Welcome to the webinar – we will begin shortly…

Managing Emissions from Ammonia-Fueled Vessels

An overview of regulatory drivers, emission types, sources, scenarios, reduction technologies, and solutions

Mærsk Mc-Kinney Møller Center
for Zero Carbon Shipping

Working group members:

ABS, Alfa Laval, bp, Daphne Technology, Hitz Hitachi Zosen, MAN Energy Solutions Future in the making, MAN, Mitsubishi Heavy Industries, Mitsui & Co., Norden, NREL Transforming Energy, NYK Line Nippon Yusen Kaisha, Stolt Tankers, Sumitomo Corporation, TGE Marine, Topsoe, TotalEnergies, Volcano Co., Ltd.

On Today's Agenda:

01 Introduction

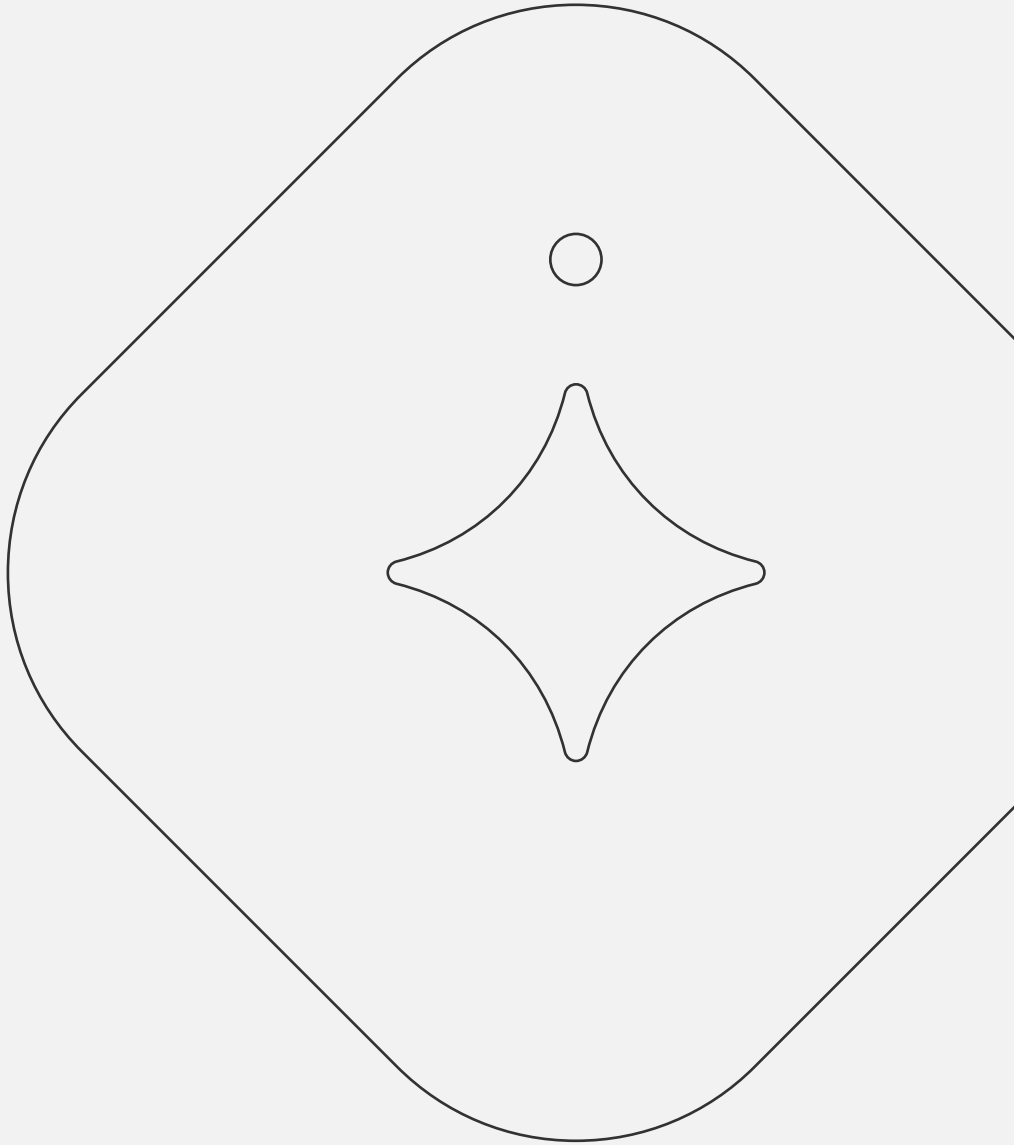
02 Paper highlights

03 Industry perspectives:

- MAN Energy Solutions
- Wärtsilä
- Alfa Laval
- Topsoe

04 Panel discussion & audience Q&A

05 Closing



Join at

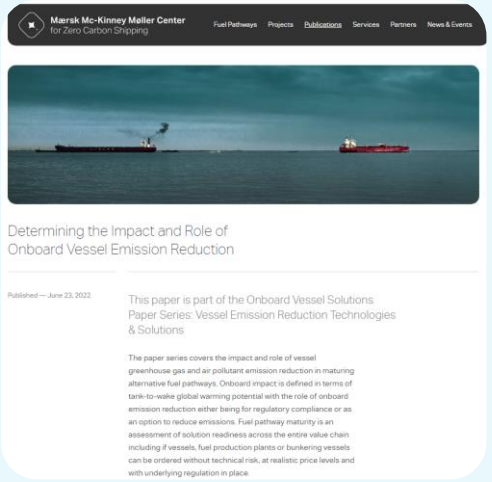
slido.com

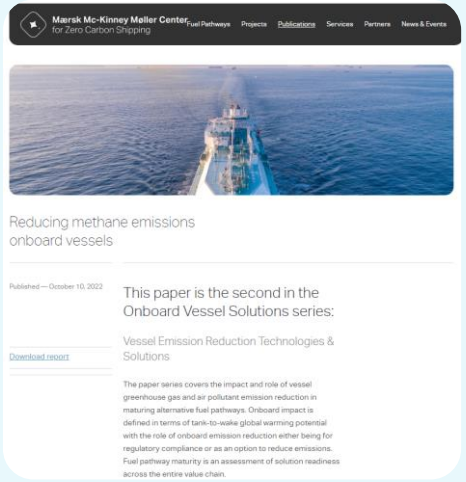
#ammonia

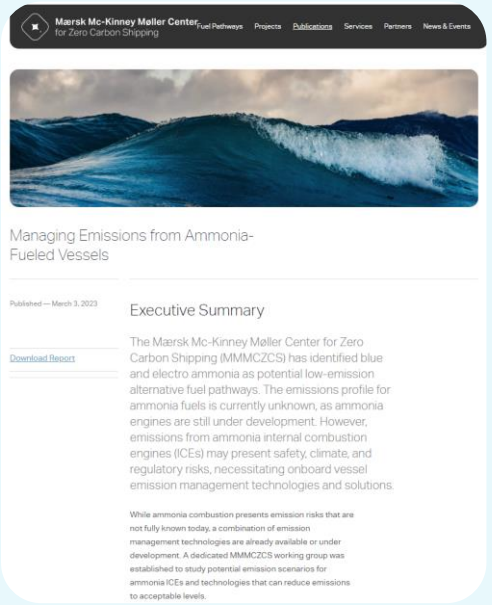
This work is part of the Onboard Vessel Solutions Paper Series:

Vessel Emission Reduction Technologies & Solutions

The paper series covers the impact and role of vessel greenhouse gas and air pollutant emission reduction in maturing alternative fuel pathways.







Bio-diesel onboard vessel handling and emission management

Coming soon!

Fuel Pathway Maturity Map

	Feedstock availability	Fuel production	Fuel storage, logistics and bunkering	Onboard energy storage & fuel conversion	Onboard safety and fuel management	Vessel emissions	Regulation & certification
E-ammonia							
Blue ammonia							
E-methanol							
Bio-methanol							
E-methane							
Bio-methane							
Bio-oils							

Knowledge of, and experience, with emissions from ammonia internal combustion engines is limited.

Until fully developed and validated ammonia engines are available, the requirements for emission reduction technologies onboard are unclear.

MATURE

Solutions are available, none or marginal barriers identified.

SOLUTIONS IDENTIFIED

Solutions exist, but some challenges on e.g., maturity and availability.

MAJOR CHALLENGES

Solutions are not developed or lack specification.

Emissions Web

Emission Type

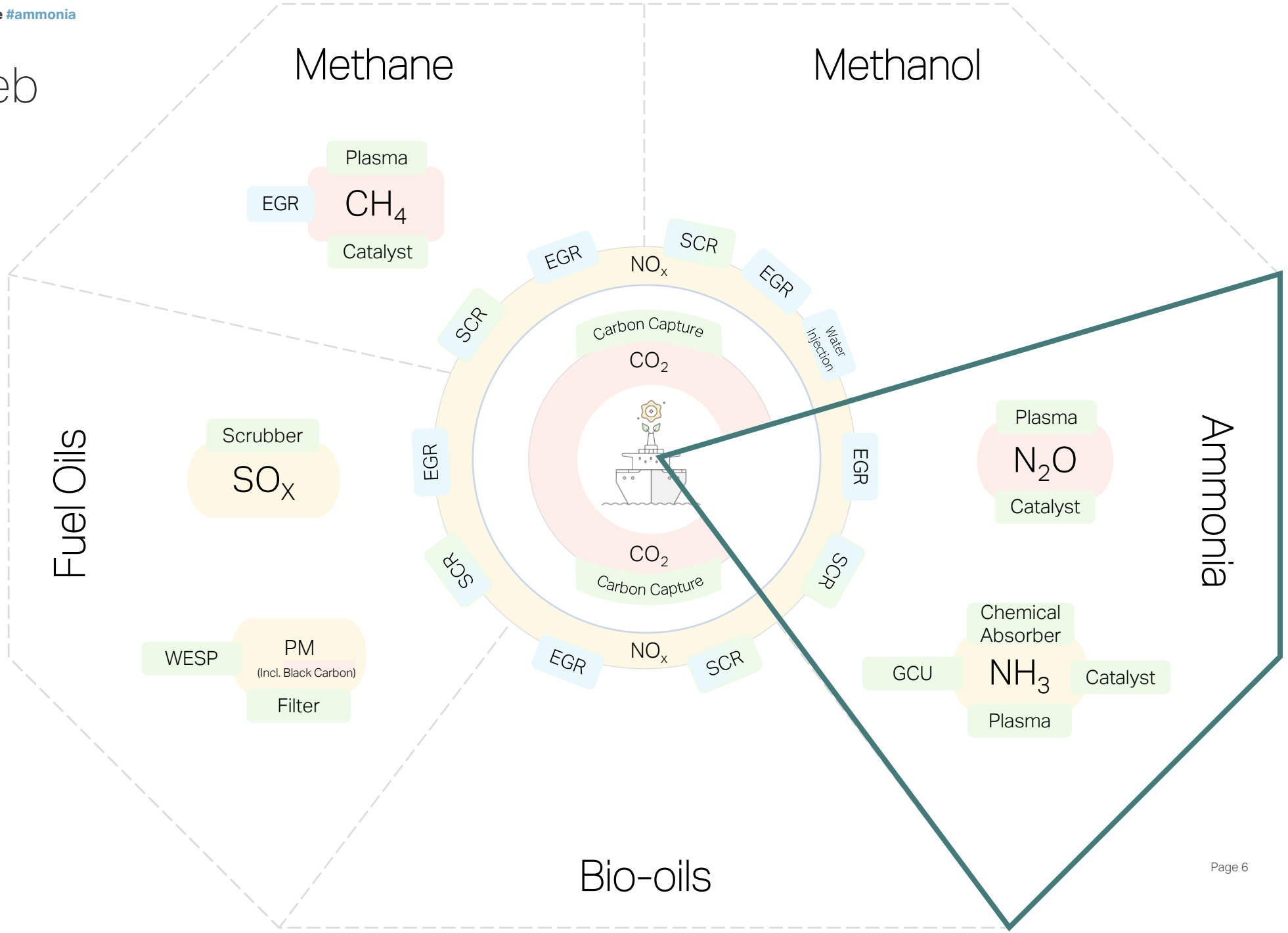
Greenhouse Gas
→ Global impact on the climate

Air pollutant
→ Local impact on human health and the environment

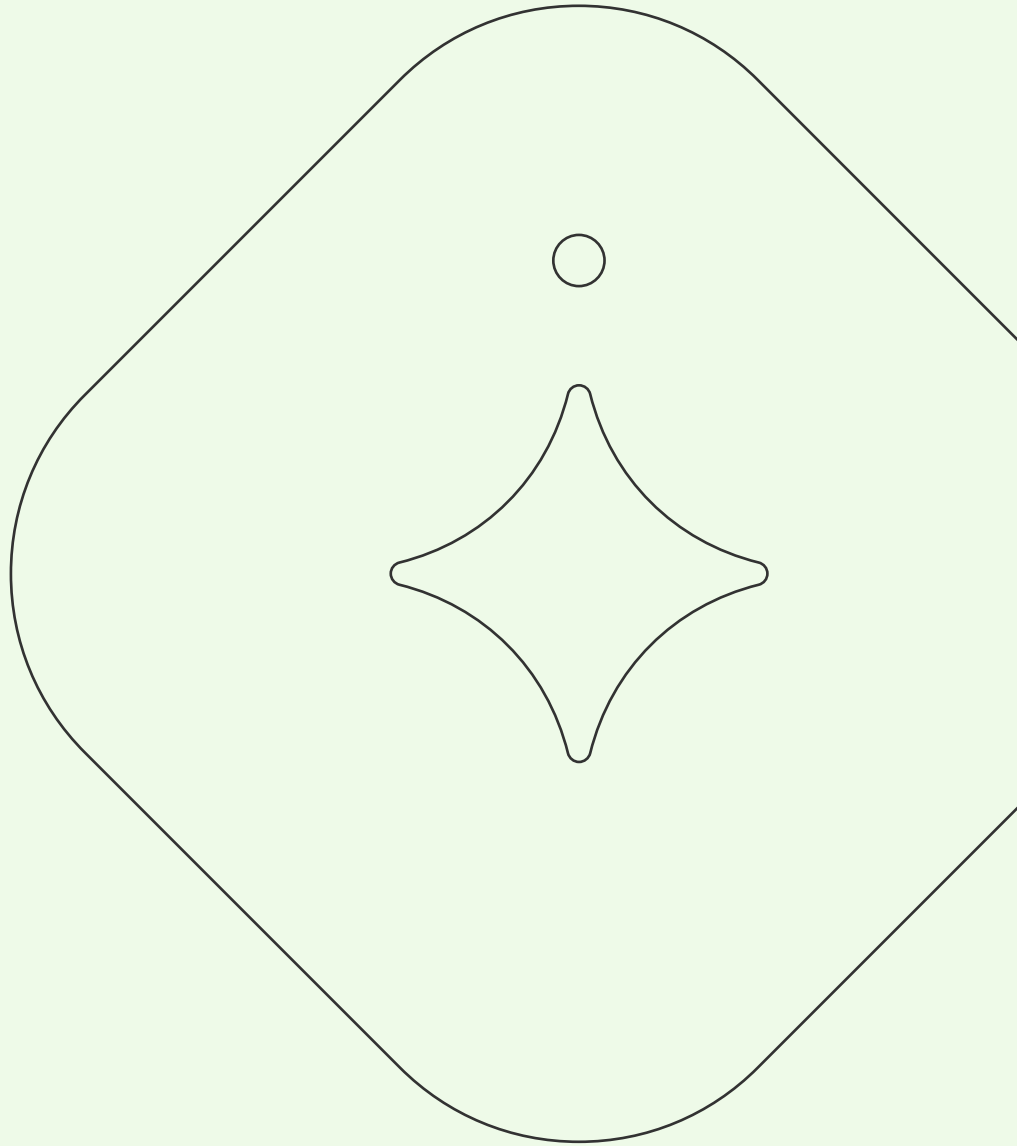
Reduction Technology

Engine technology
→ Fully integrated with engine

After treatment
→ Separate from engine, but integrated



Paper highlights



Today's objectives

Purpose of today is not to claim that:

- Ammonia is the answer to all questions
- Ammonia is the worst of evils
- All challenges around Ammonia to be addressed
  today or tomorrow

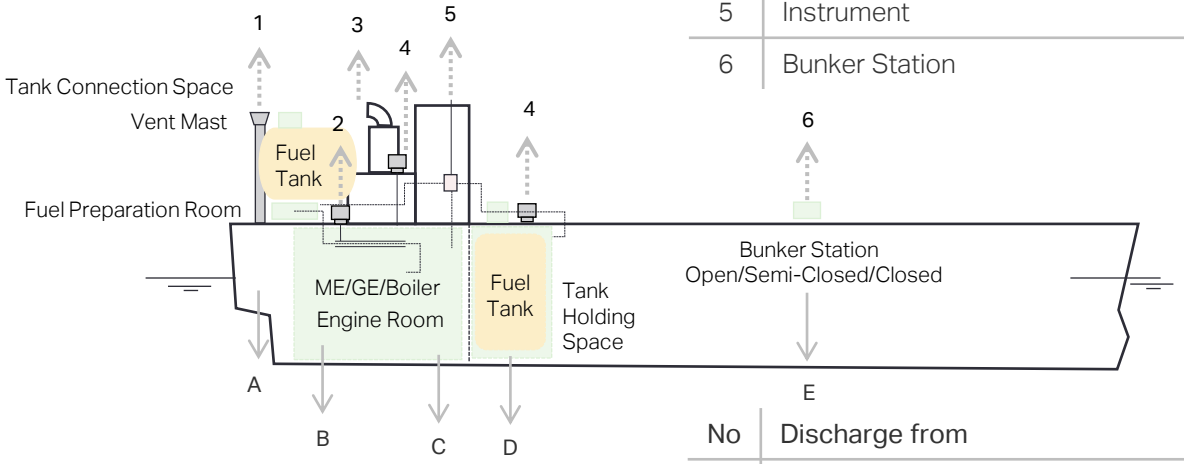
We do want to:

- Share a realistic status update, built on input gathered across "Ammonia first movers"
- Highlight outstanding challenges that are still to be solved and how to do so
- Share a recommendation for best way forward for technology development and regulators

Onboard vessel ammonia emissions sources

(for illustrative purposes; not based on a specific design)

NH_3 gas



No	Emission from	Originated
1	Gas Vent Mast	Tank & Line Safety Valve, Catch & detox System
2	Ventilation of double wall pipe system	NH_3 Fuel Liquid and Gas Piping in Engine Room , Piping from bunker station to engine room.
3	NH_3 Slip of various consumers	Main Engine, Generator Engine, Aux Boiler, GCU, Reliq. plant, Compressor
4	Ventilation of enclosed space	Machinery/Fuel handling system in that space or from surrounding space
5	Instrument	Gas detector, Calorific Meter, Calibration gas
6	Bunker Station	Hose connection/disconnection, quick coupler, emergency release system

NH_3 solution

No	Discharge from	Source
A	Deck Water Spray System	Leakages from Piping system and storage tank on exposed deck
B	NH_3 Catcher and Detox system	Main Engine, Generator Engine, Aux Boiler, GCU, if equipped, Compressor
C	Heat Exchange Fluid	Heat Exchanger (Tube/Plate)
D	Enclosed space Bilge System	Leakages from Independent tank, piping, stub piece, valve, plug etc If equipped, local water sprinkler for NH_3
E	Water Curtain / Spill Tank System	Leakages from Bunker Hose, quick coupler, emergency release system

Figure 5 – Ammonia Emissions Reduction Position Paper

Ammonia combustion emission risk triangle

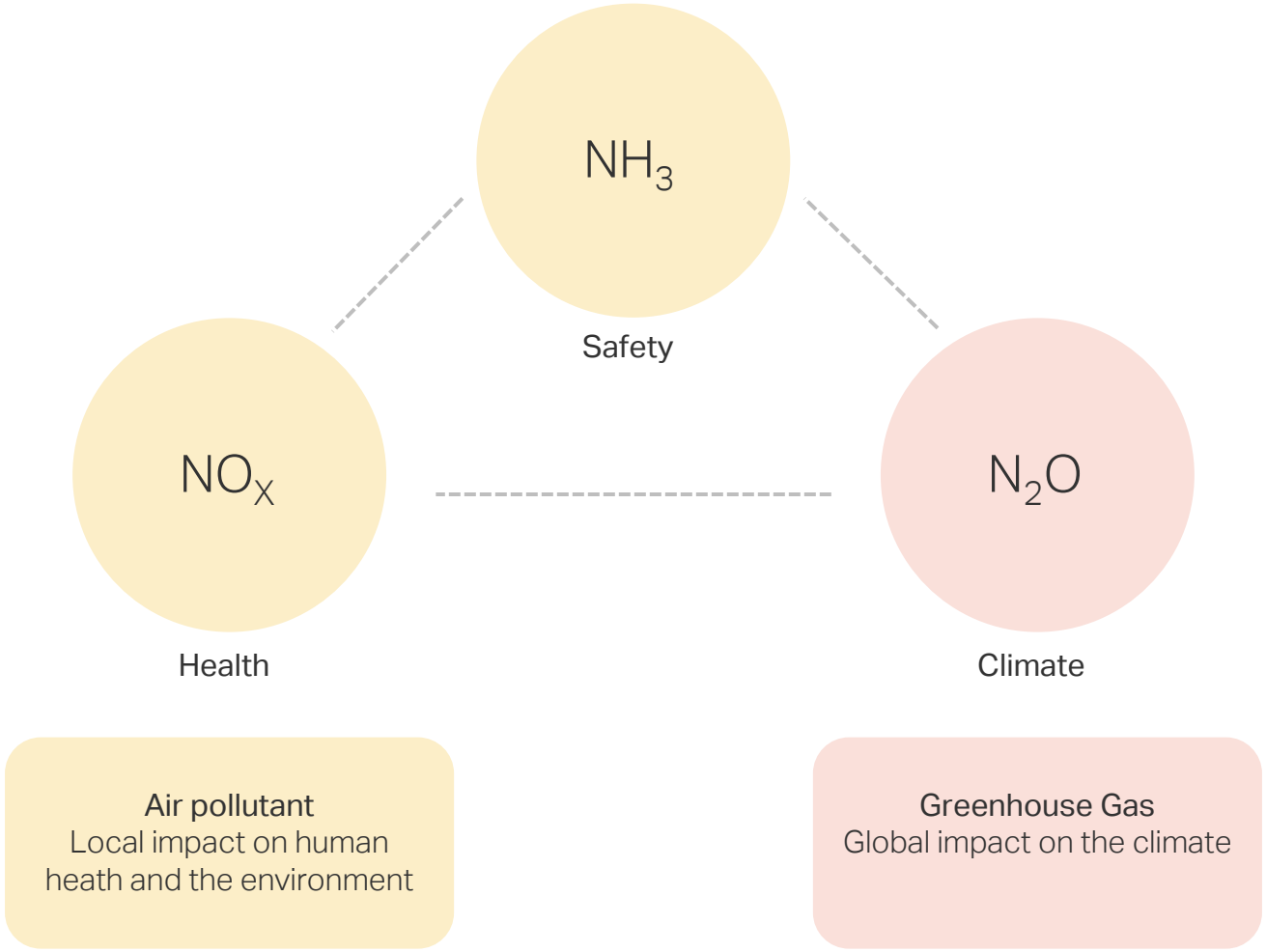
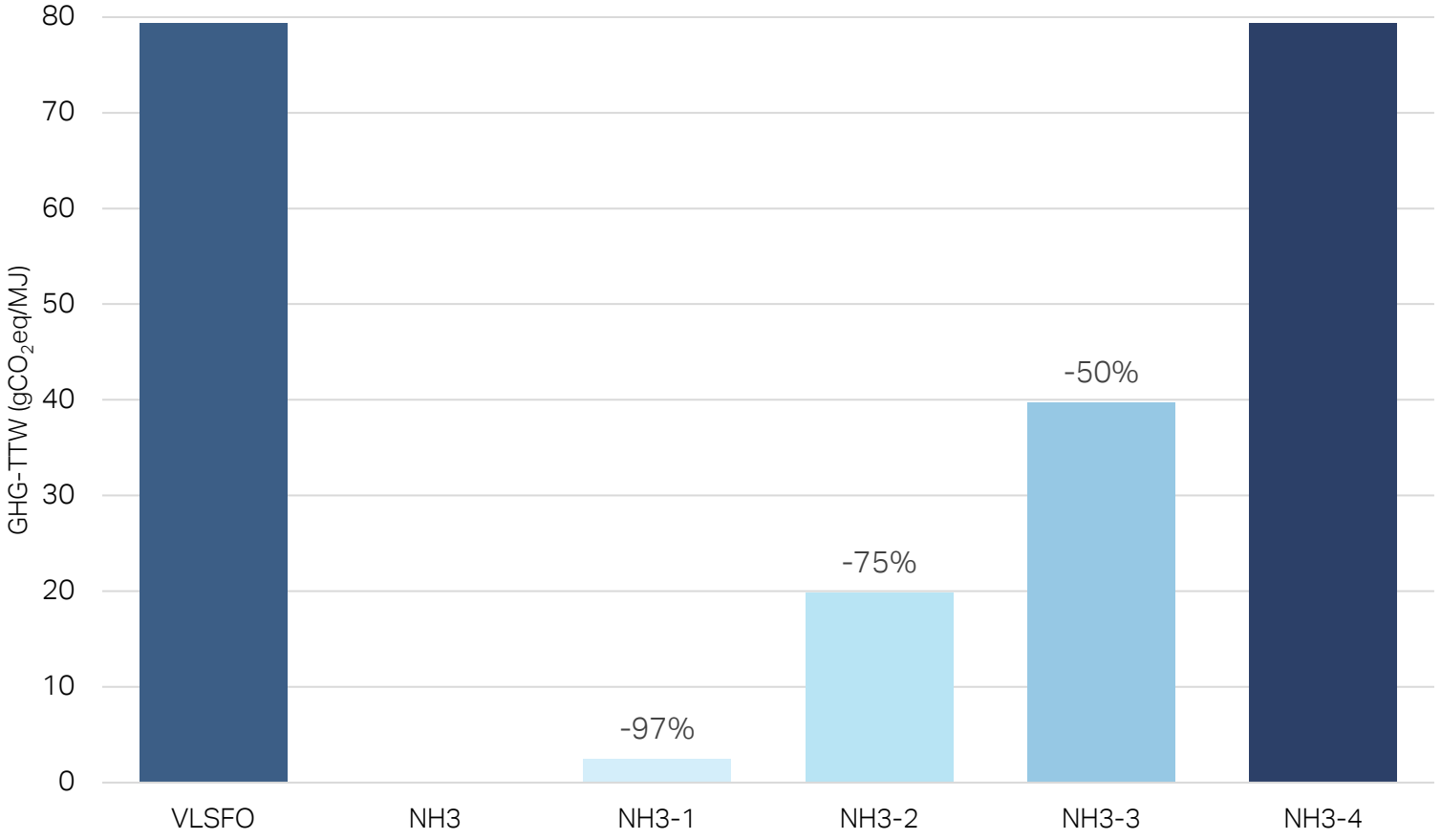


Figure 3 – Ammonia Emissions Reduction Position Paper

Ammonia limits (in ppm) from Class guidelines

Classification Society	ppm limits for release, alarm, and safety systems activation	Source
ABS	10 ppm as release/exhaust limit, gas alarms at 25 ppm and safety systems activated at 150 ppm	ABS, "Guide for Ammonia Fueled Vessels", September 2021
BV	30 ppm exposure limit, triggering shut down and other safety measures	Bureau Veritas, "AMMONIA-FUELED SHIPS TENATIVE RULES - NR671 - JULY 2022", 2022
Class NK	25 ppm as release/exhaust limit, same safety and alarm provisions as Korean Registry	ClassNK, "Guidelines for Ships Using Alternative Fuels (Edition 2.0) - Methy/Ethyl Alcohol/LPG/Ammonia, June 2022
DNV	30 ppm as release/exhaust limit, gas alarms at 150 ppm and safety systems activated at 350 ppm	DNV, RULES FOR CLASSIFICATION, Ships, "Part 6 Additional class notations, Chapter 2 Propulsion, power generation and auxiliary systems", July 2022
Korean Register	Safety systems activated at 300 ppm. Alarm sounds at 25 ppm	Korean Register, "Guidelines for ships using Ammonia as fuels (2021.26)", 2021
Lloyd's Register	Prevent venting in normal and abnormal conditions. Safety systems activated at 220 ppm and alarm sounds at 25 ppm.	Lloyd's Register, Notice No. 1, Rules and Regulations for the Classification of ships using Gases or other Low-flashpoint Fuels, December 2022

Potential impact of N_2O on total GHG emissions



	% N_2O / NH_3 fuel	g N_2O / kWh
NH_3-1	0.01757%	0.06 g/kWh
NH_3-2	0.1336%	0.47 g/kWh
NH_3-3	0.2435%	0.95 g/kWh
NH_3-4	0.5572%	1.90 k/kWh

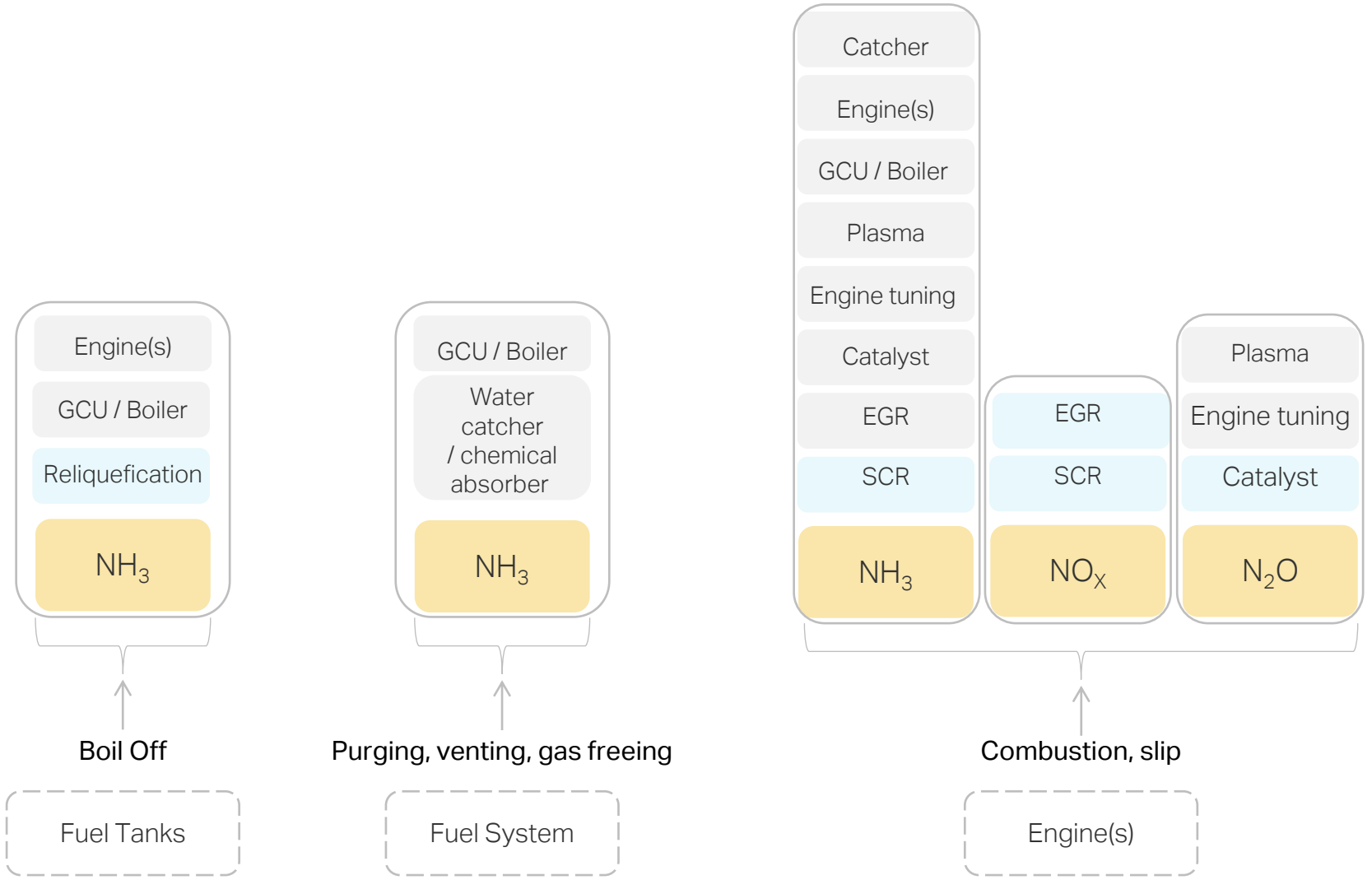
Figure 4 – Ammonia Emissions Reduction Position Paper

Working groups emission target levels

Emission	Target Level
NH_3	10-30 ppm
N_2O	0.06 g/kWh
NO_X	Tier III (≈2 g/kWh)
SO_X	N/A
PM	N/A

Table 2– Ammonia Emissions Reduction Position Paper

Ammonia-fueled vessel emission management technologies



Technology Maturity: Available | Under Development

Ammonia emission scenario 0 (base case)

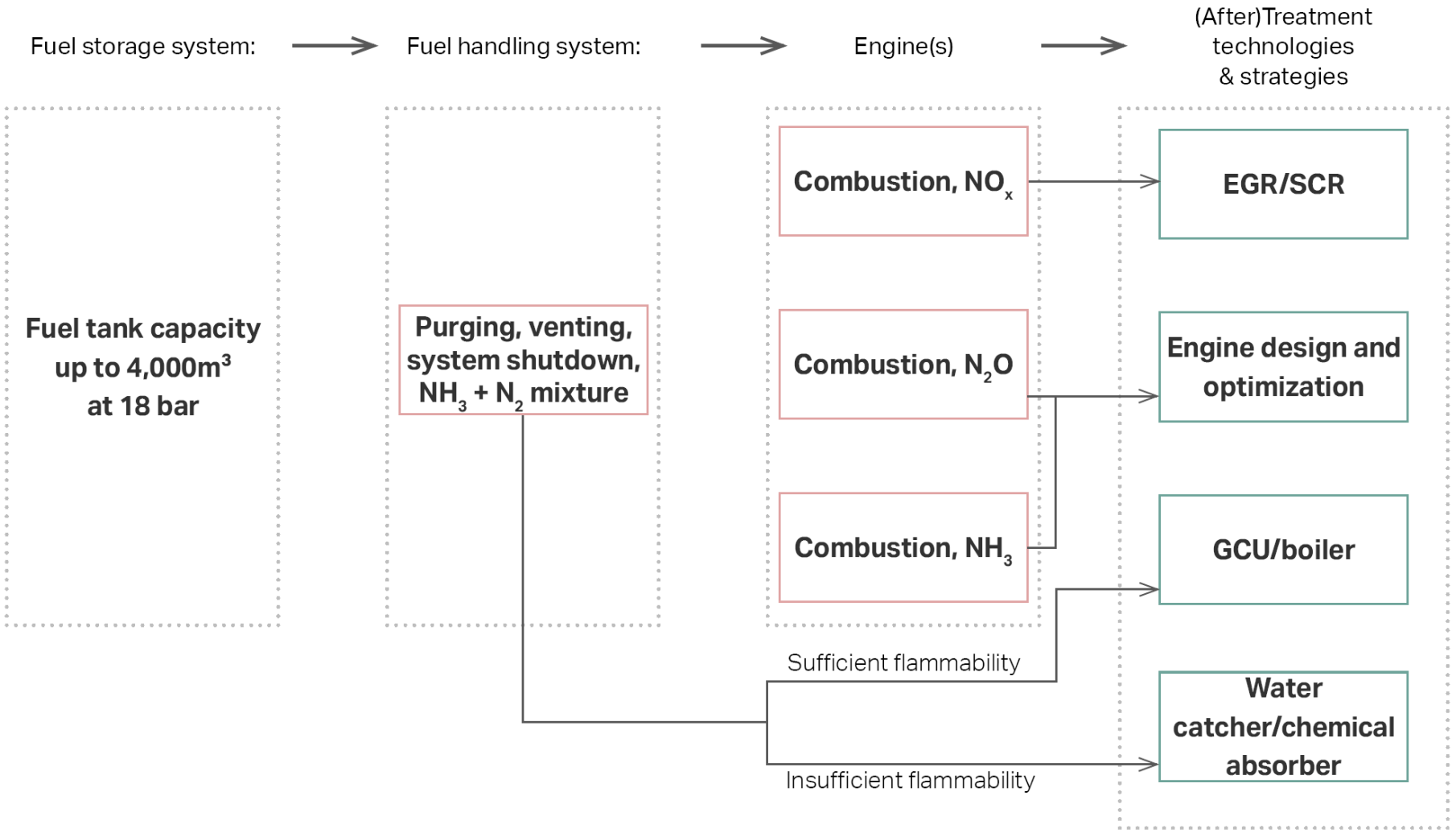


Figure 12 – Ammonia Emissions Reduction Position Paper

Ammonia emission scenario 1

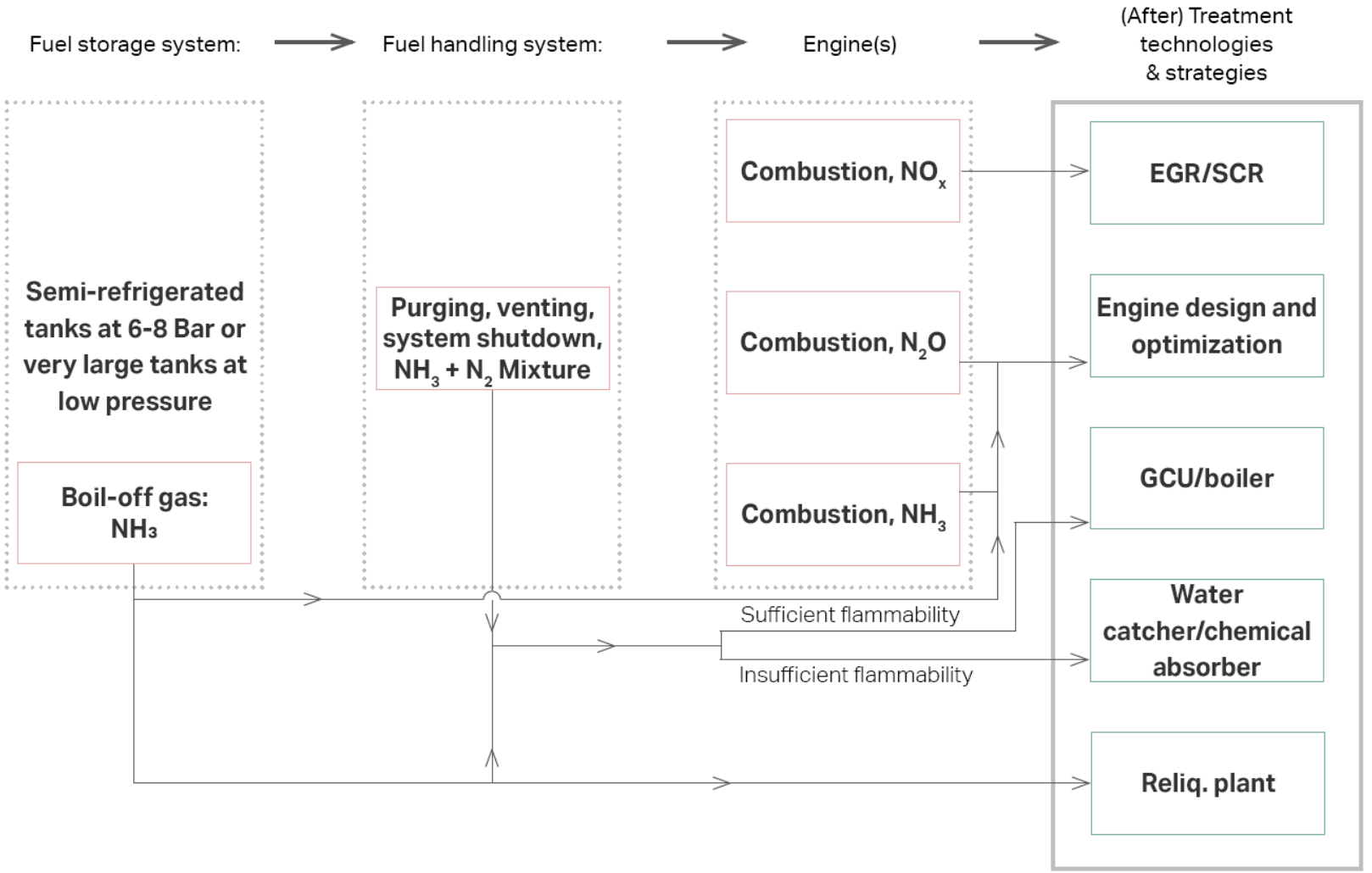


Figure 13 – Ammonia Emissions Reduction Position Paper

Ammonia emission scenario 2

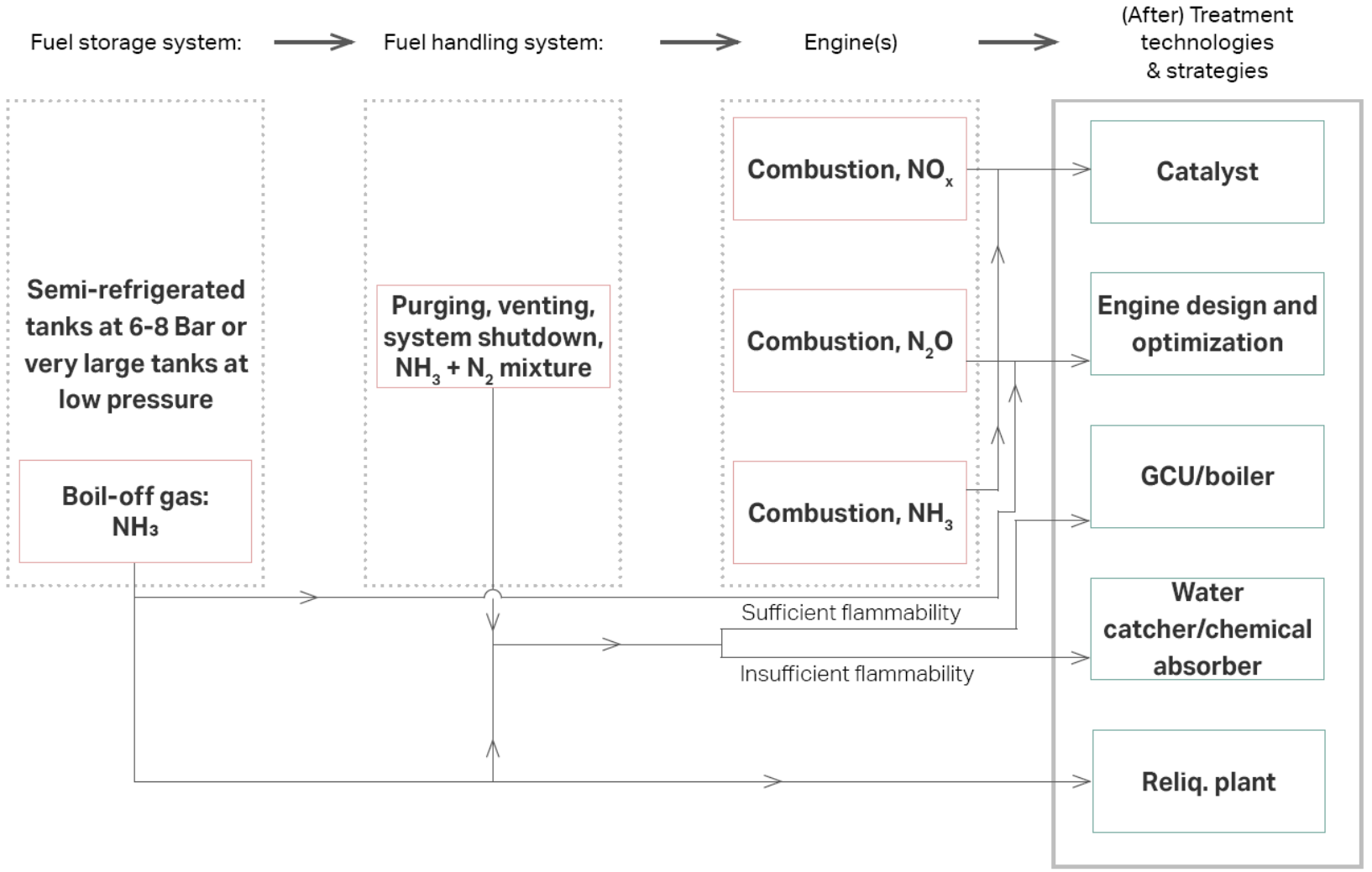


Figure 14 – Ammonia Emissions Reduction Position Paper

Conclusions

The **combination of different technologies** will play a key role in the future Engine Room of Ammonia-fueled ships. Few of these technologies are still at the development stage and direction and the pace of future development strongly depends on the **upcoming full-scale tests on 2-stroke engines**.

Engines and after-treatment technologies should be developed jointly, to ensure that material requirements, energy demand and costs are optimized.

Regulators should closely follow the upcoming tests and technology development, in order to make sure that **practical, effective and realistic targets and goals** are set from the very beginning.

The **Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping** provides the ideal platform to promote **information sharing and joint development**, through collaboration among its partners and few external stakeholders.


Join at
slido.com
#ammonia

Industry perspectives

MAN Energy Solutions
Future in the making

WÄRTSILÄ

ALFA LAVAL

TOPSOE

Our Panelists

Nikolaos Kourtidis
Two-Stroke Promotion & Customer Support at MAN Energy Solutions

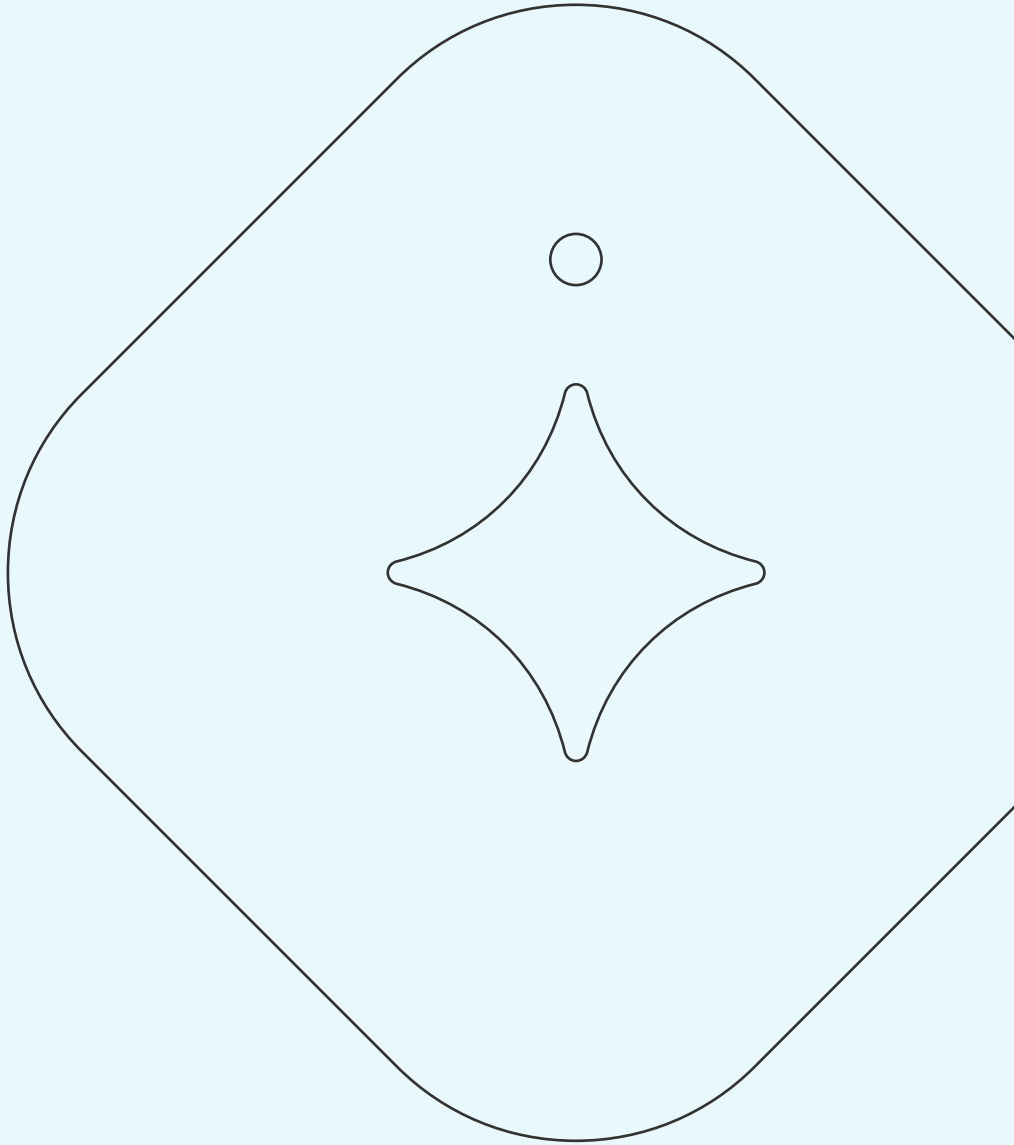
Kaj Portin
General Manager Sustainable Fuels & Decarbonization at Wärtsilä

David Jung
Business Development Manager at Alfa Laval

Janus Emil Münster-Swendsen
Secondee of Topsoe to the Mærsk Mc-Kinney Center for Zero Carbon Shipping

MAN Energy Solutions

MAN Energy Solutions
Future in the making



MAN Energy Solutions
Future in the making

MAN B&W
Ammonia engine development
MMMZCC Ammonia seminar

2-Stroke Promotion and Customer Support
March 2023

Two-stroke ammonia engine development schedule

2019

Pre-study

- ✓ NH3 combustibility investigation.

2020

Project kick-off

- ✓ 4T50ME-X test engine received as platform for the Ammonia engine development.
- ✓ HAZID workshop on engine concept.
- ✓ Combustion chamber 1st evaluation.

2021

Engine concept R&D

- ✓ Engine basic concept defined based on R&D and simulations.
- ✓ Ammonia fuel supply & auxiliary systems specified.

2022

Engine combustion and emission

- ✓ Ammonia fuel supply & auxiliary systems established in Research Centre Copenhagen (RCC).
- 1 cylinder engine and auxiliary system preparation at RCC.

2023

Full scale engine test

- 1st engine confirmation at RCC.
- Full scale design work.
- Specification of emission after-treatment.

2024

1st engine delivery to yard

- Full scale engine test at RCC evaluated for 1st commercial design.
- 1st ammonia fueled engine delivered to yard.

Ammonia engine development

The LGI combustion principle

Ammonia combustibility

- **Ammonia is not a hydrocarbon.**
- **It doesn't burn like hydrocarbons.**
- **It reacts much slower than hydrocarbons.**

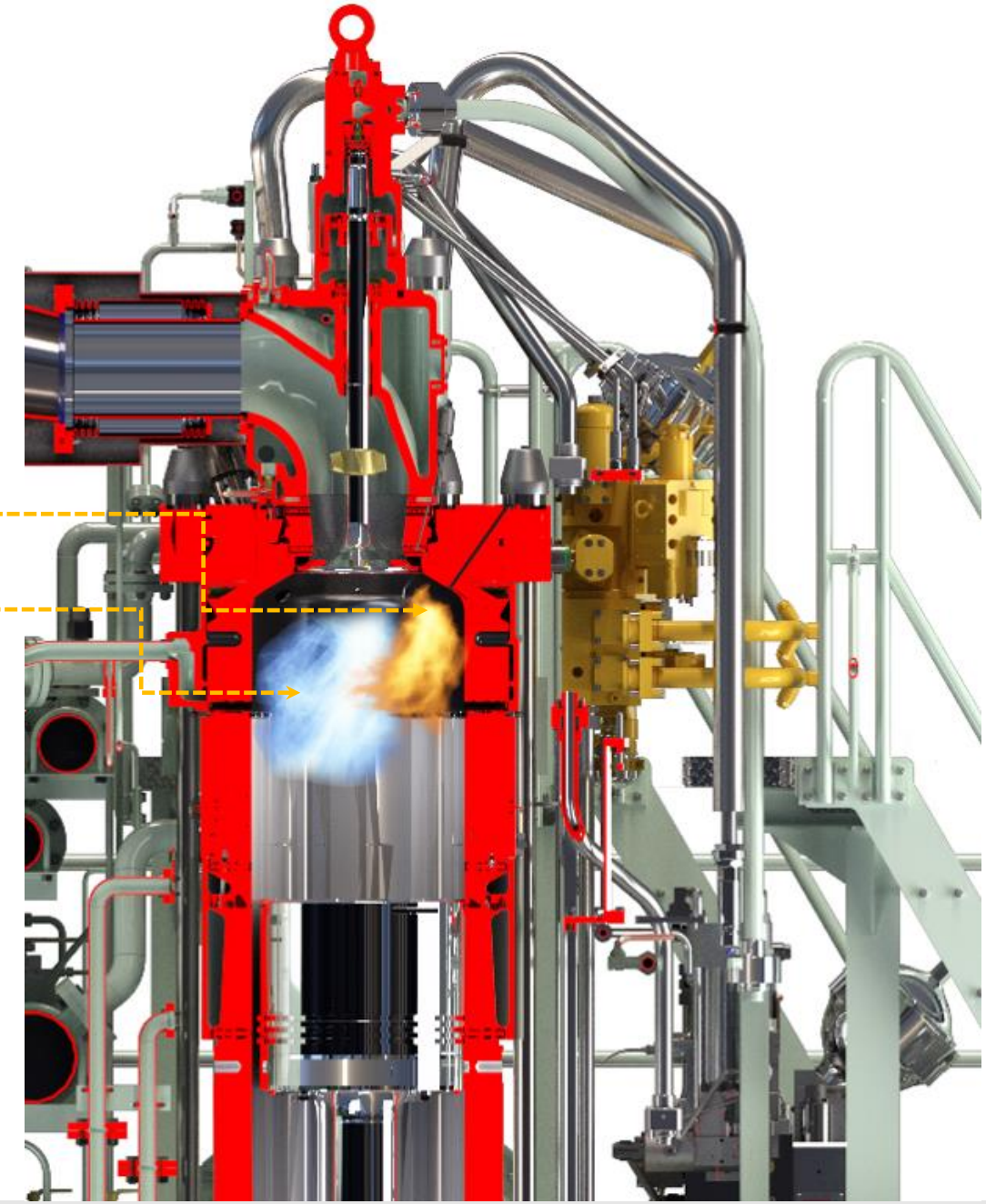
The MAN B&W ammonia engine design philosophy

"Ammonia mode":

- Small pilot flame.
- Ammonia ignited by the pilot flame.

"Liquid fuel mode":

- Identical performance as conventional fueled Diesel engine.

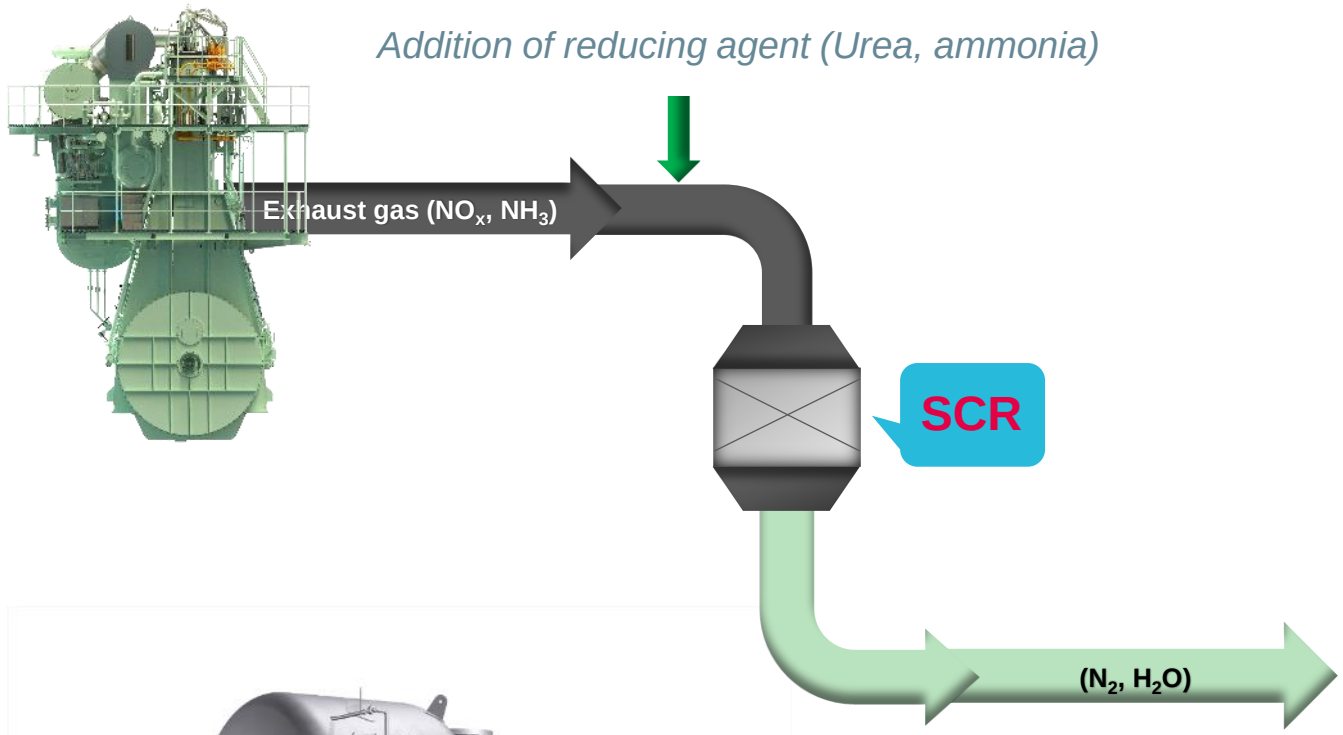


Ammonia engine development

How do we handle potential Nitrous Oxide emissions?

Nitrous oxide (N_2O) **removed by engine tuning.**

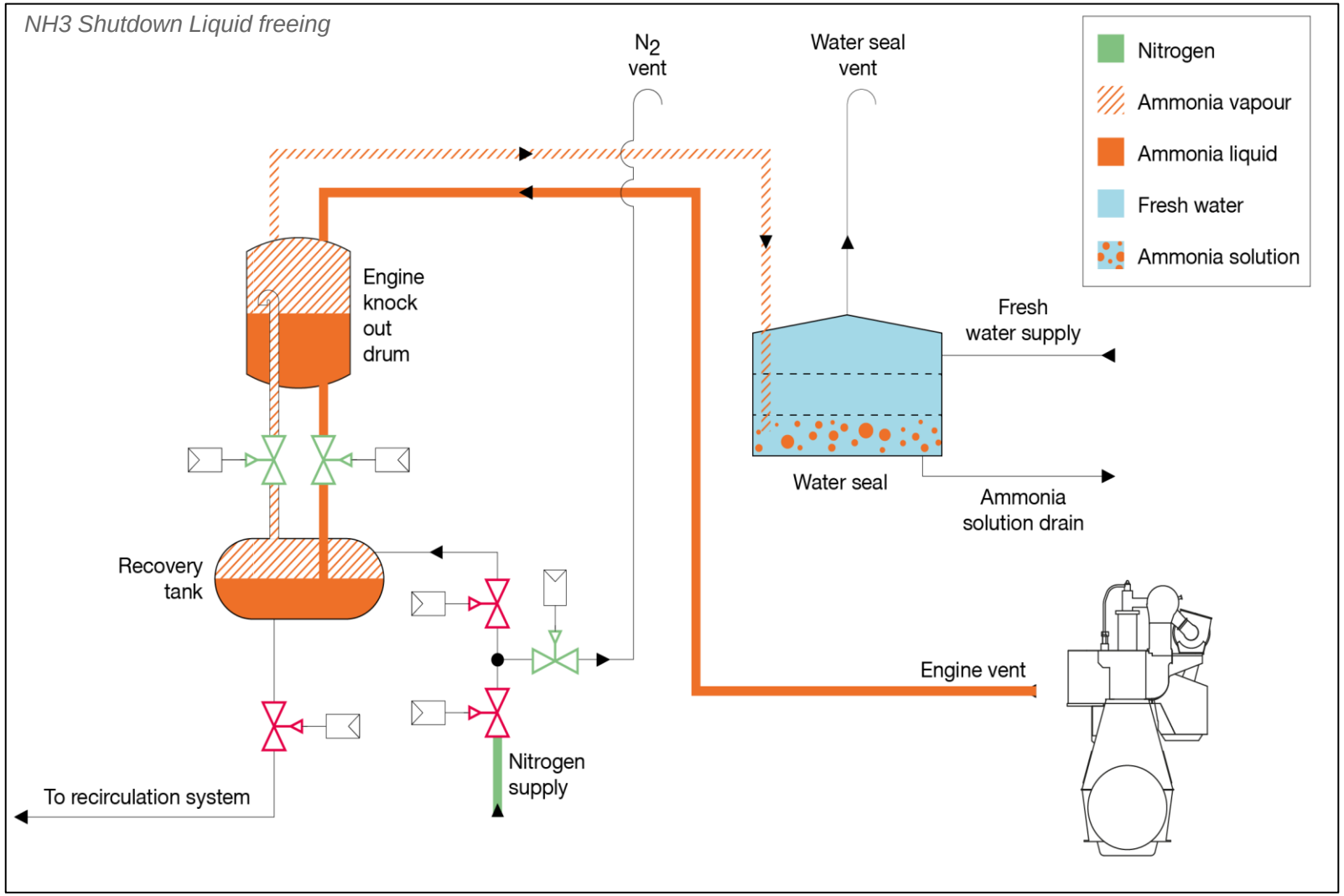
- Unburned NH_3 and NO_x is removed in the SCR reactor.
- Dosing of additional ammonia to SCR reaction if needed.
- Known SCR technology is suitable. MAN SCR reactor can be applied.
- Engine designed for both fuel oil and NH_3 as fuel.



MAN SCR

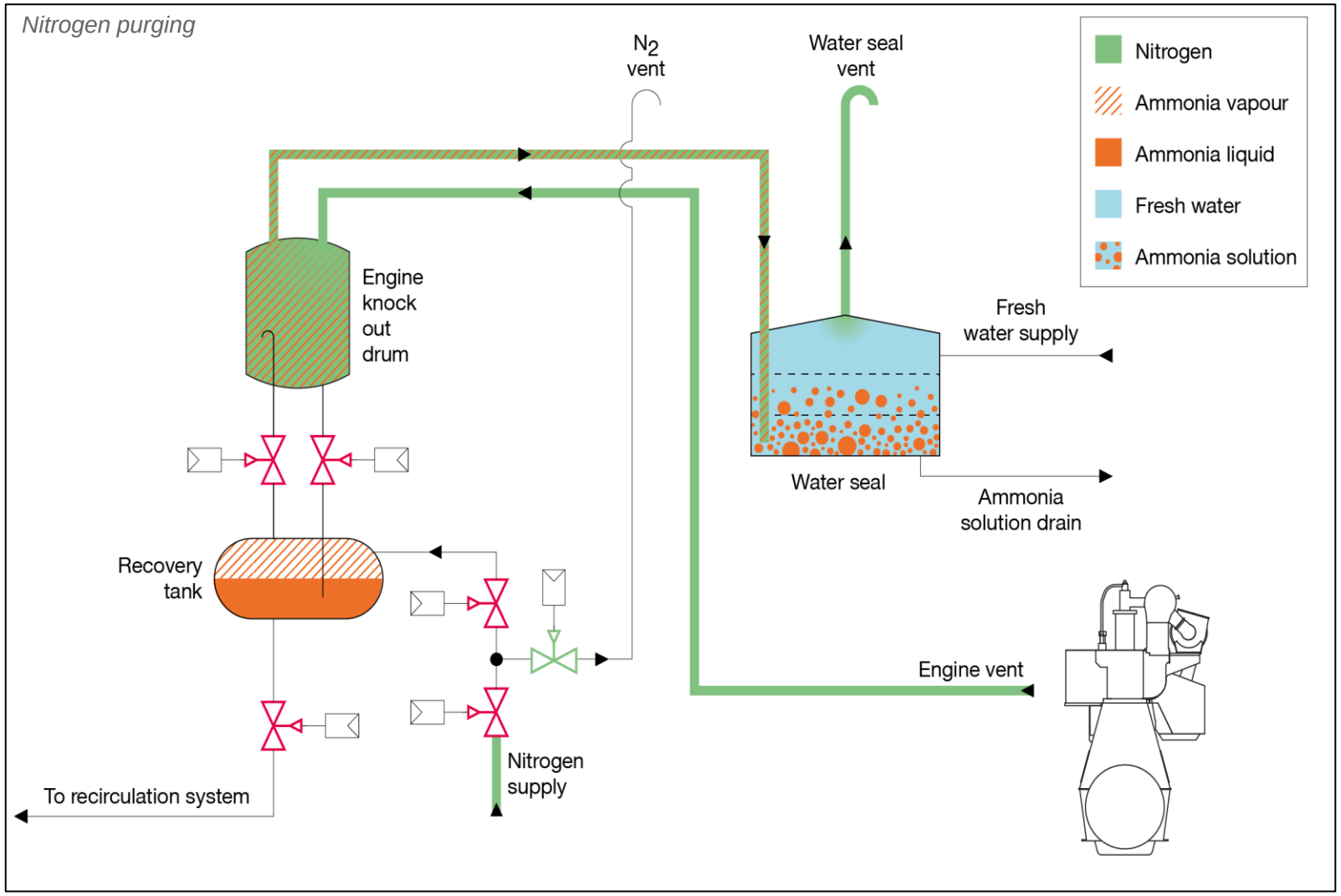
Ammonia engine development

Installation snapshot



Ammonia engine development

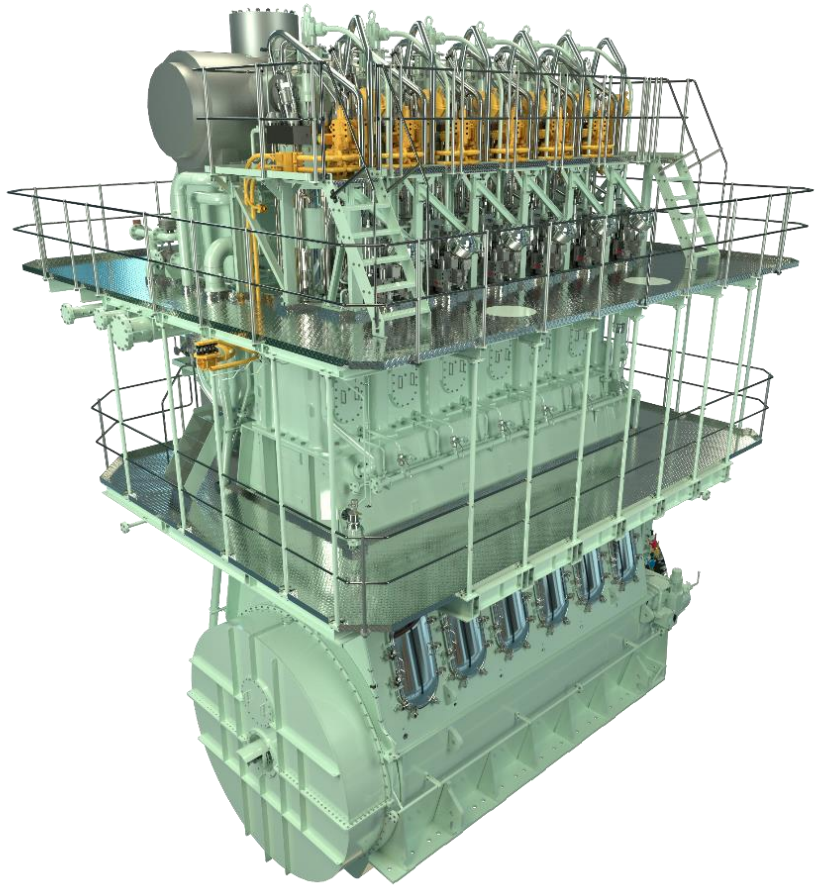
Installation snapshot



Summary

The ammonia engine is a viable solution for decarbonizing of shipping, however it must be ensured that no other emissions compromises the environmental benefits of ammonia as fuel.

- N_2O will be handled through engine tuning.
- MAN ES is also looking into N_2O handling by after-treatment, in the unlikely event that engine tuning is not sufficient to handle all N_2O.
- NO_x will be in compliance with existing TII and TIII limits.
- NH_3 emission (slip) from the combustion will be handled via an SCR.
- Ammonia is expected gain significant marked share towards end of the decade, driven by lower production cost and zero carbon properties.



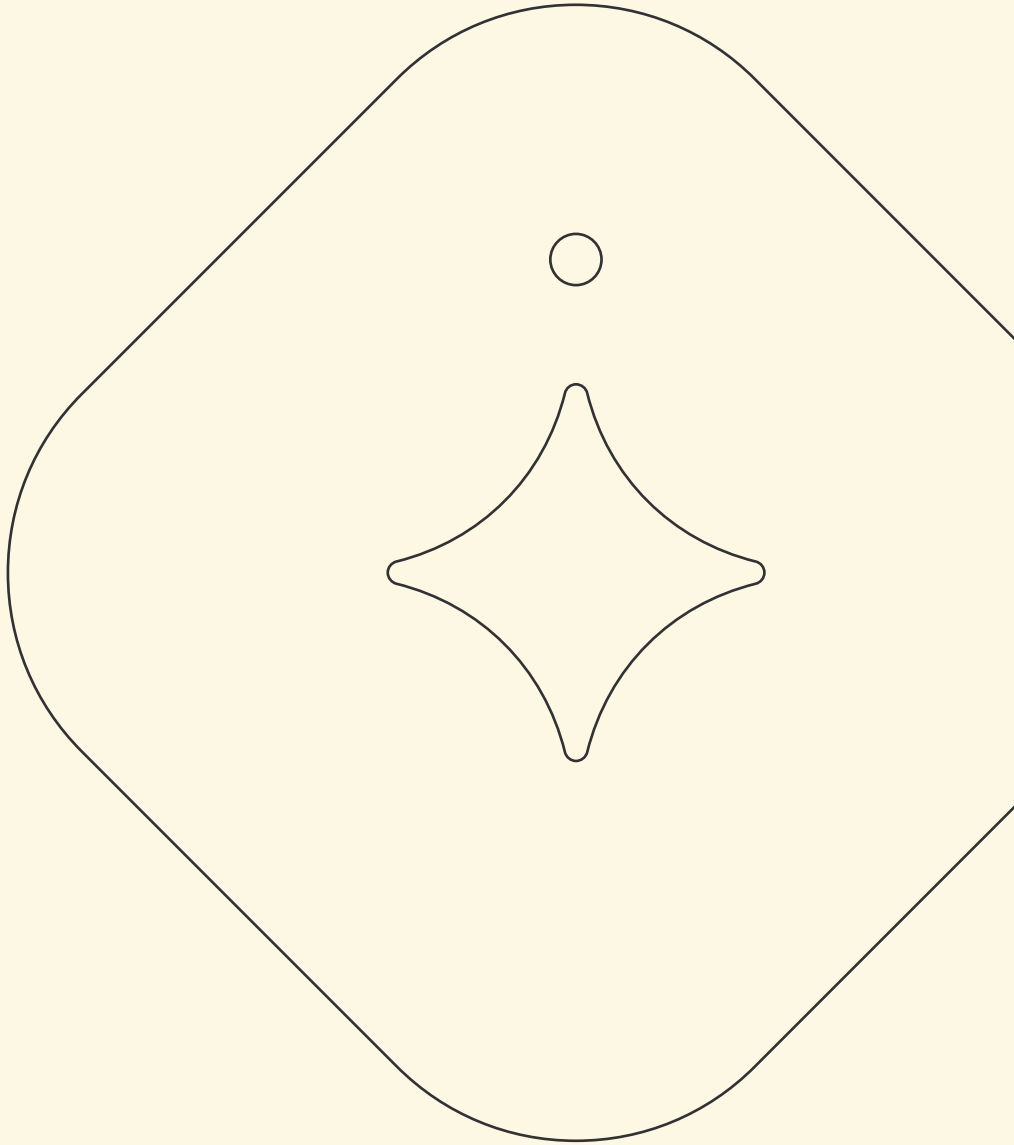
MAN Energy Solutions
Future in the making

Thank you very much!

2-Stroke Promotion and Customer Support
March 2023

All data provided in this document is non-binding.
This data serves informational purposes only and is especially not guaranteed in any way.
Depending on the subsequent specific individual projects, the relevant data may be subject to changes and will be assessed and determined individually for each project. This will depend on the particular characteristics of each individual project, especially specific site and operational conditions.

Wärtsilä



AMMONIA AS FUEL FOR WÄRTSILÄ ENGINES

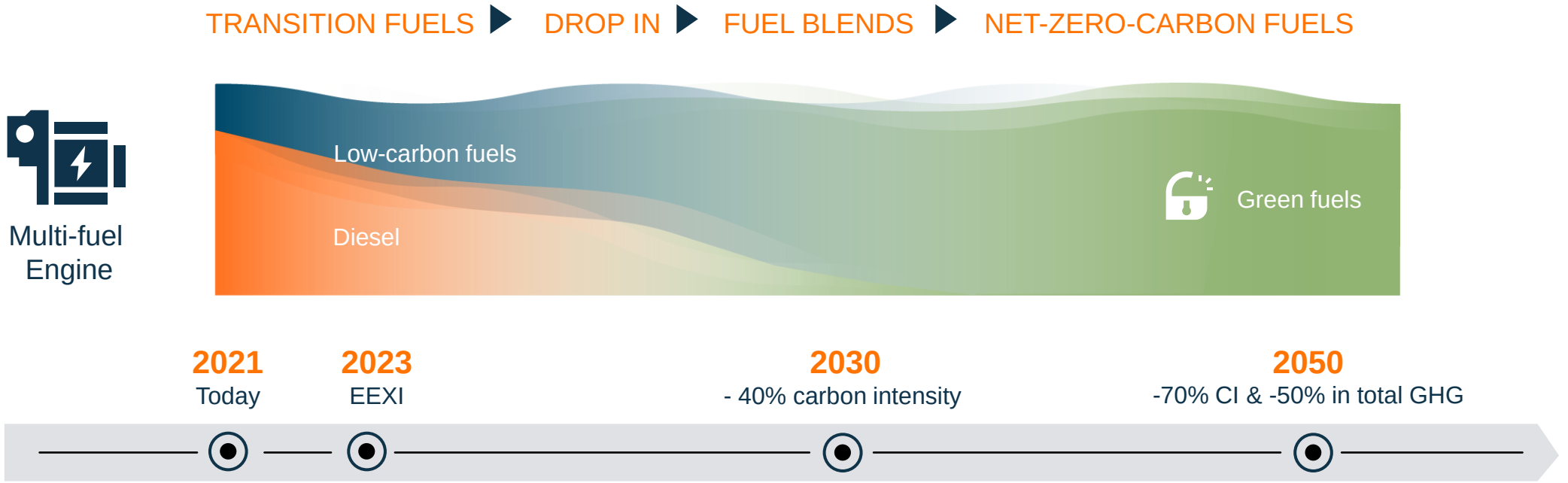
VAASA

16.2.2023

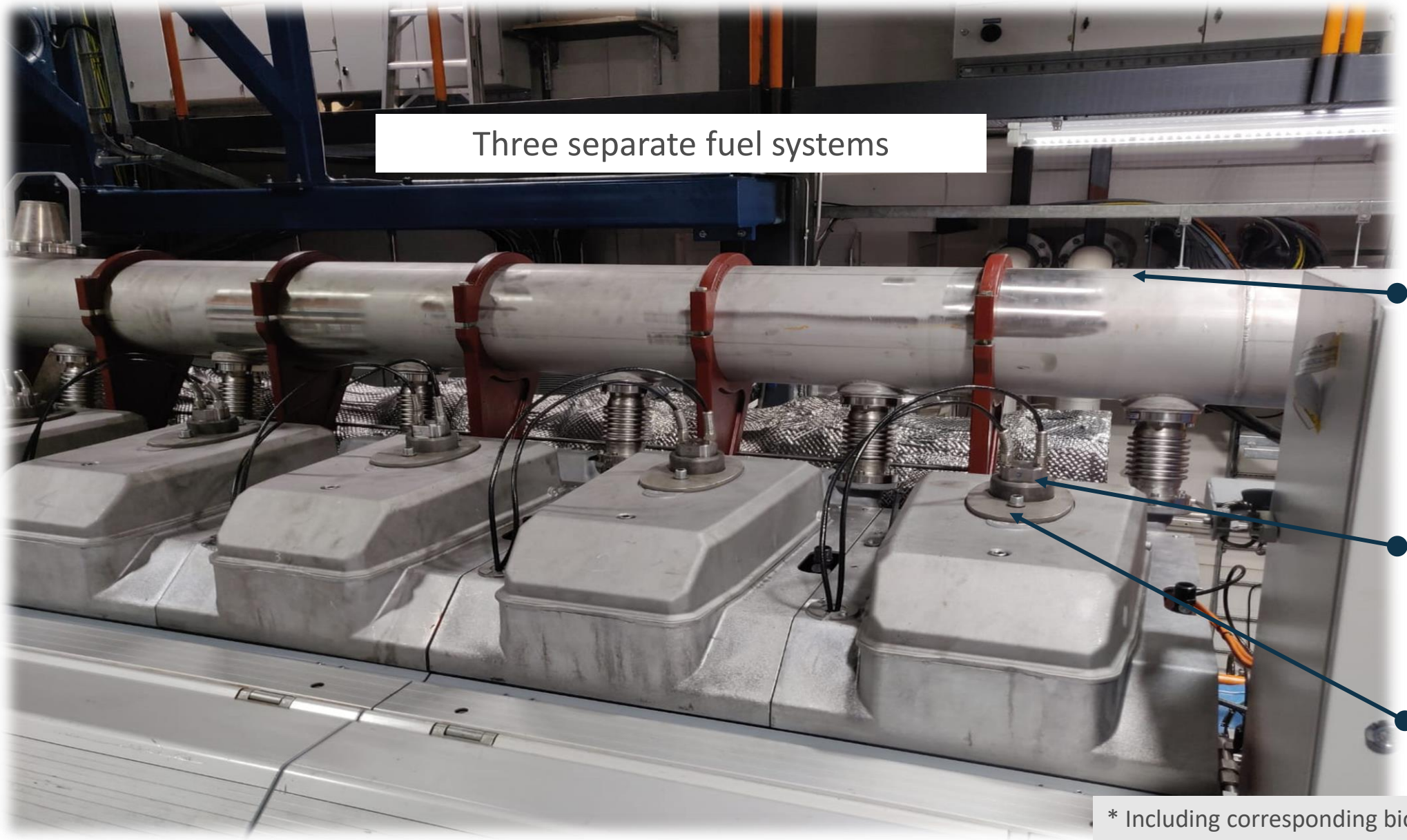
KAJ PORTIN, WÄRTSILÄ

certainty in transition

Infrastructure and availability of green fuels need time to mature –
current Wärtsilä multi-fuel technology offer a viable upgrade path



The multifuel engine prepared for Ammonia operation



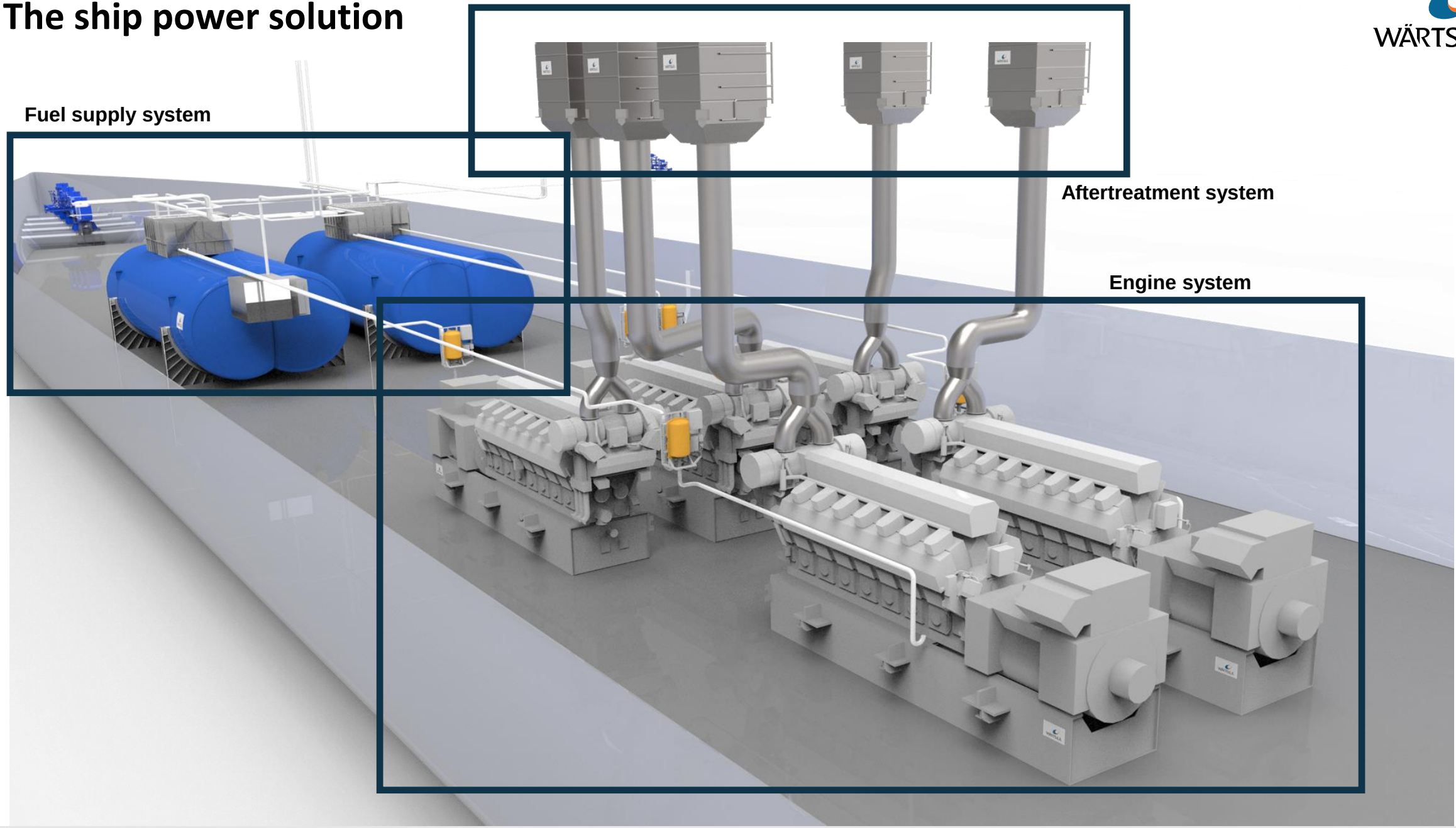
Gaseous fuels*
- LNG
- LPG
- **Ammonia**
- Hydrogen

Liquid fuels*
- HFO
- MDO
- LPG
- **Ammonia**
- Methanol
- Ethanol

Pilot fuel*
- MDO

* Including corresponding bio and synthetic fuel

The ship power solution



Areas for cooperation and development

- Legislation
- **Systems** (tank system, fuel handling, engine, exhaust and after treatment, etc.)
- Training and PPE
- Robust and safe operation on vessels and power plants
- Fuel availability and cost of operation

World's first full scale ammonia engine test - an important step towards carbon free shipping

Wärtsilä Corporation, Trade press release, 30 June 2020 at 10:01 AM E. Europe Standard Time

The technology group Wärtsilä, in close customer cooperation with Knutsen OAS Shipping AS and Repsol, as well as with the Sustainable Energy Catapult Centre, will commence the world's first long term, full-scale, testing of ammonia as a fuel in a marine four-stroke combustion engine. The testing is made possible by a 20 MNOK grant from the Norwegian Research Council through the DEMO 2000 programme.

ARTICLE

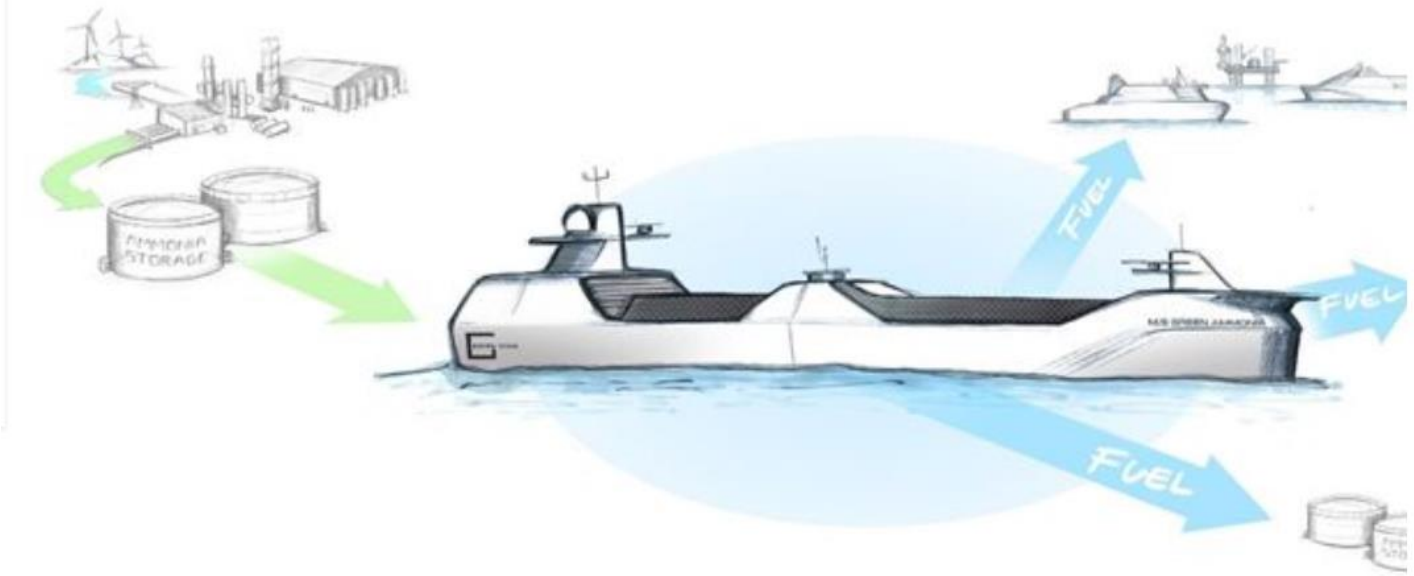
Wärtsilä, Repsol, and Knutsen to test ammonia four-stroke engine (Equinor is also a member)

By Trevor Brown on July 01, 2020

This week, engine manufacturer Wärtsilä announced "the world's first long term, full-scale, testing of ammonia as a fuel in a marine four-stroke combustion engine." The project will begin in the first quarter of 2021, at the Sustainable Energy Catapult Centre's testing facilities at Stord, Norway. It is supported by a NOK 20 million (USD 2 million) grant from the Norwegian Research Council.

Wärtsilä and Grieg to build groundbreaking green ammonia tanker

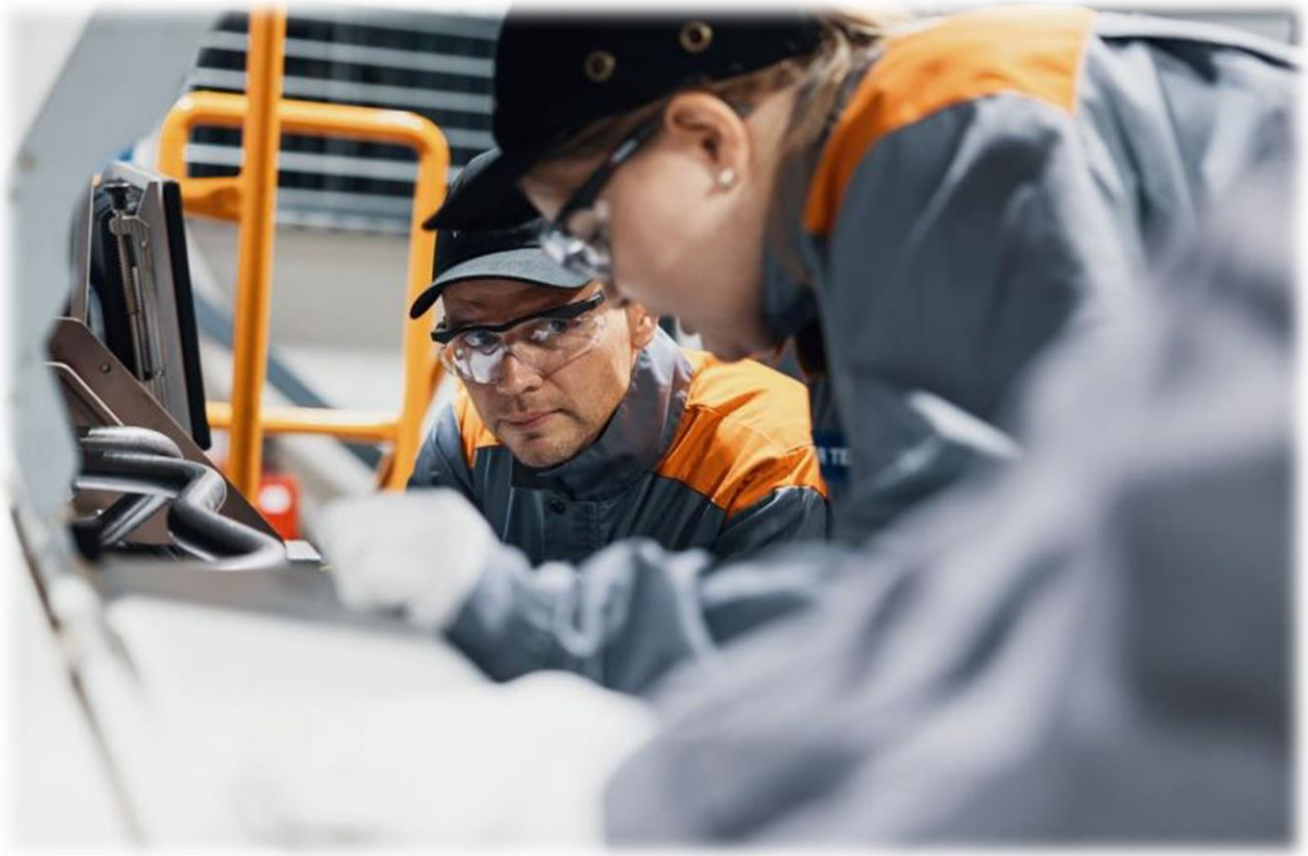
Wärtsilä Corporation, News, 18 December 2020 at 15:39 UTC+2



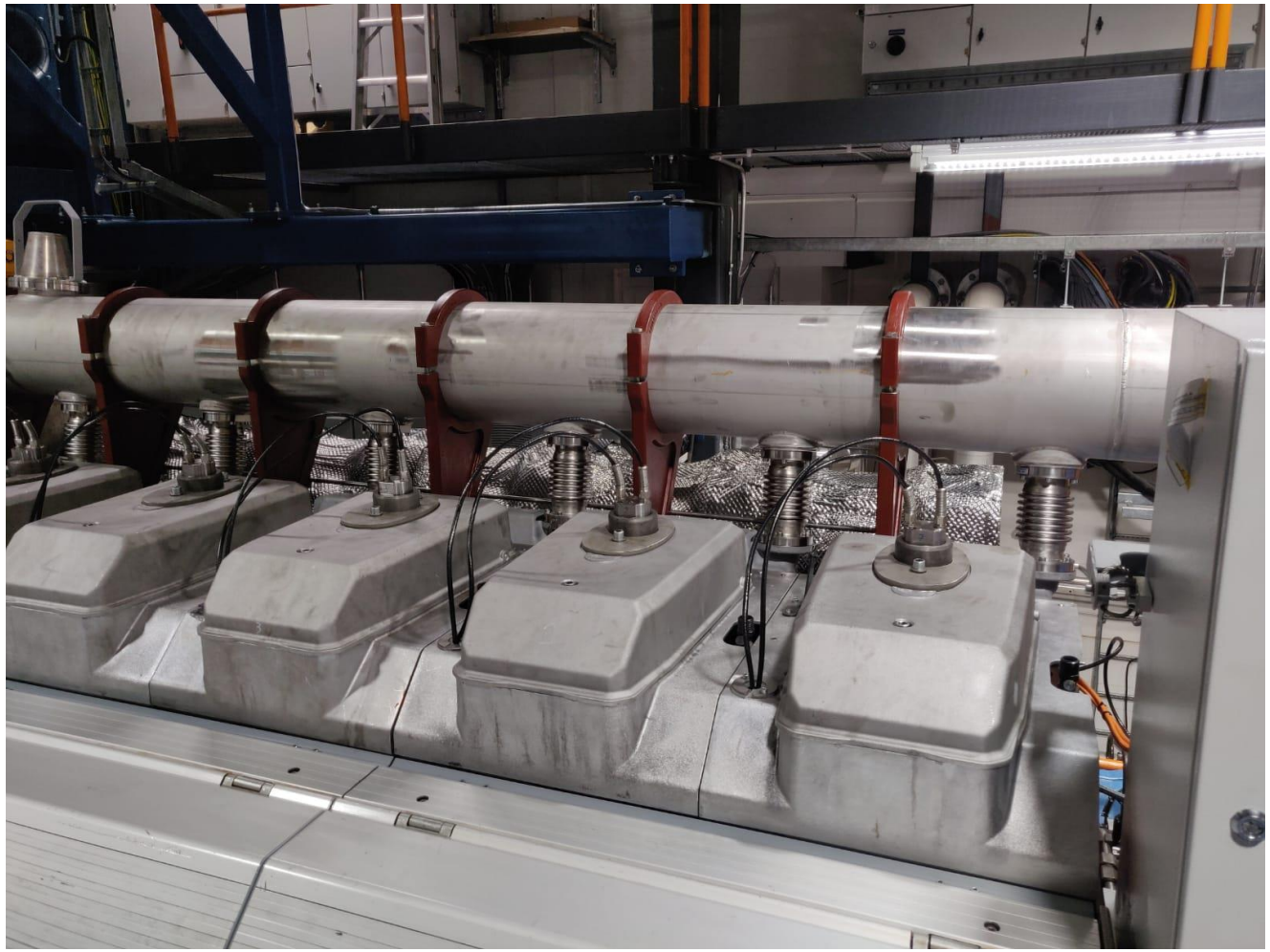
The technology group Wärtsilä and Grieg Edge, are jointly running a project to launch an ammonia-fuelled tanker producing no greenhouse gas emissions by 2024.
The MS Green Ammonia project is the result of a Nordic industrial collaboration group founded from the Zeeds (Zero Emissions Energy Distribution at Sea) initiative.
Pilot-E, the Norwegian funding scheme will support the project with a NOK 46,3 million (EUR 4.4million) grant.

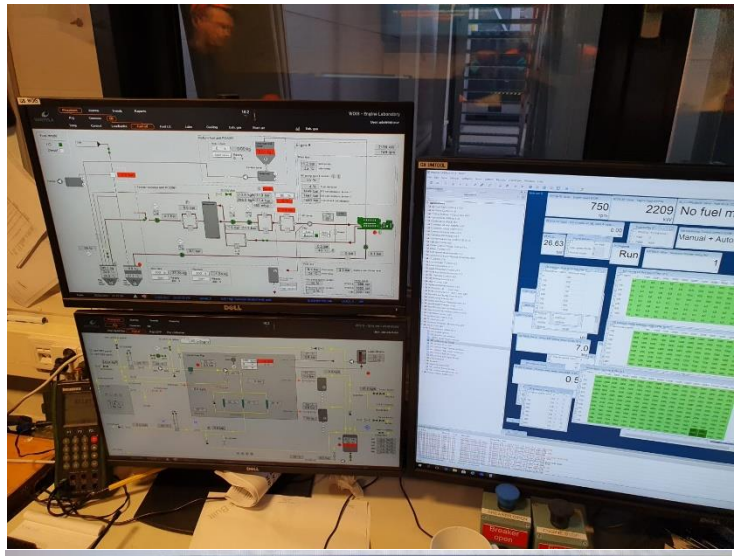
Ammonia safety

- Master’s Thesis by Laura Sariola in 2020 on engine, fuel system and engine room setup
- System approved by TUKES (Finnish authority) in June 2021
- Cooperation with Marine classification societies for Ammonia rules
- Verification of the robustness and functionality of the safety systems
- Personal Protection Equipment definition.

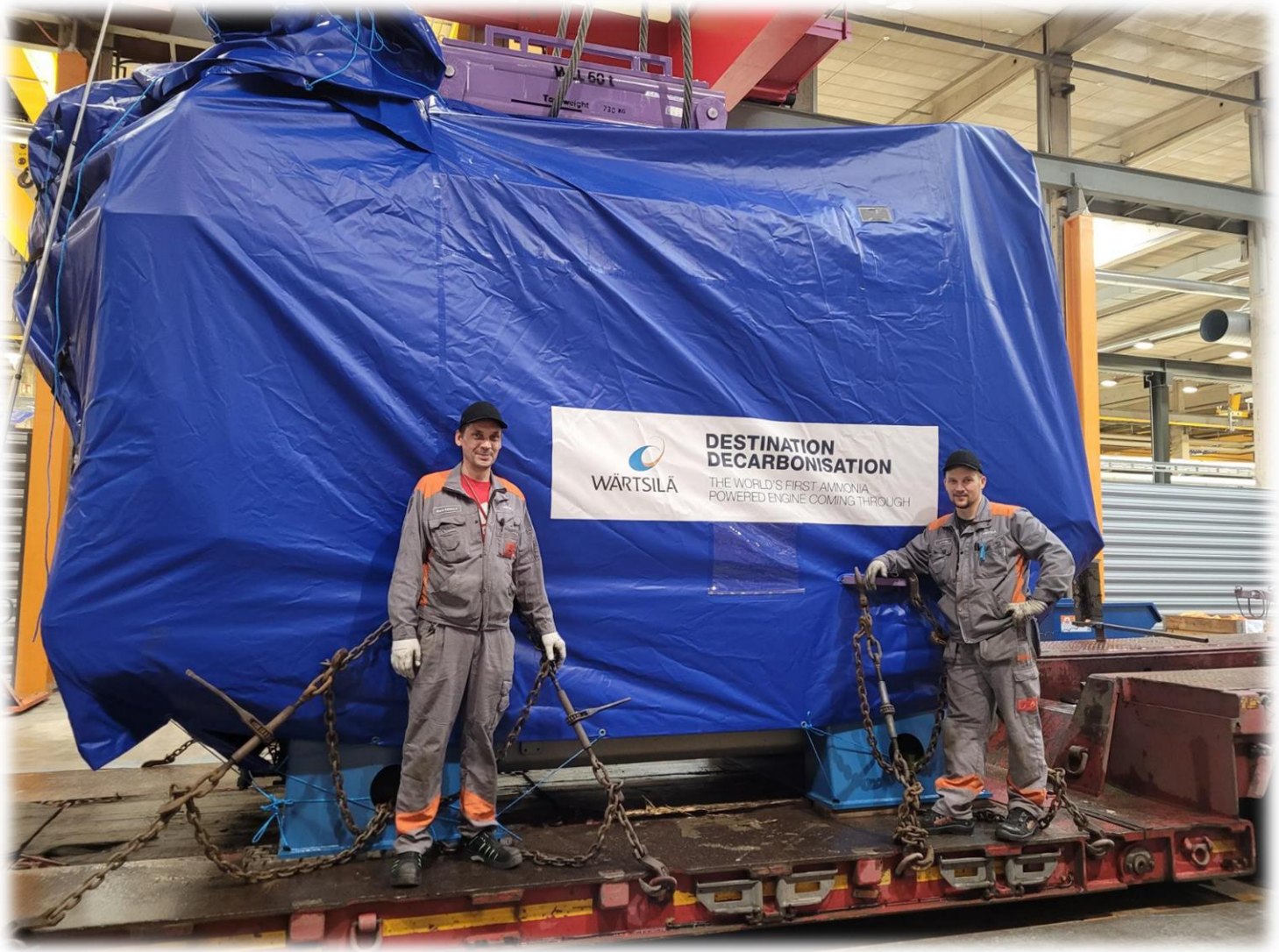


Ammonia engine tests 30 June 2021

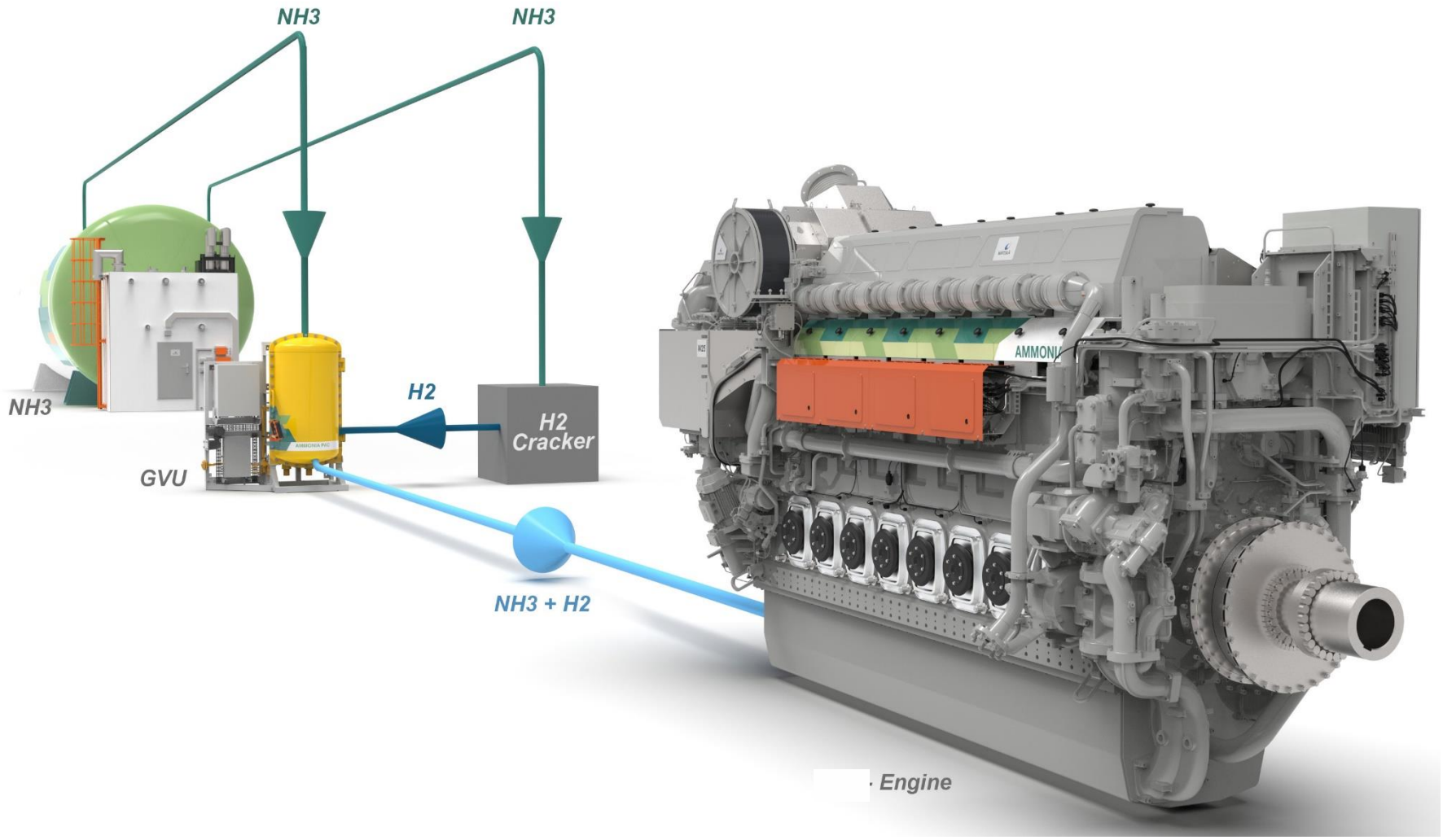




Ammonia engine tests started at Stord in Norway December 2022



Pure Ammonia engine concept with hydrogen cracking



Summary

- Decarbonising of the marine sector is urgent and requires a wide range of measures
- A successful development requires expertise and actions from many contributors
- Wärtsilä's portfolio provides several solutions towards a net-zero future
- Fuel flexibility secures a future proofed solution
- Concepts for ICE operation on the future fuels like **Ammonia**, Hydrogen, and Methanol are already being developed and demonstrated.


WÄRTSILÄ

Alfa Laval


ALFA
LAVAL

Ammonia safety system

MMM Center for ZCS Webinar, 23rd March 2023

David Jung

Alfa Laval's journey towards sustainability

– Advancing ahead for the better future

Focus on energy efficiency since 100 years

2004
Pure Thinking Environment-friendly solutions

2006-2008
1st DF Boiler & GCU

2012
Alfa Laval acquires Aalborg Industries

2014
Alfa Laval acquires Framo

2014
The Alfa Laval Test & Training Centre

2015
Fuel supply Methanol

2021
E-PowerPack launched

2021
Methanol boiler

2021
Air Lubrication – buys MPS share

2021
Oceanbird – joint venture with Wallenius

2021
Alfa Laval acquires StormGeo

2021
Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping

2022
Approval for testing Ammonia as fuel

2022
Tank cleaning– acquires ScanJet

2022
Sustainable bunker – acquires BunkerMetrics

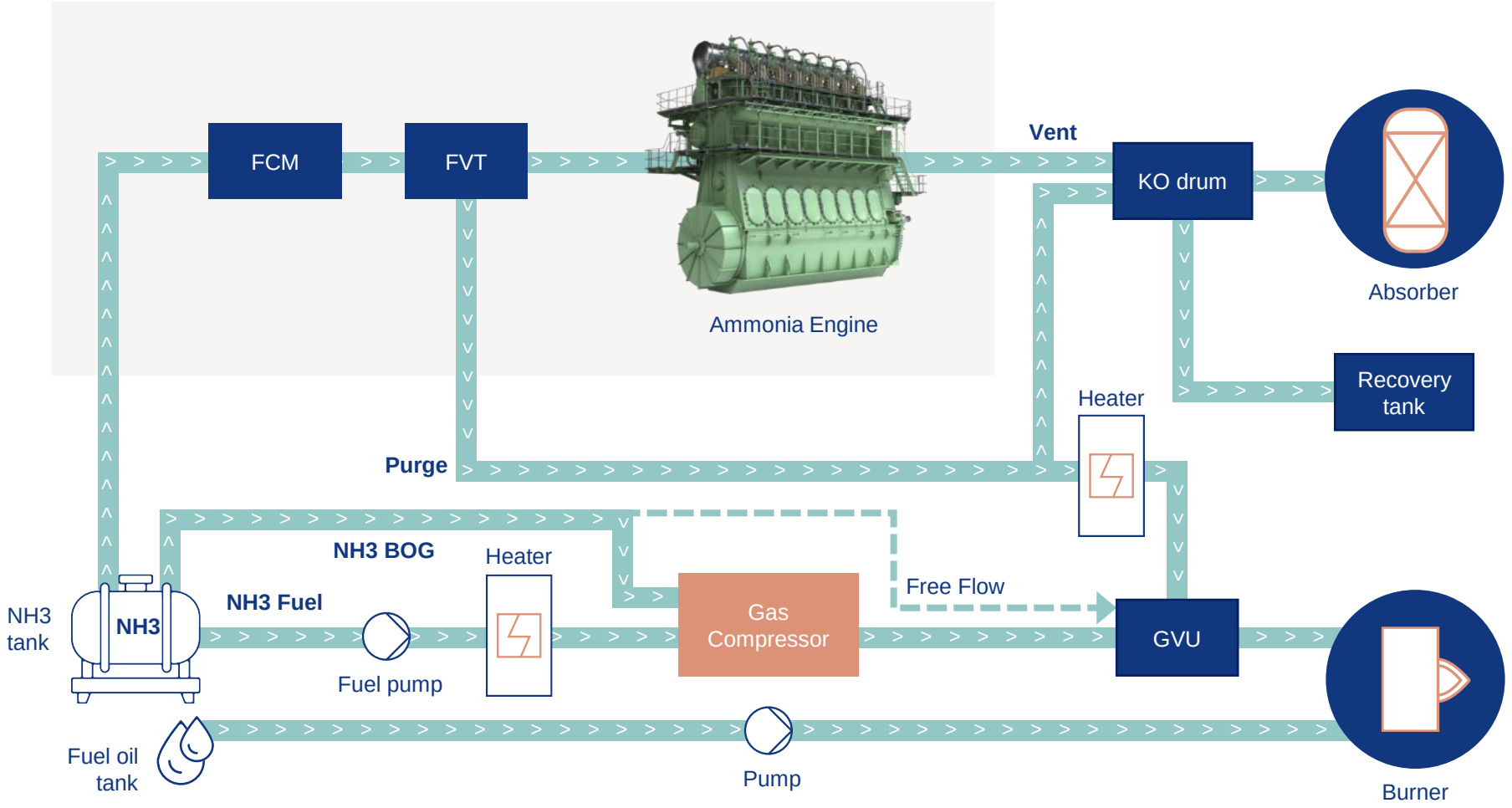
2022
Partnership with SSAB – fossil free steel

2022
Carbon capture – "project ReMarCCAble"

2023
High Speed Separators Biofuel

Ammonia emission handling

– Two pathways: thermal oxidation and chemical absorption



Test of ammonia combustion

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2022-09-06 Product news

Alfa Laval Test & Training Centre receives approval for testing with ammonia

Authorities have granted approval for testing with ammonia at the Alfa Laval Test & Training Centre. When installation of the testing setup is completed by the end of 2022, the centre will be able to work with all fuels in consideration as the marine industry decarbonizes.

Supporting the entire fuel transition

Alfa Laval will serve marine customers at all stages of their decarbonization journey, no matter which fuels they choose. As part of that strategy, the Alfa Laval Test & Training Centre will soon begin testing with ammonia. Just as it has for LNG, biofuels and methanol, the centre will deepen the knowledge of ammonia combustion and lead the development of needed onboard technologies.

"The Alfa Laval Test & Training Centre will explore ammonia's properties and its behaviour in a wide range of systems," says Alfa Laval's Lars Skytte Jørgensen, Vice President Technology Development, Energy Systems. "That includes combustion systems, such as the burners on Alfa Laval Aalborg boilers, but also fuel supply systems and fuel cells – in other words, the full chain of fuel preparation and handling, where we will look at both efficiency and safety. With our testing setup approved, we can be first off the block in the race towards ammonia implementation."

Contact

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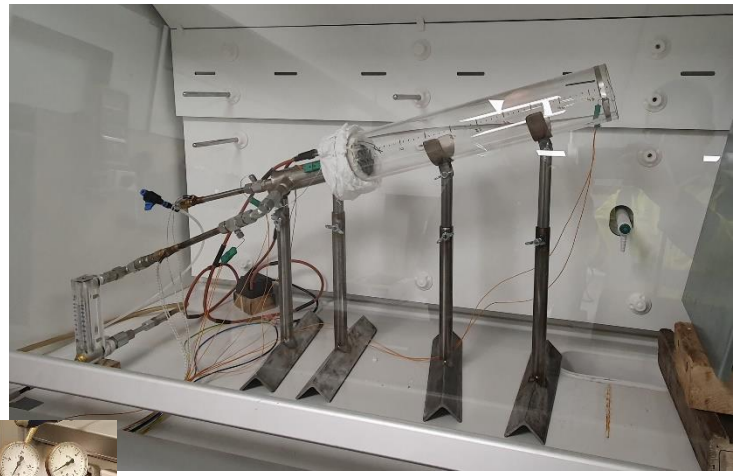
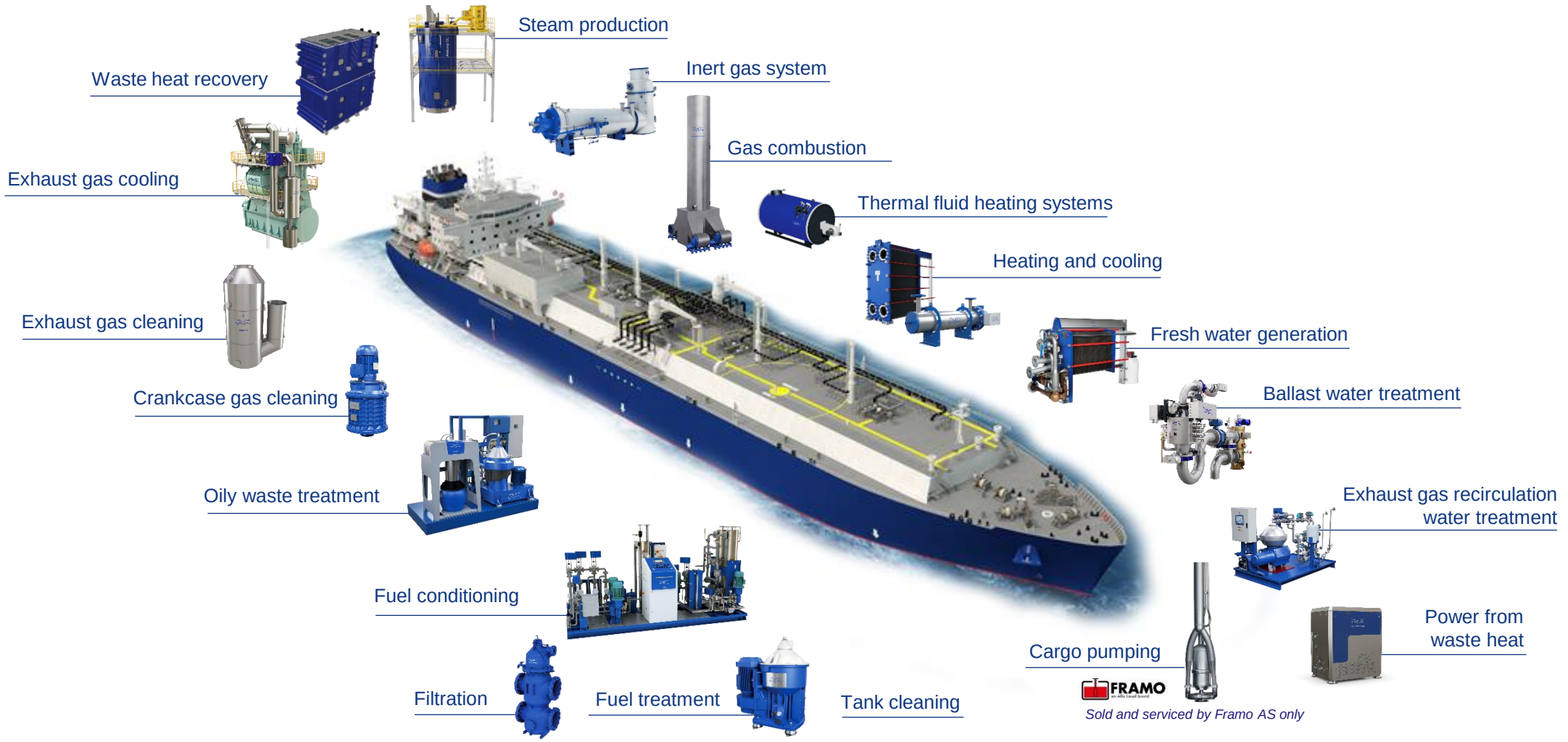


First test started recently, with more positive outcomes than expected. More tests underway.

Potentially more solutions for ammonia as fuel

From existing product portfolio as well as new developments



Newly added products

Wind propulsion

Weather intelligence

Air lubrication

Fuel cell system


ALFA
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Topsoe

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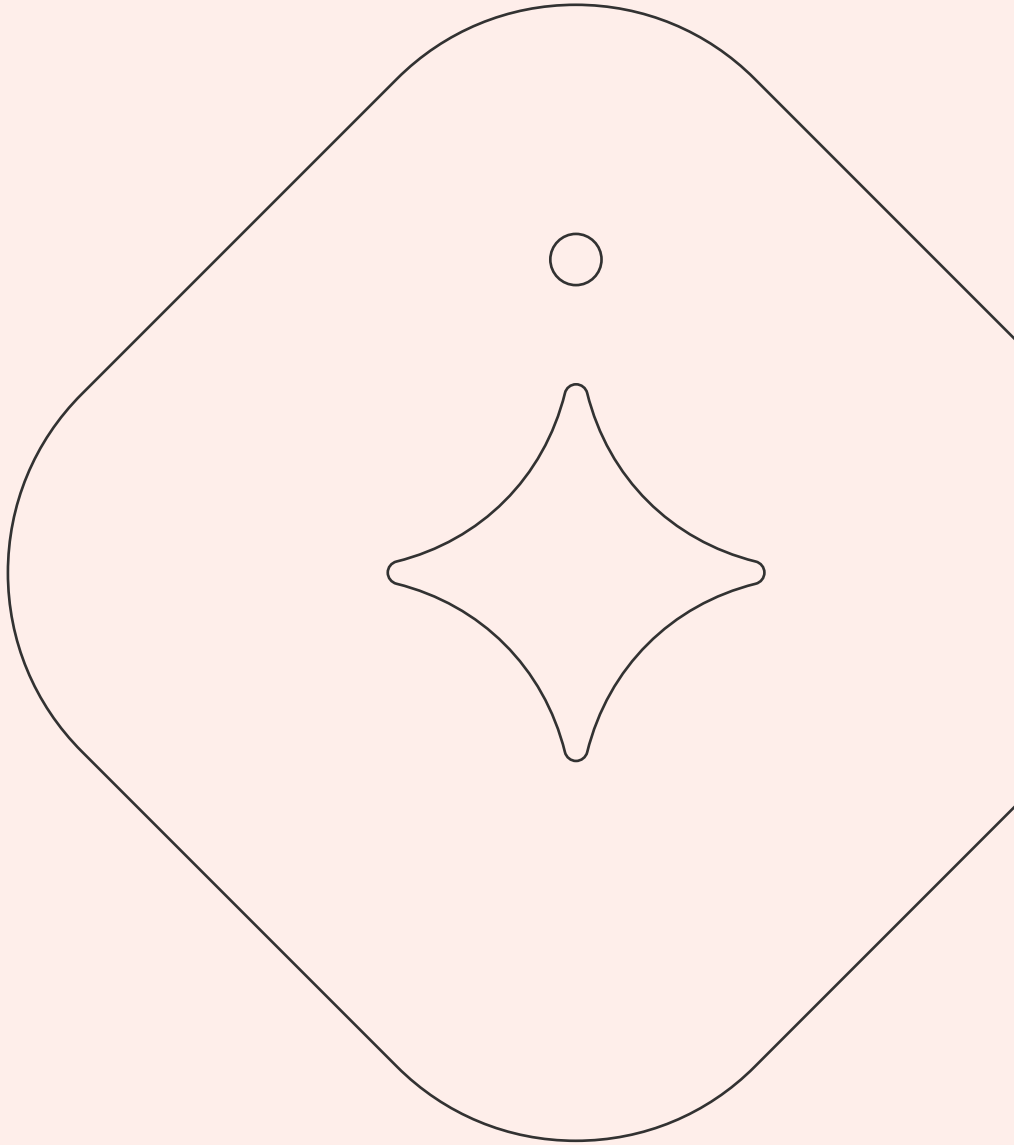

MANAGING EMISSIONS FROM NH3-FUELED VESSELS

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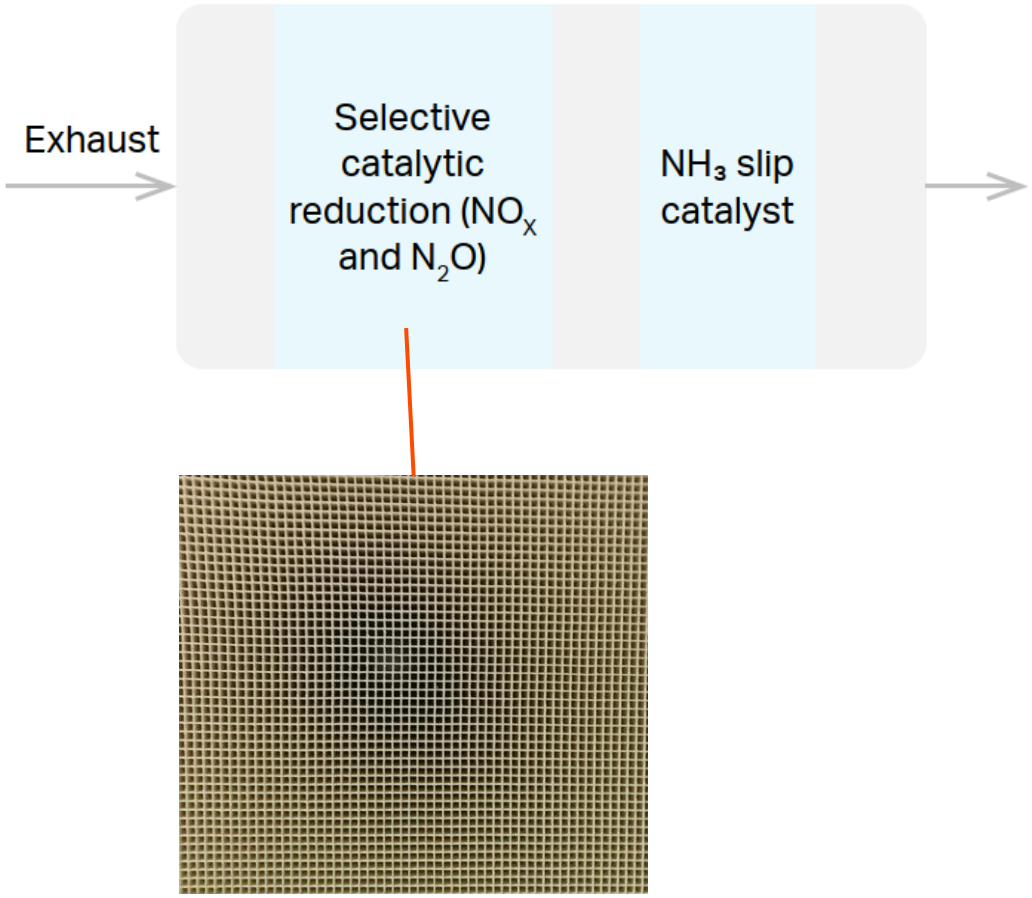
TOPSOE N_2O ABATEMENT

- Catalyst setup similar to existing DeNOx systems
- Monolith ensures low pressure drop
- 99 % N_2O removal possible
- Current temperatures preferably >400°C



TOPSOE N_2O ABATEMENT

- Projects running or under construction:
  - N_2O: 80 – 2000 ppm
  - NOx: 60 – 7000 ppm
  - Temperatures: 380 – 425°C

- Ongoing research for lower temperature activity
- Waiting for further input from engine tests

Horizon 2020 programme

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Join at

slido.com

#ammonia

Thank you for joining!

The recording & presentation will be shared with all participants shortly.

Let's stay in touch

Visit our website www.zerocarbonshipping.com and make sure to follow us on LinkedIn to stay up to date with the latest news and events.

Related Projects

→ **Ammonia Safety Study**
Quantify risks and provide safeguard solutions for ammonia-fueled vessels

→ **Nordic Green Ammonia Powered Ships**
One of the first ammonia-fueled vessel designs

→ **MAGPIE**
Demonstrate ammonia bunkering in Rotterdam

Mærsk Mc-Kinney Møller Center
for Zero Carbon Shipping