SUB-COMMITTEE ON POLLUTION PREVENTION AND RESPONSE
11th session
Agenda item 17

PPR 11/INF.4
20 November 2023
ENGLISH ONLY
Pre-session public release: ☒

ANY OTHER BUSINESS

Assessment of the impacts of the MARPOL Annex VI emission control regulations in the United States portion of the North American Emission Control Area

Submitted by the United States

SUMMARY

Executive summary:	This document presents the results of an analysis assessing the effectiveness of MARPOL Annex VI regulation 13 and 14 emission control regulations in the United States portions of the North American Emissions Control Area (ECA). This analysis, based on air quality monitoring, indicates that the regulation 14 controls have reduced sulphur oxides and particulate matter emission from international shipping. Analysis of fleet turnover and ship operating parameters shows that the expected NO_X emissions are not being achieved. Very few ships equipped with Tier III engines are operating in the United States portions of the North American ECA, and, even for those few ships, the Tier III emission control technology is often unlikely to be engaged.
Strategic direction, if applicable:	2
Output:	Not applicable
Action to be taken:	Paragraph 5
Related document:	MEPC 80/5/1

Background

1 The North American Emission Control Area (ECA) was designated by an amendment to MARPOL Annex VI in March 2010, adopted by resolution MEPC.190(60). This ECA covers coastal areas of Canada, the United States, and certain French overseas territories. The MARPOL Annex VI regulation 14 Emission Control Area (ECA) fuel sulphur limits, which apply to fuel used while a ship is operating in the ECA, began to apply in 2012, for the 1.00% sulphur limit, and in 2015, for the 0.10% sulphur limit. The regulation 13 Tier III NO_x limits, which apply only to engines installed on new ships while operated in the ECA, began to apply to ships built in 2016.

2 Now that the Tier III NO_x limits and the most stringent fuel sulphur limit have been in place for eight and nine years, respectively, an initial evaluation of their effectiveness can be performed to evaluate whether these requirements are bringing about the desired air quality improvements.

Description of the analysis

3 The United States Environmental Protection Agency performed an analysis, included in the annex to this document, to evaluate the impacts of the MARPOL Annex VI ECA fuel sulphur and engine NO_x controls. The analysis consists of two parts. The first part evaluates the impact of the ECA fuel sulphur controls using air quality monitoring data for various years. The second part evaluates the impact of the Tier III ECA NO_x controls by examining whether the fleet of international ships operating in the ECA is turning over to Tier III-compliant ships, and if they are operating at speeds consistent withthe operation of Tier III emission reduction controls.

Overall key findings

4 The key findings of the analysis are as follows:

.1 analysis of the ECA fuel sulphur controls based on air quality monitoring indicates that these controls have resulted in considerable reductions of particulate matter emissions from international shipping;

.2 analysis of the ECA Tier III NO_x controls based on ship characteristics and operations indicates that this program is not reducing the contribution of international shipping to United States. NO_x emissions;

.3 specifically, comparison of keel laid dates for the 2015 fleet and the 2021 fleet shows that very few ships equipped with Tier III engines were operated in the U.S. portions of the North American ECA in 2021, and that fleet turnover to Tier III ships is slower than expected; and

.4 in addition, analysis of satellite data for a set of ships operating in the ECA area and the non-ECA EEZ regions suggests that ships are operating at lower loads (below 25%) in the ECA. While ships may be slow steaming for a variety of reasons (reduce fuel consumption, ship speed reduction zones), these results suggest that the main Tier III NO_x emission control technology (selective catalytic reduction, SCR) is not likely engaged for much of the operation time within the ECA. This is because engines may be equipped with auxiliary control devices (ACDs) to disengage Tier III control technology under certain conditions to protect the engine; engine manufacturers may use ACDs to disable Tier III control technology below 25% load due to exhaust gas temperature concerns.

Action requested of the Sub-Committee

5 The Sub-Committee is invited to note the information provided in this document.

***

ANNEX

ASSESSMENT OF THE IMPACTS OF THE MARPOL ANNEX VI EMISSION CONTROL REGULATIONS IN THE UNITED STATES PORTION OF THE NORTH AMERICAN EMISSION CONTROL AREA

I. Introduction

The North American Emission Control Area (ECA) was designated by amendment to MARPOL Annex VI in March 2010, by resolution MEPC.190(60). The Annex VI Regulation 14 ECA fuel sulphur limits, which apply to fuel used onboard a ship while operating in the ECA, began to apply in 2012, for the 1.00% S limit, and in 2015, for the 0.10% S limit. The Regulation 13 Tier III NO_x limits, which apply only to engines installed on new ships while operating in the ECA, began to apply to ships built in 2016. Now that the most stringent phases of SO_x and NO_x standards have been in place for nine and eight years, respectively, an initial evaluation of their effectiveness can be performed to evaluate whether these requirements are bringing about the desired air quality improvements.

As shown below, air quality modelling data indicates that the fuel sulphur requirements are providing important particulate matter air quality benefits. The impacts of the NO_x limits are more difficult to assess, but analysis of ship characteristics and operations suggests the ECA NO_x requirements are not yielding the expected emission reductions and related air quality benefits. This suggests that changes may be needed to the Regulation 13 NO_x program to achieve the benefits the ECA program was intended to produce.

II. Assessment of the regulation 14 fuel sulphur requirements

The Annex VI Regulation 14.4 ECA fuel sulphur limits apply to any fuel used onboard a ship while operating in one of the designated ECAs set out in Regulation 14.3. The 0.10% ECA fuel sulphur limit began to apply in 2015 and is enforceable against all ships operating in a SO_x ECA, regardless of ship build date. This means that the full benefit of using lower sulphur ECA fuel was immediate in each designated SO_x ECA.

Due to the nature of the fuel used by international shipping and because the ECA fuel sulphur content reduction is so large and immediate, it is possible to use air quality monitoring data to evaluate the impacts of the ECA fuel sulphur controls. Studies by Robert A. Kotchenruther use source apportionment and air quality monitoring data to assess the effectiveness of the North American ECA at reducing ambient PM2.5 from high-sulphur residual fuel oil (RFO).[1] Source apportionment is a mathematical procedure for identifying and quantifying sources of ambient air pollutants. Using air quality monitoring data from coastal and near coastal sites across the United.States., Kotchenruther identified RFO combustion emissions of PM2.5 by their vanadium (V) and nickel (Ni) trace metal signatures. Kotchenruther used chemically speciated PM2.5 monitoring data with positive matrix factorization (PMF) receptor modelling to quantify the contribution of marine ship RFO combustion to PM2.5 using the chemically speciated data, which included V and Ni data. In 2016, the chemically speciated data at 22 sites were analysed

[1] Robert A. Kotchenruther, The effects of marine vessel fuel sulphur regulations on ambient PM2.5 at coastal and near coastal monitoring sites in the U.S., Atmospheric Environment, Volume 151, 2017, Pages 52-61, ISSN1352-2310,https://doi.org/10.1016/j.atmosenv.2016.12.012. (https://www.sciencedirect.com/science/article/pii/S1352231016309712). See also Robert A. Kotchenruther (2021) Source apportionment of PM2.5 at IMPROVE monitoring sites within and outside of marine vessel fuel sulphur emissions control areas, Journal of the Air & Waste Management Association, 71:9, 1114-1126, DOI: 10.1080/10962247.2021.1917463

over three time periods; two years prior to ECA implementation, 2010 and 2011, when the sulphur limit was 1.00%; 2013 and 2014; and 2015, when the sulphur limit was 0.10% in 2015. Of those 22 sites, it was determined that for 9 sites, the chemical composition of the factor associated with RFO combustion was a mixture of other sources in addition to RFO making it difficult to assess the ECA effectiveness. The remaining 13 sites where PMF results indicated a well delineated factor associated with RFO combustion were used in the analysis. Decreases in PM2.5 across the three time periods were found to be greater than 77.2% at every site except for two United States. Gulf Coast sites, which showed reductions of 33.0% and 35.4%.[2] These results suggest that implementation of the ECA was effective at reducing PM2.5. The results of this analysis are presented in figure 1, below.

In 2021, Kotchenruther expanded upon his earlier work, analysing 10 years of data including 3 years prior to the enforcement of the ECA and 4 years following the 0.10% sulphur limit implementation, for a select number of sites. RFO source resolution by PMF was improved and allowed analysis of 7 of the 9 sites originally excluded due to having PMF factors where RFO combustion was mixed with other aerosol sources. Figure 2 shows the annual average impacts comparing the pre-ECA period and the 0.10% sulphur limit period between sites, showing statistically significant reductions of PM2.5 from RFO combustion. Implementation of the ECA was shown to reduce PM2.5 by 79.0% on average. These results also suggest the ECA is achieving desired sulphur reductions. Table 1 sets out the 20 sites examined in these two studies and their abbreviated names.

Table 1: Modelled sites with PMF with defined results for RFO combustion

Site Name	Abbreviation	State
Olympic	OLYM	WA
Puget Sound	PUSO	WA
Point Reyes National Seashore	PORE	CA
Agua Tibia	AGTI	CA
Breton Island	BRIS	LA
St. Marks	SAMA	FL
Chassahowitzka NWR	CHAS	FL
Penobscot	PENO	ME
Acadia NP	ACAD	ME
Casco Bay	CABA	ME
Cape Cod	CACO	MA
Brigantine NWR	BRIG	NJ
Cape Romain NWR	ROMA	SC
North Cascades	NOCA1	WA
Makah Tribe Site #2	MAKA2	WA
Mount Rainier NP	MORA1	WA
Moosehorn NWR	MOOS1	ME
Martha's Vineyard	MAVI1	MA
Swanquarter	SWAN1	NC
Okefenokee NWR	OKEF1	GA

[2] While Kotchenruther speculated that reductions on the Gulf Coast were less than elsewhere may be due to the narrowing of the ECA zone near southeastern Florida and enforceability of the ECA in waters outside the ECA, these explanations were not tested.

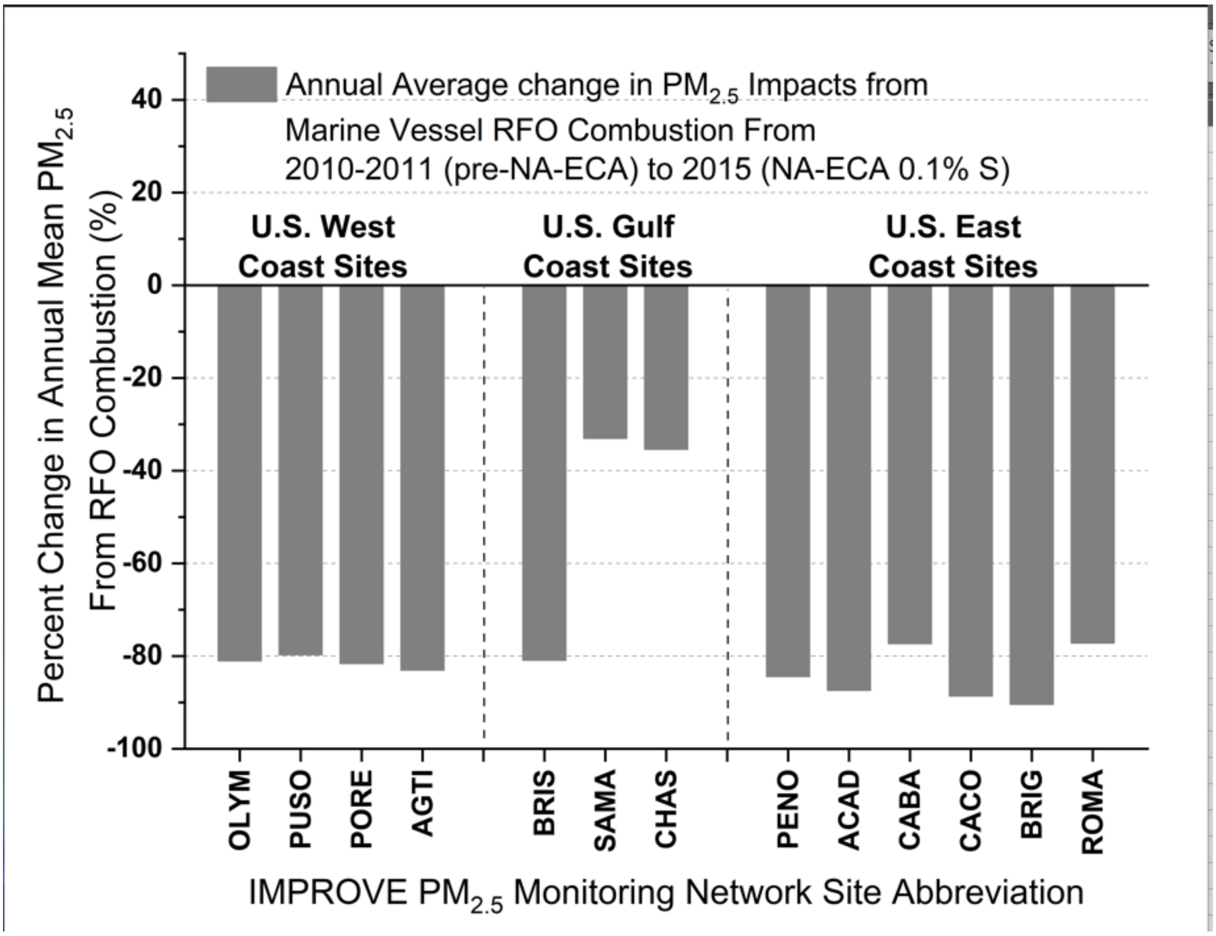

Figure 1: Annual mean change in PM2.5 from RFO combustion in 2010-2011 (pre-ECA) to 2015 (ECA 0.1% S), Selected Sites

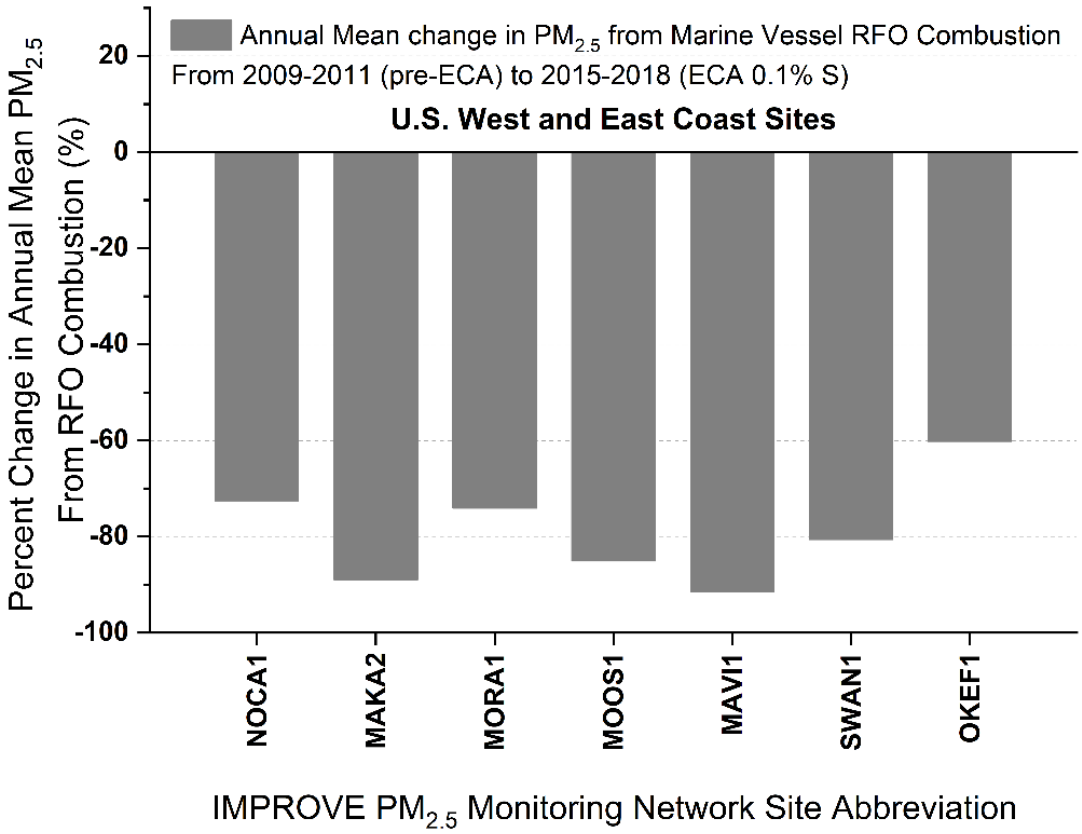

Figure 2: Annual mean change in PM2.5 from RFO combustion in 2009-2011 (pre-ECA) to 2015-2018 (ECA 0.1% S), Selected Sites

III. Assessing the regulation 13 Tier III NO_x requirements

The effectiveness of the Tier III ECA NO_x controls cannot be evaluated based on air quality monitoring data. This is mainly because unlike ship SO_x emissions, which can be identified in air quality monitoring data using RFO components, there are no elements of exhaust emissions from international shipping that permits their isolation from other sources of NO_x emissions. NO_x emissions from international shipping are similar if not identical to domestic marine and shore-based diesel engine sources. In addition, other important domestic mobile source emission control programs phased in at the same time as the Regulation 13 ECA NO_x limits (e.g. nonroad and domestic marine; various phases of highway diesel engine controls), and their effects cannot be separated from the Annex VI program.

Therefore, to assess the effectiveness of the Regulation 13.5 ECA NO_x controls, this document relies on two essential characteristics of the program:

.1 the emission requirements apply only to engines installed on new ships built beginning on a specified date; and

.2 the Tier III NO_x emission control technology apply only when the ship is operating in a NO_x ECA and that operation is within the design envelope of the Tier III certification (i.e., the engine is operating such that no Auxiliary Control Devices (ACD) permitted under Regulation 13.9 are engaged to disable the Tier III control technology). The effectiveness of the NO_x ECA program was evaluated based on:

.1 whether the fleet of international ships operating in the United States portion of the North American ECA are turning over to Tier III engines; and

.2 whether international ships equipped with Tier III engines are using the NO_x control technology as expected while they are operating in the North American ECA.

A. Assessment 1: Fleet Turnover to Tier III engines

Unlike the ECA fuel sulphur requirements, which apply to all ships all at once while they are operating in a SO_x ECA, the Annex VI Regulation 13.5 Tier III engine NO_x standards phase in over time: they apply based on the ship build date and are not retroactive to older ships operating in a NO_x ECA. Annex VI defines the build date as the date the ship's keel is laid or construction is at a similar stage.[3] For the North American NO_x ECA, that effective date is January 1, 2016. This means that the effectiveness of the Tier III ECA NO_x standards depends in part on whether there is an uptake of the technology on new ships operating in the ECA. It also depends on whether those ships are using the Tier III NO_x control technology as expected; this aspect is discussed in Assessment 2, below.

1. Description of Entrances Data

Examination of the turnover to Tier III-compliant ships is examined using annual port entrances data for foreign waterborne commerce assembled by the Army Corps of Engineers and data on ship keel laid date obtained from Clarksons *World Fleet Register* (accessed March 2021) and IHS (Information Handling Service) *Register of Ships* (obtained 2014; supplemented with additional searches September 2023).

The Army Corps of Engineers Foreign Traffic Vessel Entrances and Clearances database[4] tracks entrances for ships bringing goods into the United States at Customs port. The data set includes the following information: date of entry, the ship name, type, International Classification of Ship Type (ICST) code, registry, NRT and GRT, and draft, as well as the last port of call, whether foreign or domestic. This analysis uses data from 2015, the year before the Tier III NO_x limits went into effect, and 2021, the most recent year for which data is available.

The analysis includes the ship categories listed in table 2, which also includes the number of entrances by ships in each category for 2015 and 2021. Rather than perform the analysis for ships in all ICST categories, this analysis includes only those engaged in international trade. Table 2 shows that covered ship categories account for about 80% of all entrances for those years. Containerships had the most entrances, followed by bulk carriers and tankers. Of the excluded ships, most of those entrances for each year (about 20% of the total) are tugs, fishing ships, or barges.

[3] Regulation 2.19; renumber to 2.28 in the 2021 Consolidated Text of Annex VI.

[4] https://publibrary.planusace.us/#/series/Foreign%20Traffic%20Vessel%20Entrances%20Clearances

Table 2: Foreign Traffic Vessel Entrances, by ICST Code, 2015 and 2021 (Source: ACE Foreign Traffic Vessel Entrances and Clearances database)

Included ICST Codes	ACE Entrances - 2015		ACE Entrances - 2021		Description
111	2,823		3,005		CRUDE OIL TANKER
112	1,400		1,068		CRUDE/PRODUCTS TANKER
113	1,393		814		OIL PRODUCTS TANKER
120	8,278		8,810		CHEMICAL TANKER
130	24		84		OTHER LIQUIFIED GAS CARRIER
131	1,421		2,966		LPG CARRIER
132	68		1,087		LNG CARRIER
150	290		299		OTHER TANKER
159	77		54		OTHER TANKER NEI
210	1				OTHER BULK/OIL CARRIER
211	12		1		ORE/BULK/OIL
221	28		3		ORE CARRIER
229	9,467		8,746		OTHER BULK CARRIER
310	18,249		16,406		CONTAINER
325	4,927				VEHICLE CARRIER
330	129		154		OTHER GENERAL CARGO
331	887		449		REEFER
332	605		329		RO-RO PASSENGER
333	2,844		6,546		OTHER RO-RO CARGO
336	5,985		5,062		GENERAL CARGO-MULTI DECK NEI
338	123		135		RO-RO CONTAINER
351	7,960		2,705		CRUISE
Subtotal	**66,991**	79%	**58,723**	81%	
Other ICST	18,097	21%	13,673	19%	
Total	**85,088**		**72,396**		

While the ACE entrances data set includes the ship name and ICST category for each entrance, the ship IMO number is not always reported. For 2015, there are 106 entrances by unknown ships in the covered categories, or about 0.2% of entrances by the covered categories. For 2021, there are 418 entrances by unknown ships in the covered categories, or about 0.7% of entrances by the covered categories. The ICST codes for these ships are provided in table 3. Ships without IMO numbers are not included in the rest of this analysis. The small number of omitted ships is not expected to significantly affect the findings reported below.

Table 3: ACE Entrances by Covered Ships Without IMO Ship Identifier, 2015 and 2021

ICST	ICST Description	2015 Entrances by ships without IMO identifier	2021 Entrances by ships without IMO identifier
111	CRUDE OIL TANKER		1
112	CRUDE/PRODUCTS TANKER	2	
131	LPG CARRIER		218
150	OTHER TANKER	4	

ICST	ICST Description	2015 Entrances by ships without IMO identifier	2021 Entrances by ships without IMO identifier
210	OTHER BULK/OIL CARRIER	1	
221	ORE CARRIER		1
229	OTHER BULK CARRIER	17	4
310	CONTAINER	8	
330	OTHER GENERAL CARGO	66	153
333	OTHER RO-RO CARGO	8	16
336	GENERAL CARGO-MULTI DECK NEI		24
351	CRUISE		1
	Total included ships missing IMO No.	106	418
	Total entrances by covered ships	66,991	58,729
	% entrances by covered ships	0.1%	0.7%

Due to the way the NO_x regulations are structured, with the Tier III ECA NO_x standard applying based on the year the keel was laid, it is necessary to know the keel laid date of the ships that entered the United States. This analysis uses data from Clarksons *World Fleet Register* (accessed March 2021), filling in with data from IHS *Register of Ships* (obtained 2014; supplemented with additional searches September 2023) for ships lacking keel laid dates in the Clarksons database. Table 4 shows that keel laid dates were identified for all but 34 ships in the covered categories that entered the United States. in 2015 (0.4%), and all but 15 ships that entered the United States. in 2021 (0.2%). Ships without IMO numbers are not included in the rest of this analysis. The small number of omitted ships is not expected to significantly affect the findings reported below.

Table 4: Covered Ships with Known and Unknown Keel Laid Dates, 2015 and 2021

	2015	2021
Known included ships with keel laid dates	8705	9662
Known included ships without keel laid dates	34	15
% Covered ships without keel laid dates	0.4%	0.2%

Engines installed on ships constructed on or after January 1, 2016, must comply with the Tier III ECA NO_x limits while the ship is operating in the ECA. It is difficult to obtain consistent information about the tier of standards for engines installed on ships. However, under MARPOL the date of ship construction is tied to the date the keel is laid or is at a similar stage of construction. Therefore, this analysis assumes that ships with keel laid date beginning in 2016 comply with the ECA limits.

2. Analysis: Entrances by Ships with Tier III Engines

For the Tier III ECA NO_x limits to be deemed to be successful, it is necessary to show that ships with Tier III-compliant engines are entering the United States in numbers that are consistent with expected turnover of the fleet to new, 2016 and later ships. This is done by comparing the 2021 fleet with the fleet of ships that entered the United States in 2015. If there is a sharp difference between these years, it can be concluded that fewer Tier III ships are entering the United States than expected and the Tier III ECA NO_x limits are not delivering the expected air quality benefits.

Table 5 shows the number of entrances to United States ports by keel laid date, for 2015 and 2021. Included ships are those with keel laid dates from 1999, the year before the initial 2000 effective date of the Regulation 13.3 Tier I NO_x limits, through 2021. Ships with keels laid in these years represent 78% of total entrances by known covered ships in 2015 and 90% of total entrances by known covered ships in 2021. The data indicate that for groups of ships that entered the United States in these years, many keels were laid in 2008, when Annex VI was significantly amended to include the Tier II and Tier III NO_x limits, and again in 2015, the year before the Tier III ECA NO_x limits went into effect for the North American and United States Caribbean Sea ECAs. This is significant, because it suggests that large numbers of ships were constructed in the early years of each standard using keels that pre-dated the standards, and therefore were not subject to the new standards.

Table III5: Number of United States Port Entrances by Ship Keel Laid Date, 2015 and 2021

Keel Laid Date	Ship Entrances – 2015		Ship Entrances – 2021	
1999	1909	2.8%	929	1.6%
2000	2379	3.6%	1001	1.7%
2001	2478	3.7%	1198	2.0%
2002	3514	5.2%	1416	2.4%
2003	1741	2.6%	956	1.6%
2004	5311	7.9%	3538	6.0%
2005	2791	4.2%	2042	3.5%
2006	4415	6.6%	4303	7.3%
2007	4531	6.8%	3490	5.9%
2008	6974	10.4%	5900	10.0%
2009	3909	5.8%	3263	5.6%
2010	4892	7.3%	4214	7.2%
2011	2803	4.2%	2499	4.3%
2012	976	1.5%	1318	2.2%
2013	1818	2.7%	2159	3.7%
2014	1353	2.0%	2860	4.9%
2015	132	0.2%	8919	15.2%
2016			157	0.3%
2017			435	0.7%
2018			740	1.3%
2019			872	1.5%
2020			826	1.4%
2021			61	0.1%
Total Entrances by covered ships	66991		58723	
Total entrances by covered ships keel laid 1999-2021	51926		53096	
% total entrances by covered ships keel laid 1999-2021	78%		90%	

An examination of the number of entrances by ships with keel laid dates in the six years prior to the entrance year (2010-2015 and 2016-2021), set out in table 6, shows that the share of the port entrances by these newer ships is considerably smaller for 2021 than for 2015: 5% vs 18%.

Table 6: Number of Entrances, Covered Ships, Keel Laid Dates Within 6 Years of Entrance Year, 2015 and 2021

	2015	2021
Total Entrances, all years	66991	58723
Total entrances, 1999-2021	51926	53096
% Total entrances 1999-2021	78%	90%
Total entrances keel laid dates in 6 previous years	11974	3091
% Total entrances keel laid dates in 6 previous years	18%	5%

Figures 3 and 4 compare the share of port entrances for each year based on keel laid date and build date, for the 16 years prior to the entrance dates (1999-2015, 2005-2016). Figure 3 shows the percentage of entrances by ships of the same age based on keel laid year. For 2021, there is a significant decline in the share of entrances by ships with more recent keel laid dates, and that decline coincides with the effective date of the Tier III ECA NO_x limits, 2016. This is in stark contrast with the results in figure 4, which shows the percentage of entrances by ships of the same age based on build year. When build year is considered, the differences between 2015 and 2021 entrances are much smaller, especially for 0 to 3 years from the entrance date. In figure 3, the increase in builds for years 4 through 9 for 2015 entrances represents ships built in 2006 through 2011; this is carried over in years 10 through 15 for 2021 entrances. What is notable about the results reported in figures 3 and 4 is that while the distribution of build years of ships that entered the United States in 2015 and 2021 are not significantly different, the distribution of keel laid dates are. This suggests a significant effort by ship builders and owners to avoid the Tier III ECA NO_x limits.

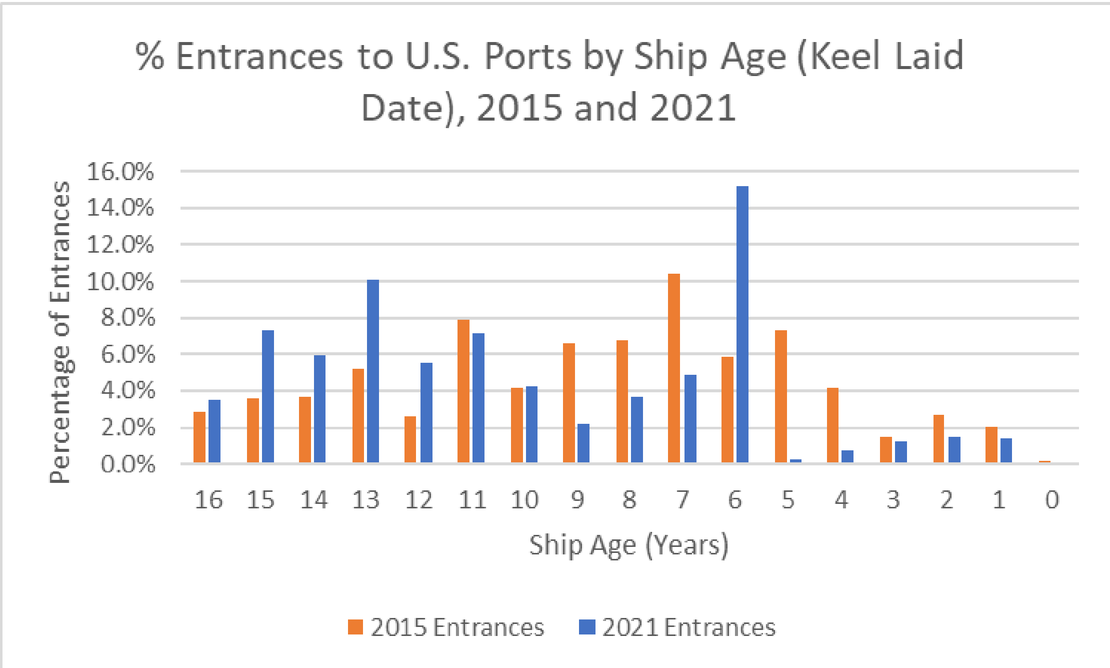

Figure 3: Comparison of Share of Port Entrances by Keel Laid Date, 2015 and 2021

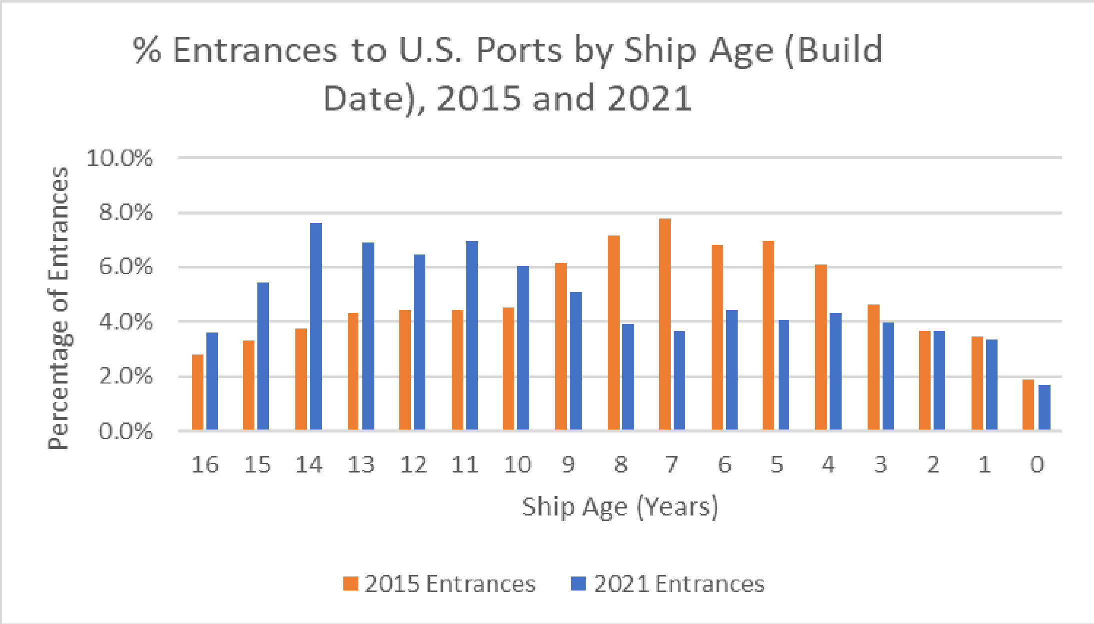

Figure 4: Comparison of Port Entrances by Build Date, 2015 and 2021

3. Summary of Assessment I

The above information suggests that the number of ships that entered the United States in 2021 and that comply with the Annex VI Tier III ECA NO_x limits is less than expected, based on the experience of the 2015 fleet, and therefore the standards do not appear to be achieving their goal of reducing NO_x emissions from international shipping in the United States. Very few of the ships that entered the United States in 2021 (about 5%) had keel laid dates beginning in 2016 and are presumably Tier III compliant, even though many of those ships were built in 2016 and later. This is a much smaller percentage of ships that entered the United States in 2016 with keel laid dates within 6 years of the year of entry (18%).

4. Additional Discussion

As described above, the number of port entrances by ships built beginning in 2016, when the ECA Tier III NO_x limits began to apply, is much smaller than expected based on the fleet profile in 2015. While it is difficult to know precisely why this is the case, there are at least two candidate explanations: evasive behaviour on the part of ship owners and builders to evade the standards, and a change in the Regulation 13.5 program that effectively changed the nature of the program and removed the incentive to equip ships with Tier III compliant engines.

Because the Tier III ECA NO_x limits are tied to the keel laid date and not the ship build date, and because it is much simpler to "lay" a keel than it is to build a ship, it is not surprising that ship builders and owners sought to lay as many keels as possible in 2015 to avoid triggering the 2016 engine requirements. This evasive behaviour can be observed in a simple analysis comparing the keel laid dates to build dates. The data presented in table 7 sets out the relationship between the ship build date and the ship keel laid date for ships that entered the United States in 2021. These data show that for 1995-2015, the keels of most new builds were laid either in the build year or the year before. In 2016, however, there was a significant change. Only 1 of the ships built in 2016 that entered the United States in 2021 had a keel laid date of 2016; 496 had a keel laid date of 2015 and 88 had a keel laid date of 2014 or earlier. Most of the ships built in 2017 through 2020 had a keel laid date 2 or more years earlier than the build date. Only for ships built in 2021 did more than half the ships have keel laid dates closer to the build date again (55%).

Table 7: Relationship Between Build and Keel Laid Dates, 2021 Ship Entrances

Build Year	Keel Year same as Build Year	Keel Year 1 year earlier than build year	% keels same year as build or 1 year earlier	Keel Year 2 or more years earlier than build year		Total ships built per year
1995	6	12	82%	4	18%	22
1996	9	22	94%	2	6%	33
1997	11	13	89%	3	11%	27
1998	15	23	81%	9	19%	47
1999	18	42	90%	7	10%	67
2000	26	65	83%	19	17%	110
2001	50	42	87%	14	13%	106
2002	38	75	91%	11	9%	124
2003	38	98	88%	19	12%	155
2004	95	92	79%	50	21%	237
2005	66	226	93%	23	7%	315
2006	111	123	59%	165	41%	399
2007	117	238	73%	129	27%	484
2008	160	232	74%	141	26%	533
2009	148	325	82%	106	18%	579
2010	173	336	73%	191	27%	700
2011	114	409	78%	146	22%	669
2012	53	328	57%	282	43%	663
2013	49	175	43%	295	57%	519
2014	91	243	74%	120	26%	454
2015	147	351	80%	123	20%	621
2016	**1**	**496**	**85%**	88	15%	585
2017		3	1%	**529**	**99%**	532
2018	9	20	8%	337	92%	366
2019	47	85	27%	358	73%	490
2020	52	95	36%	263	64%	410
2021	17	132	55%	122	45%	271
						9518

This disturbance in keel laid dates is also illustrated in table 8, which shows that 2,150 keels, or about 22.6% of ships that entered the United States in 2021 had keels laid in 2015.

Table 8: Keel Laid Dates for Ships that Entered United States, 2021

	No. Keels Laid for ships that entered United States in 2021	
1990	1	0.0%
1992	1	0.0%
1993	3	0.0%
1994	17	0.2%
1995	33	0.3%
1996	33	0.3%
1997	40	0.4%
1998	90	0.9%
1999	94	1.0%
2000	80	0.8%
2001	143	1.5%
2002	189	2.0%
2003	146	1.5%
2004	642	6.7%
2005	213	2.2%
2006	535	5.6%
2007	406	4.3%
2008	763	8.0%
2009	569	6.0%
2010	961	10.1%
2011	676	7.1%
2012	245	2.6%
2013	465	4.9%
2014	535	5.6%
2015	2150	22.6%
2016	8	0.1%
2017	24	0.3%
2018	104	1.1%
2019	151	1.6%
2020	184	1.9%
2021	17	0.2%
Total Keels Laid	9518	

To evaluate the above findings, we can compare the actual number of ships that entered the United States in 2021 with what would have occurred if fleet turnover had been the same as for 2015. This is done by simply comparing the keel laid dates for the ships that entered the United States in 2021 with those of 2015. Figure 5 shows the difference between actual and expected build dates and indicates that the ships that entered the United States in 2021 are older than those that entered in 2015. Figure 6 shows the difference between actual and expected keel laid dates and indicates a significant difference since Year 6 (2015), illustrating the expected number of ships that would be in compliance with the Tier III NO_x limits that were missing from the 2021 fleet.

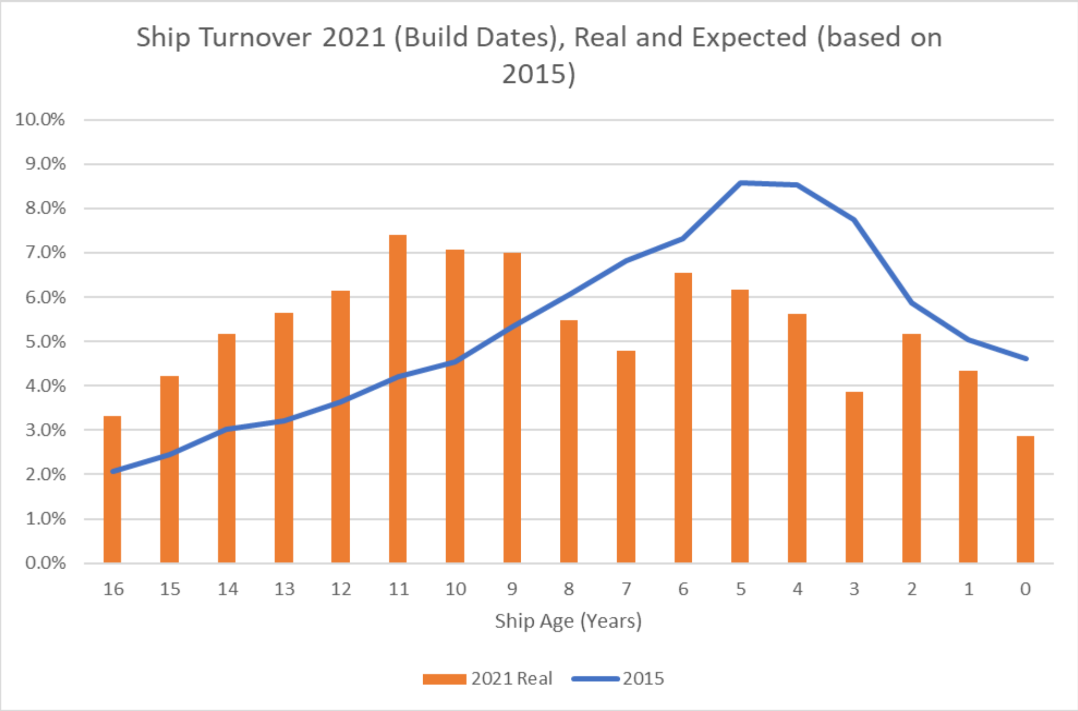

Figure 5: Actual and Expected Ship Turnover, 2021 Fleet, Build Dates

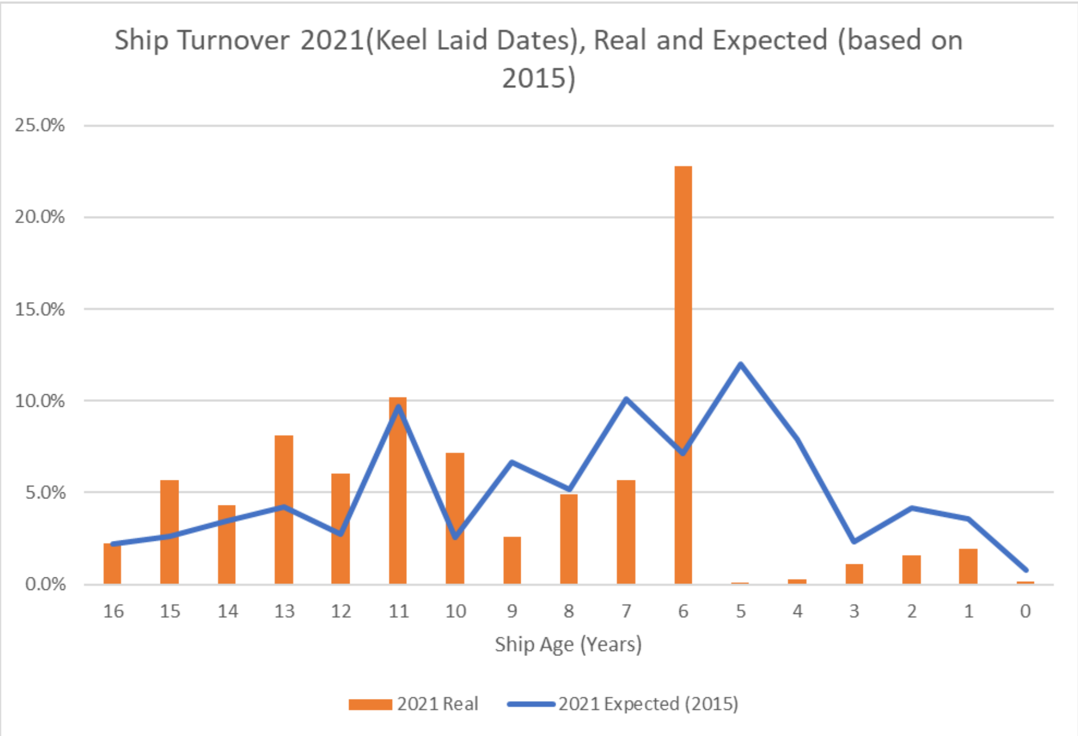

Figure 6: Actual and Expected Ship Turnover, 2021 Fleet, Keel Laid Dates

A 2014 amendment to Annex VI that changed the structure of the program may also have contributed to the slow turnover described above.

An important aspect of the Tier III I limits, as adopted in 2008, pertains to their effective date, 2016. These standards were originally designed to be retroactive, meaning that engines installed on ships built beginning in 2016 would be required to meet the Tier III limits while operating in any NO_x ECA designated in the future. This approach was intended to encourage owners to install Tier III-compliant technology on ships built beginning 2016 if they expected to operate those ships in ECAs designated at any time in the future (for example, in North America, Europe or Asia), or provide room for the installation of such technology in the future. It was expected that most ship builders would install the technology on ships expected to be used in North America, Europe, or Asia. The ship operators would only use the Tier III technology in a designated ECA, however; outside an ECA it could be disengaged. In addition to providing large emission benefits to future ECAs, this approach was expected to deter avoidance behaviour whereby new ships would continue to be built with only Tier II technology and older, pre-2016 ships would be used in designated ECAs.

In 2014, well after designation and entry into force of the North American ECA in 2011 but before the Tier III NO_x effective date, Annex VI was amended in a way that significantly affected the structure of the NO_x requirements. The 2008 Annex VI amendments included a Tier III NO_x technology review to verify that technology was being developed to enable compliance with the limits. The review provision (Regulation 13.10) specified that the effective date of the standards could be adjusted accordingly. The correspondence group that carried out the technology review recommended that the 2016 effective date be retained. However, some IMO Member States disagreed, insisting that more time was necessary. The issue was taken up at the 66th meeting of the Marine Environment Protection Committee in March 2014. The majority of delegations who spoke at that meeting favoured retaining the original effective date. However, there was also support for a 5-year delay for either all ECAs or only future ECAs. After discussion, a compromise 3-part compromise solution was reached:

.1 retention of the 2016 compliance date for currently designated NO_x ECAs (the North American and United States Caribbean Sea ECAs);

.2 revision of the compliance date to 2021 for large yachts in those ECAs; and

.3 for future ECAs, the compliance date would be based on "the date of adoption of [the future] emission control area, or a later date as may be specified in the amendment designating the NO_x Tier III emission control area, whichever is later.[5]

The 2014 amendment had two important effects. First, and most obviously, it would postpone the impact of the Tier III requirements in newly designated NO_x ECAs. For the Baltic and North Sea NO_x ECAs, which subsequently were designated and went into effect in 2021, this means a 5-year loss of emission benefits. That benefit loss will accumulate over the useful life of the relevant ships built from 2016 through 2020, whose engines are not required to use Tier III NO_x controls. Second, and perhaps more pernicious, it made it more attractive for owners to refrain from including Tier III emission control technology on new ships. Not only would ships built after 2016 not be precluded from operating in future NO_x ECAs, but the change also created an incentive to build new Tier II ships that could be used elsewhere and use older, pre-2016 ships in the sole designated NO_x ECA, the North American ECA.

5 See MEPC.261(66), 4 April 2014. Amendments to the annex of 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; see also MEPC 66/21, report of the Marine Environment Protection Committee on its sixty-sixth session, 25 April 2014, para 6.25 through 6.39.

B. Assessment II: Ship Use of Tier III Technology

The Tier III ECA NO_x limits apply only when the engine is operated in a NO_x ECA; when it is operated elsewhere, the Tier II controls apply. This means that Tier III compliance technologies are intended to be on/off.

Most engines certified to the Tier III NO_x ECA limits employ selective catalytic reduction (SCR) technology. Turning off the SCR unit results in operating savings for the ship as reductant is not required to be used. For this reason, the unit is turned off when the ship is operating outside a NO_x ECA. However, the unit can also be turned off when the ship is operating inside a NO_x ECA, in specific circumstances. Regulation 13.9 of MARPOL Annex VI allows for the engine and/or its ancillary equipment (including the SCR system) to be protected against operating conditions that could result in damage or failure, through the use of an approved auxiliary control device (ACD). This provision is important for SCR systems. Under normal SCR operating conditions, ammonia in the form of a urea in water solution is used to catalytically reduce NO_x to nitrogen and water. This chemical reaction is dependent on the inlet exhaust gas temperature. When engine exhaust temperatures are too low, the amount of thermal energy available in the exhaust is insufficient to facilitate the NO_x reduction reaction. Also at low temperatures, sulphuric acid formed during combustion from the sulphur in the fuel can react with the ammonia forming solid ammonium bisulphate. This product can build up in SCR components and negatively impact SCR and engine operation. Therefore, engines equipped with this Tier III emission reduction technology are typically certified with declared ACDs that are designed to disengage the SCR unit at specified exhaust temperatures.

Lower exhaust temperatures will occur when the ship is operating at reduced speed. Over the last 10 years, increases in fuel prices have led to an increase in slow steaming to reduce fuel consumption and operating costs. In addition, some coastal areas have Vessel Speed Reduction (VSR) zones to reduce air emissions or address other environmental or safety concerns. For example, a VSR established in 2001 at the ports of Los Angeles and Long Beach in California to reduce emissions set a speed limit between 10 and 15 knots, depending on ships type, within 20 to 40 nautical miles from shore[6].

There is also growing concern that low-speed operation affects the operation of Exhaust Gas Recirculation (EGR) system emission control. A review of EGR equipped engine technical files reveals that the EGR system is typically turned off via an auxiliary control device (ACD) at 12% load when the engine is being downloaded and not turned on until the 15% load point when the engine is being uploaded (different on/off points are due to the effects of load hysteresis). This operational load limit is necessary because the engine is supplied with less oxygen from the turbocharger at low load. This, in combination with the recirculated exhaust gas, leads to incomplete combustion. There is also a large time delay in the measurement of the oxygen content in the scavenge air receiver, which adversely affects combustion and black smoke control. Thus, the EGR system is disengaged to prevent damage to the EGR and engine components. This is of concern because if the Tier III technology is disengaged in an ECA, the Tier II technology would apply.

Justifications given for the use of the EGR shutdown ACD is that very low load engine operation is not considered to be part of the typical steady state operating points for ocean-going ships, as the ship design is optimized for operation at far higher engine loads. Manufacturers consider the low load operating time, where EGR is turned off, to be time-restricted and only occurring when the ship is leaving or approaching the port. They claim that these ACDs are active for less than one hour of operation for passage to or from the harbour.

[6] https://www.epa.gov/ports-initiative/marine-vessel-speed-reduction-reduces-air-emissions-and-fuel-usage#:~:text=Ports%20such%20as%20Los%20Angeles,such%20as%20reduced%20berthing%20fees
See also https://ww2.arb.ca.gov/resources/documents/vessel-speed-reduction-ocean-going-vessels

1. Analysis: Load Profiles for Ships with Tier III Engines

This analysis uses AIS data to examine the extent to which ships are operate in the United States portions of the North American NO_x ECA at speeds slow enough to disengage the Tier III controls. For the purpose of this analysis, we assume that this occurs for operation below 25% of the engine's Maximum Continuous Rating (MCR).

The analysis requires ship activity data (ship speed and engine load) for a set of ships that operated in the United States portions of the North American ECA in 2022. The ship activity data used in this analysis is Automatic Identification System (AIS) data acquired from the US Coast Guard's (USCG) Nationwide AIS (NAIS) database.[7] The AIS data as queried from the NAIS database contains position and speed reports from ships aggregated at five-minute intervals over a specified geographic and temporal window.

The set of ships examined in this study was created based on ships that visited the United States in 2019 that could be confirmed as having a keel laid date consistent with the Tier III NO_x ECA requirements (i.e., 2016 or later). After verifying that these ships visited the United States in 2022, the result was a list of 95 ships. We queried the NAIS database for global data covering all of calendar year 2022 for this set of 95 ships, identified by their Maritime Mobile Service Identity (MMSI) numbers. We were able to retrieve data for 88 of the 95 ships. Ship specific data such as MCR, maximum speed, and service speed were retrieved from the IHS *Register of Ships* database and joined to the AIS data using MMSI number.

To obtain the relevant load factors, for each reported five-minute interval in the data set a load factor was estimated using the propeller law:

$$L = M\left(\frac{V}{V}\right)^3$$

where V and V_{max} are the ship's reported operating speed, and maximum operating speeds, and M is a sea-margin term that accounts for deviations from calm water conditions dues to wind and waves. Engine load factors were calculated using the ship's maximum speed if it was an available field. Otherwise, the maximum speed was calculated from the service speed, which is assumed to be 94% of the maximum speed. The service margin was assumed to be 1.15.[8] To avoid assigning loads greater than a ship's MCR, the load factor was set to one for the cases where a load factor greater than one was calculated. This situation could occur in situations where a ship is traveling with favourable currents or winds. Finally, to avoid including times when ships were likely at berth, at anchor, or operating under tug assistance, all activity under two knots was excluded from the analysis.

A heatmap of the estimated engine loads for the sampled ships is shown in figure 7. The dark grey areas indicate regions of the High Seas where there are no territorial claims. The blue shaded areas indicate waters within an Exclusive Economic Zone (EEZ). The light blue lines outline the North American and Caribbean ECAs. As the figure shows, the sampled ship activity covers much of the globe, with the majority of traffic occurring in the north Atlantic and north Pacific oceans.

[7] https://www.navcen.uscg.gov/automatic-identification-system-overview

[8] US EPA, *Ports Emissions Inventory Guidance: Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emissions*, EPA-420-B-22-011, 2022

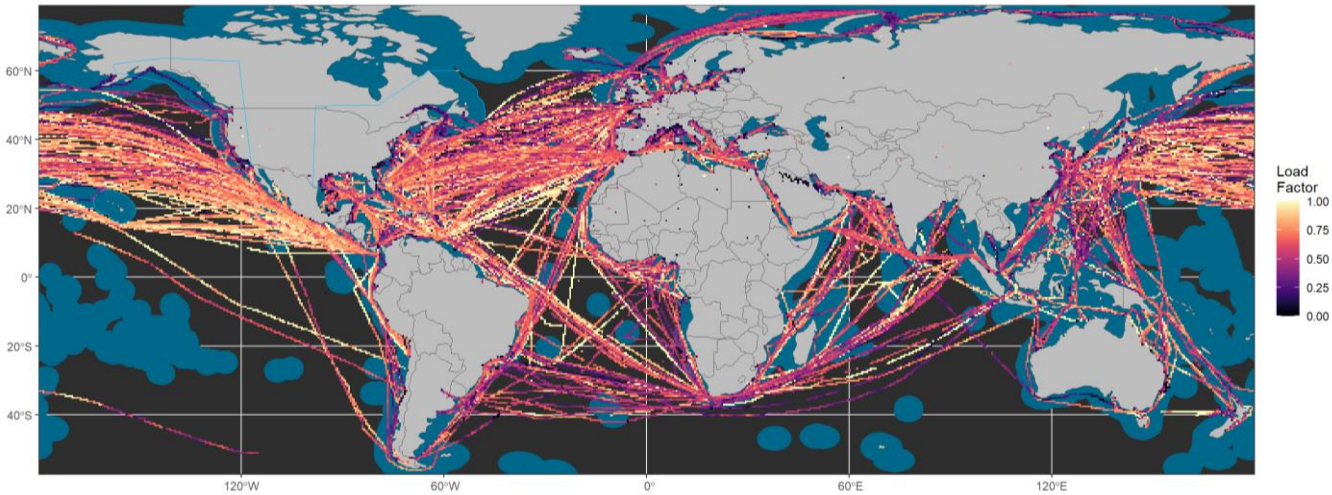

Figure 7: Map of median estimated engine load for sampled ships.

The ship activity data was partitioned into the following geographic regions for analysis: North American and Caribbean ECAs, United States Exclusive Economic Zone (United States EEZ) not within an ECA, Foreign (non-United States) EEZs, and High Seas. Figure 8 shows histograms of estimated ship engine load for each of these geographic regions. The solid vertical lines indicate the median load factor for each region, and the dashed vertical lines indicate the 25th and 75th percentile load factors. For each of these histograms there is a conspicuous spike for the maximum load factor bin. This is due to any estimates of loads greater than 100% MCR being reassigned to a load factor of one. Likewise, there is generally a larger value in the lowest load factor bin relative to the next adjacent bin. This most likely indicates port and anchorage related activity that was not captured by the two knot minimum speed criteria.

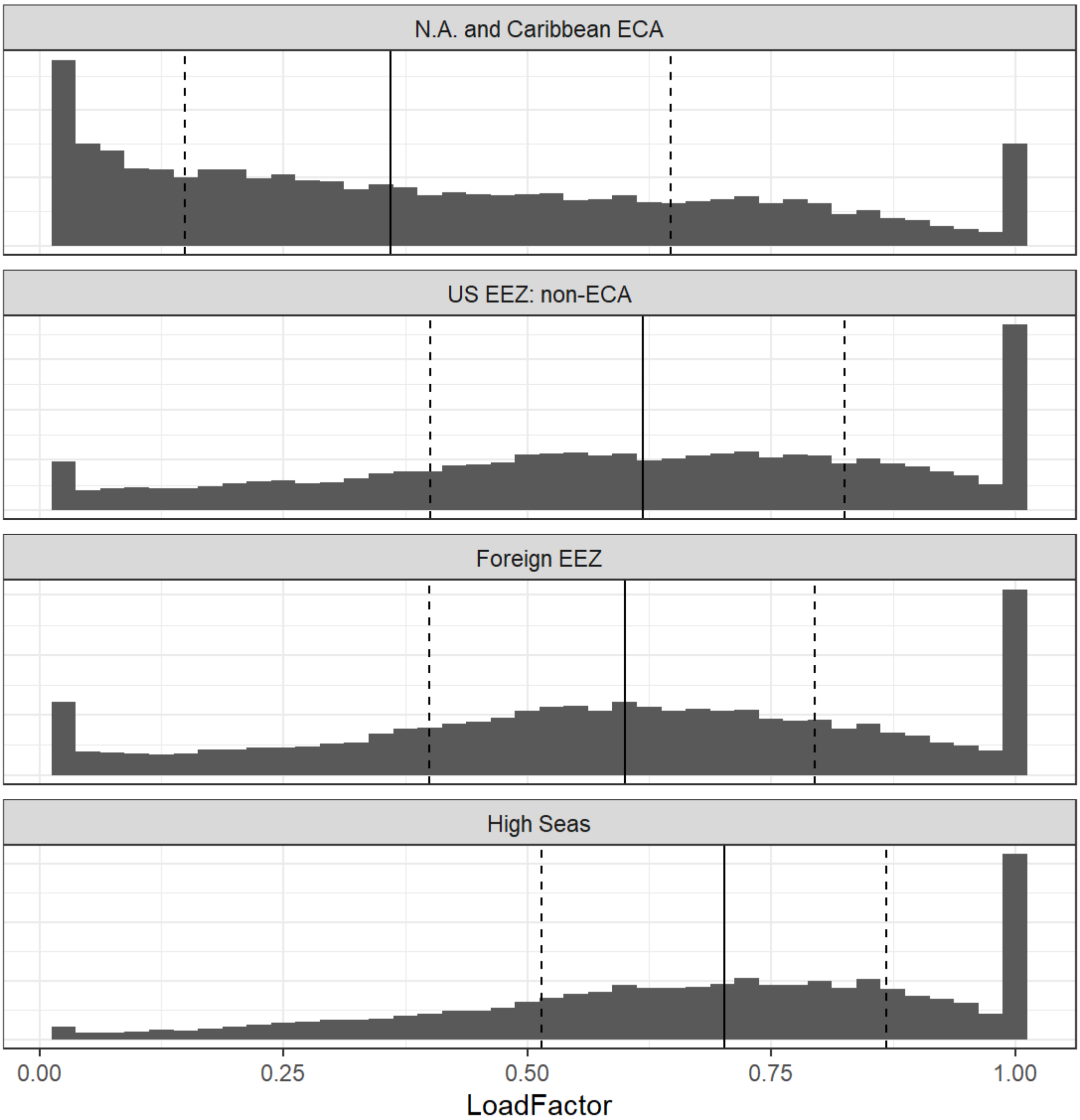

Figure 8: Histograms of estimated ship engine load factors for ships operating in different geographic regions.

The histogram labelled High Seas shows activity that is broadly distributed between load factors of 0.5 and 0.875, with tails towards both the high and low load limits, and very little indication of port and anchorage activity. The Foreign EEZ distribution looks similar, though shifted towards somewhat lower load factors, and with a clear indication of port activity in the lowest load bin. The United States EEZ but non-ECA histogram is generally similar to the Foreign EEZ distribution. It is worth noting that this region is limited geographically, and only includes regions of western Alaska, regions west of Hawaii, and some small regions north and south of Puerto Rico. The only major port facilities in this region are in the western parts of Alaska. Finally, the load factor distribution for the North American and Caribbean ECAs looks very different from the other regions. Within the ECAs most of the ship activity falls below a load factor of 0.375. This distribution show no clear maximum and has a downward sloping trend from the lowest load bin towards the maximum load bin. The difference in the load distributions between the ECA regions and the non-ECA EEZ regions suggests that ships are operated differently within the ECAs than they are in analogous geographic regions that are expected to have a similar mix of port and offshore cruise activity. Table 9 summarizes the data presented in figure 8 along with the percentage of activity that was estimated to occur below the 25% threshold for SCR use, and the 12% threshold for ERG use. For the Tier 3 ships sampled for this study, these results suggest that SCR is likely not being used 38% of the time, and that EGR is not engaged 21% of the time while operating in the NO_x ECAs. This is in contract to activity in other EEZs where only 14% of activity falls below the SCR threshold, and only 7% fall below the EGR threshold.

Table 9: Summary of ship load activity by geographic region

Geographic Region	25th percentile load factor	Median load factor	75th percentile load factor	activity below 25% load	activity below 12% load
N.A. and Caribbean ECAs	0.15	0.36	0.65	38%	21%
US EEZ: non-ECA	0.40	0.62	0.83	14%	7%
Foreign EEZ	0.40	0.60	0.79	14%	7%
High Seas	0.51	0.70	0.87	7%	3%

2. Summary of Assessment II

For Tier III NO_x technology, such as SCR and EGR, to operate effectively, a minimum exhaust gas temperature must be achieved. Under the current structure of the NO_x standards, there is little incentive to maintain high exhaust temperatures below 25% load, which is the lowest load point on the emission test cycle. Our study showed that approximately 38% of the operation of Tier III engines, in the ECA, is below 25% load. Under these conditions, it is not likely that the anticipated NO_x reductions associated with the Tier III NO_x standards are being achieved.

IV. Conclusion

The North American ECA was expected to result in significant NO_x reductions, leading to significant human health and environmental benefits. Unfortunately, due to changes in MARPOL Annex VI and ship operations, these benefits are not being realized. Given expected increases in international ship transportation, and the impacts on human health and the environment, the Committee should examine ways to address ship NO_x emissions and put the Annex back on the path to protecting human health and the marine environment.

___