, PM pollution especially affects regions nearby to shipping lanes and surrounding ports. It is unsurprising that some countries and regions with significant regional air pollution decided to regulate sulphur content of marine fuels ahead of MARPOL limits by imposing more stringent caps on sulphur content of marine fuel. Those areas already subject to more stringent caps will see zero effect from the 2020 global sulphur cap.

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[213] Above n 207, Ringbom 'Layers', 366-367.

[214] Even the EU, in the preamble to the Directive 2012/33/EU, noted that the experience with the 1999 Directive showed the need for a stronger monitoring and enforcement regime, with Member States ensuring 'sufficiently frequent and accurate sampling of marine fuel placed on the market or used on board ship as well as regular verification of ships' log books and bunker delivery notes…'. Member States should also establish a system of effective, proportionate and dissuasive penalties for non compliance…(17). More detailed reports, and harmonised reporting generally, were also required. (18).

[215] Bevan Marten, *Port State Jurisdiction and the Regulation of International Merchant Shipping* (Hamburg Studies on Maritime Affairs, 2014) 7.5.

[216]A MEPC subcommittee was tasked with overseeing the implementation through 2018 and 2019. : IMO Meeting Summary, PPR 4th Session 16-20 January 2017. Through 2018 and 2019, much of the MEPC's work concerned implementation of the sulphur cap: as outlined in n129-131 above, MEPC74 approved a plethora of guidelines.

[217] As to the structural difficulties of regulating in this area, see Alan Khee-Jin Tan, *Vessel-Source Marine Pollution: the Law and Politics of International Regulation* (Cambridge University Press, 2005).

Controversy surrounds the national or regional imposition of stricter caps on sulphur content of fuel used by foreign ships. Lawyers and academics have mused over whether tighter regulations might be invalid on the grounds they are 'not in conformity' with international law: in other words, being stricter than MARPOL, such laws may exceed the scope of that State's legislative and enforcement powers under international law.[218] Similar arguments were aired in a judicial challenge to EU laws that included aviation in the EU emissions trading scheme. That challenge was unsuccessful.[219] Suffice to say that the dominant view amongst academics seems to be that the imposition of certain stricter standards by a port state is permissible and may be characterised as an exercise in territorial jurisdiction.[220] International law does not give a right to ships to enter foreign ports, and therefore port states may impose conditions for access;[221] although there is little explicit guidance into just how far a port state can go.[222] On that basis a port state may impose its own requirements concerning fuel and reporting on ships visiting the port, so long as they are reasonable.[223] In any event, the extent of the inconsistency between national and international limits has been reduced since 1 January 2020 because some countries had merely brought forward the operational date of the 0.5% sulphur limit. At the other end of the spectrum, and also adding to the complexity, is that some party States may decide not to enforce the 2020 cap for domestic voyages.[224] And, of course, some States are not parties to Annex VI at all.

A new patchwork of regulation is also developing as regards the discharge of wastewater from scrubbers (briefly discussed below at 5.2.6). Individual States have begun imposing bans on the discharge of wastewater from scrubbers within port waters.[225] These bans are over and above the requirements of MARPOL Annex VI; but so long as the State seeks to ban discharges within its

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[218] James Harrison, 'Pollution of the Marine Environment from or through the atmosphere' in *The IMLI Manual on International Maritime Law Vol III* (OUP, 2016) 191. For example, Henrik Ringbom, 'The Changing Role of Flag, Port and Coastal States under International Law' chapter in *General Trends in Maritime and Transport Law 1929 – 2009*; at IV; Alan Khee-Jin Tan, 'The EU Ship Source Pollution Directive and coastal state jurisdiction over ships' (2010) *Lloyd's Maritime and Commercial Law Quarterly* 469, 476 onwards; James Harrison, 'Pollution of the Marine Environment from or through the atmosphere' in *The IMLI Manual on International Maritime Law Vol III* (OUP, 2016) 191; Robin Churchill, 'Port State Jurisdiction Relating to the Safety of Shipping and Pollution from Ships – What Degree of Extra-territoriality?' (2016) 31 *International Journal of Marine and Coastal Law* 442; Natalie L Dobson and Cedric Ryngaert, 'Provocative climate protection: EU "Extraterritorial" regulation of maritime emissions' (2017) *International and Comparative Quarterly* 295; Bevan Marten, 'Port State Jurisdiction, International Conventions and Extraterritoriality: an Expansive Interpretation' (2018) 8 VUWLRP 7, 17 and authorities cited there.

[219] Case C-366/10 *The Air Transport Association of America & ors v The Secretary of State for Energy and Climate Change* [2011] See Sanja Bogojević, 'Legalising Environmental Leadership: A comment on the CJEU's Ruling in C-366/10 on the Inclusion of Aviation in the EU Emissions Trading Scheme' (2012) *Journal of Environmental Law 345.*

[220] Churchill, above, n218, 454.

[221] Henrik Ringbom, 'The European Union and International Maritime Law – Lessons for the Asia Pacific Region' (2016) 30 *Australia and New Zealand Maritime Law Journal* 67, 70 – 71.

[222] See Henrik Ringbom, 'Regulation of ship-source pollution in the Baltic Sea (2018) 98 *Marine Policy* 246, 247.

[223] See authorities cited at n218 above.

[224] It has been reported that Indonesia, a party State to Annex VI, announced it would not enforce the 2020 cap for vessels on domestic voyages, only to backflip weeks later: Bernadette Christina Munthe, Roslan Khasawneh, 'Indonesia will not enforce IMO low-sulphur fuel rules on domestic fleet' *Reuters.com* (online, 26 July 2019); Bernadette Christina Munthe, 'Indonesia will implement IMO low sulphur fuel rule on schedule' *Reuters.com* (online, 20 August 2019).

[225] See 5.2.6 below.

territorial waters, they are a straightforward exercise of territorial jurisdiction over the adjacent environment.[226]

Individual states and regions unilaterally implementing stricter standards can be criticised for the resultant patchwork of regulations with which each ship must comply. Nonetheless, there can be benefits. First, where a country or region instigates stricter limits, the effect can be to put pressure on the international community via IMO.[227] Secondly, the experience of implementation can inform the international community, effectively acting as a pilot study. The EU is a good example of both these effects.[228]

5.1 Regional regulation: EU

The EU is not a direct party to MARPOL. However, it is now a key player in international maritime regulation. The EU has been anxious to impose limits of ship emissions in a way that matches or at least reflects the efforts made to reduce emissions on land.[229]

The two original IMO ECAs are adjacent to at least some EU states. They are the Baltic Sea ECA, and the North Sea ECA,. The latter extends down the east coast of the United Kingdom and along its southern coastline. Notably, the Mediterranean is not itself an ECA, and has a great deal of cruise ship traffic. This has led to claims that the older ships that are more polluting operate there.[230] There are moves afoot to prepare a case for the Mediterranean to become an ECA.[231] The western coastline of the UK and Ireland also fall outside the ECA.

Regional regulation has a larger impact than mere national regulation. 'Regionally coordinated port-state requirements…reduce the economic risk that ships might divert to a neighbouring port state with more lenient standards…'[232] The co-ordinated action of the EU over marine fuel sulphur limits has seen IMO type limits instituted swiftly, with consequent emissions benefits, by applying to ships wishing to visit the coastal waters or a port of an EU country.[233]

The EU has long taken the view that it is entitled to impose stricter requirements on ships visiting its waters.[234] Through a series of Directives and Regulations, the EU has sought to 'improve' upon IMO measures to reduce sulphur content of fuel. [235] Directive 1999/32/EC (1999 Directive), the EU imposed a sulphur fuel limit of 1.5% m/m on ships operating within the Baltic Sea and North Sea

[226] Alan Khee-Jin Tan, 'The EU Ship Source Pollution Directive and coastal state jurisdiction over ships' (2010) *Lloyd's Maritime and Commercial Law Quarterly* 469, 482.
[227] Churchill, above, n218, 453.
[228] Henrik Ringbom, 'The European Union and International Maritime Law – Lessons for the Asia Pacific Region' (2016) 30 *Australia and New Zealand Maritime Law Journal* 67, 76-77.
[229] MARPOL Protocol 1997, Annex VI, regulation 14 (1) first imposed a limit on sulphur content of fuel of 4.5%.
[230] https://www.theguardian.com/world/2018/jul/06/i-dont-want-ships-to-kill-me-marseille-fights-cruise-liner-pollution
[231] MEPC73.
[232] Ringbom, Layers above, n207, 357.
[233] Ibid, 354.
[234] The '*MSC Orchestra'* [2014] 1 Lloyd's Law Reports 496, 501 (European Court of Justice). See generally Henrik Ringbom, 'Enforcement of the Sulphur in Fuel Requirements: Same, Same but Different' above n 89; and Henrik Ringbom, 'The European Union and International Maritime Law – Lessons for the Asia Pacific Region'above n 230 ; Natalie L Dobson and Cedric Ryngaert, 'Provocative climate protection: EU "Extraterritorial" regulation of maritime emissions' (2017) *International and Comparative Quarterly* 295.
[235] Ringbom (Layers), above n 207, 358.

ECAs.[236] The 1999 Directive came into force in 2003, two years before MARPOL Annex VI - effectively an early introduction of the 1.5% limit stipulated by Annex VI. Amending Directives were made in 2005[237] and 2012,[238] and a codifying Directive in 2016 (the Sulphur Directive).[239]

The Sulphur Directive imposes a lower sulphur limit for:

- fuel used by inland waterway vessels (0.1%);[240]
- fuel used on ships whilst at berth in an EU port (0.1%);[241] and
- fuel used by passenger ships whilst in territorial seas, EEZs or pollution control zones whilst operating 'regular services' to or from any Union port (1.5%).[242] (This limit is now rendered obsolete by the 2020 global sulphur cap).

Penalties adopted by member states are to be 'effective, proportionate and dissuasive…'[243]

In the decision of *Manzi v Capitaneria Di Porto di Genova ('the MSC Orchestra')* the European Court of Justice ruled that the EU sulphur limit, although stricter than the MARPOL limit, was valid and enforceable.[244] Further, the court found that cruise ships were passenger ships 'operating regular services' as defined and therefore were required to comply with the 1.5% limit imposed by the EU.[245] In a high profile recent case, in November 2018 the French prosecuted the Master of the Carnival Ship *Azura* for buying fuel that did not comply with the applicable EU 1.5% sulphur cap for passenger vessels. The master was fined €100,000, with Carnival ordered to pay most of the fine. It is reported that Carnival intends to appeal, saying it had been told by the French Government that the limit did not apply to cruise ships.[246]

5.2 National and State based regulation of sulphur emissions from ships

It is not possible to canvas the full gamut of national regulation on the sulphur content of marine fuel. Below is a summary of a selection of national and regional regulations. While some regulations merely brought forward the starting date of the 2020 cap, others take quite a different form. The summary is a snapshot of the degree of regulatory variation (both geographically and in scope of provisions) with which ship operators need to contend.[247]

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[236] Article 4a, Directive 1999/32/EC. MAPROL Annex VI finally came into force in May 2005, at which time the 1.5% limit applied within the ECAs under international law.
[237] 2005/33.
[238] Directive 2012/33.
[239]Directive 2016/802.
[240] Art 7, Sulphur Directive.
[241] Ibid.
[242] Article 6(5), Sulphur Directive.
[243] The penalties 'may include fines calculated in such a way as to ensure that the fines at least deprive those responsible of the economic benefits derived from the infringement of the national provisions… and that those fines gradually increase for repeated infringement.' Article 18, Sulphur Directive.
[244] [2014] 1 Lloyd's Law Reports 496.
[245] See also Swedish Case No. M 8471-03, Svea Court of Appeal, Environmental Court of Appeal (Miljööverdomstolen), Judgment of 24 May 2006, referred to in Ringbom, above n 89, 12.
[246] http://www.seatrade-cruise.com/news/news-headlines/carnival-to-appeal-p-o-captain-s-fine-for-high-sulfur-fuel.html accessed 27 November 2018.
[247] Port based incentives for green initiatives are briefly mentioned at 5.3 below.

5.2.1 USA

The USA is not a party to UNCLOS but is a party to MARPOL Annex VI. As we have seen, most of USA coastal waters fall within its ECA. Engines installed on US vessels are also subject to emission standards for PM exhaust emission, which also requires the measuring of PM emissions for certification testing.[248]

California

The State of California was a 'first adopter' of local shipping emissions regulations, seeking to reduce ship emissions of PM, diesel PM, NO_x and SO_x.[249] The 2008 Regulation introduced a limit on the sulphur content limit for maritime fuel used within 24 nautical miles (nm) of its coastline by ocean going ships scheduled to enter its internal waters from mid-2009.[250] In effect, the use of compliant fuel is a condition of entry into its ports. (The US used a similar strategy to require double hull tankers into its waters in the early 1990s.)[251] The 24nm limit was the subject of an unsuccessful challenge by the Pacific Merchant Shipping Association, which claimed California could only permissibly regulate within 3 nm rather than in federal waters.[252] Fines for violations can be hefty. A shipowner whose vessel failed to switch all engines and boilers over to low sulphur fuel over 17 visits between 2009 and 2011 was reportedly fined US$283,500.[253]

California's sulphur limits have stepped down as follows:

Effective date	% fuel sulphur content
1 July 2009	Marine gas oil (MGO) 1.5%; marine diesel oil (MDO) 0.5% sulphur
1 August 2012	MGO 1%, MDO 0.5% sulphur
1 January 2014	MGO or MDO 0.1% sulphur

The introduction of the 0.1% limit predated the MARPOL North American ECA by one year. The Californian scheme is, however, not completely aligned with the MARPOL ECA. The MARPOL ECA imposes the same limit of 0.1%, but extends to a far greater area (200nm). However MARPOL permits the use of technology such as scrubbers to achieve the same reduced emissions. The Californian regulations do not permit the use of scrubbers, unless for experimental or research purposes.[254] Although the Californian regulators expect to discontinue the Regulation given the

[248] For example, *Control of Emissions from New and In-Use Marine Compression- Ignition Engines and Vessels,* Protection of the Environment, 40 Code of Federal Regulations Part 1042.
[249] *Fuel Sulfur and Other Operational Requirements for Ocean-Going Vessels within California Waters and 24 Nautical Miles of the California Baseline*, 13 CCR section 2299.2 (a).
[250] *Fuel Sulfur and Other Operational Requirements for Ocean-Going Vessels within California Waters and 24 Nautical Miles of the California Baseline* 13 CCR section 2299.2 (c): Ships engaged in continuous and expeditious navigation through Californian waters without entering internal or estuarine waters or calling at a port or facility are exempt.
[251] *Oil Pollution Act 1990* (US), s. 4115; 46 USC 3703a.
[252] US Court of Appeals (9th circuit) rejected the PMSA appeal: *Pacific Merchant Shipping Association v. Goldstene* 639 F.3d 1154 (9th Cir. 2011).
[253] The shipowner then claimed against the ship manager for negligence in failing to properly update the ship's Safety Management System: 'Ship manager fined for breach of US Sulphur emission regulations' *Maritime Risk International* May 2015.
[254] Ibid, 299.2(b)(6). See California Air Resources Board *Marine Notice 2017-1* (August 2017).

MARPOL ECA, to date California has chosen to keep its regulations.[255] The result is that ships may use scrubbers to satisfy the MARPOL ECA sulphur limits from 200 nm to 24nm, but once the ship is in Californian waters the ship must use low sulphur fuel or pay a fee in lieu of direct compliance.[256]

California also regulates the power usage[257] of certain types of ships[258] whilst at berth in major Californian ports.[259] The *At Berth Regulations* impose obligations on the owners of fleets to gradually reduce their fleetwide onboard power generation, thereby encouraging either the use of shore power or some alternative source of power/fuel on board. By 2020, fleet owners are required to have reduced their onboard diesel engine power generation by 80% of the baseline fleet emissions.[260] The Regulations also require a stepped reduction in the 'at berth' operational time limits for on board auxiliary diesel engines.

The *At Berth Regulations* extend to those supplying shore power, who must ensure the power is generated from a source that complies with prescribed emission standards.[261] In addition, terminal operators must submit plans as to how it will accommodate ship visits in accordance with the Regulations.[262] There are various ship, fleet, port and terminal reporting and recordkeeping requirements.[263] Violations are punishable under Californian law and as specified under the Health and Safety Code,[264] and there is a separate violation for every hour during which the violation subsists.[265]

Alaska

Only a fraction of Alaska's coastline is within the North American ECA. Cruise ship tourism is a major industry, and the ships visit remote and undeveloped wilderness.

Alaskan Regulation enforces emission standards imposed on ships measured by visible emissions – namely the opacity of emissions as assessed by visual means.[266] Within 3 miles of the coastline of Alaska a ship must not impede visibility through its exhaust effluent by more than 20%, except for certain limited and timed exceptions whilst manoeuvring into or out of berth.[267] Large commercial

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[255] Although there are moves to transition to reliance on the federal program alone, the Californian authorities will only do so when it is considered the federal program offers the equivalent emission reductions. California Air Resources Board *Marine Notice 2016-1* (April 2016).
[256] See California Air Resources Board *Marine Notice 2011-3* (November 2011).
[257] *Airborne Toxic Control Measure for Auxiliary Diesel Engines Operated on Ocean-Going Vessels At-Berth in a California Port* 17 (1) 7.5 California Code of Regulations (CCR) s 93118.3.
[258] passenger vessels, refrigerated cargo vessels and container vessels: *Airborne Toxic Control Measure for Auxiliary Diesel Engines Operated on Ocean-Going Vessels At-Berth in a California Port* 17 (1) 7.5 California Code of Regulations (CCR) s 93118.3 subsection (c).
[259] Defined in s 93118.3 (c)(6) as Ports of Hueneme, Los Angeles, Long Beach, Oakland, San Diego, and San Francisco.
[260] Subsection (d)(1)((C)5.
[261] Subsection (d)(1)(H).
[262] Subsection (f).
[263] Subsection (g).
[264] Subsection (h)(1).
[265] Subsection (h)(2).
[266] Opacity monitoring of cruise ship emissions was first conducted in the early 1990s: *Alaska Cruise Ship Initiative 2000 Season: Part 2 Final Report,* 6.
[267] *Air Quality Control Regulations*, s 18 AAC 50.070. See also Title 46 *Water Air Energy and Environmental Conservation* Sec 46.03.488.

passenger vessels are required to have an 'Ocean Ranger' on board; a marine engineer who is to act as an independent observer to ensure marine discharges are monitored and recorded.[268]

5.2.2 China (including SAR Hong Kong)

China's air pollution woes are well documented. Seven of the ten busiest ports in the world are located in China. One of those ports is Hong Kong. In 2010, the shipping industry was the largest source of $PM_{2.5}$ emissions – 41% of PM emissions came from navigation.[269] In Shanghai, shipping contributed 12% of SO_2, 9 % NO_X and over 5% $PM_{2.5}$ in 2010.[270]

In 2015 the Ministry for Transport introduced Domestic Emission Control Areas (DECA). These areas contribute 37% of shipping emissions in China.[271] Initially the DECAs applied to ships berthed or anchored within the waters of the Pearl River Delta (PRD), Yangtze River Delta and the Boai Bay Rim, then extended to those ships entering the zone out to the 12 nm territorial limit. [272] Within the DECA, ships are to use fuel with a sulphur content of no more than 0.5%. Approved scrubbers are permitted.

These coastal clusters encouraged the rerouting of shipping to avoid the cost of the low sulphur fuel; something that may have resulted in greater emissions.[273] However, effective 1 January 2019, that problem has been solved. The DECAs now extend beyond the 3 original areas to the whole coastline of China, such that sulphur content of fuel is now limited to 0.5% within 12 nm of the coast.[274] This was in effect an early introduction of the 2020 MARPOL limit. A further review was scheduled for late 2019, at which point a 0.1% limit may be imposed. Green port initiatives are now a priority,[275] and there are restrictions on new ship builds to limit emissions. [276]

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[268] AS 43 Sec 46.03.476.

[269] International Council on Clean Transportation Policy Update May 2016, quoting data from HK environmental Protection Department website. https://www.theicct.org/sites/default/files/publications/China%20ECZ%20Policy%20Update%20vF.pdf

[270] Fu, Q., Shen, Y., & Zhang, J. (2012). On the ship pollutant emission inventory in Shanghai port. Journal of Safety and Environment, 12(5), 57-64 as quoted by International Council on Clean Transportation Policy Update May 2016. Note that China has also implemented an ETS to control CO_2 emissions. The Shanghai pilot ETS included ports and the local shipping industry. International Carbon Action Partnership *ETS Detailed Information* (updated 27 November 2018).

[271] Mingling Fu Et al, 'National to Port Level inventories of shipping emissions in China' (2017) 12 Environmental Research Letters 114024, 6.

[272] Gard, *China makes further changes to its ECA timeline* (3 Sept 2018) http://www.gard.no/web/updates/content/26160897/china-makes-further-changes-to-its-eca-timeline. ICCT policy update 2016 contains Shanghai estimates of reductions in PM: International Council on Clean Transportation Policy Update May 2016 https://www.theicct.org/sites/default/files/publications/China%20ECZ%20Policy%20Update%20vF.pdf

[273] Xiaoli Mao and Daniel Rutherford, 'Delineating a Chinese emission control area: the Potential impact of ship rerouting on emissions' International Council of Clean Transportation White Paper (September 2018) https://www.theicct.org/sites/default/files/publications/China_Rerouting_White_Paper_20180905.pdf accessed 22 November 2018.

[274] https://www.dnvgl.com/news/update-on-emissions-to-air-regulations-for-ships-operating-in-chinese-coastal-waters-135617 accessed 15 January 2019.

[275] Over the past few years, Shanghai has been operating a pilot emission trading scheme, which included local shipping and ports.

[276] Mingling Fu Et al, 'National to Port Level inventories of shipping emissions in China' (2017) 12 *Environmental Research Letters* 114024, 2.

The position is similar in SAR Hong Kong. In July 2015 it also introduced laws requiring a switch to 0.5% fuel while at berth.[277] From 1 January 2019, those laws were replaced by a requirement that compliant fuel, or an acceptable alternative technology such as scrubbers, must be used in the waters of Hong Kong.[278]

5.2.3 Australia

Australia is a party to Annex VI.[279] Australia has relatively good air quality by international standards. That may explain why, aside from one exception mentioned below, Australia has been content to apply the sulphur content limit as set in MARPOL.[280] Nonetheless, regional and local areas do suffer from industrial air pollution.[281] Ship emissions have been newsworthy, particularly from the increasing number of cruise ships visiting Australian port cities.

At the time of writing there is only one additional restriction on sulphur content of marine fuel used in Australia. It applies only to cruise ships at berth in Sydney Harbour; a response to the public campaign over air emissions at the new inner city cruise ship terminal at White Bay. A scientific study showed shipping emissions were an important single source of human exposure to $PM_{2.5}$ in the Sydney greater metropolitan area, that cruise ships were the source of 38% of $PM_{2.5}$ shipping emissions in the greater metropolitan region of Sydney. The study also determined that 64% of marine fuel consumption in Sydney harbour occurred whilst at berth.[282]

As a result, Australian regulations now explicitly target cruise ship emissions: but only in the port of Sydney, and whilst at berth. A Marine Order requires passenger ships carrying more than 100 passengers to use fuel with a sulphur content not exceeding 0.1% m/m whilst at berth in Sydney harbour.[283]

The number of cruise ship visits to Sydney is growing, therefore local strategies to reduce ship emissions will become increasingly beneficial as the cruise industry expands.[284] The controls only apply to passenger ships, and only whilst at berth. It has been suggested that limiting the sulphur content of fuel used by all ships, throughout the Sydney port, to 0.1% would bite more deeply into PM emissions in the region.[285]A 2015 report commissioned by the NSW EPA cautioned against

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[277] Air Pollution Control (Ocean Going Vessels) (Fuel at Berth) Regulation (Cap.311, section 43) [1 July 2015]. Exemptions for scrubbers are covered in section 7.

[278] Section 4, *Air Pollution Control (Fuel for Vessels) Regulation 2018*.

[279] Enacted for Australia in the *Protection of the Sea (Prevention of Pollution from Ships) Act 1983* (Cth), Part IIID, Div 2.

[280] Ibid. Australia is also content to permit the use of relatively dirty fuel in road transport: 150ppm sulphur, as compared to 10 ppm in the EU.

[281] See Laurie Goldsworthy, Brett Goldsworthy *Modelling of ship engine exhaust emissions in ports and extensive coastal waters based on terrestrial AIS data – an Australian case study* (2015) 63 Environmental Modelling &Software 45-60, [3].

[282] R. Broome, et al, above, n22.

[283] AMSA Marine Notice 21/2016. This limit was originally stipulated by NSW legislation *Protection of the Environment Operations (Clean Air) Amendment (Cruise ships) Regulation 2015,* but there were concerns this legislation was constitutionally invalid as it was inconsistent with the Federally legislated MARPOL limits permitting 3.5%m/m sulphur content.

[284] R. Broome, et al. above, n22.

[285] Ibid, 92: compared to the use of 3.5% sulphur fuel, 'Our assessment shows that a requirement for ships to use 0.1% sulfur distillate fuel at berth would reduce peak concentrations of ship-related $PM_{2.5}$ by 75% and the average concentration by 25%. A requirement for ships to use 0.1% sulfur distillate fuel within 300 km of Sydney would reduce peak concentrations by 86% and the average concentration by 56%. Use of low-sulfur

imposing a 0.1% limit on all ships, or extending the limit beyond the berth, at least ahead of the MARPOL 2020 limits.[286]

5.2.4 Panama

From 2001 the Panama Canal Authority required ships transiting the canal to switch from HFO to a distillate fuel that complied with the MARPOL sulphur cap.[287] This is the case even if the HFO complied with the MARPOL sulphur cap in force at the relevant time. Vessels operating an approved scrubber arenot required to switch.[288]

5.2.5 Norway

Much of Norway's coastline is contained in the Baltic Sea ECA, and therefore has been the subject to the sulphur limit of 0.1% since 2015. Outside the Baltic ECA, the EU Sulphur Directive is given effect by Norwegian legislation.

The West Norwegian Fjords are UNESCO World Heritage listed. The fjords attract significant cruise ship traffic. Still conditions and steep mountains conspire to hold stack emissions in the air and around fjord communities. A report by the Norwegian Maritime Authority (NMA) found that there were periodically high levels of particles, particularly $PM_{2.5}$ and PM_1. It noted that many of the ships using the fjords are so old that NO_x limits do not apply to them. The NMA recommended that ships entering the three main fjords should be required to use low sulphur fuel even if scrubbers are installed; that there be limits imposed on the density of visible emissions of smoke; and that there be a ban on the release of washwater from scrubbers in the fjords.[289]

Norway's maritime cluster is a leader in alternative fuel R&D and is enjoying an 'electric revolution': reportedly there will be more than 60 electric powered ferries in use within the next few years.[290] The Norwegian Parliament has requested that the government implement requirements and regulations to ensure phasing in of low speed and zero emission solutions in the fjords by 2026.[291]

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fuel within 300 km of Sydney would provide more than twice the mortality benefit of using low-sulfur fuel at berth only.'

[286] NSW EPA Ship Emissions Study by DNV GL Maritime (Sydney), 6 June 2015. https://www.epa.nsw.gov.au/~/media/EPA/Corporate%20Site/resources/air/gma-ship-emissions.ashx Further, a report prepared for the Port Authority of NSW concluded that shore power benefits would be incremental only, and not cost effective. It recommended that other strategies be explored. https://www.portauthoritynsw.com.au/media/2568/appendix-2_shore-power-analysis-cost-and-benefits-study-starcrest.pdf

[287] Panama Canal Authority, Advisory to Shipping A-04-2017, Notice to Shipping N-1-2019, cl 31.

[288] Ibid.

[289] Norwegian Maritime Authority 'Pollution from ships in fjord areas with heavy cruise traffic' (5 May 2017). For other recommendations, see Part 1. Summary.

[290] 'Norway set to create zero emissions zones in fjords' Marine Log, 4 May 2018, https://www.marinelog.com/index.php?option=com_k2&view=item&id=29067:norway-set-to-create-zero-emissions-zones-in-fjords&Itemid=257 accessed 18 July 2018.

[291] Storting Parliament, (2017)-(2018) Resolution 672: https://www.stortinget.no/no/Saker-og-publikasjoner/Vedtak/Vedtak/Sak/?p=69815. Accessed 23 November 2018.

5.2.6 National regulation of scrubber washwater

Exhaust gas cleaning systems (scrubbers) have been permitted since the original Annex VI.[292]

Open loop scrubbers take in seawater as the medium for exhaust cleaning, which is then treated to remove sludge before being released back into the ocean.[293] The more expensive closed loop scrubbers do not release water into the ocean, holding it onboard for release into a designated facility.[294] Hybrids can operate in either mode.

The concern is that the wastewater from the open loop scrubber will contain metals and particulate matter that would otherwise have escaped into the air. While the end result of scrubbing is sulfate, a naturally occurring constituent of seawater, with negligible acidification effect into the sea is said to cause little harm, it is the toxic elements filtered from the HFO that are of concern to the marine environment. We may well be taking the problem from the air and injecting it into the sea.[295] The EU says 'the operation of ships installed with EGCS in particular in port waters, coastal areas or ecologically sensitive areas is expected to lead to a degradation of the marine environment due to the toxicity of water discharges.'[296]

Port states are worried about the environmental implications of releasing the washwater back into the ocean, and more countries are banning washwater discharge at least until more is known. California does not permit the commercial use of any scrubbers in its waters.[297] Singapore decided to ban the discharge of washwater from open loop scrubbers into the 'Singapore port waters' from 1 January 2020,[298] joining Belgium and Germany. Another important bunker port, Fujairah in United Arab Emirates, has followed suit;[299] China has put in place a similar ban for ships effective 1 January 2019 (albeit the ban reportedly applies only in a limited territory).[300] It is likely that more countries will follow. In the territorial waters of a State with such a ban, the ships fitted with open loop scrubbers will need to prevent discharge by switching to low sulphur fuel despite having a scrubber that complies with IMO/flag State requirements.

The IMO has heeded calls for an international approach to scrubber washwater. At MEPC74 in May 2019, the EU proposed that the Committee draw up harmonised rules on the discharge of wastewater from scrubbers, and the MEPC decided to work on a new output evaluating the environmental impacts of EGCS liquid effluents and the harmonisation of rules..[301] While there is

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[292] Regulation 14(4) in the 1997 Protocol to MARPOL. See [2007] ATS 37.

[293] See submission of Institute of Marine Engineering, Science and Technology (IMarEST) to IMO Subcommittee on Bulk Liquids and Gases, BLG 177/INF.8.

[294] As required by IMO Resolution MEPC.259 (68) *2015 Guidelines of exhaust gas cleaning systems* (2015 Guidelines) 10.4.

[295] 2015 Guidelines, Appendix 3 requires flag states to arrange sampling of washwater for, amongst other things, zinc and vanadium, and for that data to be passed onto the IMO.

[296] EU Commission Staff Working Document SWD(2019) 17 final (4.2.19) available at https://data.consilium.europa.eu/doc/document/ST-5782-2019-INIT/en/pdf.

[297] See above, n 254.

[298] Andrew Tan, Chief Executive, Maritime and Port Authority of Singapore, Opening Address to the Singapore Registry of Ships Forum 2018 (30 November 2018): https://www.mpa.gov.sg/web/portal/home/media-centre/news-releases/detail/d3ee505d-670a-4c38-a5c0-a0526bea1f1d (accessed 4 December 2018).

[299] Port of Fujairah, *Notice to Mariners No 252* (22 January 2019).

[300] Weis Zhuang, 'China has not yet placed a full ban on open-loop scrubbers' *BIMCO news and trends* 8 January 2019, at https://www.bimco.org/news/priority-news/20190108-china-open-loop-scrubbers.

[301] EU Commission Staff Working Document SWD(2019) 17 final (4.2.19) available at https://data.consilium.europa.eu/doc/document/ST-5782-2019-INIT/en/pdf. See MEPC 74/18 Report of the Marine Environmental Protection Committee on its 74th Session, 14.11.

insufficient space here to do more than note the fast pace of developments, they are to the chagrin of the many shipowners who have committed to open loop scrubbers as a means of complying with the sulphur limit.[302]

5.3 Managing ship emissions at a local level - ports

Ports are an essential part of the maritime ecosystem. Busy ports naturally bring with them a concentration of SO_x, NO_x and PM emissions. As well as ships, shoreside infrastructure and operations supporting the shipping industry contribute to those emissions particularly the transport of cargo to and from the port. The local population and port workers bear the brunt of the emissions around the port; in that sense, they bear a disproportionate burden, at least in health terms, for their country's import and export trade. Cruise ship terminals are often in the heart of a city. They can add to the woes of the local authorities attempting to control air pollution.[303] Pollution is especially discernible close to the source.[304]

Many ports are aware of their role in facilitating the reduction of emissions; both pollutants and GHG, and there are some clear leaders. As already discussed, the Californian ports are subject to formal regulation that mandates a specified reduction in ship emissions in port. In addition, they have set themselves ambitious targets as part of their corporate environmental responsibility. Whilst within a port, ships are in the internal waters of a State, and subject to the full force of their local regulations concerning environmental matters.

Some ports provide shore power, allowing the ship's auxiliary engines to be deactivated while berthed: so called 'cold ironing'. Whilst on shoreside power, the ship does not need to generate electricity by burning marine fuel to run auxiliary engines and boilers. The reduction in PM emission achieved by shoreside power can be significant: especially for cruise ships, which have high electricity demand whilst in port.[305] Differing scientific studies in various ports cite a potential PM reduction range from 30% to 71%.[306] If clean or renewable sources of power are used, shoreside electricity can also aid with GHG reduction. While the complexities and challenges of shoreside power are beyond the scope of this paper,[307] suffice to note that installing shoreside power requires

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302 Anastassios Adamopoulos, 'Global scrubber rules should not hurt early movers, lobbies argue' *Lloyd's List* (8 February 2019).

303 The now abandoned proposal for a cruise ship terminal at Enderby Wharf in Greenwich, London was one such example. See Matthew Taylor, 'Air Pollution fears fuel fight against new London cruise ship terminal' *The Guardian* (26 September 2018) https://www.theguardian.com/environment/2018/sep/26/air-pollution-fears-fuel-fight-against-huge-new-london-cruise-ship-terminal-river-thames. Ships in the Thames accounted for 1.05% of London's emissions in 2013. The Port of London Authority has implemented a green tariff scheme, discounting port charges where vessels meet an Environmental Shipping Index score of 30 or above.

304 The Danish Ecological Council in its report *Cleaner Shipping- Focus on air pollution, technical solutions and regulation* (2018) outlines air quality measurements taken near a cruise ship and 50 – 100 m downwind whilst berthed at Copenhagen. The average pollution levels measured were commensurate with pollution levels found near the most polluted streets of Copenhagen during rush hour on a calm day. (p 9).

305 The Danish Ecological Council *Cleaner Shipping- Focus on air pollution, technical solutions and regulation* 2nd ed (2018) 3.

306 See the summary of scientific reports in Friends of the Earth submission to the IMO MEPC73 'Reduction of GHG Emissions from Ships – Vessel shore power installation worldwide' MEPC 73/INF.29/Rev. 1 (17 August 2018), 7.

307 There is continuing discussion in the scientific literature. For example, see A. Innes, J. Monios "Identifying the unique challenges of installing a cold ironing at small and medium ports – the case of Aberdeen" (2018) 62 *Transportation Research Part D* 298.

significant investment by both shore and ship; the GHG savings depend on the fuel used to generate the shore electricity; as yet few ships are equipped to use it; and the relative cost of shoreside power compared with burning marine fuel can be a disincentive for ships to use it (where ports provide it as an option rather than mandating it). Where it has been successfully deployed, it has been on the back of public funding, given the public health benefit.[308] Whilst it is expected to be a more regular feature in busy ports, particularly cruise ports,[309] it is still at a nascent stage. Internationally the port industry is examining how to improve the business case for shoreside power.[310]

Other portside innovations designed to reduce emissions whilst in port include the bonnet emission capture and treatment (or 'sock on a stack'); a bonnet that fits over a ship stack to filter emissions, as well as the newer barge mounted system that directly connects to a vessel's exhaust outlets.[311]

Some ports have adopted an incentive-based approach to encourage so called 'green shipping' which may incorporate initiatives to reduce NO_x, SO_x, GHG, PM or fuel consumption. Ships receive a discount on port fees if they are adopt green practices such as slow steaming,[312] or are certificated or otherwise recognised as 'green' or 'clean' under one of the recognised schemes.[313] The proliferation of these indexes and the differing usage in different ports can be unwieldy; but it also means that shipowners can benefit from efforts to move to 'cleaner' shipping, no matter what steps they take. In that regard, the Canadian ports of Vancouver and Port Rupert have adopted a flexible program that recognises and rewards steps toward increased efficiencies or clean fuels regardless of a ship's participation in any recognised scheme.[314] Notably, these schemes can encourage specific measures to reduce PM (such as particulate filters) that are otherwise rarely targeted.

Encouraged by IMO and industry bodies, there is significant information exchange underway amongst the port communities worldwide about the reduction of emissions, both pollutants and

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308 F Ballini & R Bozzo, 'Air pollution from ships in ports: The socio-economic benefit of cold-ironing technology' (2015) 17 *Research in Transportation Business & Management* 92. https://doi.org/10.1016/j.rtbm.2015.10.007.

309 For example Southampton Port Authority aspires to be the first UK port offering shore power: APB Southampton, *Cleaner Air for Southampton*, 15. http://www.southamptonvts.co.uk/admin/content/files/PDF_Downloads/13342%20Associated%20British%20Ports%20Air%20Quality%20Strategy%20Report%20v14.pdf accessed 23 November 2018.

310 IAPH Submission, MEPC 73/7/75 (17 August 2018).

311 Port of Long Beach http://www.polb.com/news/displaynews.asp?NewsID=1256.

312 Eg the Green Flag Incentive Program, Port of Long Beach (ibid). Reducing steaming speeds below 12 knots is said to significantly reduce emissions: The University of California estimated a reduction of approximately 61% in CO_2, 56% in NO_x, and 69% in PM 2.5 by reducing cruising to 12 knots or less: CARB *IN use Emissions Test Program at VSR Speeds for Oceangoing Container Ship* prepared by University of California, Riverside, for the California Air Resource Board June 2012. As quoted in Glomeep & IAPH, IMO et al *Port Emissions Toolkit Guide No 2: Development of port emissions reduction strategies* (2018), 24.

313 Eg Environmental Ship Index; Clean Shipping Index; Green Award; Rightship GHG Emissions Rating. These are all outlined in R. Becque, F.Fung, Z. Zhu *Incentive Schemes for Promoting Green Shipping Discussion Paper* Natural Resources Defense Council (NRDC) (January 2018) found at https://www.nrdc.org/sites/default/files/incentive-schemes-promoting-green-shipping-ip.pdf accessed 29 November 2018.

314 Ibid, 18.

GHG.[315] It was resolved at MEPC74 that member States were to encourage voluntary cooperation between the port and shipping sectors to contribute to reducing GHG emissions from ships.[316]

5.4 Regulation and compliance- closing comments

Significant challenges will need to be overcome to ensure compliance with the sulphur limit and the successful reduction of sulphur emissions from ships. As always, it is important to attempt to level the playing field so that those operators complying with the rules are not outrun by those who seek to play outside the rules. Given the substantial cost of compliance, penalties must be a strong deterrent: but inevitably, penalties will vary from state party to state party. Furthermore, penalties are hollow without action to enforce the rules, which necessitates high rates of inspection and sample testing by individual Party States.

It is also inevitable that there will be significant variation between the enforcement efforts of different States. At one end of the spectrum, some regions, like the EU, will continue to actively engage in monitoring for compliance of the MARPOL and their own additional limits. Some States will likely continue their own local, national and regional regulation as well, imposing their own, stricter, standards on ships visiting their waters and ports. (The banning of scrubbers operating in open mode is a recent example of a localised response.) However, undoubtedly there will be States at the other end of that spectrum; state parties who are unable to undertake effective rates of inspection and prosecution to ensure compliance with IMO requirements; or whose penalties are so low that the risk of getting caught is worth taking. The IMO is well aware of this. IMO initiatives seek to share expertise and knowhow about regulation, compliance and enforcement of the sulphur cap [317] to avoid the spectre of 'ports of convenience'.[318] There should also be a significant push to encourage non-parties to Annex VI to become signatories, to avoid the prospect that such countries may permit and even encourage less efficient ships to continue to use HFO in their waters.

6 Conclusion

The 0.5% sulphur cap on marine fuel has been on the horizon since 2008. Despite the challenges of monitoring and enforcement, the 2020 sulphur cap is expected to lead to a significant reduction in SO_x emissions from ships. But what of PM emissions?

It seems likely that the reduction in emissions of SO_x will result in a reduction in the formation of shipping-associated *secondary* sulphate particulates. However, from a health perspective, there is little compelling evidence that these particles are toxic per se beyond acting as a marker of toxic emissions, although health effects due to their particulate nature, and interaction with/modification

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[315] See for example Glomeep & IAPH, IMO et al, *Port Emissions Toolkit Guide No 1: Assessment of Port Emissions (2018)* Glomeep & IAPH, IMO et al *Port Emissions Toolkit Guide No 2: Development of port emissions reduction strategies* (2018); International Association of Ports and Harbours' *World Port Sustainability Program* launched in April 2018.[316] Res. MEPC.323(74).

[316] Res. MEPC.323(74).

[317] Ibid.

[318] Bevan Marten 'Port State Jurisdiction, International Conventions, and Extraterritoriality: an expansive interpretation' (2018) 8 (1) *Victoria University of Wellington Legal Research Papers* 7/2018, 5 quoting Erik Molenaar 'Port State Jurisdiction' in Rüdiger Wolfrum (ed) *The Max Planck Encyclopaedia of Public International Law* (Oxford University Press, Oxford:2010) par 4.

of known toxic PM components cannot be ruled out on the basis of the limited evidence.[319] Likely more detrimental to health are *primary* particulates. It is here where there is mixed evidence as to the suitability of sulphur regulations in ameliorating the health risks. This is because, while emissions of certain toxic metals and organic carbon species may be reduced by the new sulphur regulations, there may be increased particle number emissions of certain ultrafine particle size modes with lower sulphur fuels. This is compounded by the reported poor efficacy with which these particles are removed by conventional inertial exhaust scrubbings systems. The coming years are likely to see a considerable growth in the body of literature around ultrafine PM, but the current evidence base suggests that their contribution to the effects of inhaled PM may considerably outweigh their small contribution to its overall mass.

Given the well-known health consequences of PM from shipping sources, it is unfortunate that at an international level there has been no explicit target reduction for PM, or even initiatives to implement monitoring of PM emissions, whatever the issues which may be posed by this. It is especially unfortunate that in the current regulatory environment ships that choose to employ scrubbers are not required to use scrubbers that are highly efficient at removing PM.

The evidence suggests that the sulphur content of fuel is not a suitable proxy for PM insofar as reducing toxic potency is desired; such a view has been shown to be overly simplistic and therefore must be regarded as outdated. As evidence mounts as to health effects of fine and ultrafine PM, perhaps pressure will grow for specific measures that monitor and reduce PM emissions from ships. However, it is more likely that measures for further PM reduction will be swept up in the next wave of regulation and compliance directed at drastically reducing and then eliminating the use of fossil fuels altogether. A combination of known measures and new and significant innovation will be required to attain those lofty targets for GHG reduction set by MEPC in 2018 whilst still ensuring shipping is available to undertake transport work so critical to international trade. Reducing reliance on fossil fuels will, as well as contributing to moderating climate change, ultimately greatly diminish the problem of PM emissions from ships.

It is clear that the implementation of the 2020 sulphur cap should not be the end of concerns over the pollutant effect of sulphur or PM emissions from ships.

[319] Flemming Cassee et al, 'Particulate matter beyond mass: recent health evidence on the role of fractions, chemical constituents and sources of emission' (2013) 25 (14) *Inhalation Toxicology* 802 doi: 10.3109/08958378.2013.850127