MAN Energy Solutions
Future in the making

MAN B&W Ammonia engine

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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.

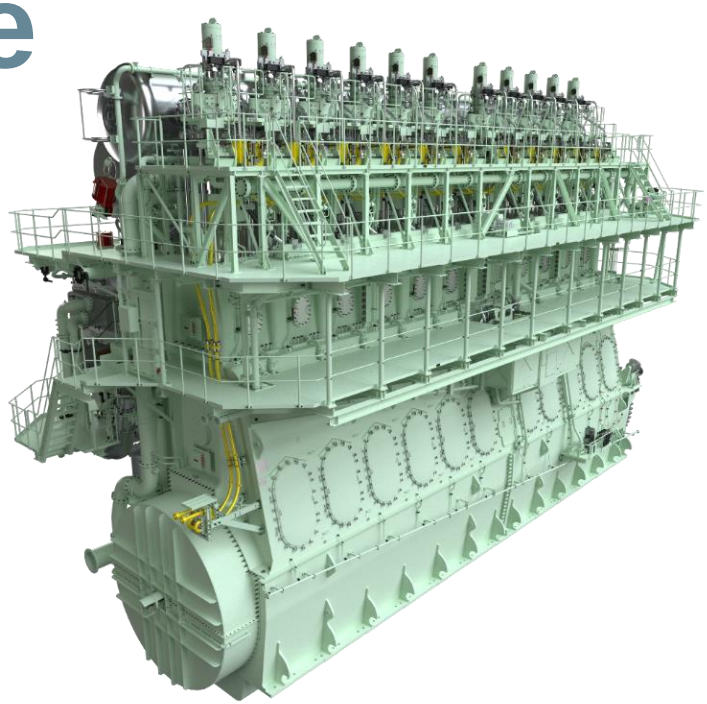
Agenda

1 MAN B&W engines for new marine fuels

2 Ammonia engine development

3 Future-proof propulsion

1 MAN B&W engines for new marine fuels



MAN Energy Solutions: We are committed to decarbonization

~ 80-90% of global freight is transported by sea.

Shipping is responsible for **~ 3 %** of the global CO2 emissions.

~ 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 pathways

MAN Energy Solutions supports all

LNG | Ethane | Methanol | LPG | Ammonia

ME-GI | ME-GA | ME-GIE | ME-LGIM | ME-LGIP | → 2024

GI: Gas Injection

GA: Gas Admission

GIE: Gas Injection Ethane

LGIM: Liguid Gas Injection Methanol

LGIP: Liguid Gas Injection LPG

MAN B&W two-stroke engines for alternative fuels

Engine delivery for TOTE Maritime.

Engine delivery for TEEKAY LNG.

ME-GI retrofit for Nakilat.

1st sea trial on methanol.

1st sea trial on ethane.

First order of MAN B&W 6G60ME-LGIP engines by Exmar.

15 x MAN B&W ME-LGIP Retrofit orders for BW LPG. Dry dock 2020.

Hapaq Lloyd 9S90ME-C ME-GI retrofit. Dry dock 2020.

2011 2012 2013 2014 2015 2016 2017 2018 2019 2020

ME-GI test at RCC.

Demonstration test at HHI.

Demonstration test at MES.

Development of ME-LGI.

Ethane development.

LGIP cylinder installed on research engine.

ME-GA test at RCC.

Ammonia engine project started.

RCC: Research Center in Copenhagen
HHI: Hyundai Heavy Industries
MES: Mitsui engineering & Shipbuilding

2 Ammonia Engine Development


Research Centre Copenhagen
New test engine underway (2020)

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 and established in RCC.

2022

Engine combustion and emission

- 1st engine confirmation at Research Centre Copenhagen (RCC).
- Specification of emission after-treatment done.

2023

Full scale engine test

- Full scale engine test at RCC evaluated for 1st commercial design.

2024

1st engine delivery to yard

- Ammonia engine in engine programme.
- 1st ammonia fueled engine delivered to yard.

Alternative fuels

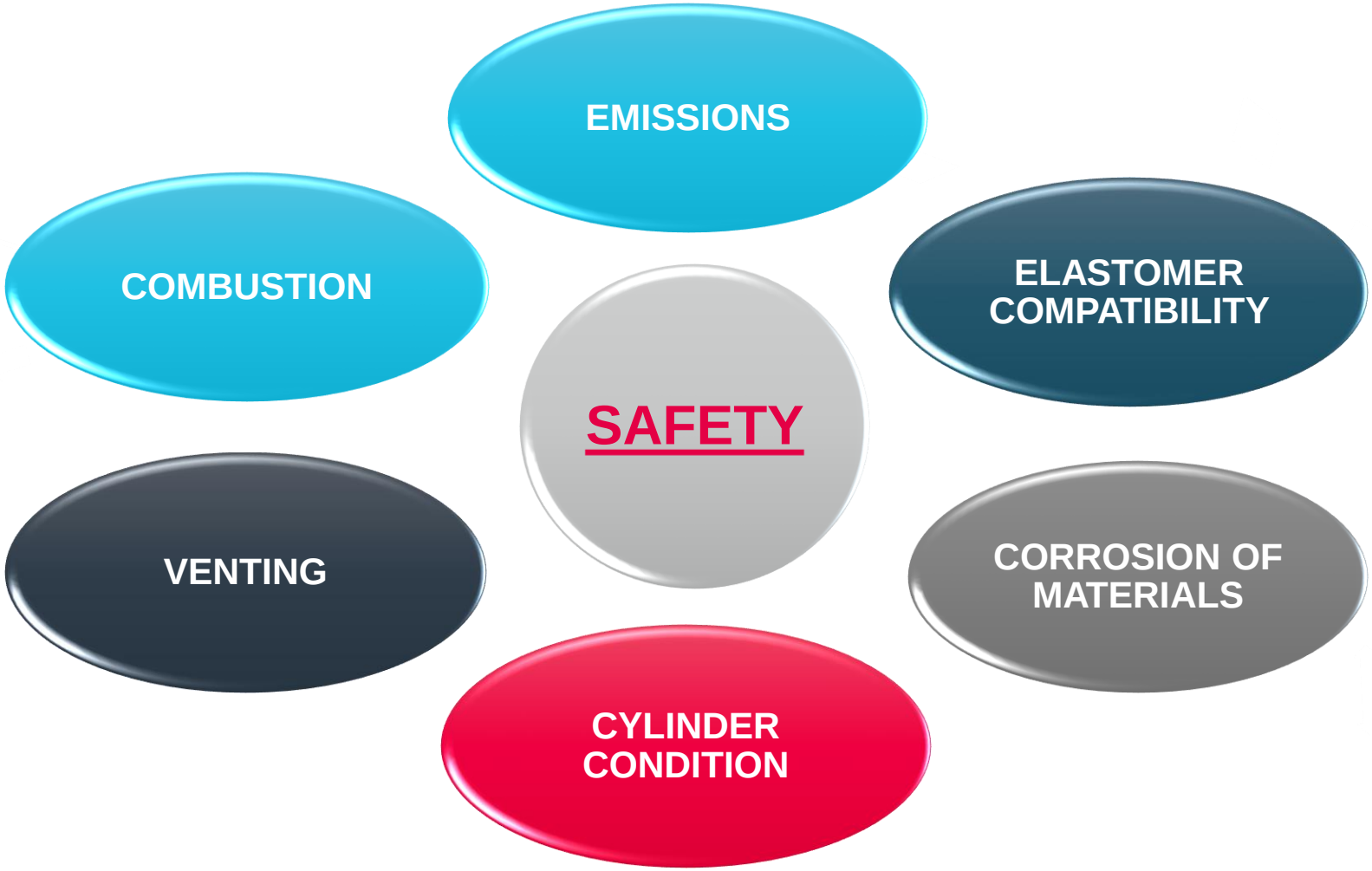
Properties

Energy storage type	Specific Energy MJ/kg	Energy Density MJ/L	Required Tank Volume m^3. (1)	Supply pressure bar	Injection pressure bar	Tank-to-wake Emission Reduction Compared To HFO Tier II			
MGO	42,7	35,9	1000	7-8	950	SO_x	NO_x	CO2	PM
Liquefied natural gas (LNG -162 °C)	50,0	22,4	1602	300	300	90-99%	20-30%	24%	90%
Liquid ethane gas (LEG -88 °C)	47,5	17,1	2099	380	380	90-97%	30-50%	15%	90%
liquefied petroleum gas (LPG -42,4 °C)	46,0	23,5	1527	53	600-700	90-100%	10-15%	13-18%	90%
Methanol	19.9	15,8	2272	13	500	90-97%	30-50%	11%	90%
Ammonia (liquid -33 °C)	18,6	11,5	3121	83	600-700	100%	will require Tier III equipment	>95%	>90%
Hydrogen (liquid -253 °C)	120	8,5	4223						

- *1: Given a 1000 m^3 tank for MGO. Additional space for insulation is not calculated for in above diagram. All pressure values given a high pressure Diesel injection principle.*

Ammonia engine development

Main focus areas in the development



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 water in 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.

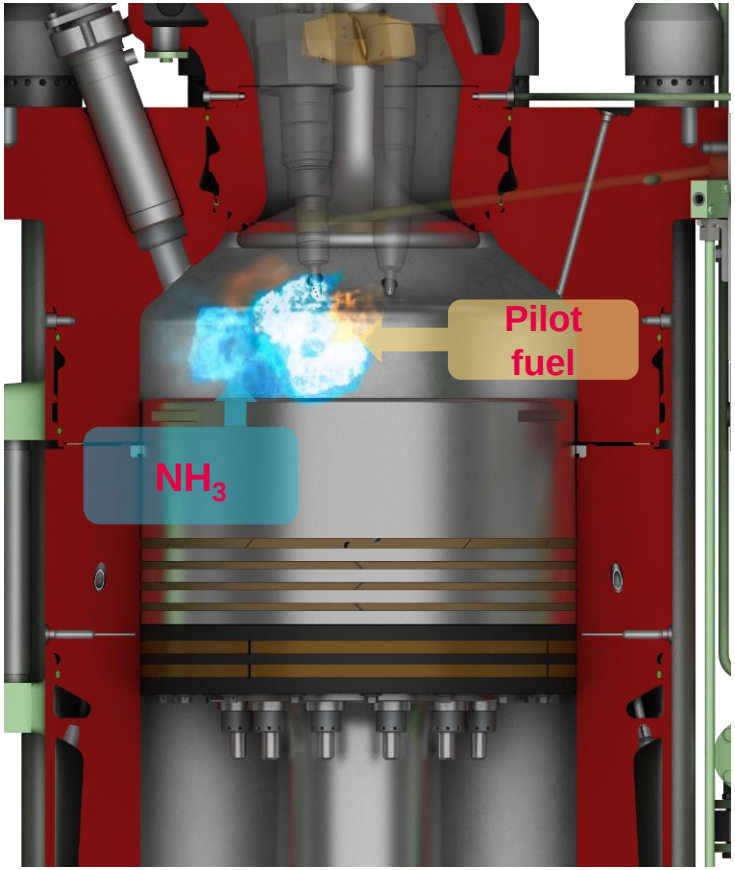
The MAN B&W ammonia engine design philosophy

"Ammonia mode":

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

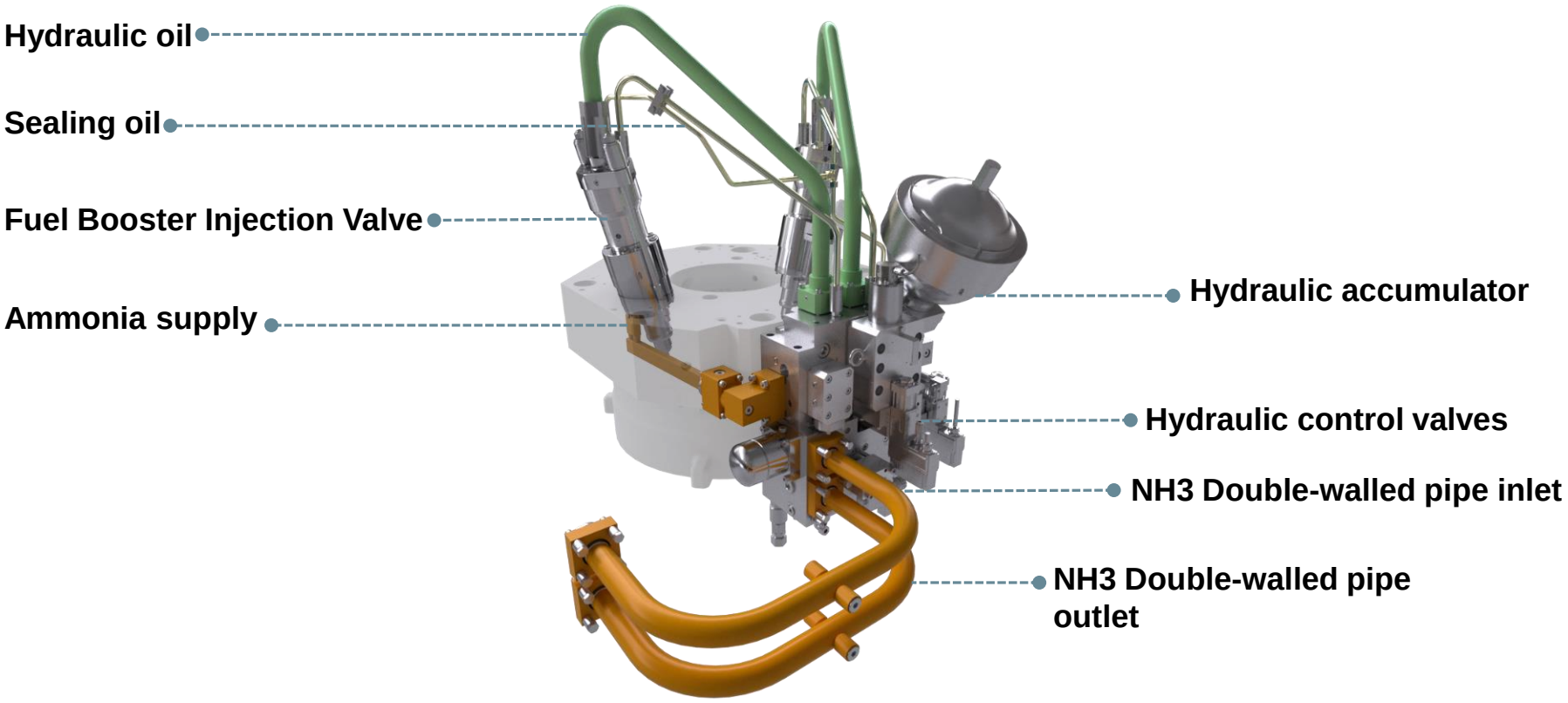
"Liquid fuel mode":

- Identical performance as conventional fueled Diesel engine.



Ammonia engine development

The LGI injection system

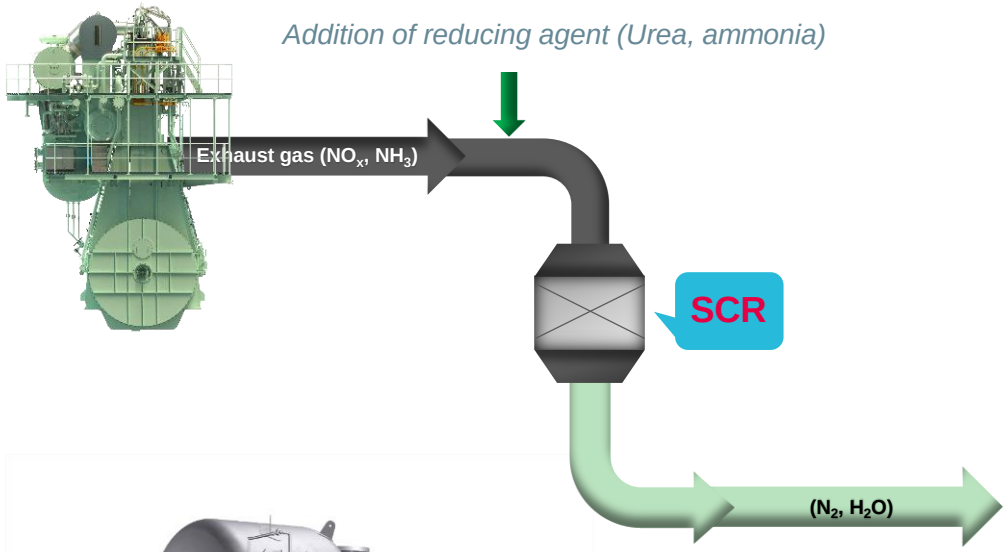


Ammonia engine development

How do we handle potential Nitrous Oxide emissions?: Emission abatement by engine tuning

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

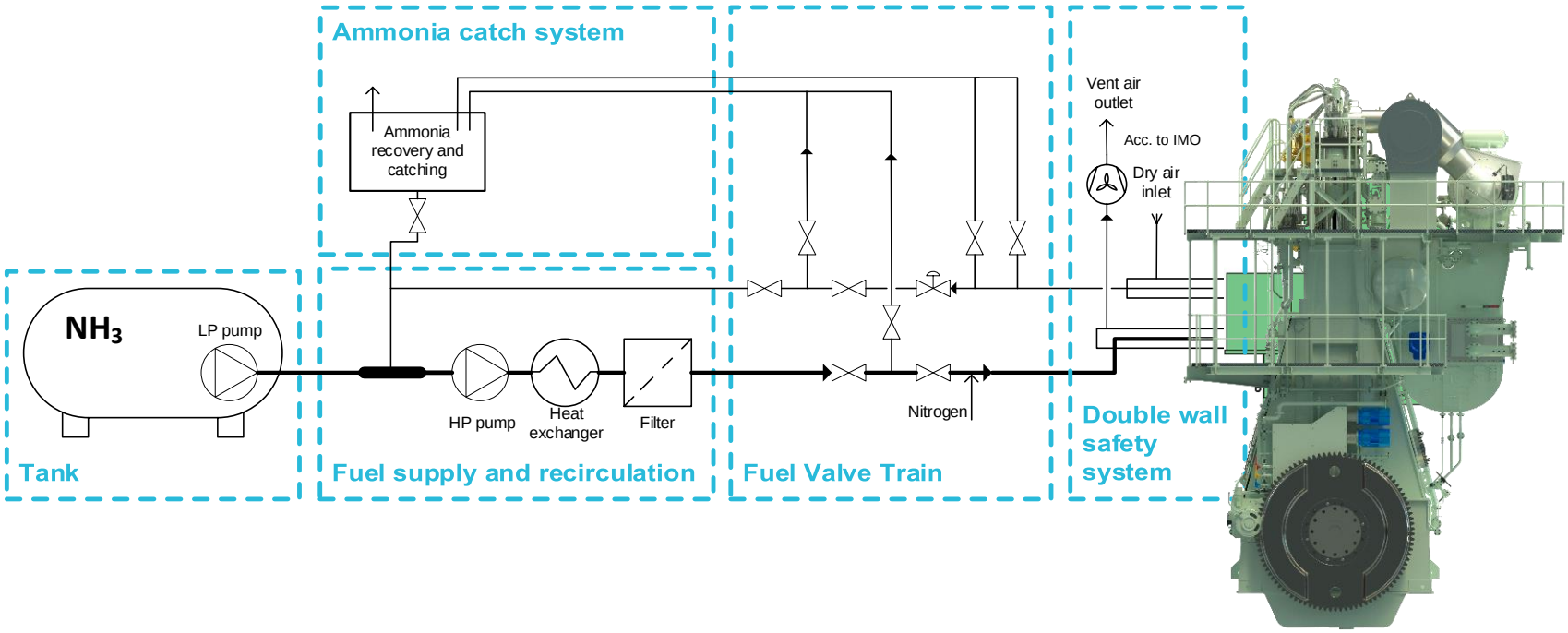
- Unburned NH_3 and NO_x is removed in the SCR reactor.
- Dosing of additional ammonia to SCR reaction if needed.
- Known SCR technology is suitable. MAN SCR reactor can be applied.
- Engine designed for both fuel oil and NH_3 as fuel.



MAN SCR

Ammonia engine development

Auxiliary systems



Preliminary FGSS specification available on request.

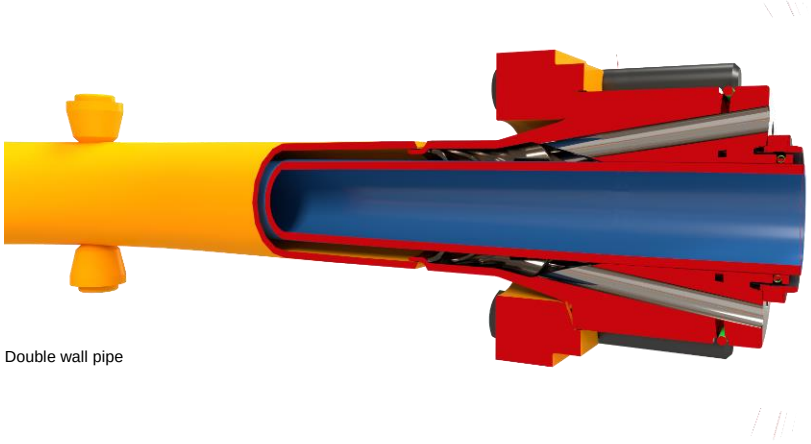
Ammonia engine development

Safety

Safety principle based on well known dual fuel technology

Safe operation ensured by:

- Thorough risk assessment and identification of hazardous zones on the vessel.
- Double walled fuel pipes with supervision of pipe integrity.
- Leakage detection principles from well known dual fuel technology.
- Purging media is N_2.
- Ammonia catch system for purging.



Double wall pipe

Ammonia engine development

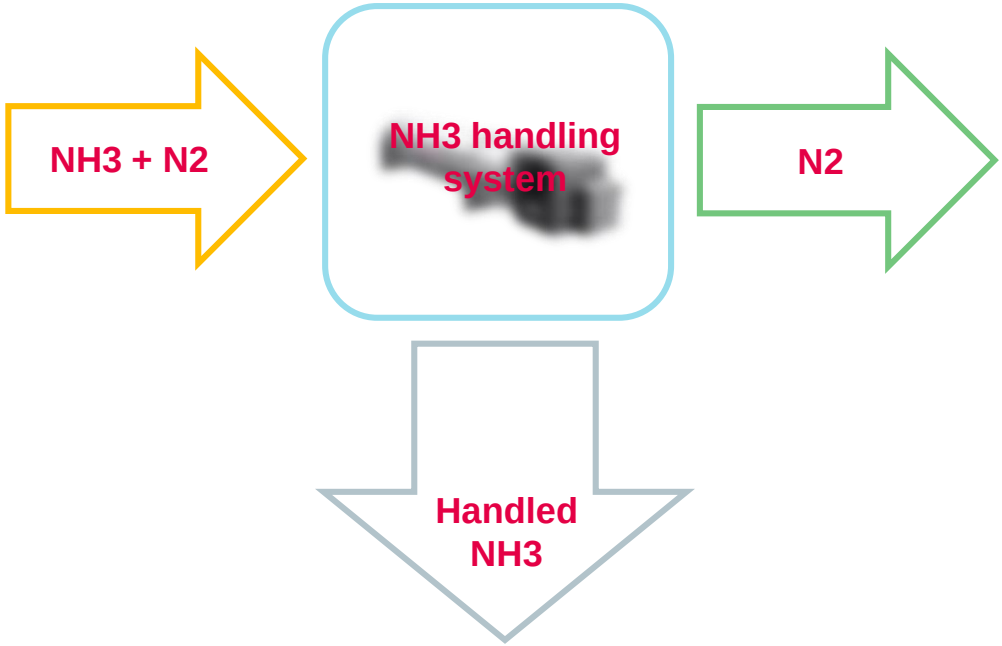
Ammonia catch system

Requirements

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

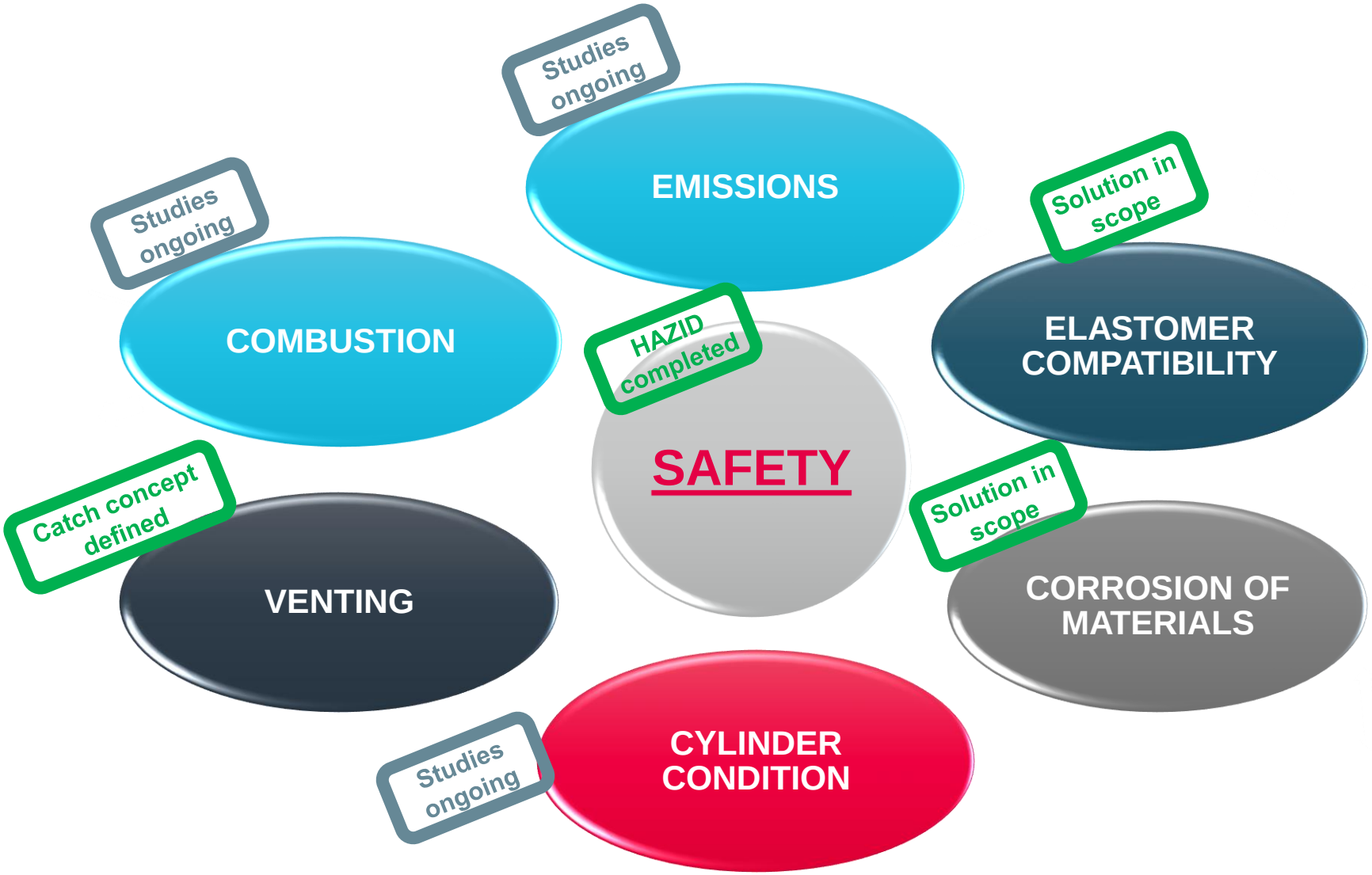
Status

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



Ammonia engine development

Main focus areas in the development



Ammonia engine development

Emissions and pilot fuel concept

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.
- SO_x and particulate matters reduced significantly.

We are targeting a pilot oil energy fraction of approximately 5%

3 Future-proof propulsion

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	MC	ME-B	ME-C	ME-GI	ME-GA	ME-GIE	ME-LGIM	ME-LGIP
0-0.50% S VLSFO	Design	Design	Design	Design	Design	Design	Design	Design
HFO	Design	Design	Design	Design	Design	Design	Design	Design
Biofuels	Design	Design	Design	Design	Design	Design	Design	Design
LNG	-	-	Retrofit	Design	Design	Retrofit	Retrofit	Retrofit
LEG (Ethane)	-	-	Retrofit	Retrofit	-	Design	Retrofit	Retrofit
Methanol / Ethanol	-	-	Retrofit	Retrofit	-	Retrofit	Design	Retrofit
LPG	-	-	Retrofit	Retrofit	-	Retrofit	Retrofit	Design
Ammonia	-	-	Retrofit	Retrofit	-	Retrofit	Retrofit	Retrofit

Solutions for retrofitting to alternative fuels
- Now adding Ammonia (NH3)

Future-proof engine technology.

MAN B&W ME-C engines are future-proof and can be retrofitted to use LNG, LPG, Ethane, Methanol and Ammonia as fuel.

Proven track record of engine conversions.

In Service

– ME-GIE: 1

– ME-GI: 3

– ME-LGIP: 12

In process and on order

– ME-LGIP: 3

*Pictures courtesy of BW Gas. 15 VLGCs will be retrofitted to LPG propulsion with MAN B&W engines.

References

LR awards AiP to ammonia-fuelled 23,000 TEU ultra-large container ship.

MAN Energy Solutions

Press release
Copenhagen, 21.10.2020

MAN Energy Solutions to Lead Danish Consortium Developing Ammonia-Fuelled Engine for Maritime Sector

Industry leaders join forces on ammonia-fuelled tanker project.

Trafigura to Co-Sponsor Development of MAN Energy Solutions Ammonia Engine

Multinational commodity-trading company lends support to green initiative

OCI

Press Release

Amsterdam, The Netherlands / 5 March 2021

OCI N.V. Enters into Agreements with MAN Energy Solutions, Hartmann Group and Eastern Pacific Shipping to Create Marine Value Chain and Start Commercialization by 2023/24 of Ammonia and Methanol as the Shipping Fuels of the Future

Hyundai Mipo Dockyard wins LR approval for ammonia-powered ship

VESSELS

July 24, 2020, by Jasmina Ovcina

MAN Energy joins forces with Imabari-led team to develop ammonia-powered ships

MAN Energy Solutions
Future in the making

Muchas gracias!

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