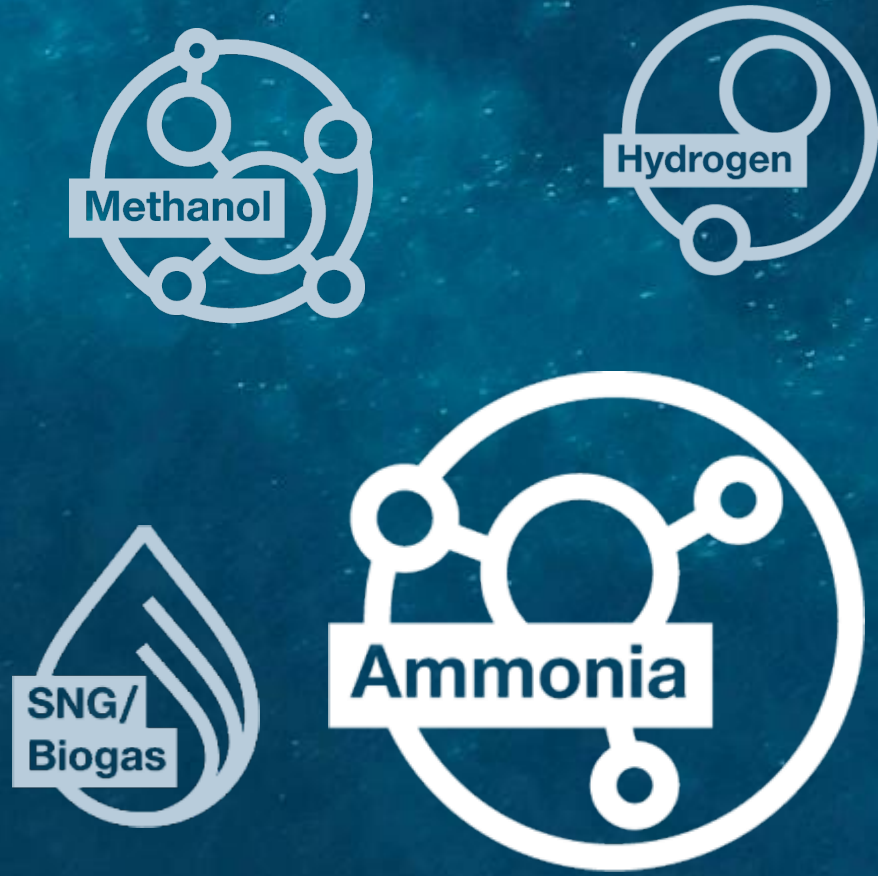
MAN Energy Solutions
Future in the making

Ammonia as a Shipping Fuel in 2 Stroke Engines

NTIK, Hamburg 13.12.2022

Colin Peesel
Senior Sales Manager Engine & Marine Systems



Agenda

1 MAN-ES brief introduction

2 MAN B&W engines for alternative fuels

3 Alternative fuel outlook

4 Ammonia engine development

5 Market introduction and future-proof propulsion

6 Summary

1 MAN-ES brief introduction


Moving big things to zero
We engineer systems for deep decarbonization in sectors that matter most

Company profile

MAN Energy Solutions enables its customers to achieve sustainable value creation in the **transition towards a carbon neutral future**.

Addressing tomorrow's challenges within the **marine, energy and industrial sectors**, we improve efficiency and performance at a systemic level.

Leading the way in advanced engineering **for more than 250 years**, we provide a unique portfolio of technologies.

Headquartered in Germany, MAN Energy Solutions employs some **14,000 people at over 120 sites globally**. Our after-sales brand, MAN PrimeServ, offers a vast network of service centers to our customers all over the world.

Strategic Business Areas

Marine

Energy & Storage

Industries

Aftersales MAN PrimeServ

KPI‘s 2021

14.062 Employees worldwide

3,3 Mrd € Revenue

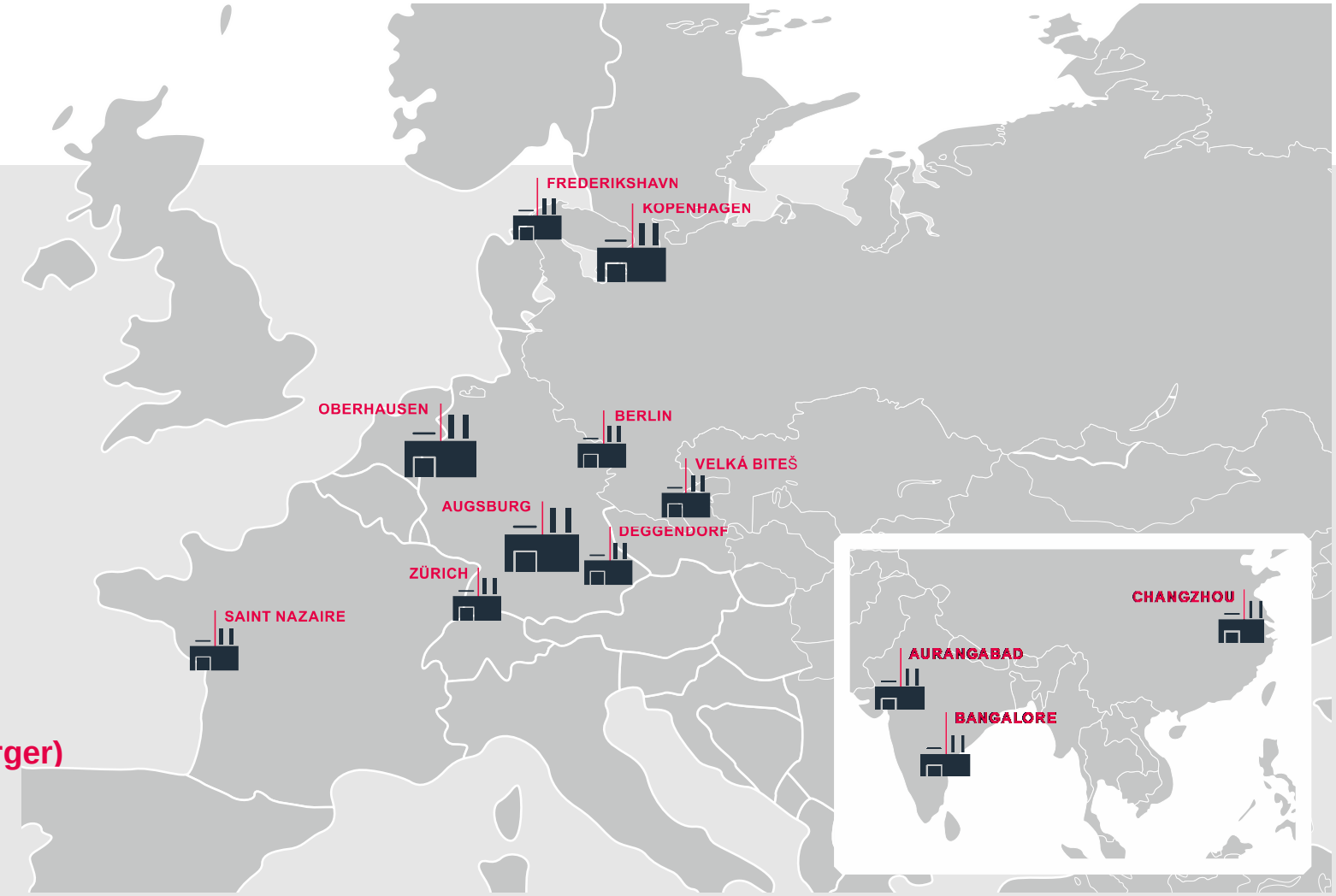
Our design and production network

Sites across Europe and Asia

9 Production sites in Europe

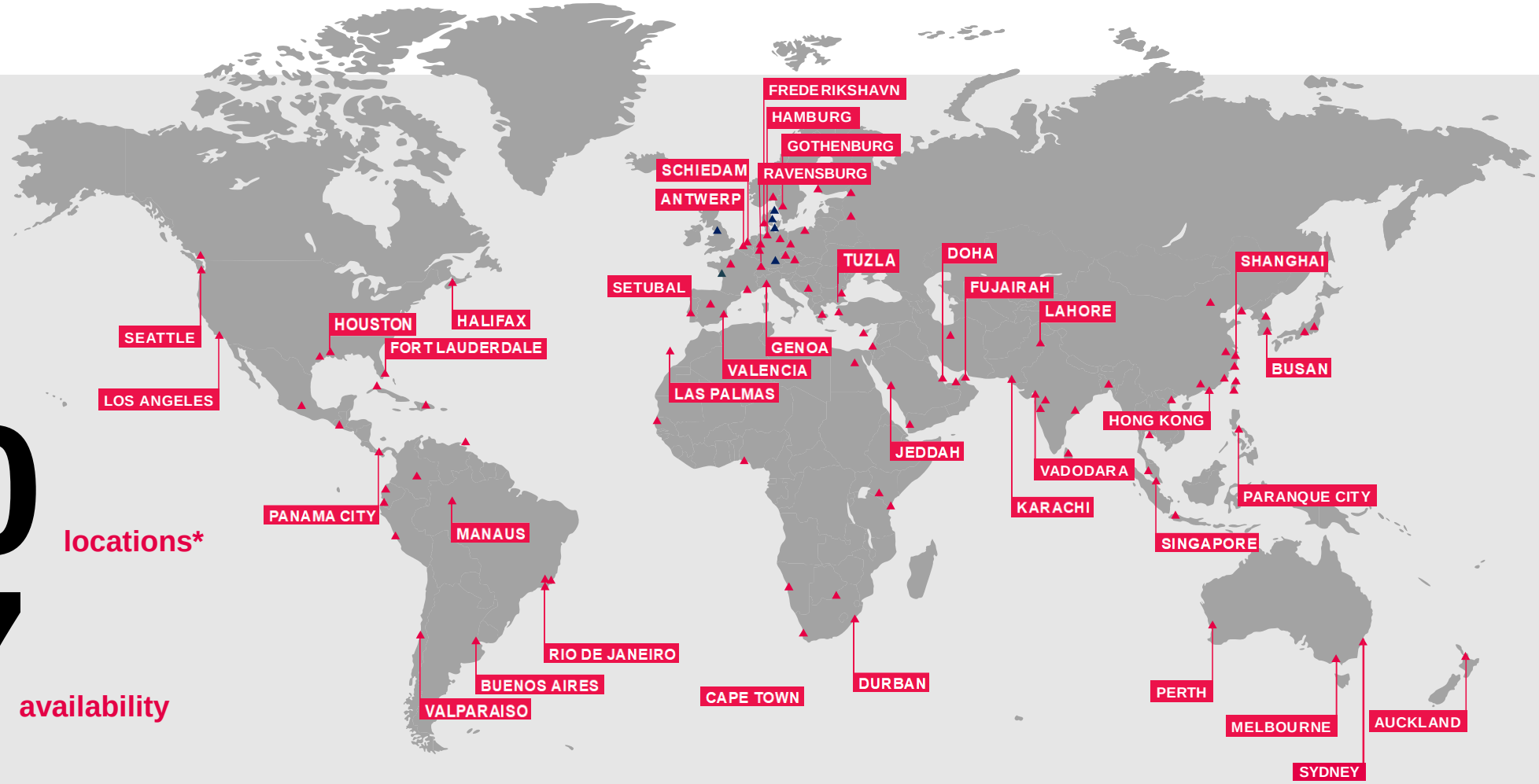
3 Production sites in Asia

30 Licensees in 7 countries (two- and 4-stroke, turbocharger)



Our global aftersales network

MAN PrimeServ



>140 locations*

24/7 availability

*Number of countries served by headquarters, service locations or responsible sales partners.

Marine: Navigating the course ahead

Comprehensive solutions and products for maritime applications

- Two-stroke and four-stroke engines for marine applications

  (Output range from 450 kW to 82.4 MW)
- Marine GenSets

  (Output range from 450 kW to 11.2 MW)
- Engine controls for integrated engine and exhaust gas treatment systems (SCR, EGR)
- Propellers and aft-ship systems (FPP, CPP)
- Axial and radial turbochargers for two-stroke and four-stroke engines, injection systems, systems electronics
- Electrical and battery hybrid marine solutions
- Fuels: heavy fuel oil, diesel, gas, dual fuel, multi fuel (Methanol, Ethane, LPG)

Full-Liner: From components to complete marine propulsion systems incl. fuel gas supply systems (MAN Cryo)

2

MAN B&W engines for alternative fuels

Motivation - We are committed to decarbonization
Guess why?

~ 80-90%

…of global freight is transported by sea.

~ 3%

…of the global CO2 emissions are released by the shipping industry

~ 50%

…of global freight is transported by a MAN ES engine.

Our engines are responsible for ~ 1.5 % of the global CO2 emissions, so we have a significant impact on the global maritime sustainability agenda.

Powering sustainable shipping by opening clear routes

MAN Energy Solutions supports all

LNG		Ethane	Methanol	LPG	Ammonia
ME-GI	ME-GA	ME-GIE	ME-LGIM	ME-LGIP	→ 2024

MAN B&W two-stroke engines for alternative fuels

2011
ME-GI
test at RCC

2015
Development
of LGIM

2016
Development
of ME-GIE

2018
ME-LGIP
test at RCC

2019
Development of
ME-GA

2020
Ammonia engine
development
started

Extensive experience in the development of dual-fuel engines

2 stroke DF engines — status quo – 10/2022

1000
2s DF engines

54% of orders are DF in 2022

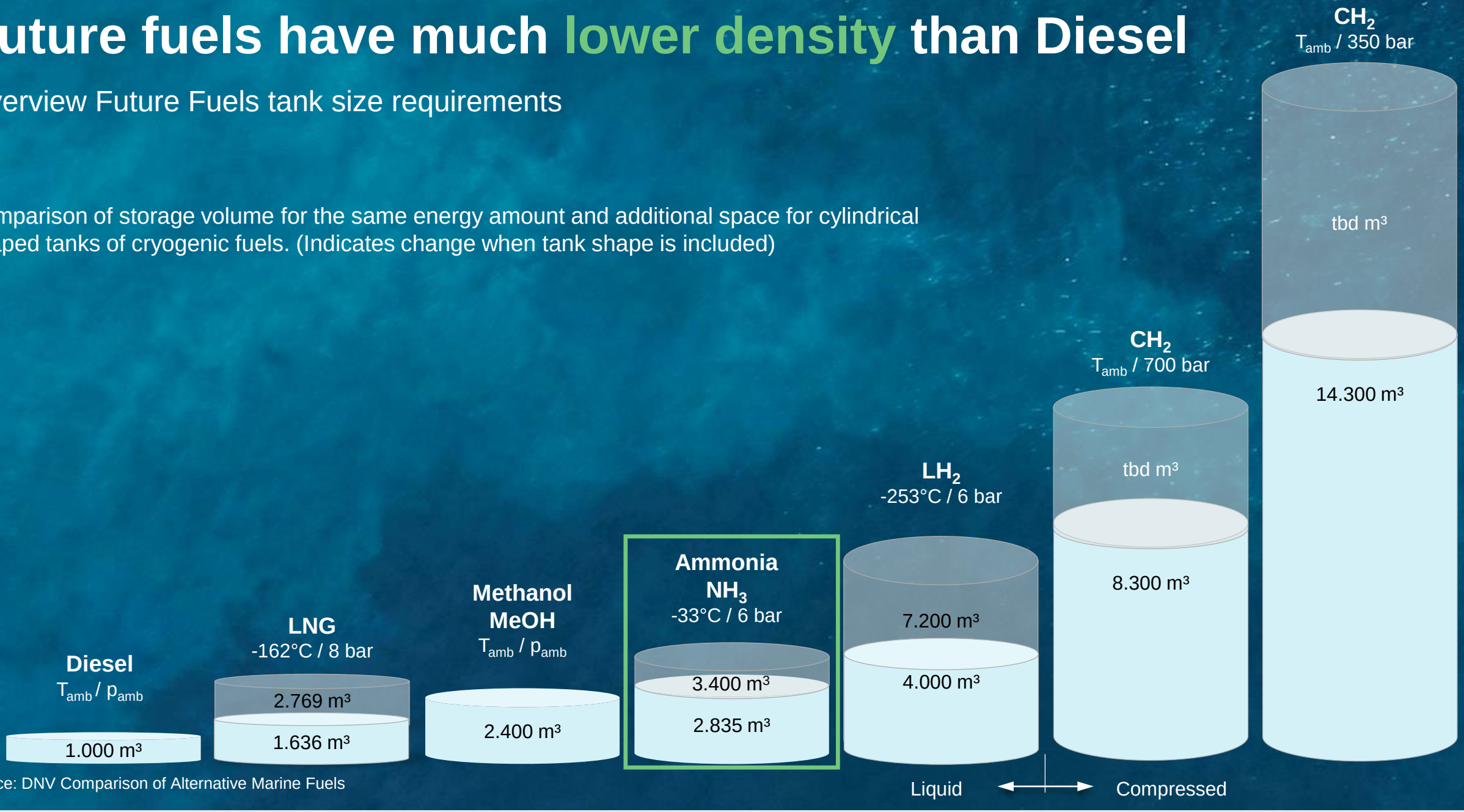
22 GW total DF power

263 DF vessels in service

Future fuels have much lower density than Diesel

Overview Future Fuels tank size requirements

Comparison of storage volume for the same energy amount and additional space for cylindrical shaped tanks of cryogenic fuels. (Indicates change when tank shape is included)

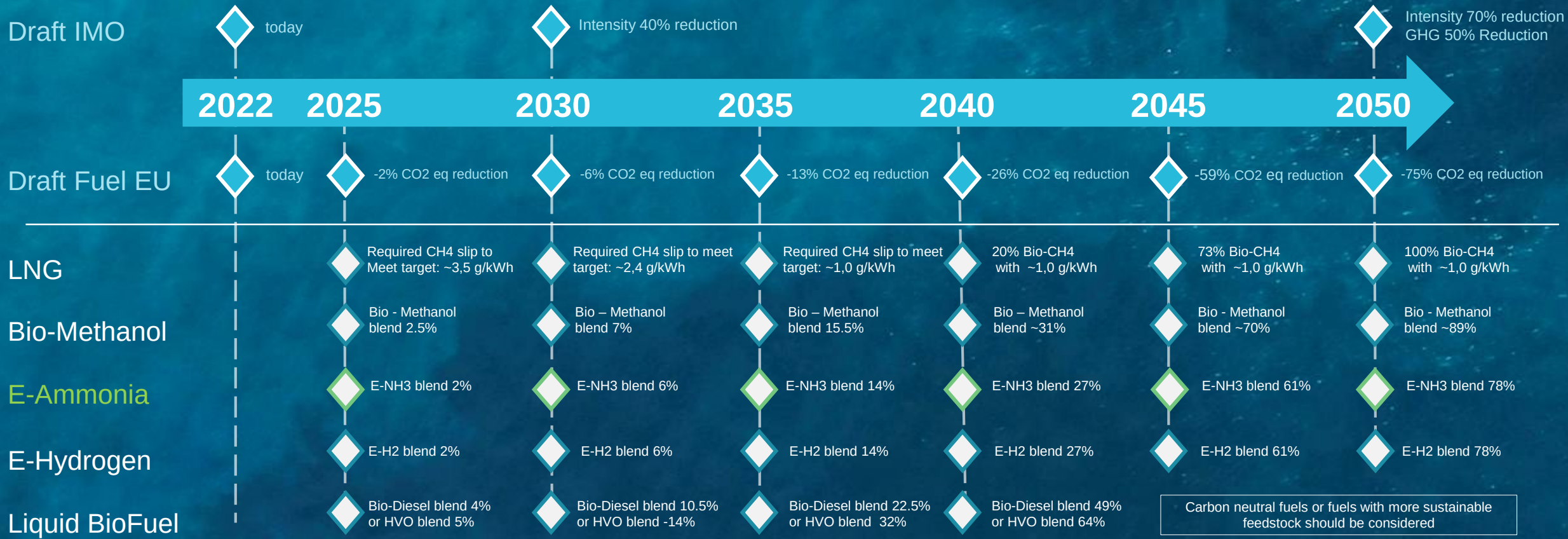


Source: DNV Comparison of Alternative Marine Fuels

Generic De-fossilization/carbonisation pathways

Overview Future Fuels & Emissions

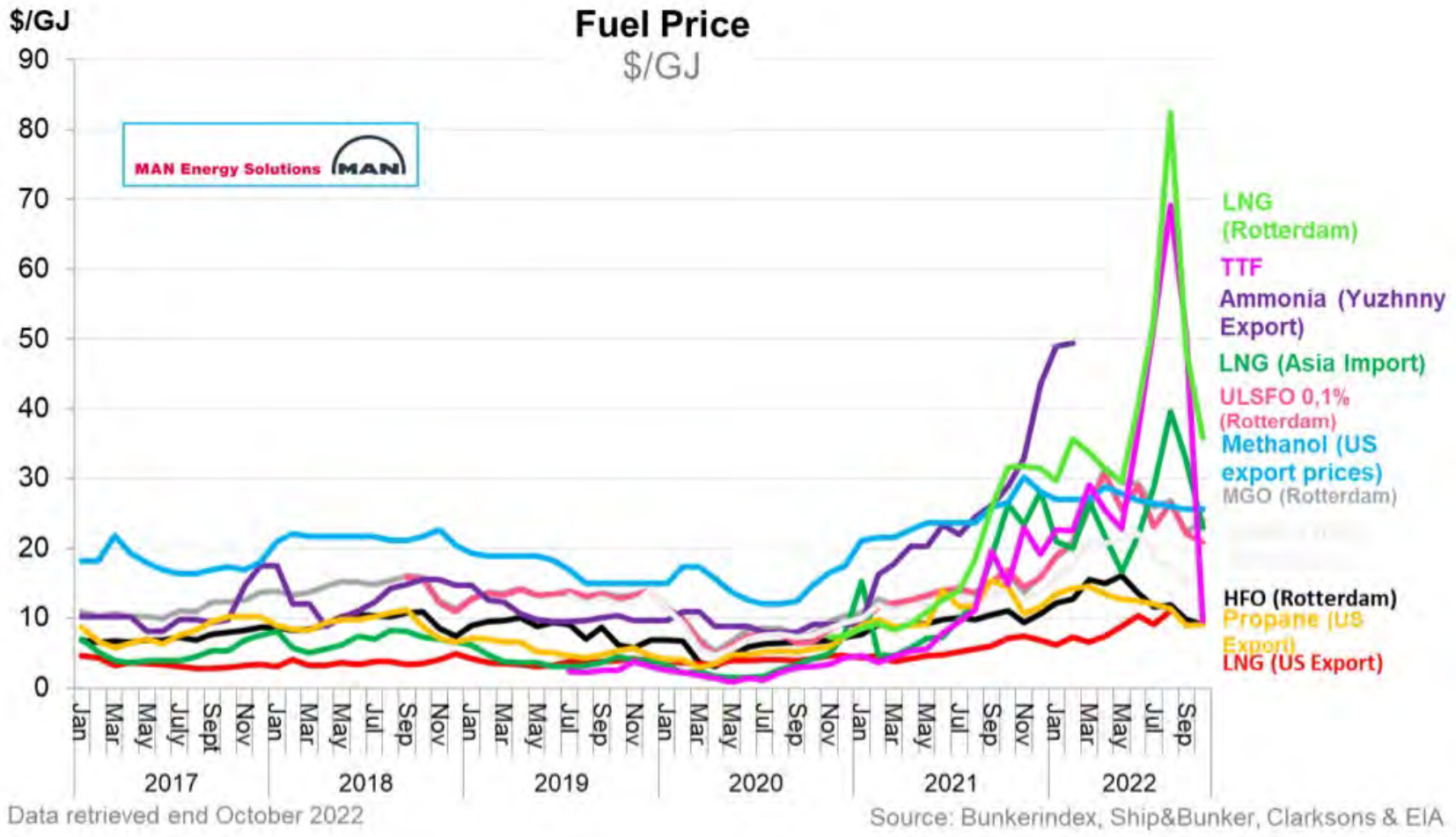
- all % are in energy share with MGO
- Some uncertainty with E-NH3 values!



Many decarbonisation paths are possible to meet future legislation

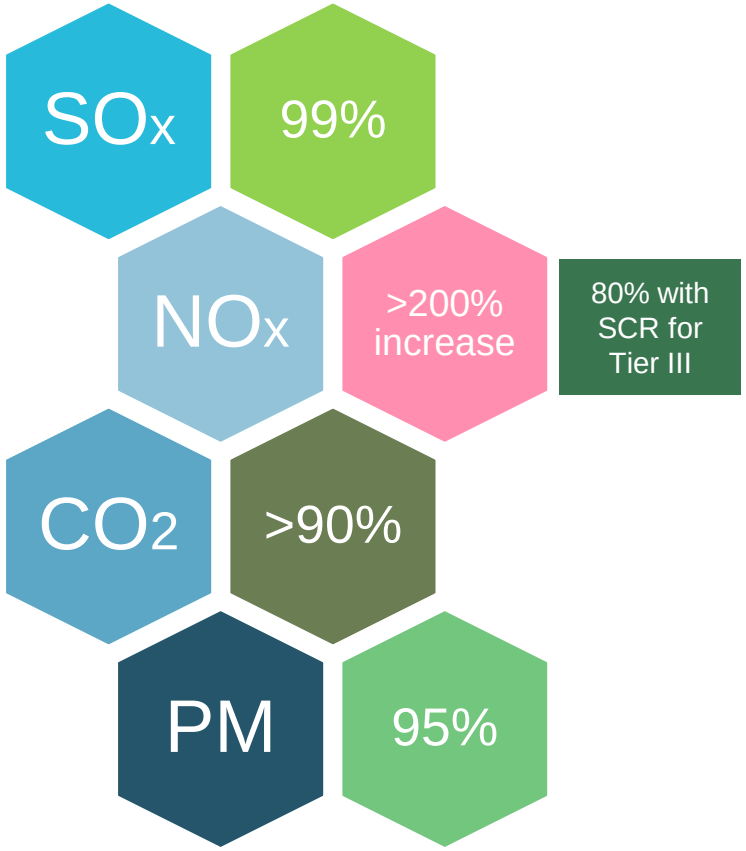
Fuel price development - overview

(Status October 2022 - without CO_2 taxation)



Ammonia – NH3

Emission reductions compared to HFO Tier II (tank-to-wake)*



* Indication. Assumes HPDI technology at 75% engine load

Aspect	Impact
• CO2e [g/MJ] acc. to Fuel EU Fit for 55	• 121 (conventional) • 0 (green)
• Efficiency	• Similar to current DF engines
• Equivalent tank volume • (includes tank shape)	• 3,4 x Diesel 1,2 x LNG
• Storage	• -33°C / 6 bar
• Ignitability	• With diesel
• Power output in ammonia mode	• 90 - 100%
• Challenges	• Toxic • Odour

! Grey Ammonia is $C0_2$ neutral only tank-to-wake, for well-to-wake $C0_2$ neutrality green ammonia is needed

Ammonia – NH3

Availability: Worldwide ammonia ports

Storage & handling

- Storage below -33°C at 6 bar
- Highly toxic to people & environment
- Leakage detection necessary
- Personal protection equipment necessary

Conclusion

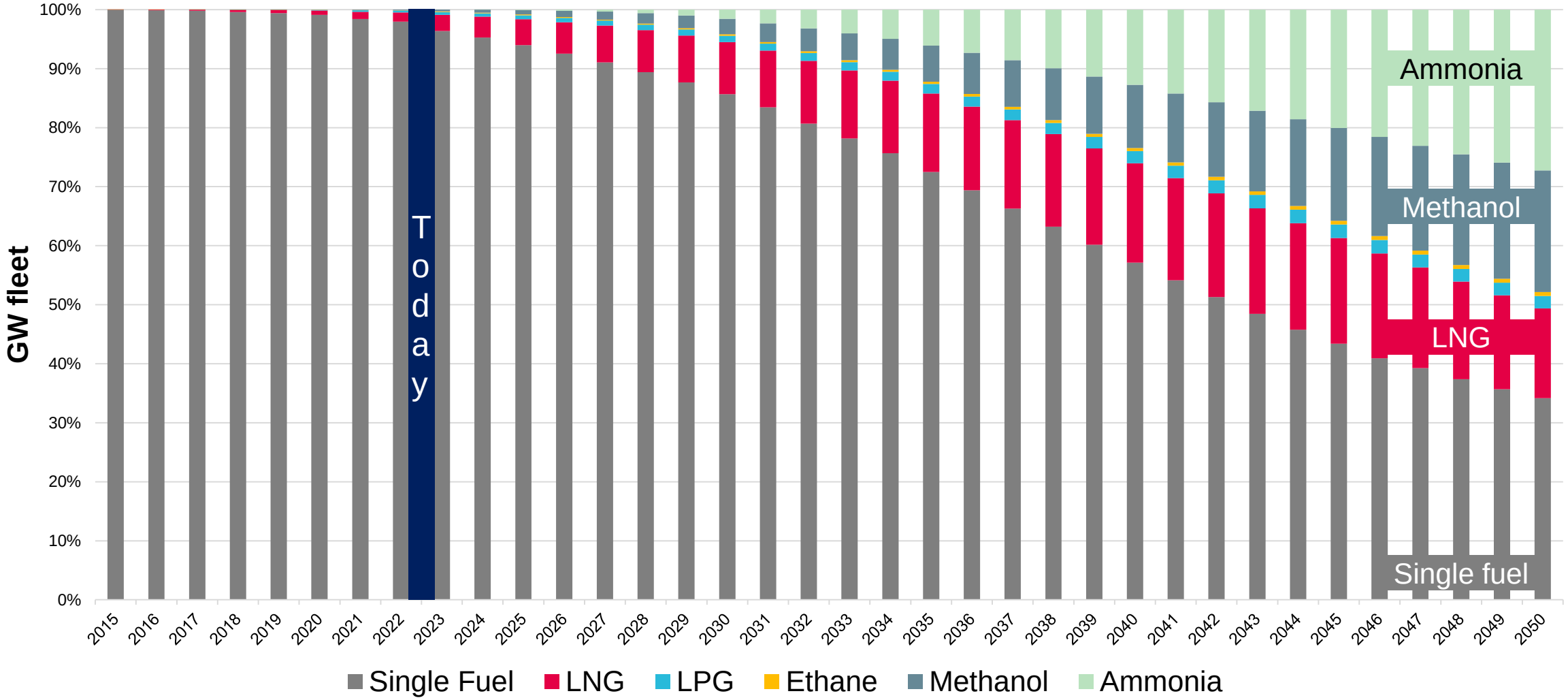
- Highly toxic to people & environment
- Cylindrical pressure tanks require more space
- Green ammonia CO2e emission free
- Conventional ammonia widely available
- Attention to N2O slip (GWP factor ~ 265)

! Grey ammonia widely available, hardly any blue or green ammonia

3 Alternative fuel outlook

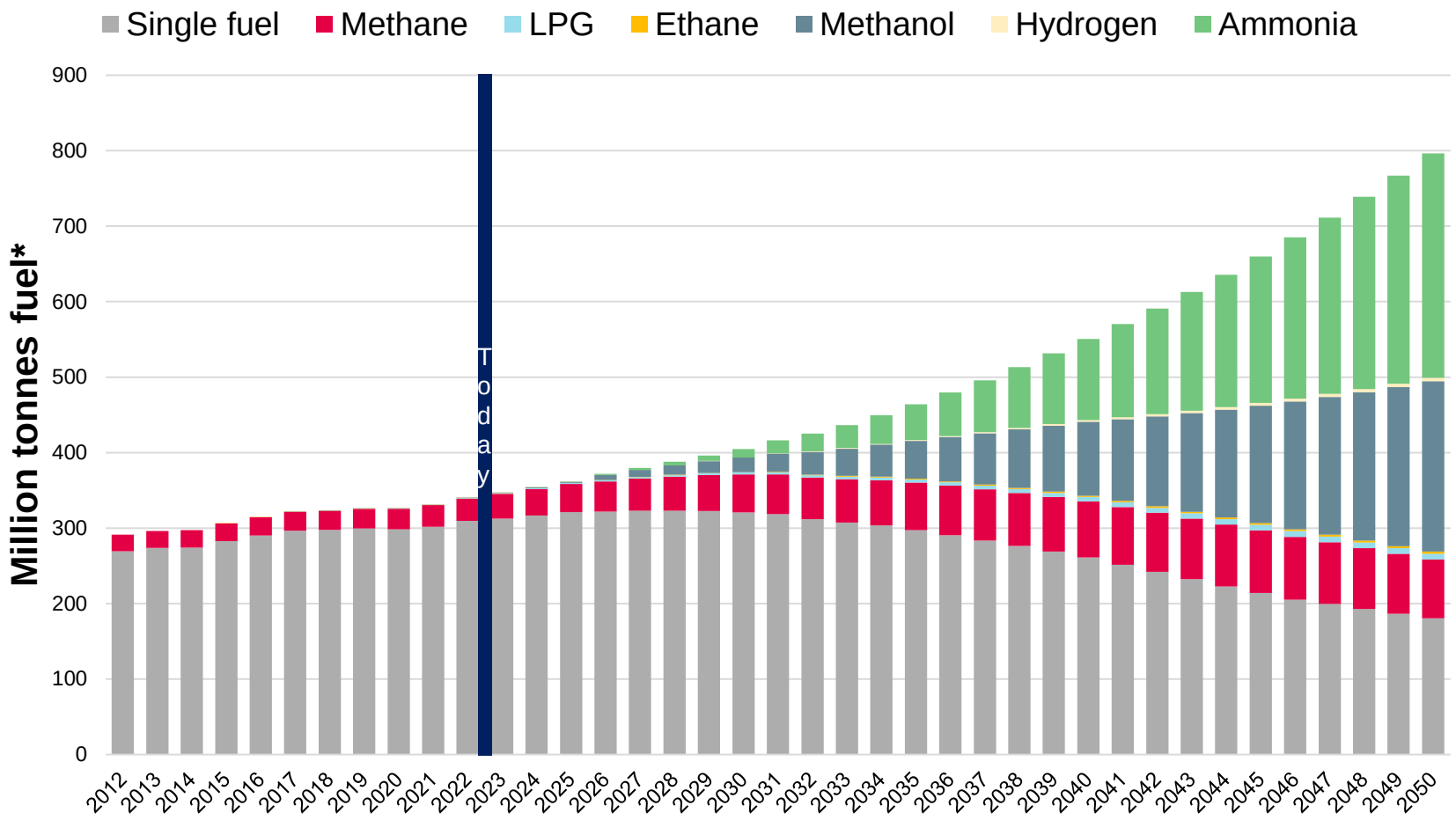
Two-stroke fuel mix forecast towards 2050 (Fleet)

Distribution of 34% single fuel, 27% Ammonia, 21% Methanol, and 15% LNG expected in 2050



Assumptions: Scenario is based on known factors such as world trade growth, EEDI, EEXI, expected CO2 regulation (currently unspecified), etc.

Expected fuel share of tomorrow

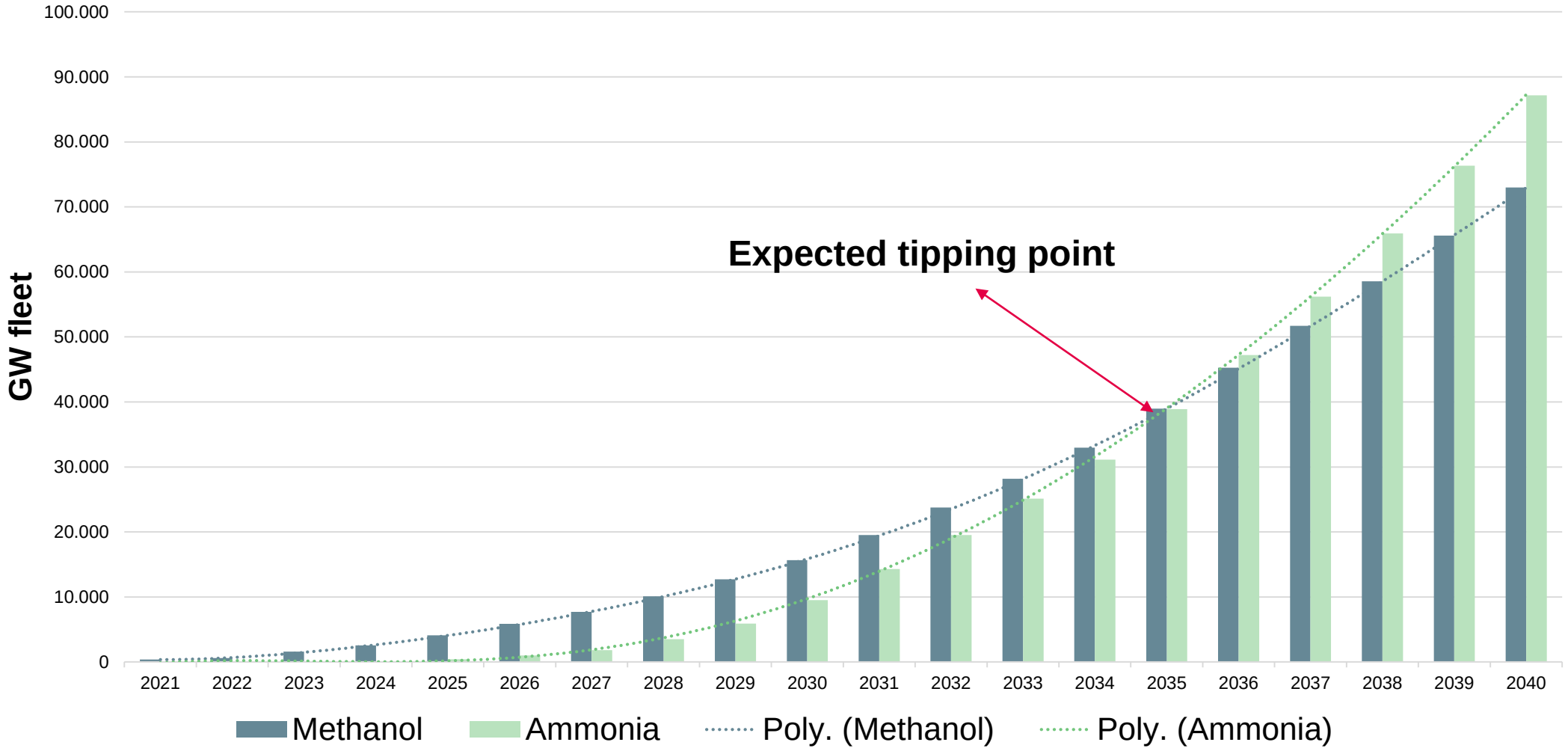


- Drivers of methanol and ammonia uptake are availability of technology, consumer demand, expectation of future CO2e regulation and/or carbon pricing
- Other factors such as efficiency, batteries, ship design, operational improvements contribute to decarbonization

Only newbuilding included in graph; a more or less gradual transition to green fuels is built into each fuel which then contains both a fossil and green share
*Mass of the fuel types: Energy content of fuels varies due to differences in gravimetric heating value

Two-stroke fleet fuel mix: focus methanol and ammonia

Methanol is expected to have a fast uptake based on technology experience and market demands, ammonia as a new fuel will have a responsible introduction emphasizing safety (S-shaped curve).



4 Ammonia engine development

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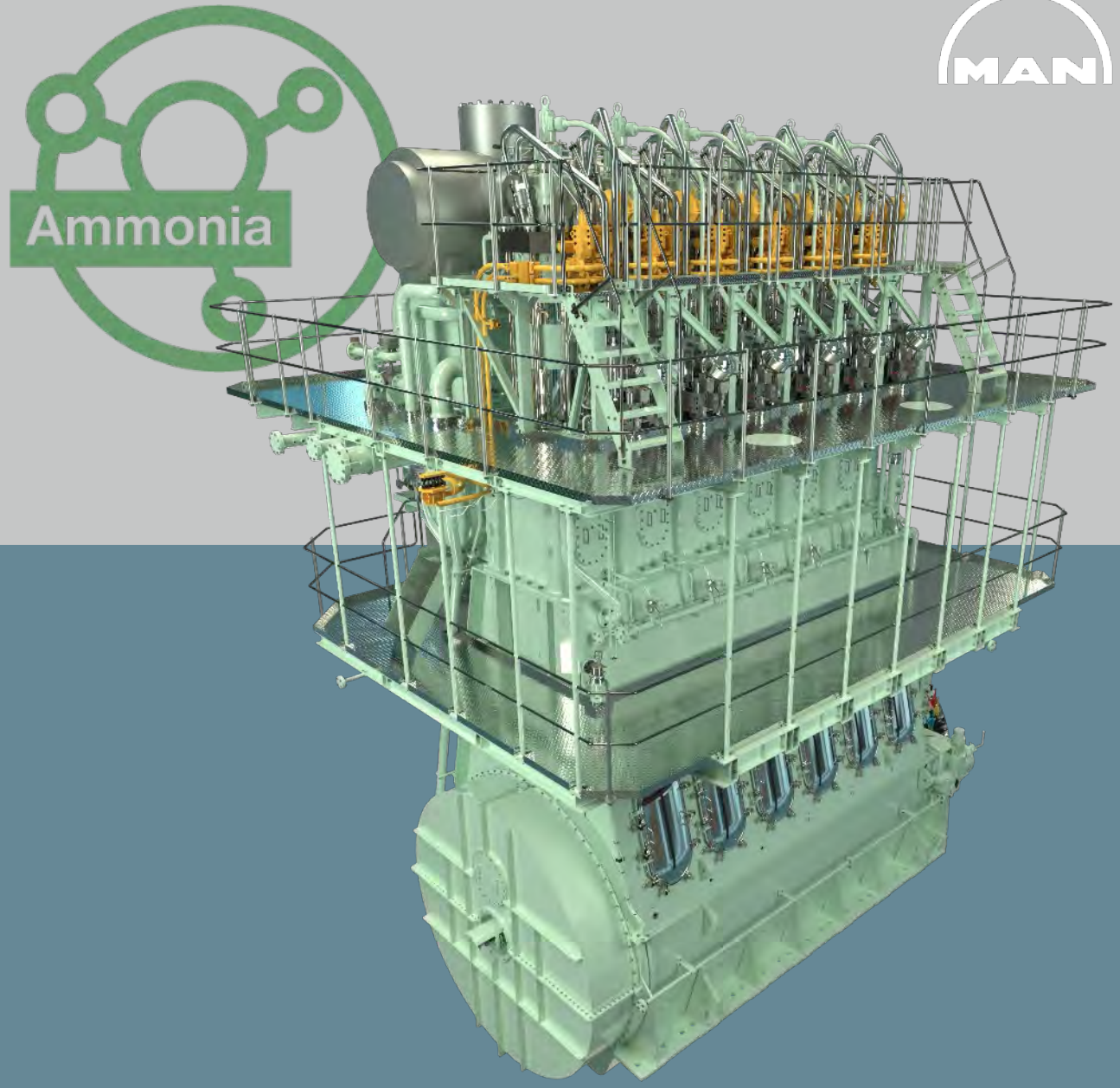
MAN B&W Ammonia engine




2024
Ammonia
The first MAN B&W
Ammonia fueled engine will be
delivered to a shipyard

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.

Two-stroke ammonia engine development schedule

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

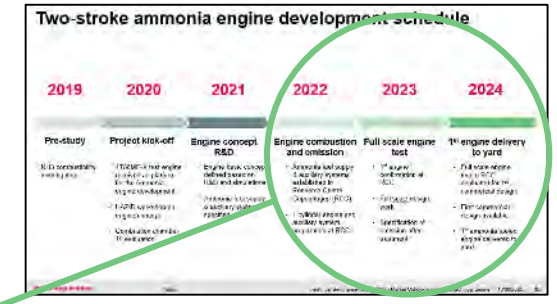
Full scale engine test

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

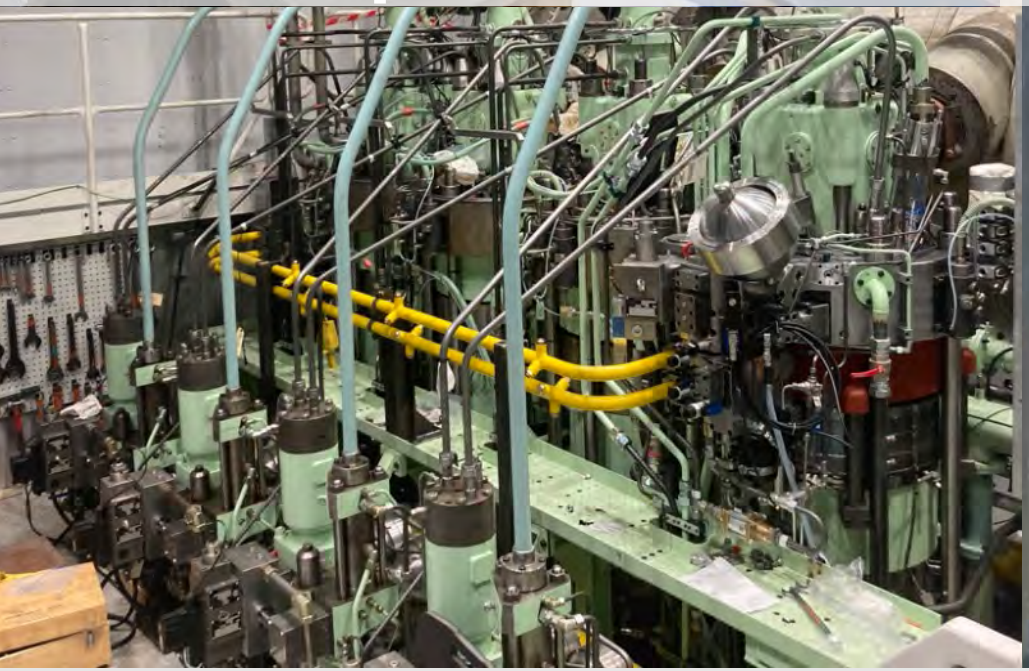
2024

1st engine delivery to yard

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




Components at RCC for ammonia engine development



RCC ammonia tank and bunkering facilities

Status December 2022

Installation at RCC

- We are now **finalizing all the installations around the engine**, such as bunkering and supply, with safety as the overall guiding principle.
- We have **not started our test engine yet**. It’s due to a shift in priorities. We want to finish some of the surrounding systems in another way, or more elaborately than before.
- We expect to **start** the engine test campaign sometime at the **beginning of next year**.

Ammonia engine development

Materials

Fuel Supply System

- 316L steel is recommended.
- To be welded with backing gas / pickling.

LGI injection system

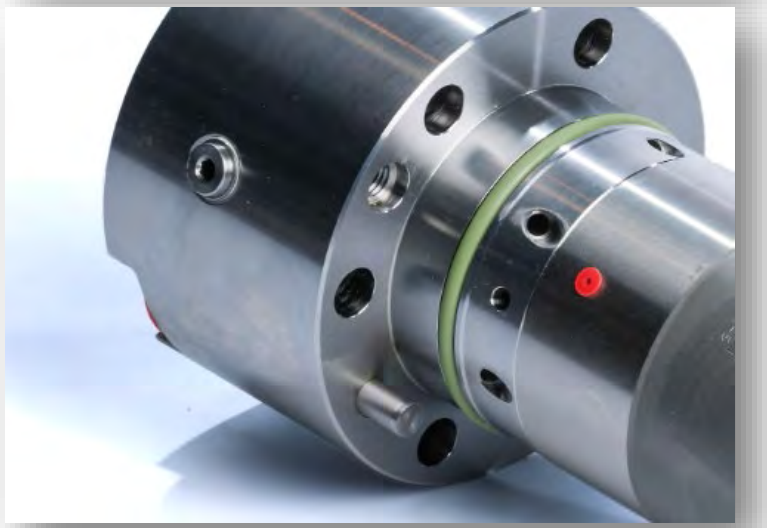
- Current materials expected to perform satisfactorily.

Elastomers

- Suitable material found for both O-rings and accumulators.

Stress corrosion cracking

- is solved by the industry already, by requiring small amount of waterin the ammonia and requirements to the steel grades, welding procedures etc.



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.

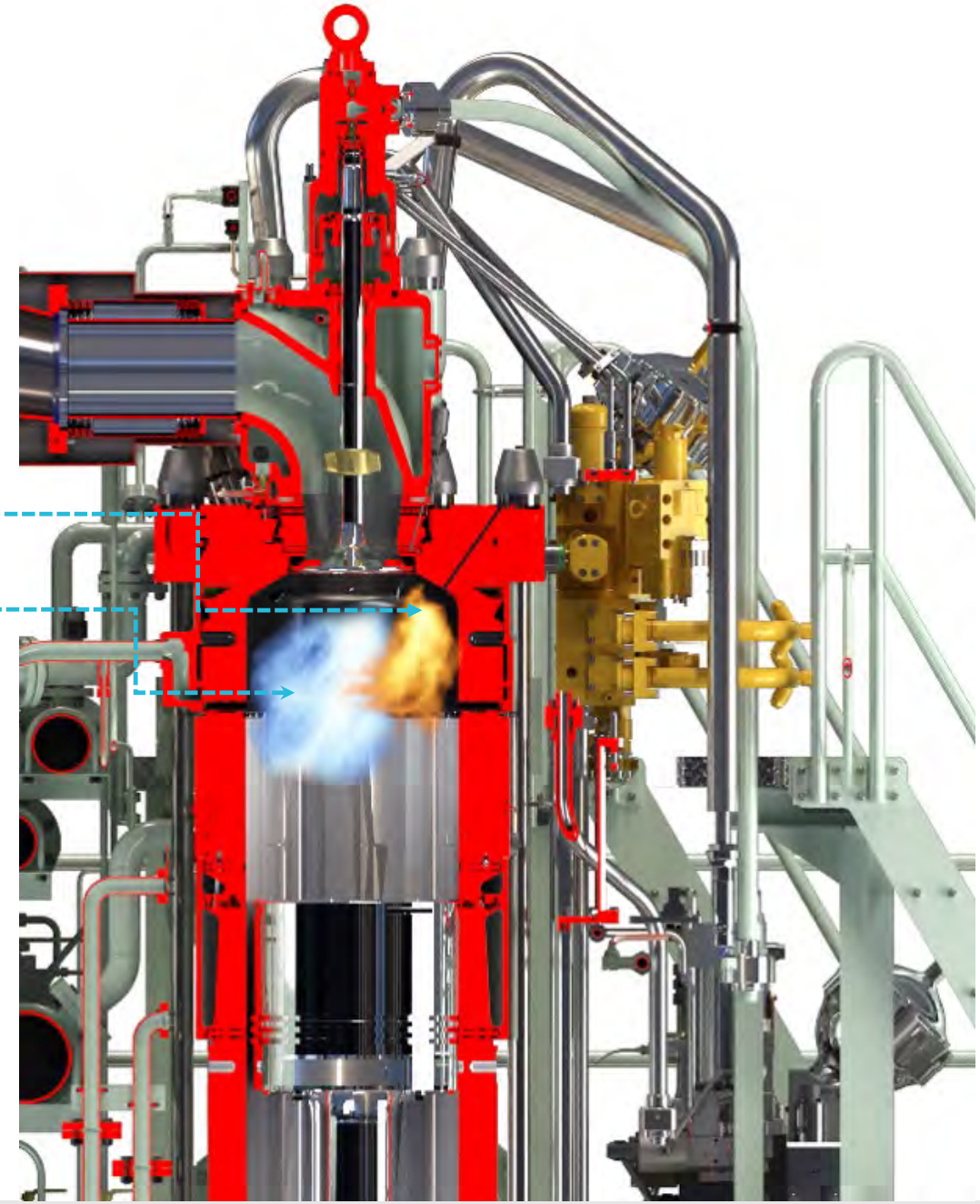
The MAN B&W ammonia engine design philosophy

"Ammonia mode":

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

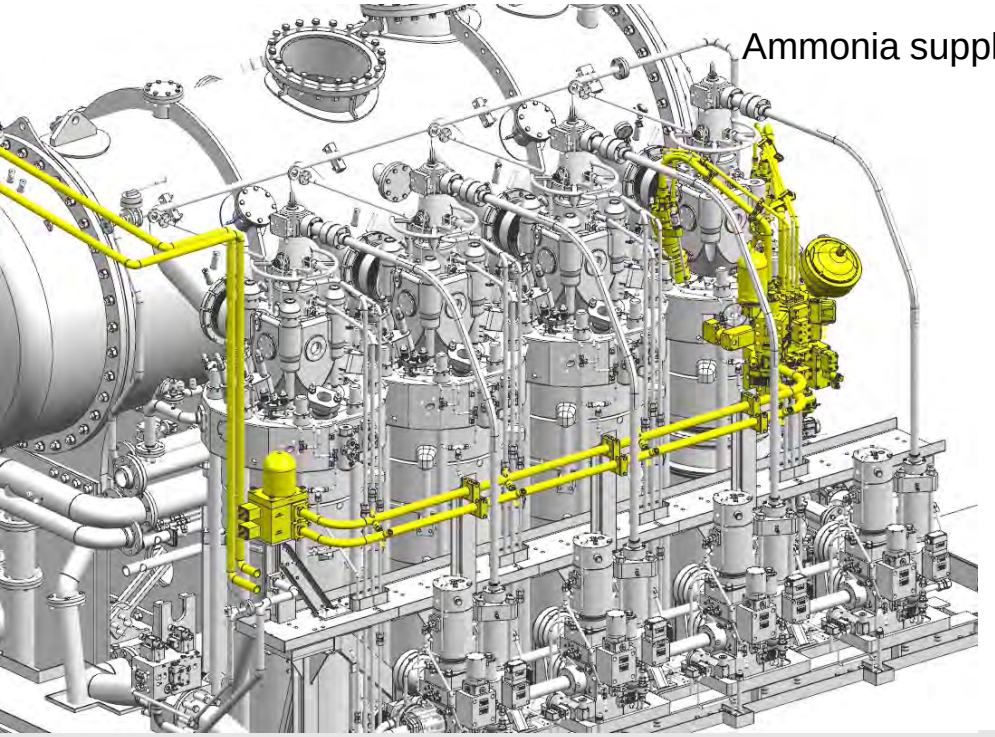
"Liquid fuel mode":

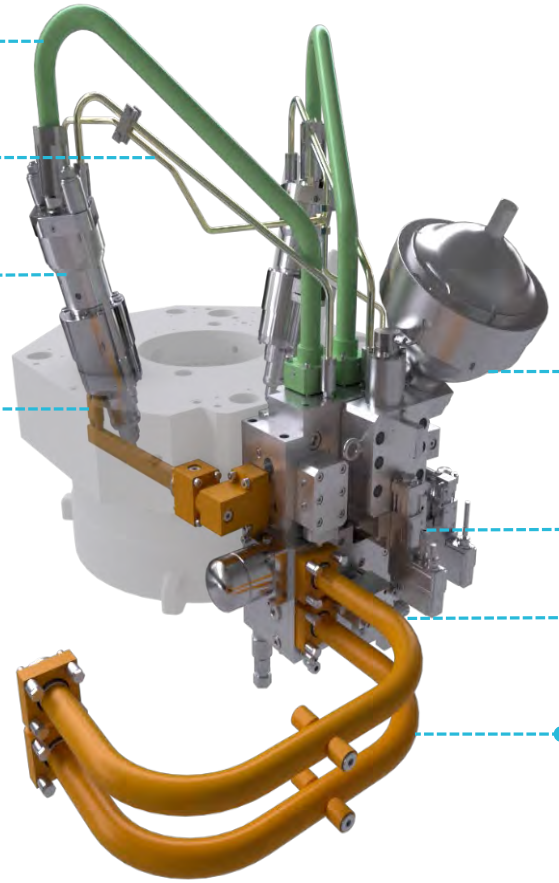
- Identical performance as conventional fueled Diesel engine.



Ammonia engine development

MAN Research Centre Copenhagen (RCC) & The LGI injection system



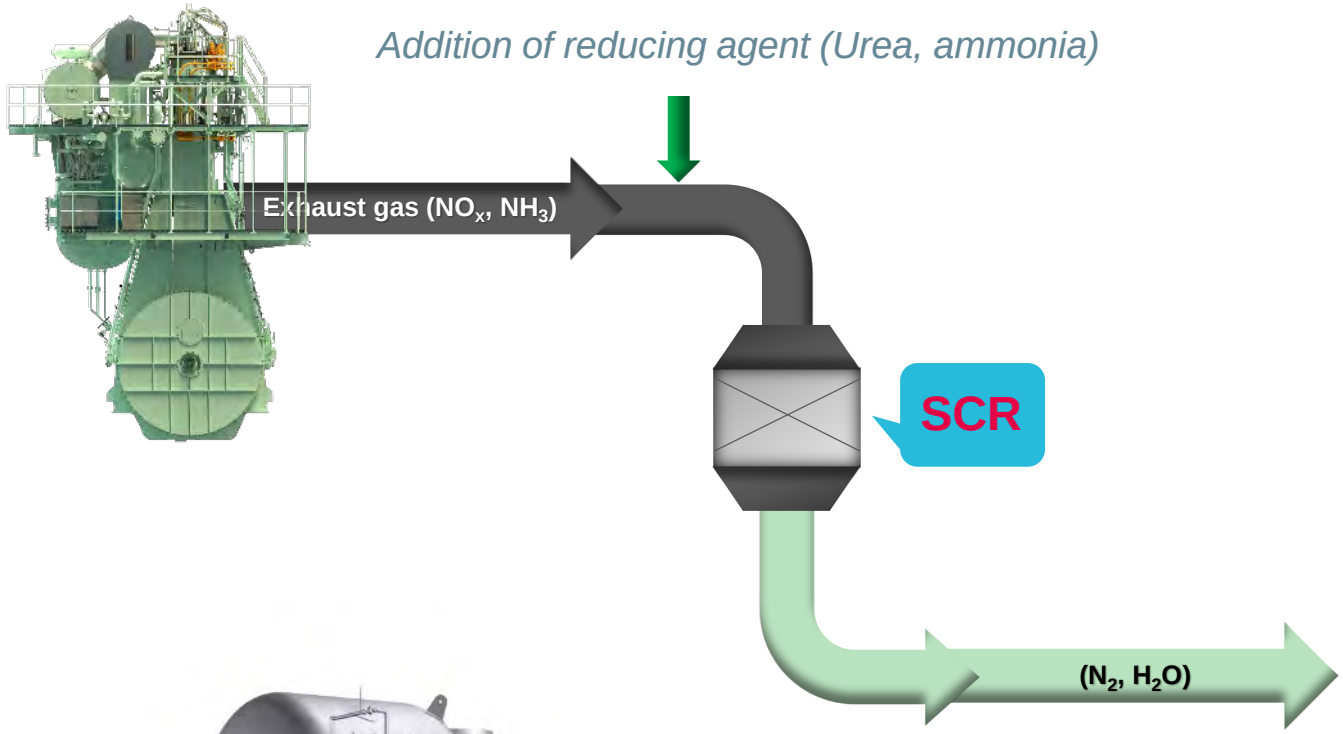


Ammonia engine development

How do we handle potential Nitrous Oxide emissions?

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

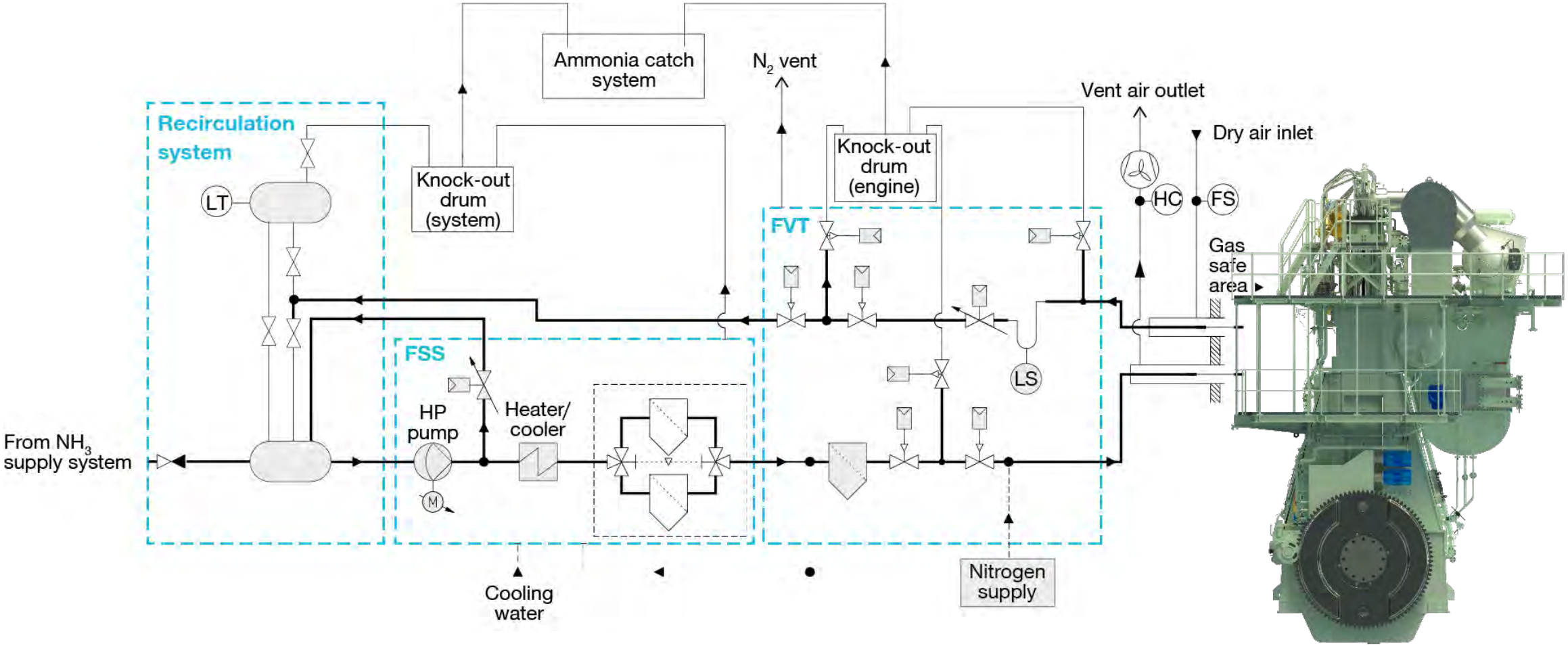
- Unburned NH_3 and NO_x is removed in the SCR reactor.
- Dosing of additional ammonia to SCR reaction if needed.
- Known SCR technology is suitable. MAN SCR reactor can be applied.
- Engine designed for both fuel oil and NH_3 as fuel.



MAN SCR

Ammonia engine development

Auxiliary systems



Ammonia engine development

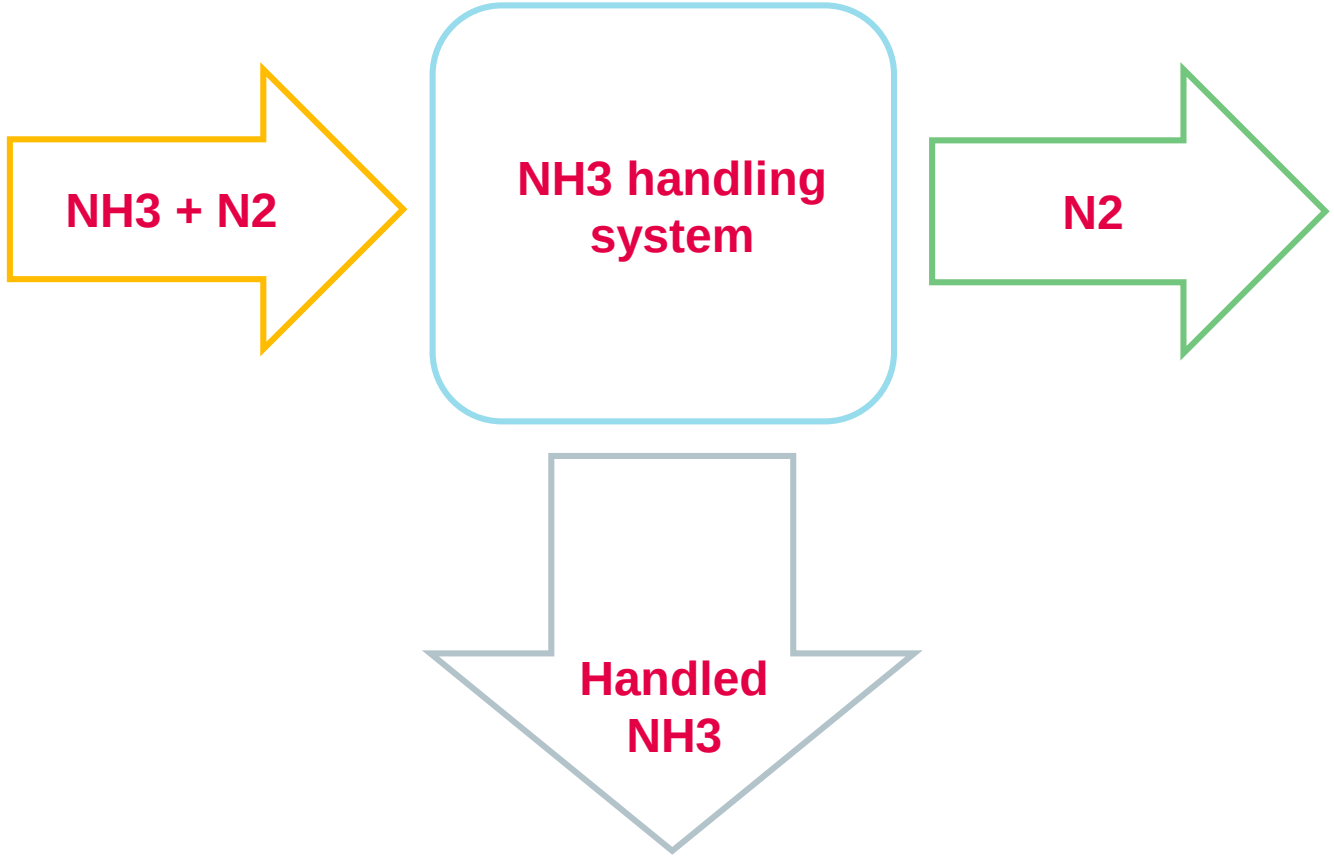
Ammonia catch system

Requirements

- Catch blow off ammonia safely
- Avoid ammonia odor and toxicity
- To work even in the event of system failure

Status

- Small scale test at our research center completed with good results
- Full scale solution being designed
- Patent pending



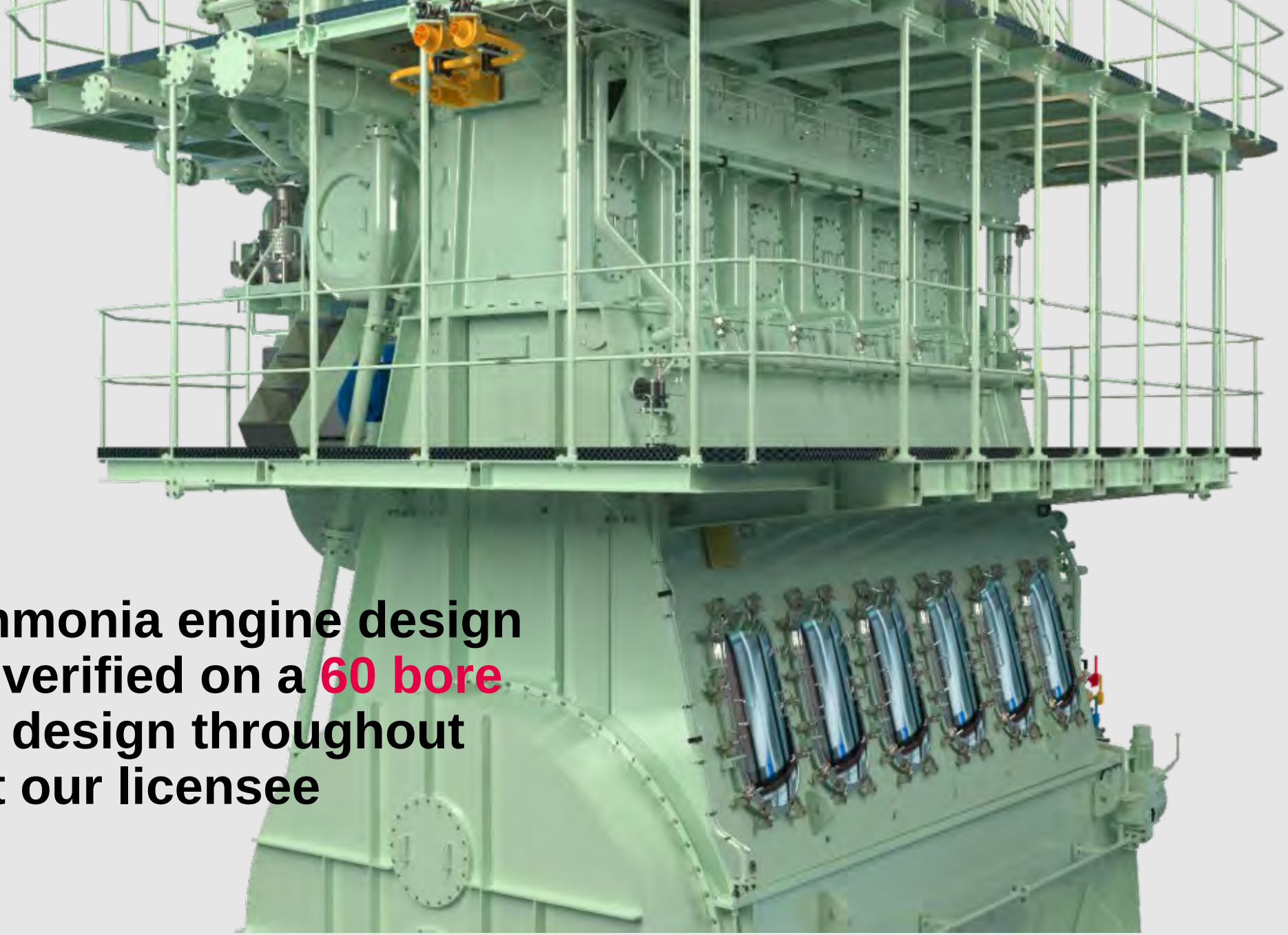
Ammonia engine development

Main focus areas in the development

Safety	HAZID completed
Corrosion of Materials	Solution in scope
Elastomer Compatibility	Solution in scope
Odor / Venting	Catch concept defined
Combustion	Studies ongoing
Emissions	Studies ongoing
Maintenance Intervals	Studies ongoing

5

Market introduction & Future-proof propulsion



The ammonia engine design will be verified on a 60 bore engine design throughout 2024 at our licensee

Ammonia engine - market introduction

Delivery of the first ammonia engine to a shipyard ultimo 2024.
Available for general ordering after obtaining positive seagoing service experience.

Event:	**Commercial 60 bore engine design tested and verified (FAT).**	**Positive seagoing service experience obtained.**
Action:	**Delivery of the engine to a shipyard.** **Start of initial limited sales*.** **2nd bore size announced.**	**Design available to licensees to order and produce from.** **Start of unlimited sales .**

* Number of engines in limited sales release will be based on risk evaluation

The 60-bore engine

Typical applications

VLGC

Container feeders

Panamax & newcastlemax bulk carriers

PCTC

LR1 & LR2 tankers

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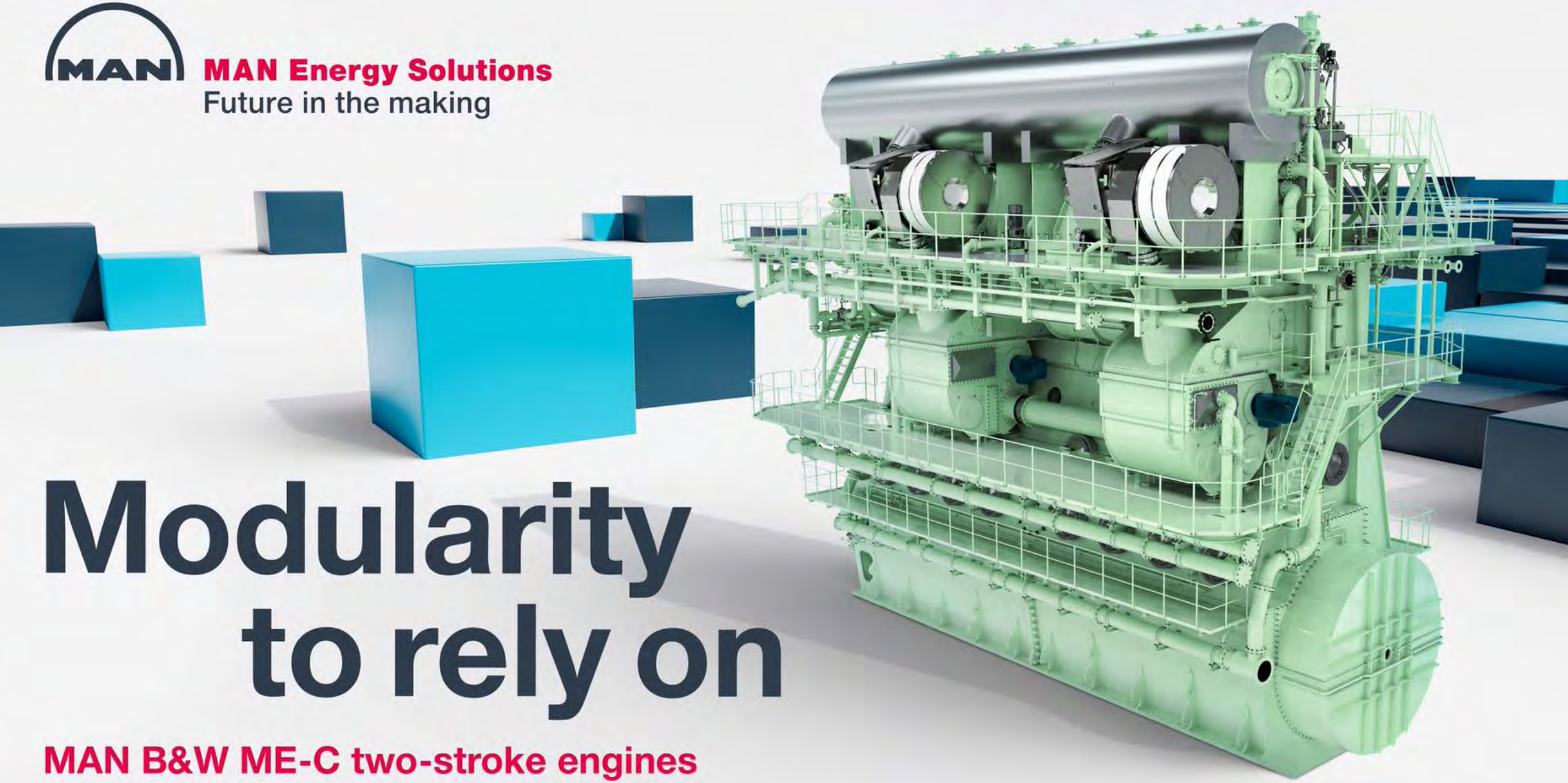

Modularity to rely on

MAN B&W ME-C two-stroke engines

Modular design enables extensive retrofit options

By ensuring full fuel flexibility and extensive retrofit capabilities with a proven record, MAN Energy Solutions future proof your investment

Fuel types	ME-C	ME-GI	ME-GA	ME-GIE	ME-LGIM	ME-LGIP
Fuel oil	✓	✓	✓	✓	✓	✓
LNG	Retrofit	✓	✓	Retrofit	Retrofit	Retrofit
LEG (Ethane)	Retrofit	Retrofit	-	✓	Retrofit	Retrofit
Methanol	Retrofit	Retrofit	-	Retrofit	✓	Retrofit
LPG	Retrofit	Retrofit	-	Retrofit	Retrofit	✓
Ammonia	Retrofit	Retrofit	-	Retrofit	Retrofit	Retrofit

Retrofit of engines is a proven concept.

22 vessels completed, 4 on order

MAN B&W two-stroke retrofits (19 engines)		
Nakilat	”Rasheeda”	**LNG** retrofit of 2 x 2s Main Engines on 1 x LNG Carrier
Hapag Lloyd	”Brussels Express”	**LNG** retrofit of 2s Main Engine on 1 x Container vessel
Navigator LLC	”Navigator Aurora”	**Ethane** retrofit of 2s Main Engine on 1 x Ethane Carrier
BW LPG	15 vessels	**LPG** retrofit of 2s Main Engines on 15 x LPG Carriers
MAN four-stroke retrofits (4 engines)		
Wessels Reederei	”Wes Amelie”	**SNG** retrofit of 4s Main Engine on 1 x Container vessel
Baleària	”MV Napoles”, ”MV Sicilia”	**LNG** retrofit of 2 x 4s Main Engines on 2 x RoPAX vessels
GIE Dragages-Ports	”Samuel de Champlain”	**LNG** remotorization of 2 x 4s Main Engines on 1 x Dredger
Retrofit projects on order		
Matson Inc.	”Daniel K. Inouye” + sister	**LNG** retrofit of 2s Main Engine on 1+1 x 3600 TEU
Tianjin Southwest	”Gas Gemini”, ”Gas Aquarius”	**LPG** retrofit of 2s Main Engine on 2 x LPG carriers






6

Summary

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.
- NH3 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
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Thank you.

MAN Energy Solutions SE

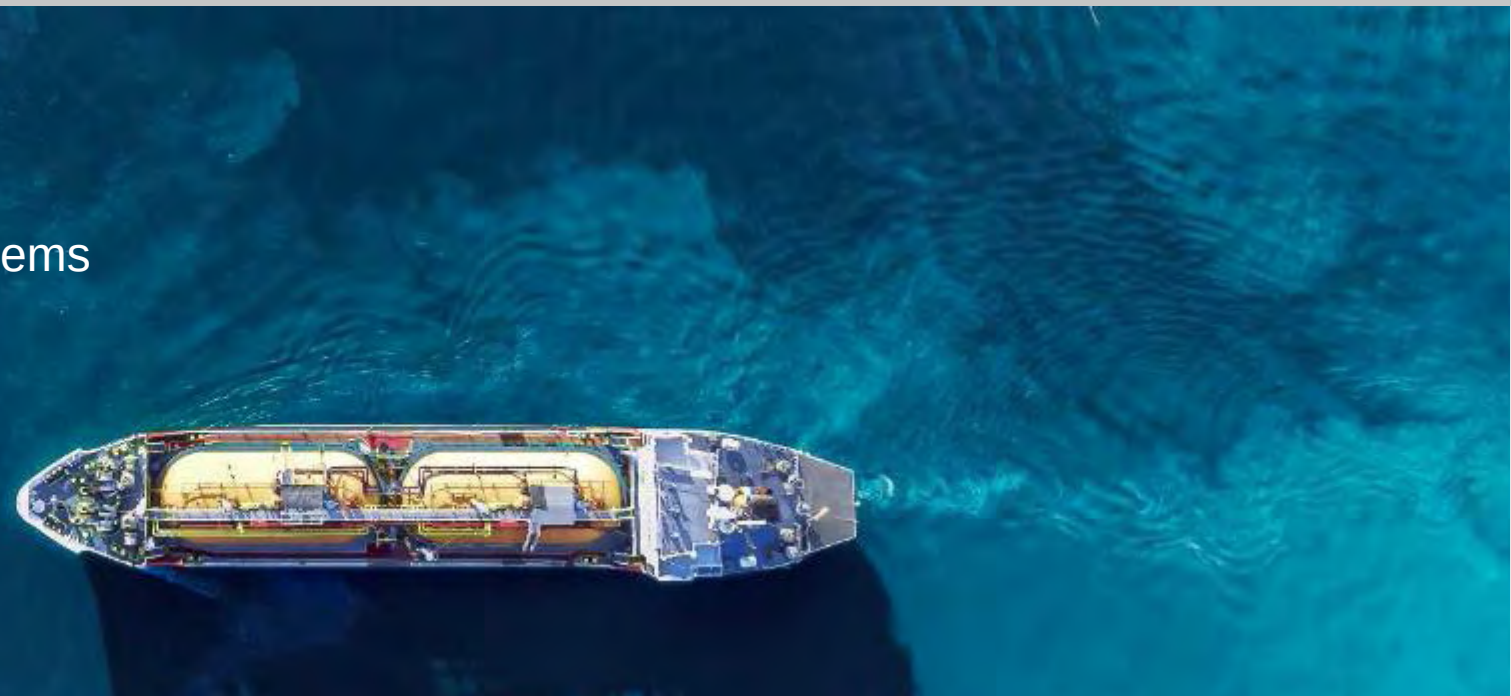
Colin Peesel

Senior Sales Manager Engine & Marine Systems

T +49 151 25 64 84 33

Colin.Peesel@man-es.com

www.man-es.com



Q&A

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