MAN Energy Solutions
Future in the making

2-stroke propulsion carbon free fuels

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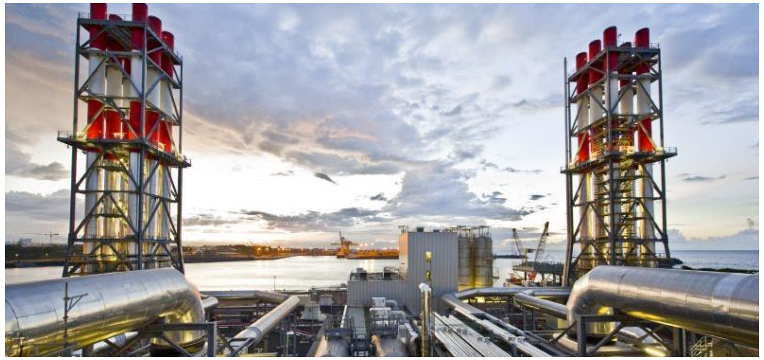
MAN Energy Solution strategic business areas

Engines & Marine Systems

Power Plants

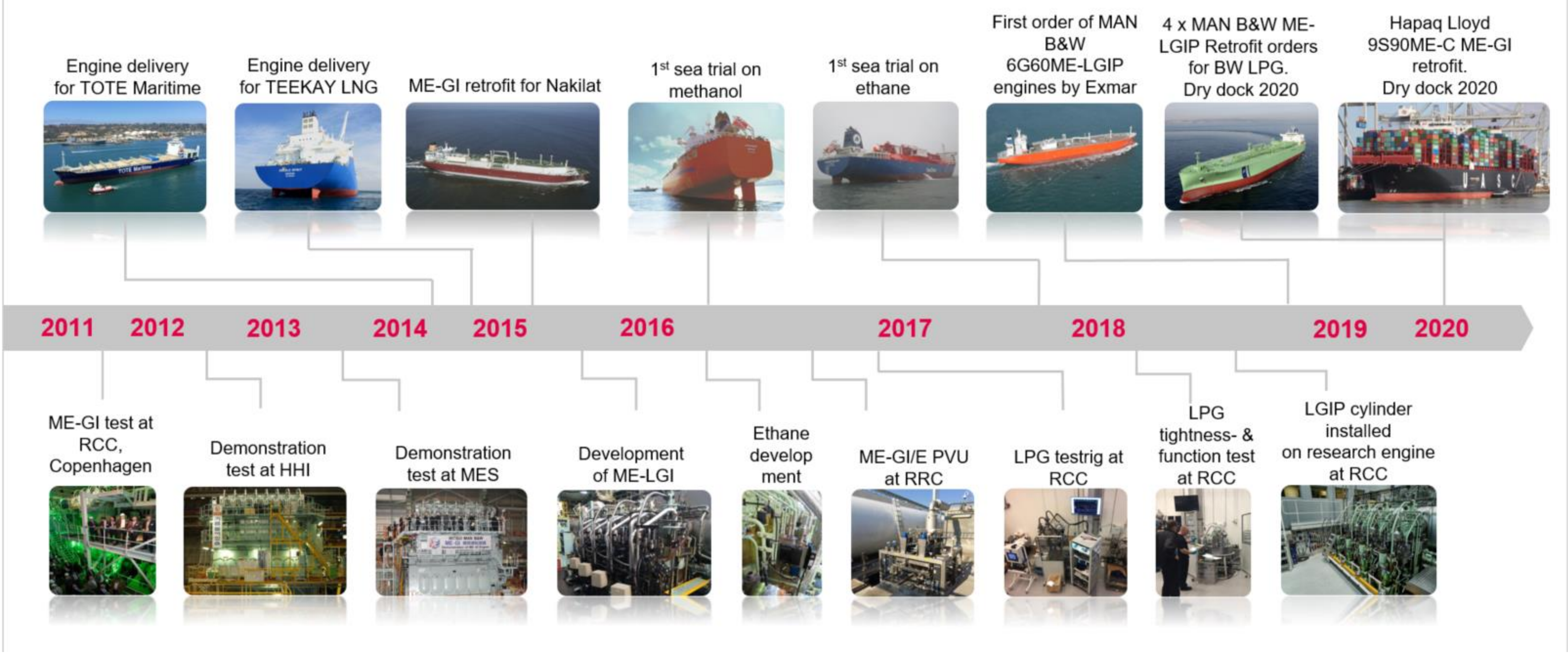


Turbomachinery

Aftersales MAN PrimeServ

MAN B&W dual fuel technology

Timeline



Marine decarbonization

CO_2 from 300 mill ton fuel oil per year!

Short term propulsion solutions :

- Lower ship speed
- New fuels with lower GHG emisson will be needed to meet EEDI
- To increase the efficiency; solutions like PTO, WHR will be more common

Long term propulsion solutions:

- Two-stroke engines will remain as the most dominating propulsion solution
- Carbon- free produced methanol, ammonia, LNG and biofuels will be available
- All above fuel types can be burned in the two-stroke ME-C, ME-GI or ME-LGI engine
- Engine efficiency above 50% (60% incl. WHR & PTO)

Development of an ammonia-fuelled ME-LGI engine:

- It is established that ammonia works in an internal combustion engine
- Engine development will be completed according to market demands

New 2-stroke propulsion technologies and outlook to future challenges

Agenda

Green Ammonia as a fuel in shipping
- Why?
- How?
- Challenges?

How - The MAN B&W ME-LGI injection equipment concept
- Possible adaption to Ammonia
- Retrofit prospect

EEDI requirements alternative fuel as a possible solution
- Ammonia in this context

Green Ammonia as a fuel in shipping

Why

Renewables

Batteries?

Hydrogen

Methanol

Syn-LNG

Ammonia

Syn-Crude

Green Ammonia as a fuel in shipping

Why

- NH_3 has the obvious advantage of not containing any carbon that will lead to CO_2 emission. Common for all other power to x medias (except Hydrogen) is that they will require Carbon in some form. Meaning CO2 will be a commercial commodity as well

- Ammonia is suitable for fuel in an internal combustion engine with high efficiency

- Storage, transportation and bunkering of Ammonia is uncomplicated compared to Hydrogen

Alternative fuels

Properties and practicalities

Energy storage type	Specific Energy MJ…	Energy Density…	Required Tank Volume m3.[1]	Supply pressure…	Injection pressure bar	Emission Reduction Compared To HFO Tier II			
						SO_x	NO_x	CO2	PM
HFO	4(				950				
Liquefied natural gas (LNG -162 °C)	5				300 METHANE	90-99%	20-30%	24%	90%
					380 ETHANE	90-97%	30-50%	15%	90%
LPG (including Propane / Butane)	4				600-700	90-100%	10-15%	13-18%	90%
Methanol	1(				500	90-97%	30-50%	5%	90%
Ethanol	2				500				
Ammonia (liquid -33 °C)	18				600-700	100%	Compliant with regulation	>95%	>90%
Hydrogen (liquid -253 °C)	1								
Marine battery market leader, Corvus, battery rack	0,								
Tesla model 3 battery Cell 2170*. [2]	0,8	2.5	14000						

Energy storage type	Estimated PtX efficiency
Liquefied natural gas (LNG -162 °C)	0,56
LPG (including Propane / Butane)	
Methanol	0,54
Ethanol	
Ammonia* (liquid -33 °C)	0,60
Hydrogen (liquid -253 °C)	0,68

- *1: Given a 1000 m^3 tank for HFO. Additional space for insulation is not calculated for in above diagram. All pressure values given a high pressure Diesel injection principle.*
- *2: Values for Tesla battery doesn't contain energy/mass obtained for cooling/safety/classification . https://insideevs.com/tesla-model-3-2170-energy-density-compared-bolt-p100d/*

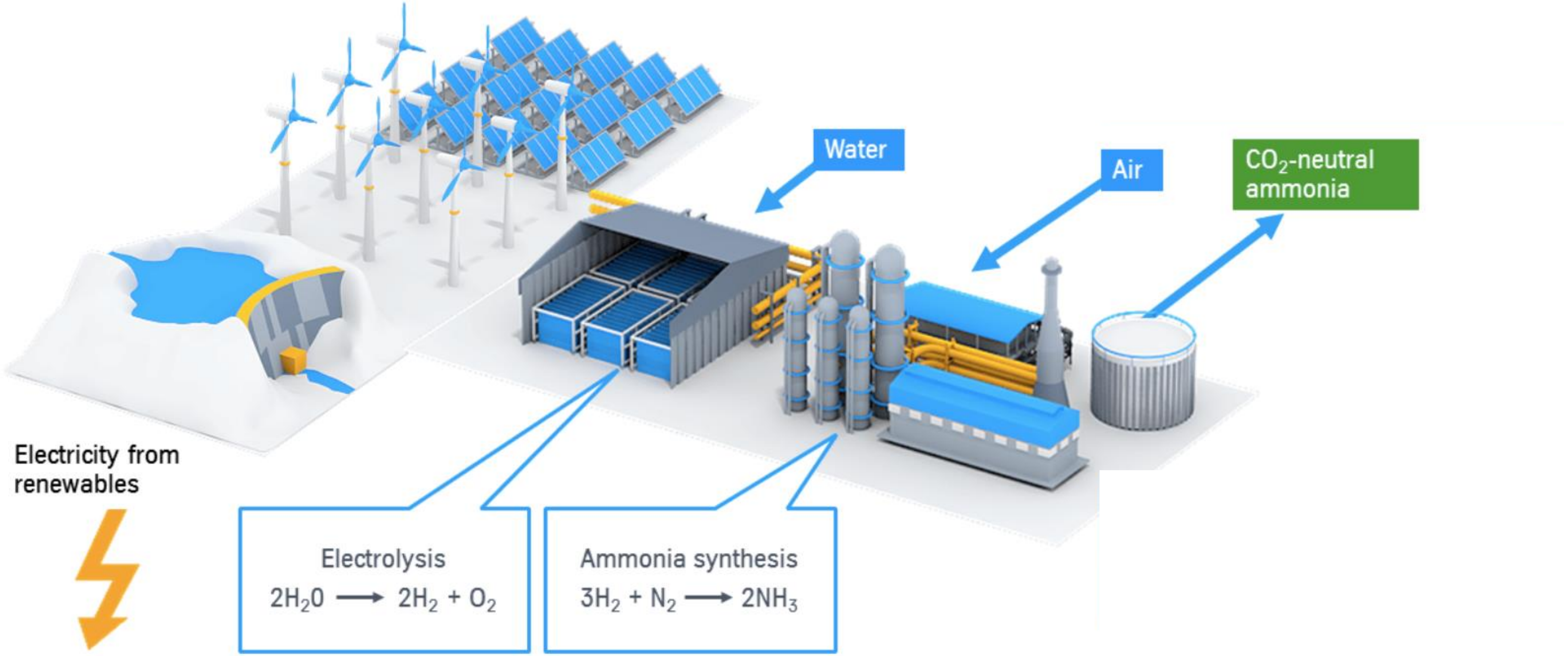
Green Ammonia as a fuel in shipping

How

- **Renewable energy**
- **Electrolysis**
- **Haber-Bosch process**
- **2-stroke engine with directly coupled propeller**

ThyssenKrupp ammonia plant using renewable energy

How



Green Ammonia as a fuel in shipping

Main challenges

- Current production
  The majority of the Ammonia today is being produced on a large scale by steam reforming of fossil fuels (mainly natural gas) and utilizing the Harber-Bosch process to form Ammonia.
  This is process has a efficiency of around 50% (kJ to kJ), considering the input of from fossil fuels the largest part of todays ammonia production is labelled as “grey”

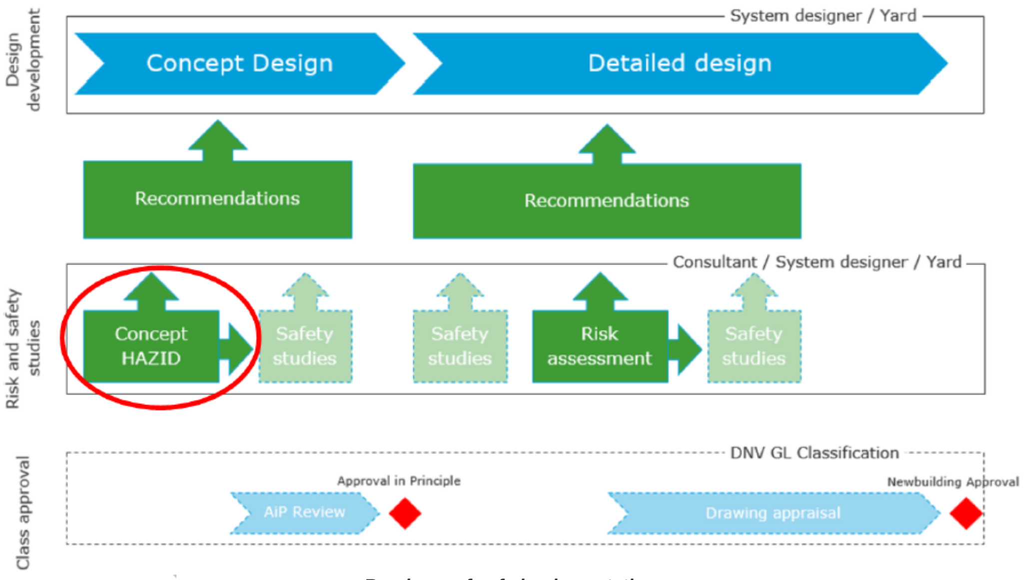
- Infrastructure
  The obvious first movers for ammonia as marine would be ammonia carrying ships, this would be an excellent intermediate step to showcase and mature the technology to motivate further investment into green-ammonia infrastructure

- Handling
  Ammonia is toxic and it is corrosive but it is already well known in the industry, both as coolant, as cargo and as fertilizer.

Ammonia as fuel
- A summary of HAZID study

Background, Scope and Objectives

- Navigator Gas, MAN, Babcock LGE and DNVGL are conducting a joint industry project (JIP) to evaluate the application of ammonia as fuel for ships
- A two-day HAZID workshop was conducted with the relevant parties including Norwegian flag to evaluate the ammonia's fuel system's ability to operate a ship safely and reliable and to identify any potential major hazards or showstoppers
- The concept HAZID follows the roadmap for safe implementation, as part of the risk and safety studies of the conceptual design phase



Roadmap of safe implementation

Approach and Highlights

- The risk ranking was a quantitative assessment by the HAZID team ranking the likelihood of occurrence and their respective consequences. The risk matrix definition and risk acceptance criteria were defined following the DNV GL Recommended Practice for Technology Qualification

		Likelihood				
		1	2	3	4	5
Severity	1	L	L	L	M	M
	2	L	L	M	M	M
	3	L	M	M	M	H
	4	M	M	M	H	H
	5	M	M	H	H	H

Risk Matrix

- Twenty five events were identified during the workshop, giving a total number of 13 recommendations. These recommendations were all assigned to one or more responsible parties - operator, fuel system designer or engine designer, in addition to the yard which was not part of this workshop
- One consequence was rated with high risk. Four consequences were rated with medium risk and six consequences were rated low risk
- Some of the items ranked as high or medium risk was not necessarily considered to pose as significant risks to safety provided the correct safety measures are implemented. However, as this is a new concept and still in early stages of the design, some aspects of the design has yet to be decided

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Testing of novel fuels

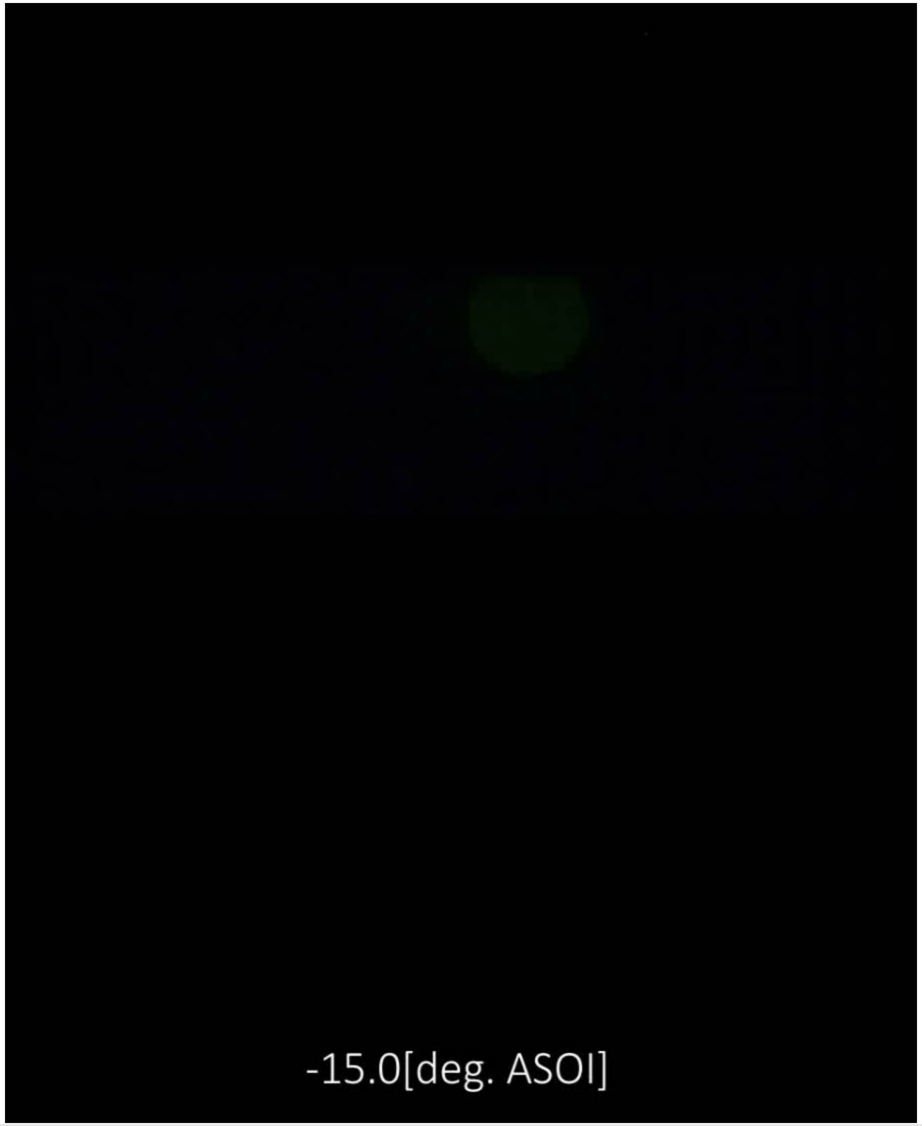
Prof. Takasaki, Kyushu University

Marine gas oil

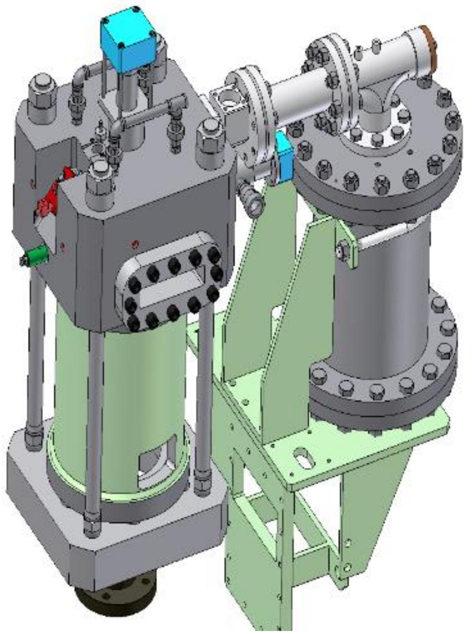
Methanol

Methane

Ethane



KYUSHU UNIVERSITY



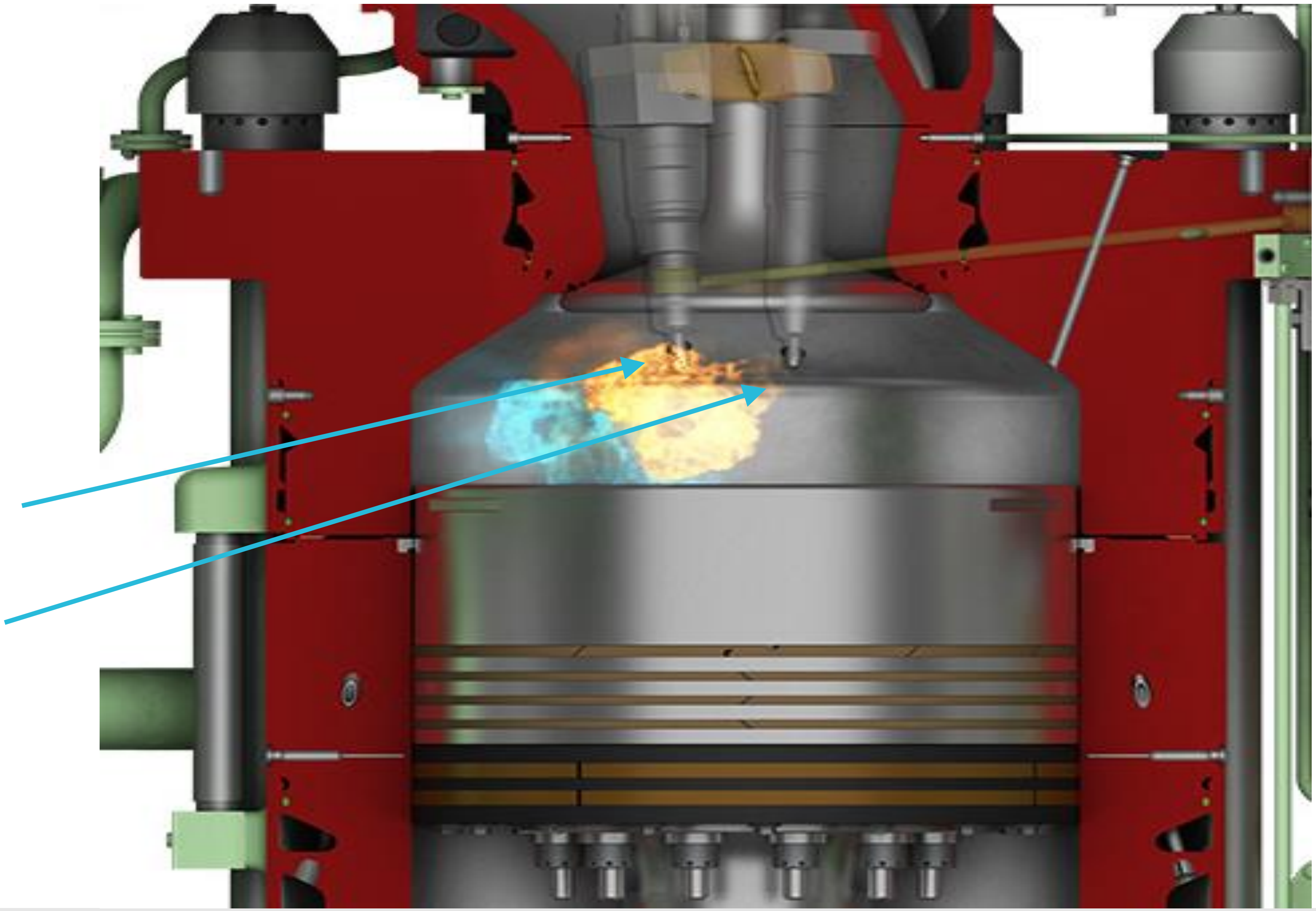
Kyushu RCEM

- Supercharged condition by two-stage compression
- Optical access
- Multi-fuel injector

Takasaki et al. CIMAC 2016

ME-GI/LGI Combustion Principle

- The ME-GI/LGI engine is a dual fuel engine
- Diesel combustion process →
- High efficiency

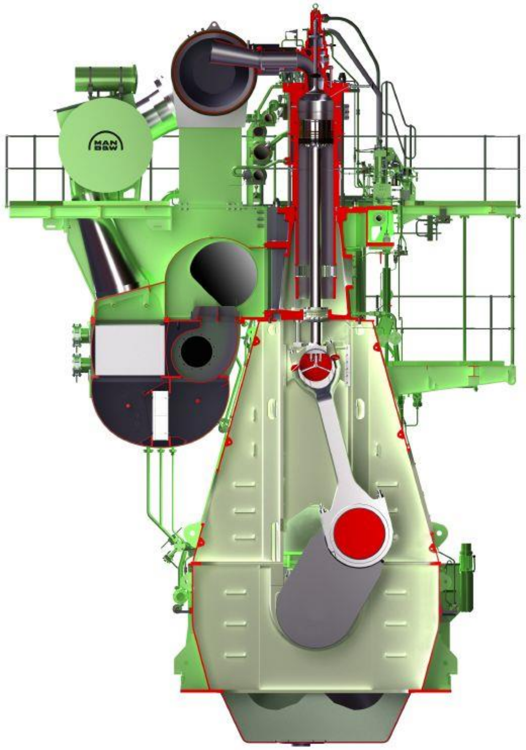


The MAN B&W ME-LGIP Engine

Possible adaption to Ammonia

Ammonia is difficult to combust, but..

- The large combustion chamber of a 2-stroke crosshead diesel gives us a significant advantage when it comes to slow burning fuel
- The stroke and low speed of the engines works to our advantage as well



In our 2-stroke engine we can ignite a mixture of oil and water at a 1/5 ratio!
The combustion properties of ammonia are not expected to be a problem.

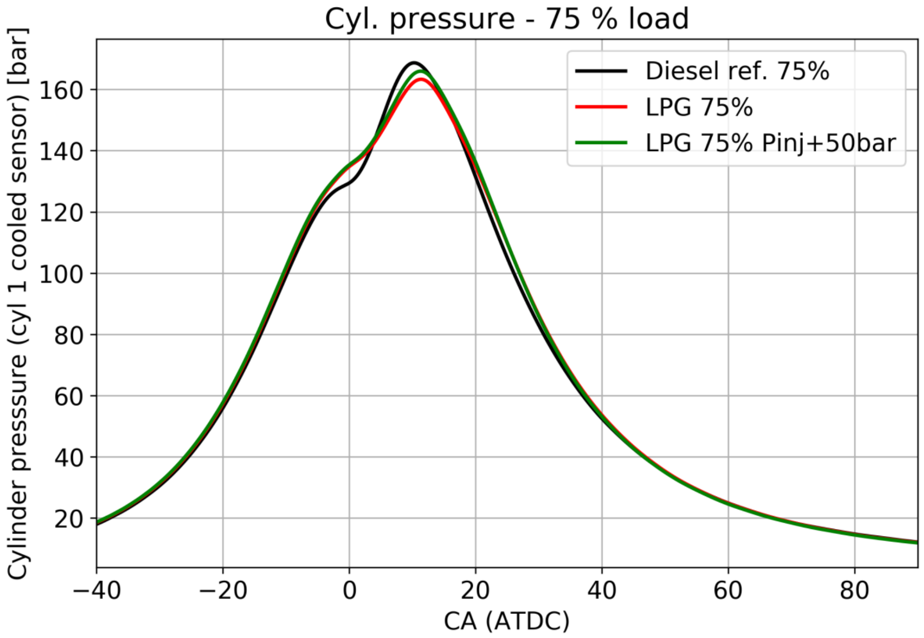
ME-LGIP Retrofit

Performance

Performance Comparison for ME-C vs. ME-LGIP

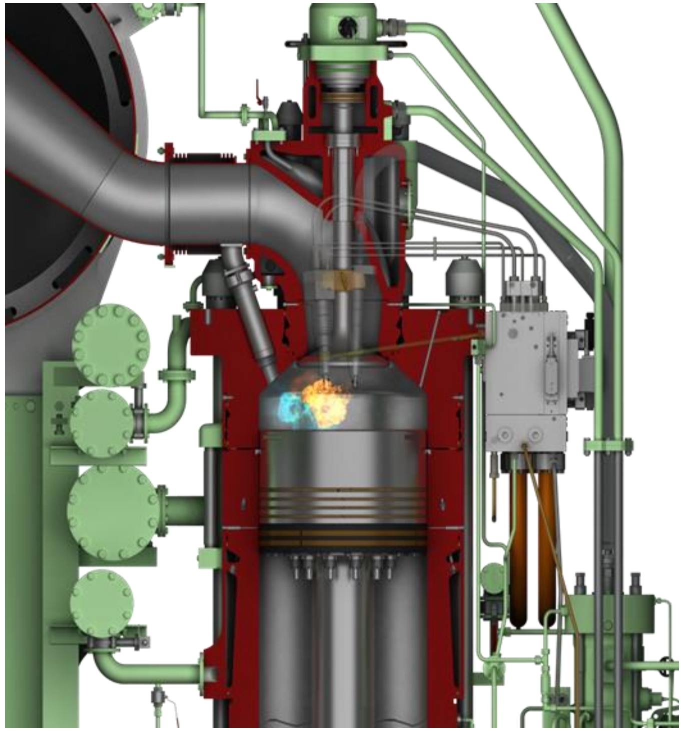
– **Same Engine Performance**

– **Confirms similar Engine Efficiency on gas after conversion**



Yellow = Pilot/Fuel Oil

Blue = Gas



ME-LGIP Retrofit

Conversion Timeline

Timeline

– **Parent Engine Test Available**

  – Order should be placed 14 months before 1st docking date. Different steps in the timeline will overlap

Engineering
- 6 months
  Pending on final scope

Production & Transportation
- 9 months

Conversion/installation
- 1-2 months

Sea & Gas Trial
- ¾ months

– **Parent Engine Test not Available**

  – Order should be placed 18 months before 1st docking date

Engineering
- 6-11 months
  Pending on final scope

Production & Transportation
- 9 months

Parent Engine Test
- 3½ months

Conversion/installation
- 1-2 months

Sea & Gas Trial
- ¾ months

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IMO resolution MEPC.304(72)

Initial IMO strategy on reduction of GHG emissions from ships

Level of ambition

Carbon intensity of ship to decline

– Strengthening of EEDI requirements for new ships

Carbon intensity of shipping to decline

– 40% reduction p

– 70% reduction p

GHG emission from shipping to decline

– 50% reduction of GHG emissions by 2050 relative to 2008

Timelines*

Short-term measures: 2018–2023

– EEDI improvement (Energy Efficieny Design Index)

– SEEMP improvement (Ship Energy Efficiency Management Plan)

– Speed regulation

mpounds)

– Low-carbon/zero carbon fuels introduction

– Operational energy efficiency requirements

– Market-based measures

Long-term measures: > 2050

– Zero carbon/fossil-free fuels for 2050 and later

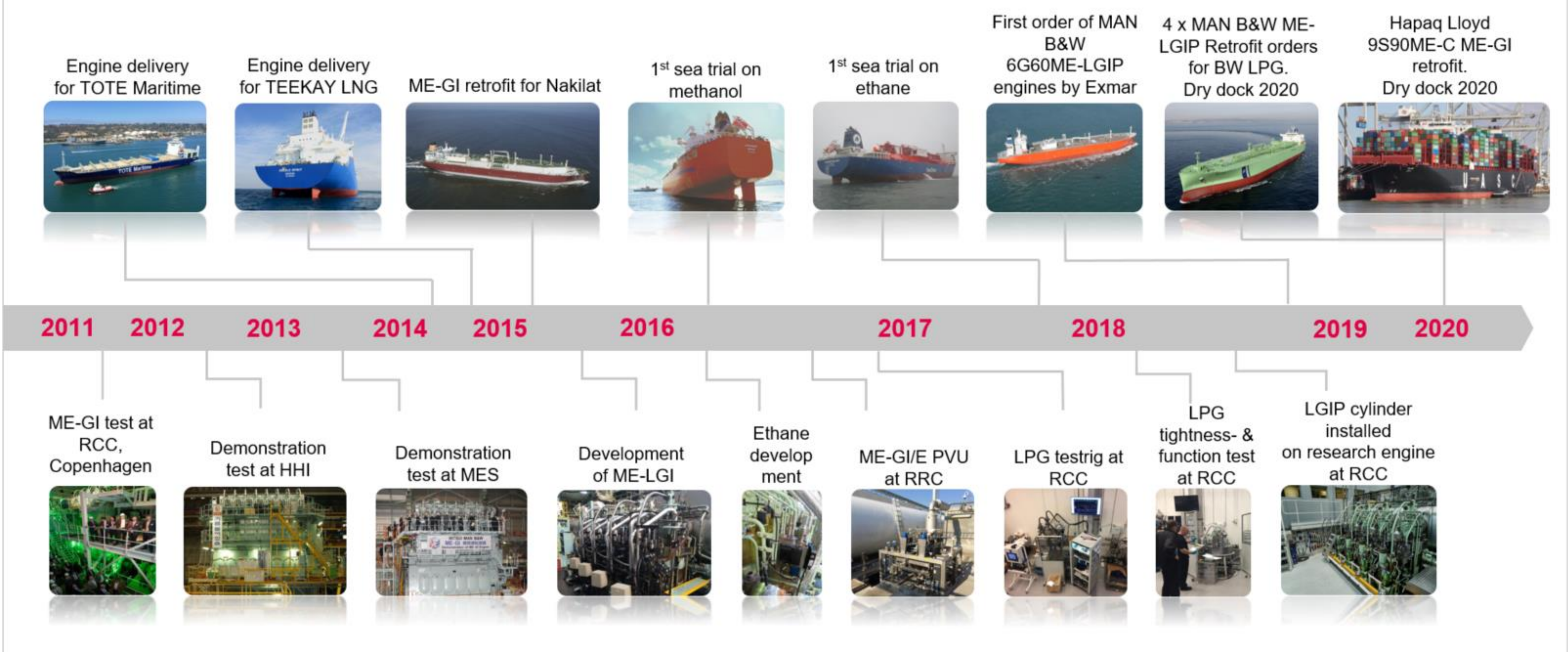
Long-term measures: > 2050

– Zero carbon/fossil-free fuels for 2050 and later

* Selected measures

MAN B&W dual fuel technology

Timeline



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