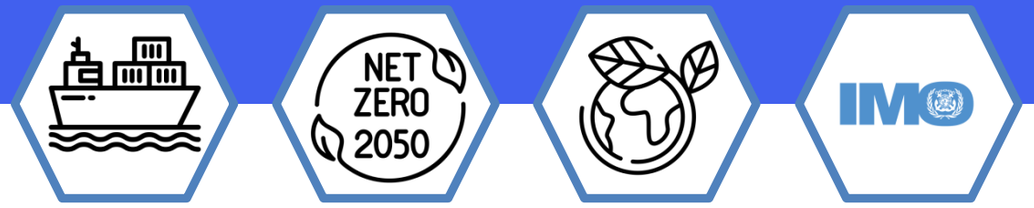
Proposed Revision to Reflect Requirements of the Operation for the SCR Recording Device

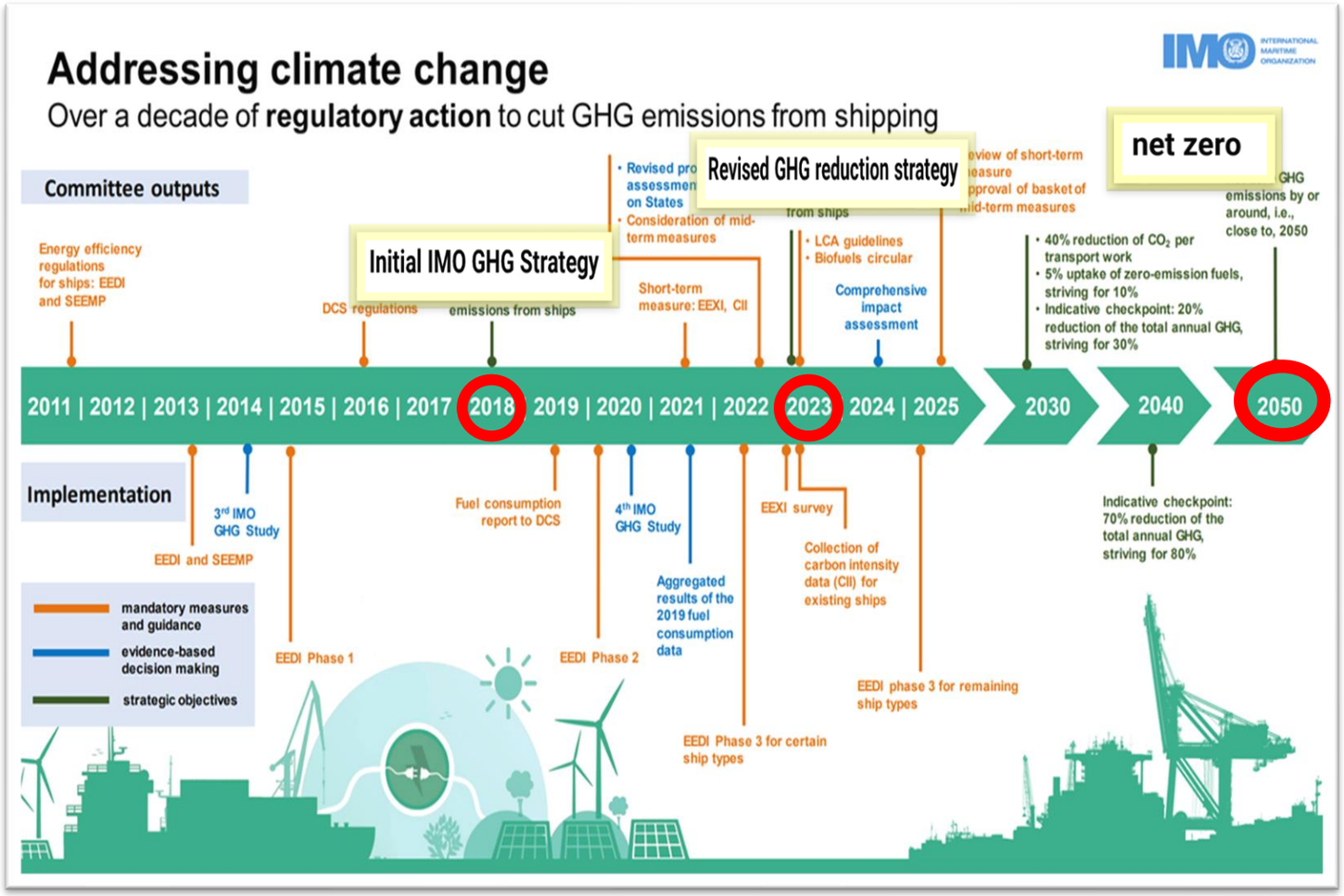
Team “NOx”

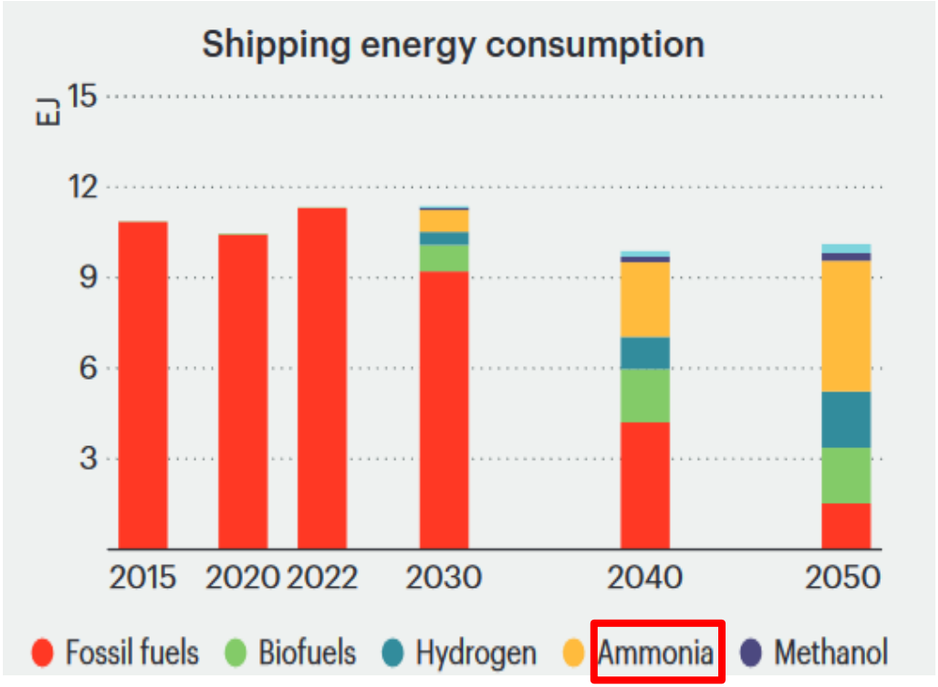


INDEX

BACKGROUND

1. 2023 IMO strategy on reduction of GHG





⇨ **Carbon- free fuel : Ammonia (NH_3)**

Promising alternative fuel

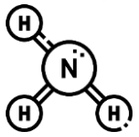
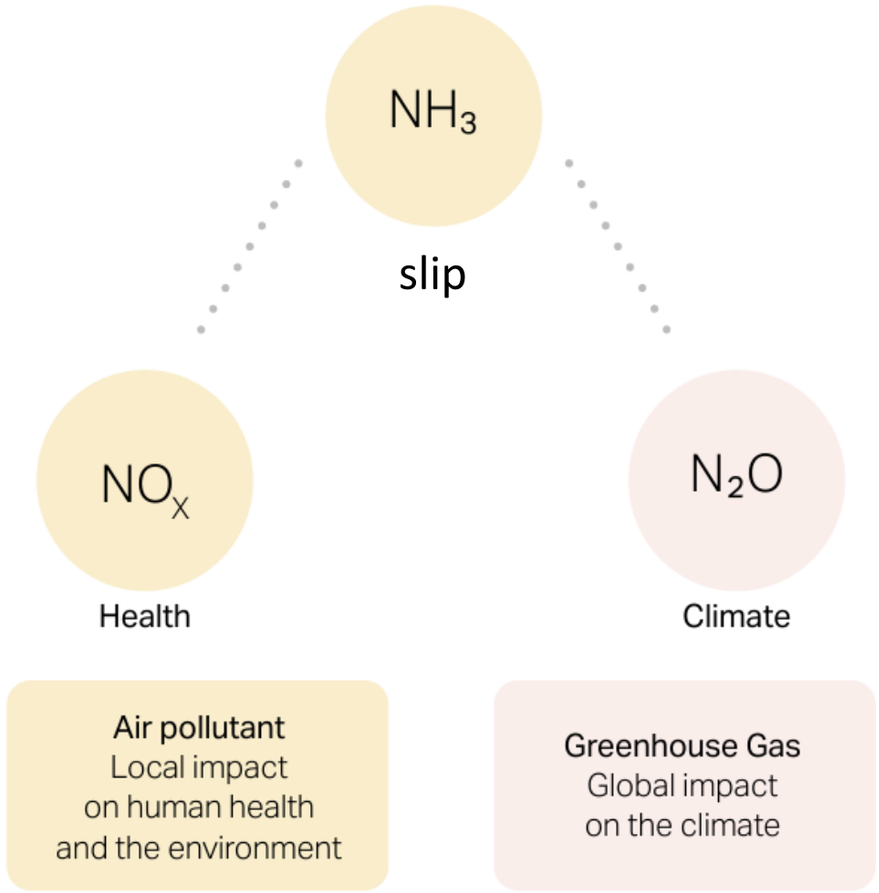


Photo1: 2023 IMO Strategy on Reduction of GHG Emissions from Ships.
Photo2: From Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach (IEA, 2023)

2. Ammonia combustion emission risk



→ **NOx**

Ammonia Contains nitrogen, leading to higher NOx emissions.

Health

- **NOx, due to its low solubility, affects the respiratory system.**

Climate

- **N_2O, global warming potential 265 times CO_2**

→ **NH3 slip**

Unburned ammonia released via exhaust.

Photo1: Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping

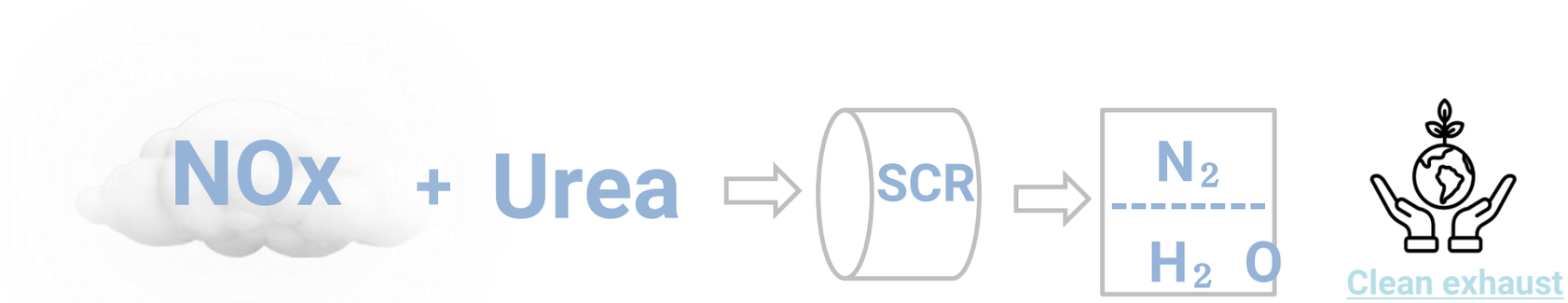
3. MARPOL Annex VI Reg.13 – SCR

Title	MARPOL *** / MARPOL 2024 Amendment (81st) / Reg. 13
Effective Date	8/1/2025

Regulation 13

Nitrogen oxides (NOx)

5.3 The tier and on/off status of marine diesel engines installed on board a ship to which paragraph 5.1 of this regulation applies which are certified to both Tier II and Tier III or which are certified to Tier II only shall be recorded in such logbook or electronic record book[15] as prescribed by the Administration at entry into and exit from a NOx Tier III emission control area, or when the on/off status changes within such an area, together with the date, time and position of the ship.

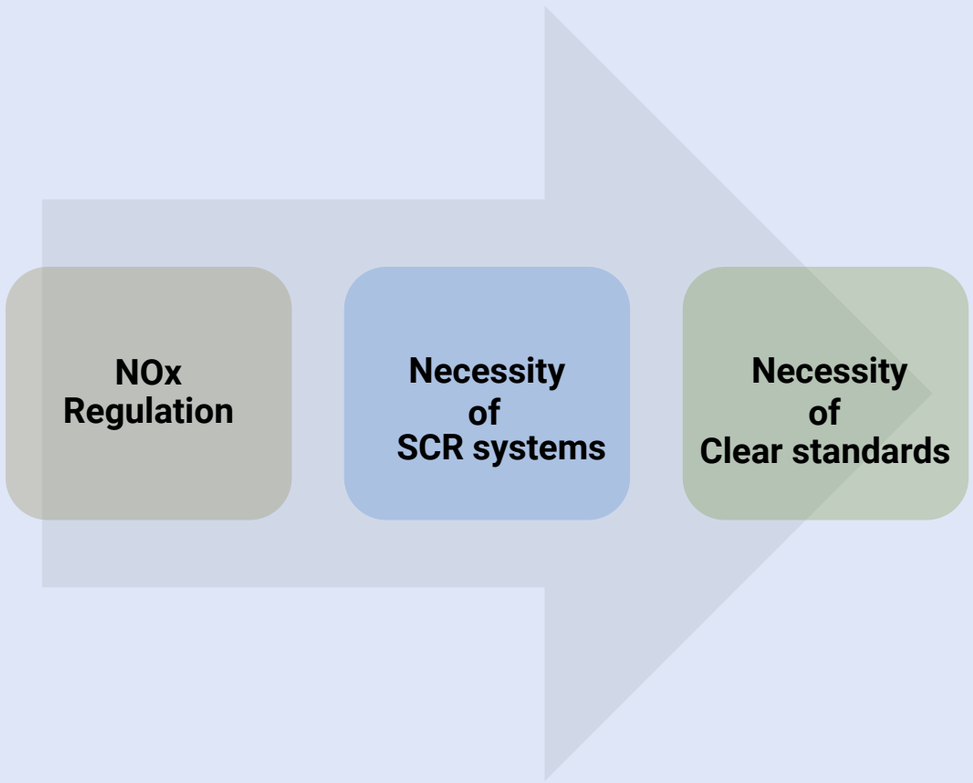


SCR SYSTEM

Selective Catalytic Reduction

Photo1: MARPOL VI REG.13 NOx

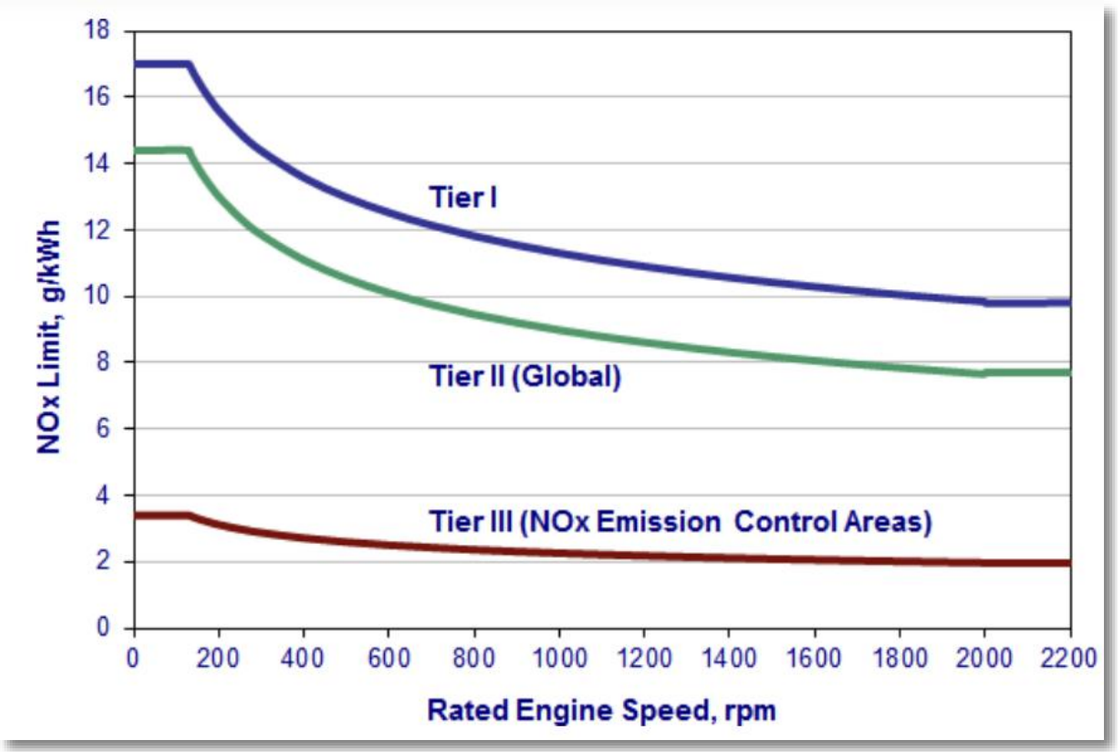
PROBLEM ANALYSIS



1. The regulations of diesel engine NOx emissions

According to the current IMO Nox emission standards, they are categorized as Tier II and Tier III.

Tier	Ship construction date on or after	Total weighted cycle emission limit (g/kWh) n = engine's rated speed (rpm)		
		n < 130	n = 130 - 1999	n ≥ 2000
I	1 January 2000	17.0	45·n(-0.2) e.g., 720 rpm – 12.1	9.8
II	1 January 2011	14.4	44·n(-0.23) e.g., 720 rpm – 9.7	7.7
III	1 January 2016	3.4	9·n(-0.2) e.g., 720 rpm – 2.4	2.0



Tier II: Approximately 15-20% reduction compared to Tier I
Tier III: Approximately 80% reduction compared to Tier I

Photo 1&2: MARPOL Annex VI Nitrogen Oxide emission limits

2. Necessity of SCR Systems for Ammonia Fuel Use

SCR is mandatory for pure ammonia engines in ECA zones, while ammonia-hydrogen engines must always use SCR

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ENVIRONMENTAL RESEARCH
LETTERS

LETTER

Climate and air quality impact of using ammonia as an alternative shipping fuel

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Keywords: shipping, decarbonization, air quality, $PM_{2.5}$, ozone, ammonia energy, public health
Supplementary material for this article is available online

Abstract

As carbon-free fuel, ammonia has been proposed as an alternative fuel to facilitate maritime decarbonization. Deployment of ammonia-powered ships is proposed as soon as 2024. However, NO_x, NH_3 and N_2O from ammonia combustion could impact air quality and climate. In this study, we assess whether and under what conditions switching to ammonia fuel might affect climate and air quality. We use a bottom–up approach combining ammonia engine experiment results and ship track data to estimate global tailpipe NO_x, NH_3 and N_2O emissions from ammonia-powered ships with two possible engine technologies (NH_3–H_2 (high NO_x, low NH_3 emissions) vs pure NH_3 (low NO_x, very high NH_3 emissions) combustion) under three emission regulation scenarios (with corresponding assumptions in emission control technologies), and simulate their air quality impacts using GEOS–Chem high performance global chemical transport model. We find that the tailpipe N_2O emissions from ammonia-powered ships have climate impacts equivalent to 5.8% of current shipping CO_2 emissions. Globally, switching to NH_3–H_2 engines avoids 16 900 mortalities from $PM_{2.5}$ and 16 200 mortalities from O_3 annually, while the unburnt NH_3 emissions (82.0 Tg NH_3 yr^{-1}) from pure NH_3 engines could lead to 668 100 additional mortalities from $PM_{2.5}$ annually under current legislation. Requiring NH_3 scrubbing within current emission control areas leads to smaller improvements in $PM_{2.5}$-related mortalities (22 100 avoided mortalities for NH_3–H_2 and 623 900 additional mortalities for pure NH_3 annually), while extending both Tier III NO_x standard and NH_3 scrubbing requirements globally leads to larger improvement in $PM_{2.5}$-related mortalities associated with a switch to ammonia-powered ships (66 500 avoided mortalities for NH_3–H_2 and 1200 additional mortalities for pure NH_3 annually). Our findings suggest that while switching to ammonia fuel would reduce tailpipe greenhouse gas emissions from shipping, stringent ammonia emission control is required to mitigate the potential adverse effects on air quality.

Table 1. Description of the engine technology and policy scenarios considered in this study. SCR refers to selective catalytic reduction (assumed to be 90% effective), which converts NO_x and NH_3 into N_2 in 1:1 ratio under ideal conditions. NH_3 scrubbing is assumed to remove 95% of NH_3 slip after SCR.

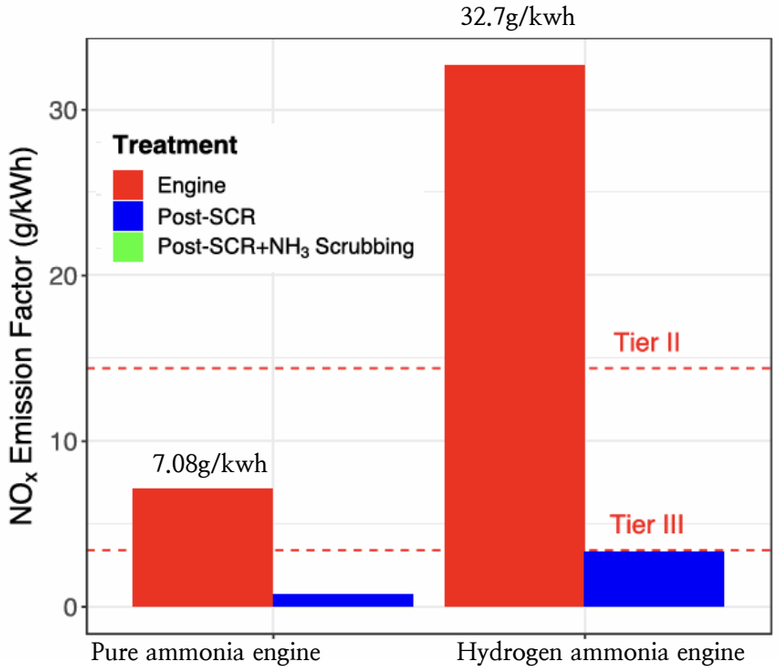
Scenario name	Emission control inside current ECA	Emission control outside current ECA	Equivalent policy scenario
Baseline	Zhang *et al* (2021b) inventory for 2015 shipping with 0.5% sulphur cap		
Post-2020 NO_x baseline	Baseline with Tier III NO_x (post-2020) standard imposed globally		
$[NH_3–H_2]_{2020}$	SCR	SCR	2020 NO_x limit
$[NH_3–H_2]_{NH3\_ECA\_LIM}$	SCR + NH_3 scrubbing	SCR	Additional NH_3 limit in ECA
$[NH_3–H_2]_{GLOB\_LIM}$	SCR + NH_3 scrubbing	SCR + NH_3 scrubbing	Global NO_x and NH_3 limits
$[Pure\ NH_3]_{2020}$	SCR	None	2020 NO_x limit
$[Pure\ NH_3]_{NH3\_ECA\_LIM}$	SCR + NH_3 scrubbing	None	Additional NH_3 limit in ECA
$[Pure\ NH_3]_{GLOB\_LIM}$	SCR + NH_3 scrubbing	SCR + NH_3 scrubbing	Global NO_x and NH_3 limits

- **2020 scenario follows IMO 2020 regulations, with Tier II NOx limits outside ECAs and Tier III limits within ECAs.**

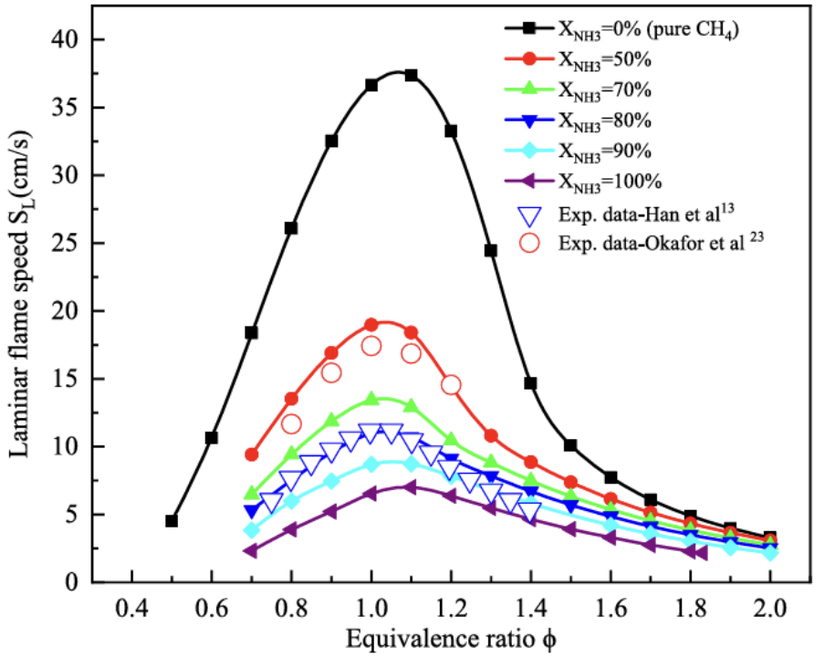
Photo 1&2:: Climate and air quality impact of using ammonia as an alternative shipping fuel

2. Necessity of SCR Systems for Ammonia Fuel Use

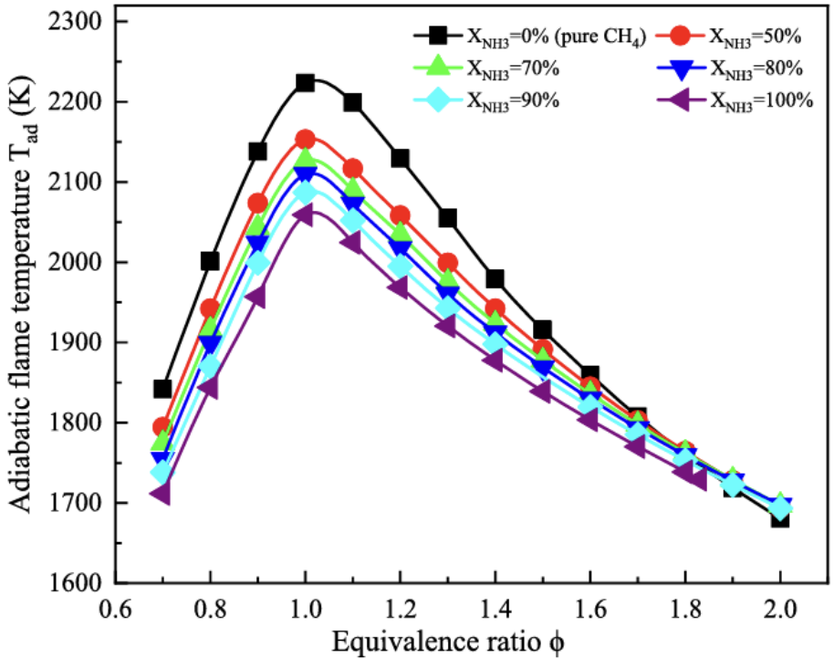
While pure ammonia yields remarkably low NOx emissions, its practical application remains unfeasible



NOx emissions according to engine type



Laminar flame speed for NH3-CH4-air at various equivalence ratios



Adiabatic flame temperature for NH3-CH4-air at various equivalence ratios

Photo 1: Climate and air quality impact of using ammonia as an alternative shipping fuel
Photo 2: Effect of CH4 ,Pressure ,and Initial Temperature on the Laminar Flame Speed of an NH3−AirMixture

3. Necessity of Clear Standards for SCR Systems

There is a necessity to establish a clear standard for SCR by referencing scrubber standards to provide precise guidelines

Fuel oil sulphur limits recorded in regulations 14.1 and 14.4 and corresponding emissions values

Fuel Oil Sulphur Content (% m/m)	Ratio Emission SO_2(ppm)/CO_2(% v/v)
4.50	195.0
3.50	151.7
1.50	65.0
1.00	43.3
0.50	21.7
0.10	4.3

Note: The use of the Ratio Emissions limits is only applicable when using petroleum based Distillate or Residual Fuel Oils. See Appendix II for application of the ratio method.

Sulphur content IMO must meet the SOx ratio requirements through scrubbers

RESOLUTION MEPC.340(77)

(adopted on 26 November 2021)

2021 GUIDELINES FOR EXHAUST GAS CLEANING SYSTEMS

5 SCHEME B – EGCS APPROVAL, SURVEY AND CERTIFICATION USING CONTINUOUS MONITORING OF EMISSION RATIO

5.4.2 SO2(ppm) and CO2(%) and, to not less than one decimal place, the Emission Ratio should be continuously monitored and recorded against the applicable Emission Ratio limit onto a data recording and processing device at a rate which should not be less than 0.0035 Hz whenever the EGCS is in operation. This monitoring may be suspended for service and maintenance periods of gas analyser and associated equipment as required by the OMM. Zero and span check calibration and instrument drift data should, as given in the OMM, be either recorded by the data recording system or manually entered in the EGCS Record Book as appropriate to the means used.

Standards for scrubber data recording devices

Photo 1: IMO table linking Fuel Sulphur Content with equivalent SO_2/CO_2 Ratio
Photo 2: Resolution MEPC.340(77)

SCRUBBER GUIDELINES

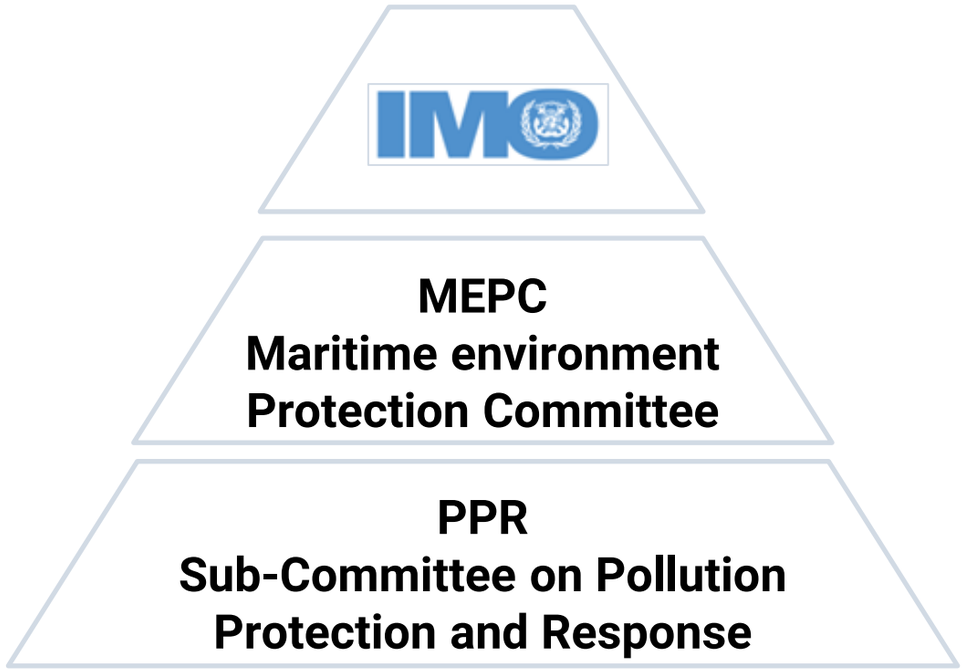
MARPOL ANNEX VI

+

SCR GUIDELINES

SOLUTIONS

1. New Regulations for ammonia engines



A Proposal for amendments of MARPOL ANNEX VI REGULATION 13 & SCR guidelines (MEPC 291(71))

- To operate the SCR whenever ammonia engine is in operation
- SD 2 : Integrate new, emerging and advancing technologies in the regulatory framework
- PI 2.1 : #of proposals submitted to IMO to incorporate new, emerging and advancing technologies into the regulatory framework

1. New Regulations for ammonia engines

MARPOL ANNEX VI CHATPER III

Regulation 13
Nitrogen oxides (NOx)

5.3 The tier and on/off status of marine diesel engines installed on board a ship to which paragraph 5.1 of this regulation applies which are certified to both Tier II and Tier III or which are certified to Tier II only shall be recorded in such logbook or electronic record book15 as prescribed by the Administration at entry into and exit from a NOx Tier III emission control area, or when the on/off status changes within such an area, together with the date, time and position of the ship

Regulation 13
Nitrogen oxides (NOx)

5.3.1 The tier and the period whenever SCR is operation of marine ammonia engines installed on board a ship to which paragraph 5.1 of this regulation applies which are certified to both Tier II and Tier III or which are certified to Tier II only shall be recorded in such logbook or electronic record book15 together UTC and ship's position as given by a Global Navigational Satellite System (GNSS)

SCR GUIDELINES

ANNEX 13
RESOLUTION MEPC. 291(71)

2017 GUIDELINES ADDRESSING ADDITIONAL ASPECTS OF THE NOX TECHNICAL CODE 2008 WITH REGARD TO PARTICULAR REQUIREMENTS RELATED TO MARINE DIESEL ENGINES FITTED WITH SELECTIVE CATALYTIC REDUCTION (SCR) SYSTEMS

8.1 The recording and processing device should be of robust, tamper-proof design with read-only capability.
8.2 The recording and processing device should record, whenever the ammonia engine is in operation together UTC and ship's position as given by a Global Navigational Satellite System (GNSS)
8.3 data recording and processing device at a rate which should not be less than 0.0035 Hz whenever the ammonia engine is in operation

Photo 1 & 2 : MARPOL ANNEX VI Regulation 13 Nitrogen Oxides(NOx)

2. Scrubber Regulations can be referred

Regulation 14

Sulphur oxides (SOx) and particulate matter

SOx Emission Control Area

Fuel oil sulphur content (% m/m)	Emission Ratio SO2(ppm)/CO2(% v/v)
0.50	21.7
0.10	4.3

RESOLUTION MEPC.340(77)

(adopted on 26 November 2021)

2021 GUIDELINES FOR EXHAUST GAS CLEANING SYSTEMS

5 SCHEME B – EGCS APPROVAL, SURVEY AND CERTIFICATION USING CONTINUOUS MONITORING OF EMISSION RATIO

5.4.2 SO2(ppm) and CO2(%) and, to not less than one decimal place, the Emission Ratio should be continuously monitored and recorded against the applicable Emission Ratio limit onto a data recording and processing device at a rate which should not be less than 0.0035 Hz whenever the EGCS is in operation. This monitoring may be suspended for service and maintenance periods of gas analyser and associated equipment as required by the OMM. Zero and span check calibration and instrument drift data should, as given in the OMM, be either recorded by the data recording system or manually entered in the EGCS Record Book as appropriate to the means used.

7 DATA RECORDING AND PROCESSING DEVICE

7.1 The recording and processing device should be of robust, tamper-proof design with read-only capability.

7.2 The recording and processing device should record, whenever the EGCS is in operation, the data described in 4.4.7, 5.4.2, and 10.3 as applicable, including overboard discharges from any associated tanks within the system, against UTC and ship's position as given by a Global Navigational Satellite System (GNSS) and whether the ship was inside or outside an Emission Control Area as given by regulation 14.3 at that time. The device should also be capable of:

Photo 1 : MARPOL ANNEX VI Regulation 14, Sox Emission Control Area
Photo 2 : Fuel oil sulphur limits and corresponding Emission Ratio limit values
Photo 3 : ANNEX RESOLUTION MEPC. 340(77)

Limitations

Anticipated points

CONCLUSION

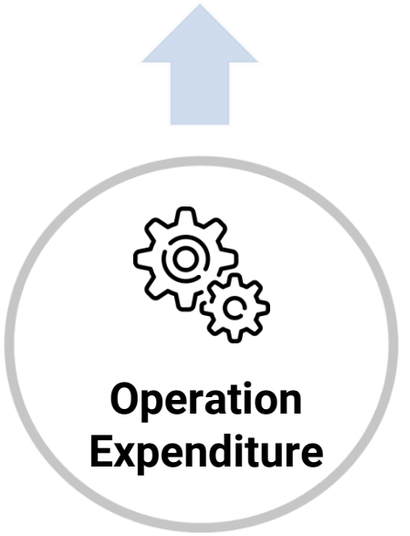
1. Limitations

MAN ES predicts ammonia engine must be dual fuel engine

Table 1

Energy storage type	Supply energy	Energy density	Required tank volume	Supply pressure	Injection pressure	Emission reduction compared to HFO Tier II			
	MJ/kg	MJ/L	m^3 *1	bar	bar	%	%	%	%
HFO	40.5	35	1,000	7-8	950	SO_x	NO_x	CO_2	PM
Liquefied natural gas (LNG -162°C)	50	22	1,590	300 methane 380 ethane	300 methane 380 ethane	90-99 90-97	20-30 30-50	24 15	90 90
LPG (including Propane / Butane)	42	26	1,346	50	600-700	90-100	10-15	13-18	90
Methanol	19.9	15	2,333	10	500	90-95	30-50	5	90
Ethanol	26	21	1,750	10	500				
Ammonia* (liquid -33°C)	18.6	12.7	2,755	70	600-700	90-95	Tier	95	90
Hydrogen (liquid -253°C)	120	8.5	4,117						
Marine battery market leader, Corvus, battery rack	0.29	0.33	106,060						
Tesla model 3 battery Cell 2170 *2	0.8	2.5	14,000						

Table 1: Physical and chemical fuel properties related to combustion in two-stroke engines, where *1 is based on a 1000 m^3 HFO tank, the additional space required for insulation is not included in the table. All pressure values are for high-pressure injection and *2 the values for the Tesla battery do not contain the energy/mass needed for cooling/safety/classification



The amount of fuel,
SCR Running Hour & maintenance

Photo 1 : MAN ES technical paper, Engineering the future two-stroke green-ammonia engine, November 2019.

2. Anticipated points through amendments

Eco-friendly operation for ammonia engines	IMO Strategic Directions	IMO Performance Indicator
	SD 3 : Respond to climate change and reduce greenhouse gas emissions from international shipping	PI 3.3 [US$ expenditure on funding of technical cooperation activities and major projects related to energy efficiency and reduced emissions] PI 3.5 [% of energy used by international shipping originating from zero and near-zero GHG emission technologies, fuels and energy sources]

Continuous operating SCR is our key amendments, whenever ammonia engine is operating

Photo 1 : MAN ES successfully conducted combustion tests on a research ammonia combustion engine developed at their Copenhagen Research Center.

References

[1]2023 IMO Strategy on Reduction of GHG Emissions from Ships
[2]From Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach (IEA, 2023)
[3] Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping
[4] MARPOL VI REG.13 NOx
[5] Photo 1&2: MARPOL Annex VI Nitrogen Oxide emission limits
[6] Climate and air quality impact of using ammonia as an alternative shipping fuel
[7] Effect of CH4 ,Pressure ,and Initial Temperature on the Laminar Flame Speed of an NH3−AirMixture
[8] IMO table linking Fuel Sulphur Content with equivalent SO_2 /CO_2 Ratio
[9] Resolution MEPC.340(77)
[10] MARPOL ANNEX VI Regulation 13 Nitrogen Oxides(Nox)
[11] ANNEX 13 RESOLUTION MEPC. 291(71)
[12] MARPOL ANNEX VI Regulation 14, Sox Emission Control Area
[13] Fuel oil sulphur limits and corresponding Emission Ratio limit values
[14] ANNEX RESOLUTION MEPC. 340(77)
[15] MAN ES technical paper, Engineering the future two-stroke green-ammonia engine, November 2019
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Thank you