MAN Energy Solutions
Future in the making

Ammonia = Hydrogen 2.0

Conference in Melbourne 22 - 23 August 2019

Lars Bryndum
22nd Aug 2019

MAN Energy Solutions

Agenda:

1 MAN Energy Solutions

2 Two-stroke marine dual fuel engines

3 Ammonia as fuel and cargo

4 Market drivers

The history of MAN Energy Solutions

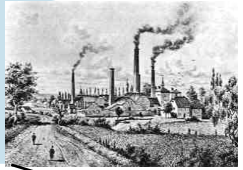
History of mergers and acquisitions in heavy industries.

1758: St. Antony Eisenwerke, Oberhausen

1840: Sandersche Masch.fabrik Augsburg

1841: Eisengießerei u. Masch. fabrik Klett & Comp. Nürnberg

1873: Börsengang der Gutehoffnungshütte (GHH)



1908: M.A.N. Masch.fabrik Augsburg-Nürnberg

1865: Burmeister and Wain is founded

1921: GHH acquires majority share of M.A.N.

1980: M.A.N. acquires Burmeister and Wain Diesel A/S

1986: M.A.N. merges with GHH, renamed MAN AG

2007: Volkswagen AG becomes main shareholder of MAN AG

2011: MAN becomes part of the Volkswagen Group

2018: MAN Energy Solutions leaves MAN and becomes a subsidiry of VW

Member of the Volkswagen group

MAN Energy Solutions is part of a brand family

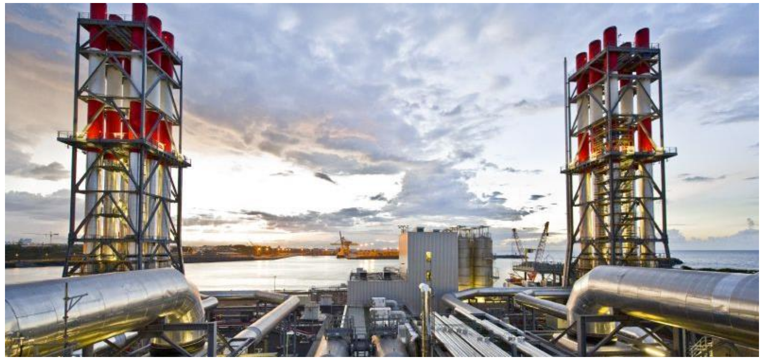
Automotive Division			Financial Services Division
Passenger Cars Business Area	**Commercial Vehicles Business Area**	**Power Engineering Business Area**	
VW	VWN (Nutzfahrzeuge)	MAN Energy Solutions	Dealer and customer financing
Audi	Scania	Renk	Leasing
Skoda	MAN Truck & Bus		Direct bank
Seat			Insurance
Bentley			Fleet management
Porsche			Mobility offerings
Others			

MAN Energy Solutions - strategic business areas

2018 key figures

Engines & Marine Systems

Power Plants



Turbomachinery

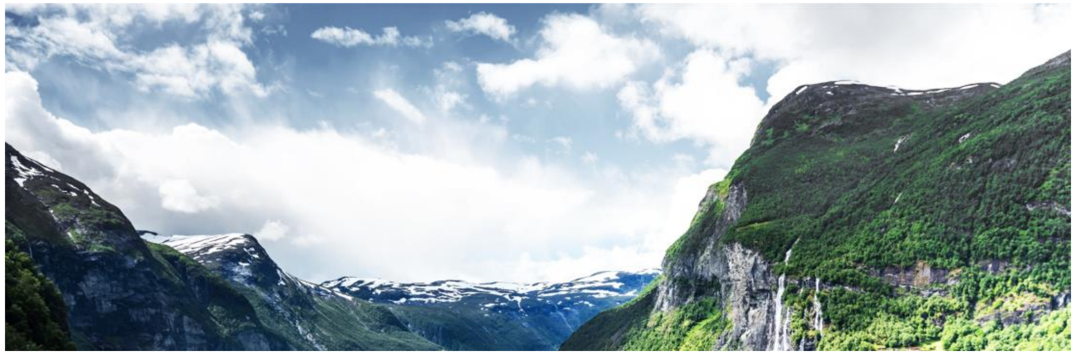
Aftersales MAN PrimeServ

14,727 employees worldwide

3.1 bn € revenue

MAN Energy Solutions

New Name New Strategies



Decarbonization

calls for new technologies

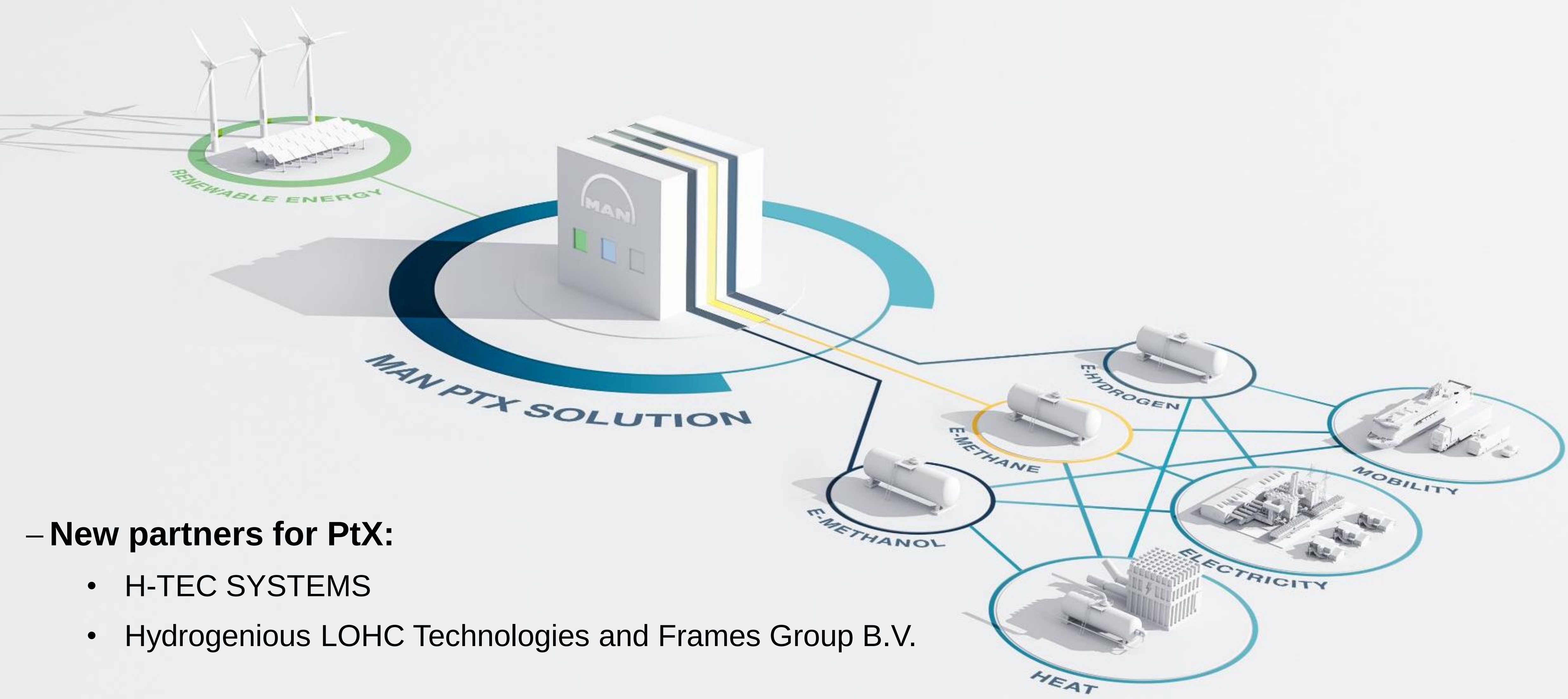
- Limit global warming to below 2° Celsius
- Carbon neutrality until 2050

Digitalization

makes entirely new business models possible

- Intelligent software embedded in every device
- Data analytics enable unprecedented insights

MAN Power-to-X (PtX)



– **New partners for PtX:**
  - H-TEC SYSTEMS
  - Hydrogenious LOHC Technologies and Frames Group B.V.

MAN B&W 2-stroke engines

– **prime mover for marine propulsion output: 3 to 82 MW**

– **prime mover for power generation   output: 13 to 67 MW**

- High Fuel Flexibility
  (Biofuel, LNG, LPG,…Ammonia(?))
- High efficiency (>51%)
- High reliability
- High capacity factor (~90%)
- Long technical lifetime (up to 40 years)
- Low maintenance costs
  (0.66 €/MWh)

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 per transport work by 2030 relative to 2008
- 70% reduction per transport work by 2050 relative to 2008

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
- Methane slip regulation
- VOC regulation (Volatile Organic Compounds)

Mid-term measures: 2023–2030

- Low-carbon/zero carbon fuels introduction
- Operational energy efficiency requirements
- Market-based measures

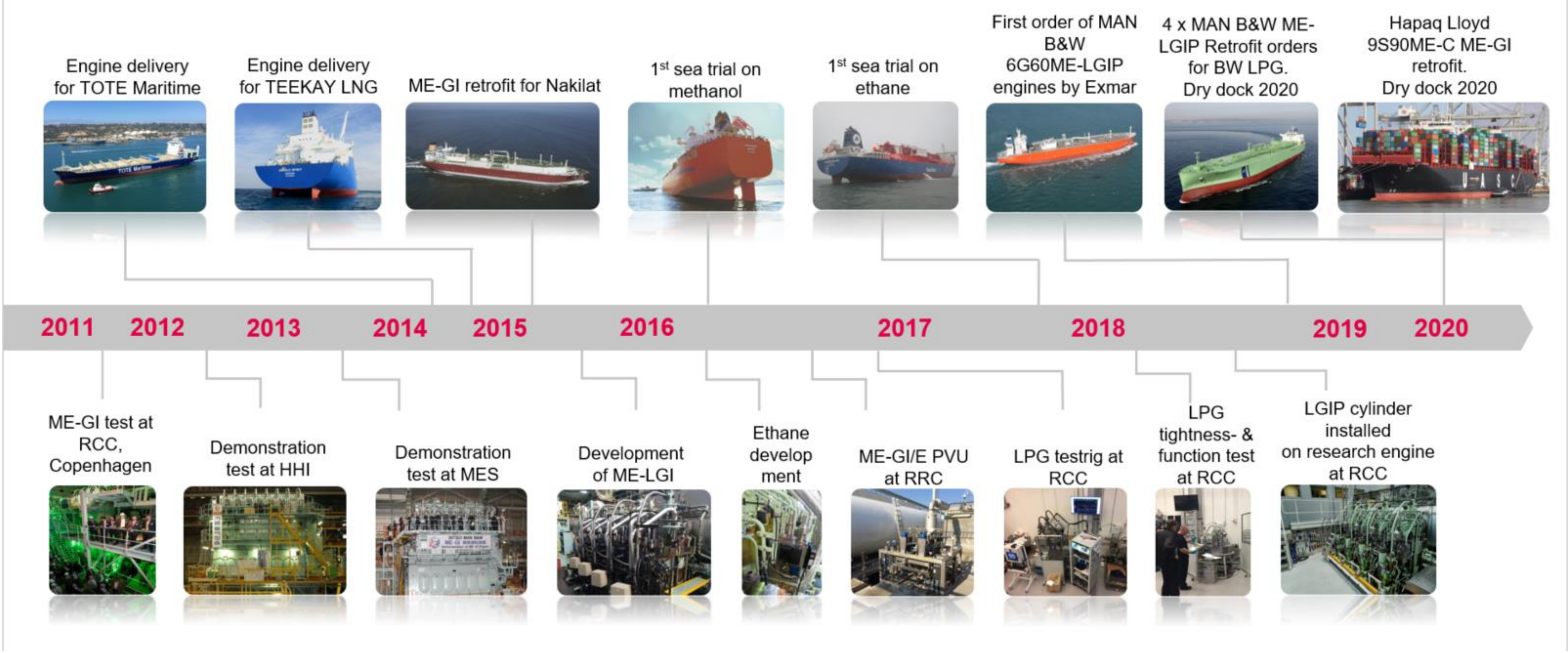
Long-term measures: > 2050

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

* Selected measures

MAN B&W Two-stroke – multifuel engines

Historical timeline



Orders including options

No. of engines	Engine type			Mk.	Gensets
5	S	90	ME-C-GI	10.5	
8	G	90	ME-C-GI	9.5, 10.5	
4	S	80	ME-C-GI	9.5	
6	S	70	ME-C-GI	7, 8.2, 10.5	6 x 9L28/32 DF
160	G	70	ME-C-GI	9.2, 9.5, 10.5	8 x 7L35/44 DF
5	L	70	ME-C-GI	8.2	15 x 9L28/32 DF
2	S	60	ME-C-GI	10.5	
8	S	50	ME-C-GI	8.2, 9.5	
5	G	50	ME-C-GI	9.5	8 x 7L28/32 DF / 4 x 5L28/32 DF
4	G	45	ME-C-GI	9.5	4 X 5L23/30 DF / 8 x 8L23/30 DF
11	G	50	ME-B/ME-C –LGIM	9.3, 9.5, 10.5	
3	S	50	ME-B-LGIM	9.3	
17	G	60	ME-C-GIE	9.5	
3	G	50	ME-C-GIE	9.5	
16	G	60	ME-C-LGIP	10.5, 9.2	
1	S	60	ME-C-LGIP	10.5	

Total dual fuel engines including options **258 engines**

Total power main engine **5 GW**

Total dual fuel 2-Stroke in service **107 engines**

Accumulated service hours > **500.000 hours**

Methane
Methanol
Ethane
LPG

Ammonia, NH_3 as green fuel produced with renewable energy

Ammonia is the logic option

SIEMENS Gamesa RENEWABLE ENERGY

NH_3 advantages as green fuel:

- No carbon. Clean combustion without CO_2 or carbon
- Can be produced 100% by electrical energy
- Can easily be reformed to H_2 and N_2
- Can be stored with high energy density at < 20 bar
- Low risk of fire. Relatively specific ratio of NH_3 and air (15-25%) is required to sustain combustion
- (Toxic)

Alternative fuels

Properties

Energy storage type	Specific energy MJ/kg	Energy density MJ/L	Required tank volume m³.[1]	Estimated PtX efficiency	Supply pressure bar	Injection pressure bar	Emission reduction compared to HFO Tier II			
HFO	40,5	35	1000		07-aug	950	SO_x	NO_x	CO2	PM
Liquefied natural gas (LNG -162 °C)	50	22	1590	0,56	300 Methane	300 METHANE	90-99%	20-30%	24%	90%
					380 ETHANE	380 ETHANE	90-97%	30-50%	15%	90%
LPG (including Propane / Butane)	42	26	1346		50	600-700	90-100%	10-15%	13-18%	90%
Methanol	19.9	15	2333	0,54	10	500	90-97%	30-50%	5%	90%
Ethanol	26	21	1750		10	500				
Ammonia* (liquid -33 °C)	18,6	12,7	2755	0,65	50?	600-700				
Hydrogen (liquid -253 °C)	120	8.5	4117	0,68						
Marine battery market leader, Corvus, battery rack	0,29	0,33	106.060							
Tesla model 3 battery Cell 2170*.[2]	0,8	2.5	14000							

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

Testing of novel fuels

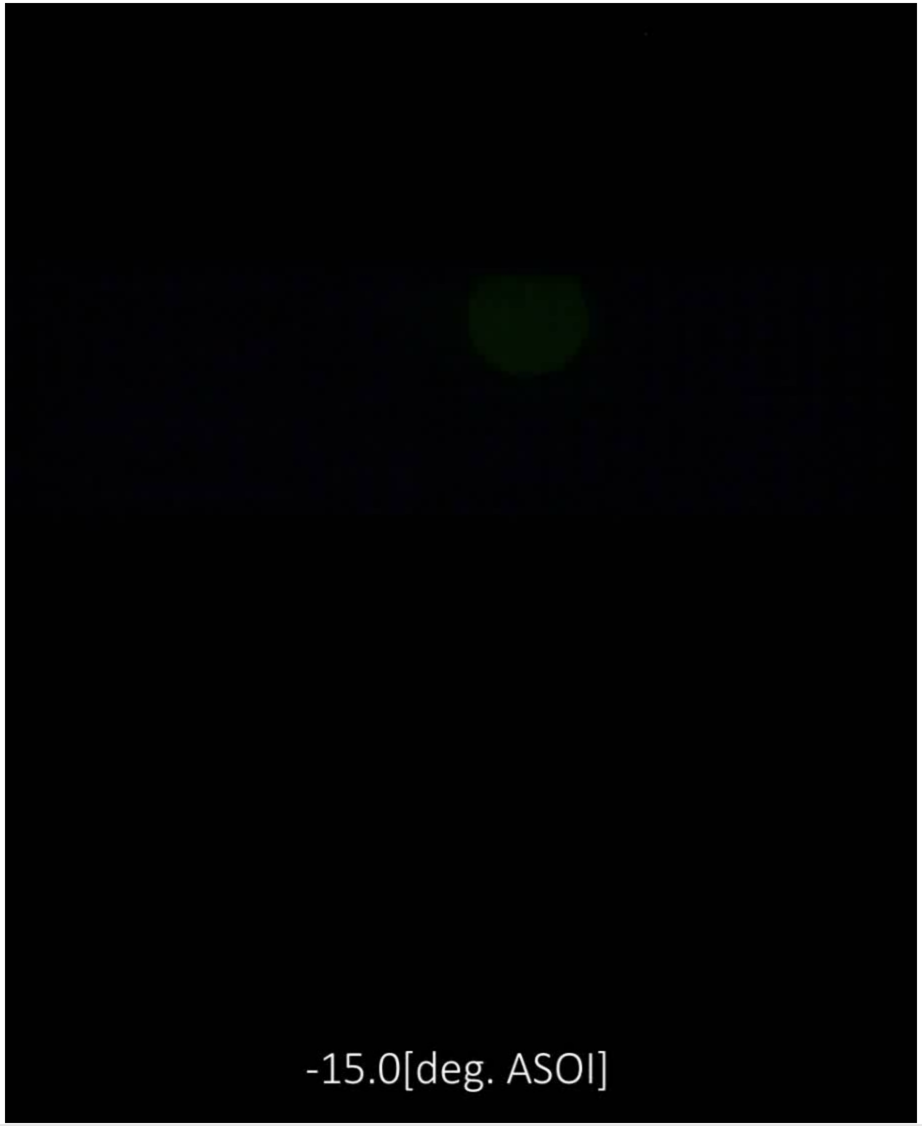
Prof. Takasaki, Kyushu University

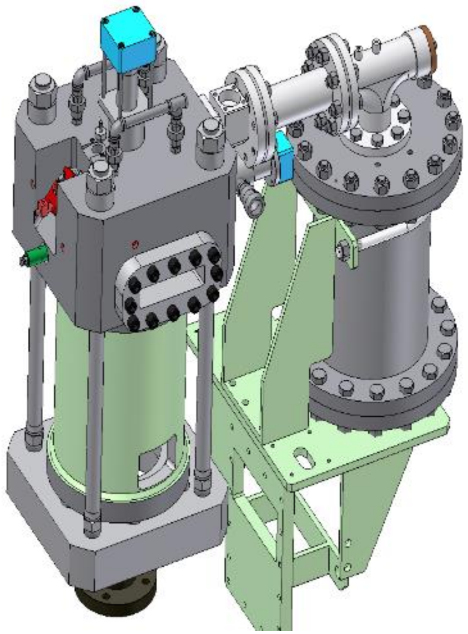
Marine gas oil

Methanol

Methane

Ethane





Kyushu RCEM

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

Takasaki et al. CIMAC 2016

Ammonia as Fuel

DNV·GL

Ammonia has lately been requested as potential fuel source on Gas Carriers.

DNVGL has experience related to Ammonia as cargo, but also as refrigerant.

DNVGL found this possible and doable, however following items must be addressed

- Safety items and fuel need comply with IGC Code requirements. Gas Fuel supply principles follow code principles
- Risk Assessment need to be made to ensure same safety level as methane fuel
- Gas Valve Unit spaces, fuel preparation rooms or other spaces containing equipment with Ammonia where there are enclosed pipes containing ammonia, should comply with requirements in DNVGL rules for Ammonia as refrigerant. Hence DNVGL Rules Pt.4 Ch.6 Sec.6
- As 2016 IGC Code prohibits the use of toxic products as fuel, DNVGL propose that flag acceptance is requested and an amendment proposal of the code is made.

The new MAN B&W ME-LGIP engine

Same system to be used for NH_3

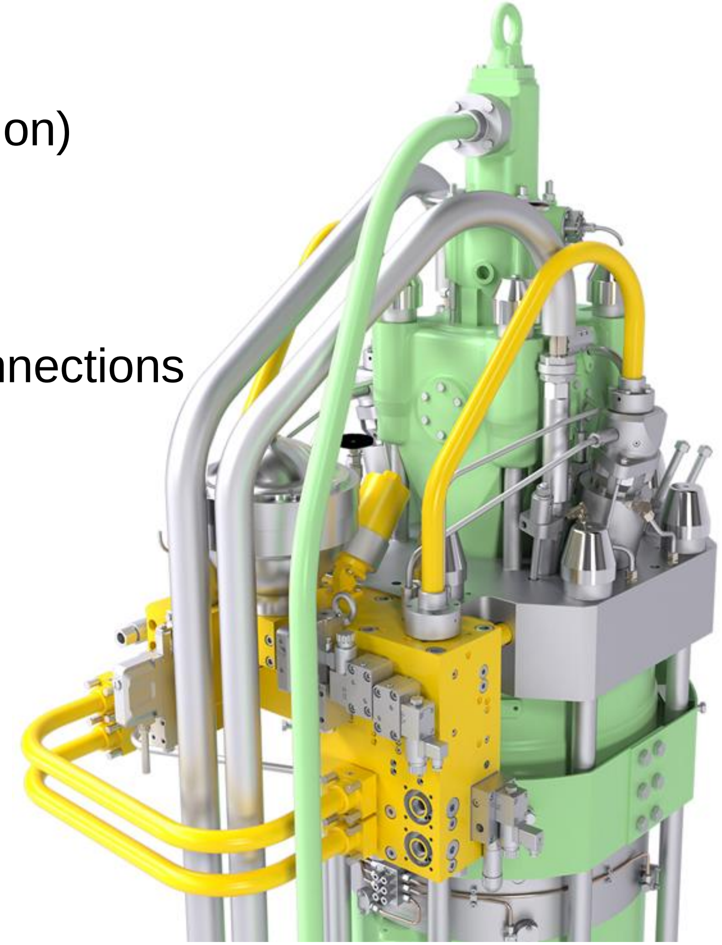
Valve control block:

– ELWI-valve (fuel pressurization)

– ELGI-valve (injection timing)

– Hydraulic accumulator

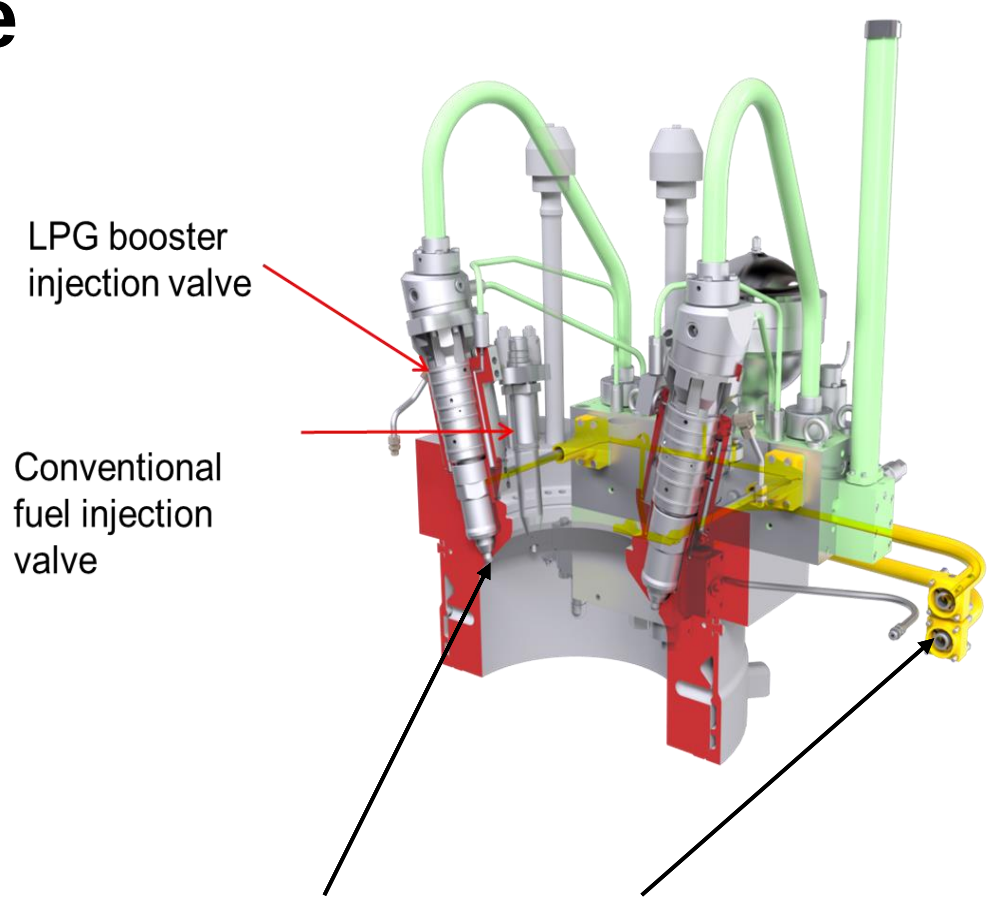
– Hydraulic and sealing oil connections



Double-wall gas piping:

– LPG inlet

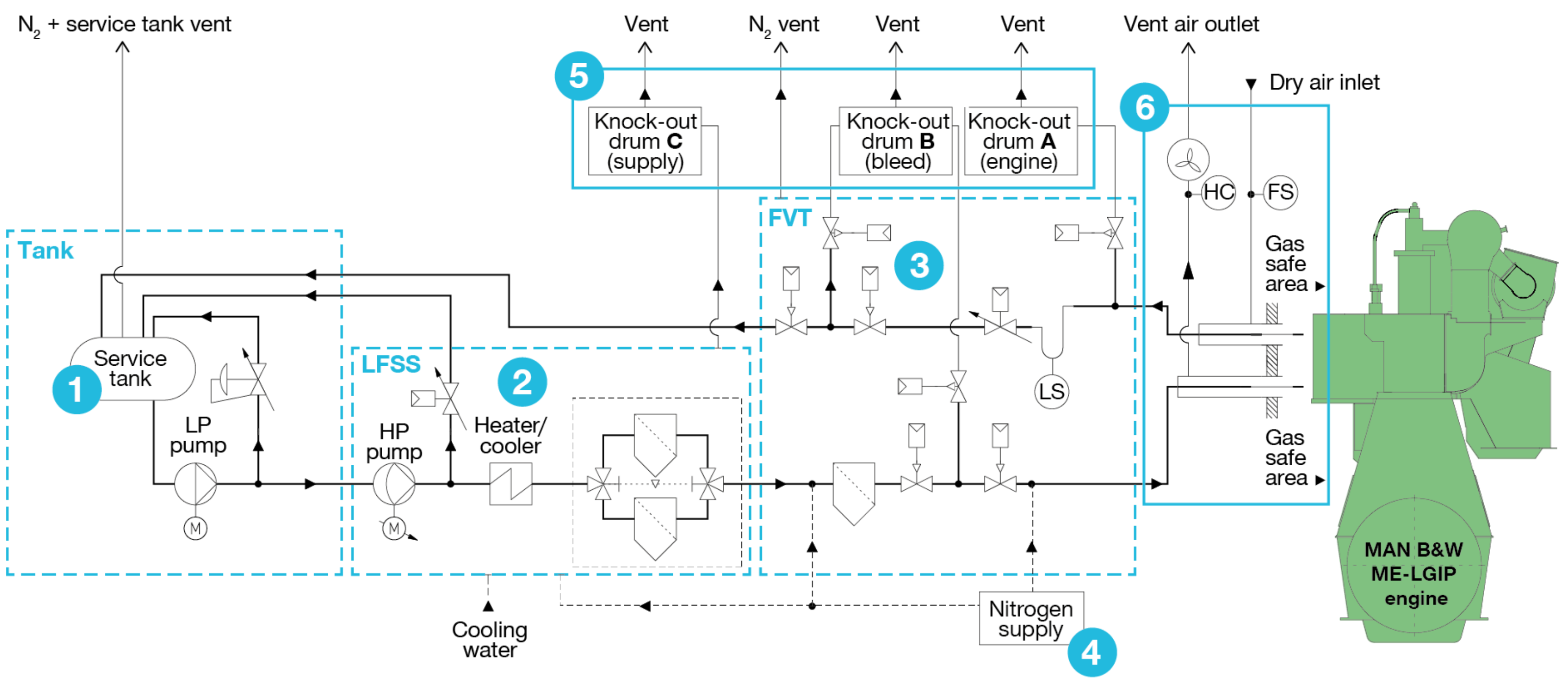
– LPG return

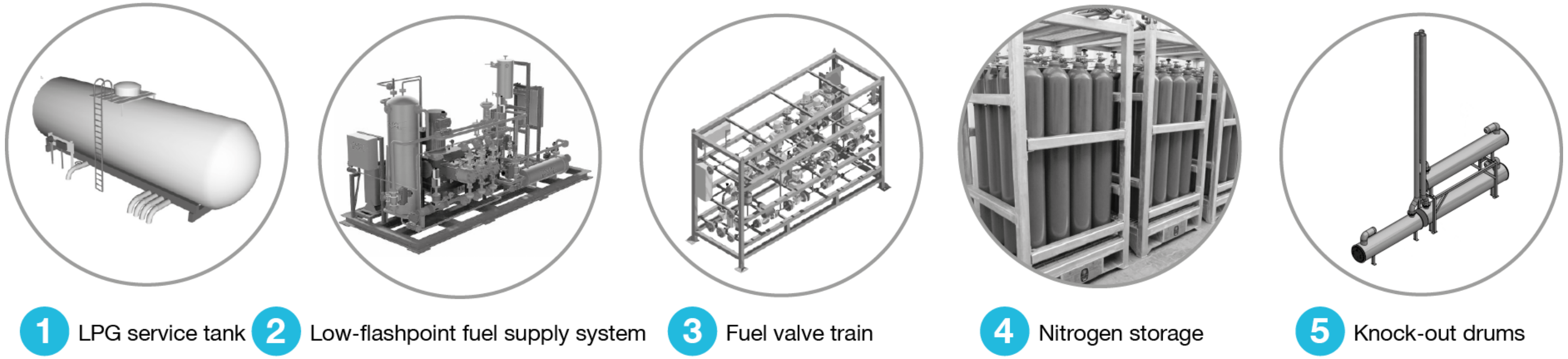


	Injection pressure	Supply pressure	
	bar		
ME-GI	200-380	200-380	Common rail
ME-LGI	600-800	8-50	Pressure booster valve

The MAN B&W ME-LGIP engine

This engine type can be modified to burn ammonia as well.





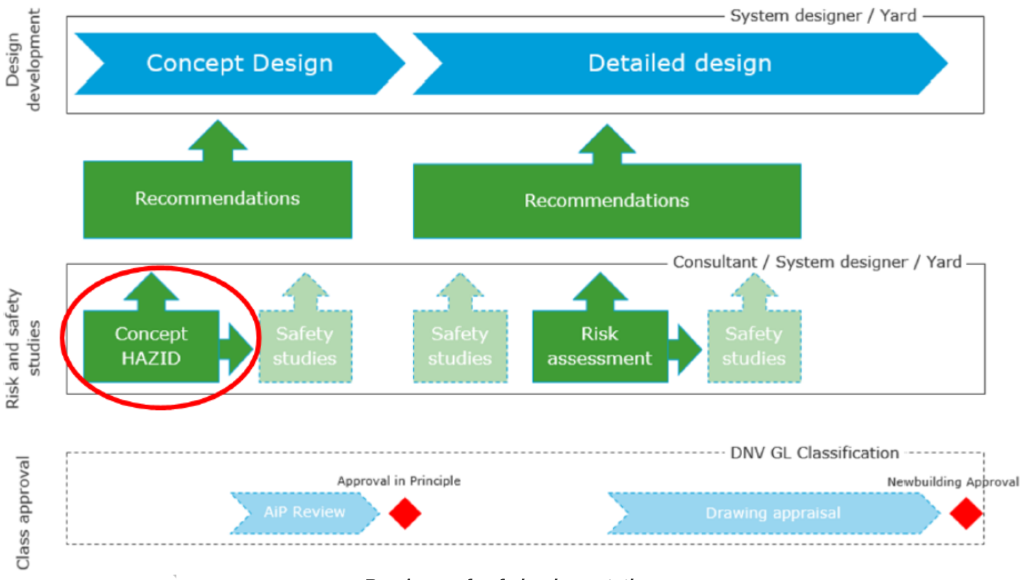
- **Development time of an ammonia engine 2-3 years**
- **We will be ready when the market comes**
- **Thermal efficiency 50%**

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

Renewable energy stakeholders

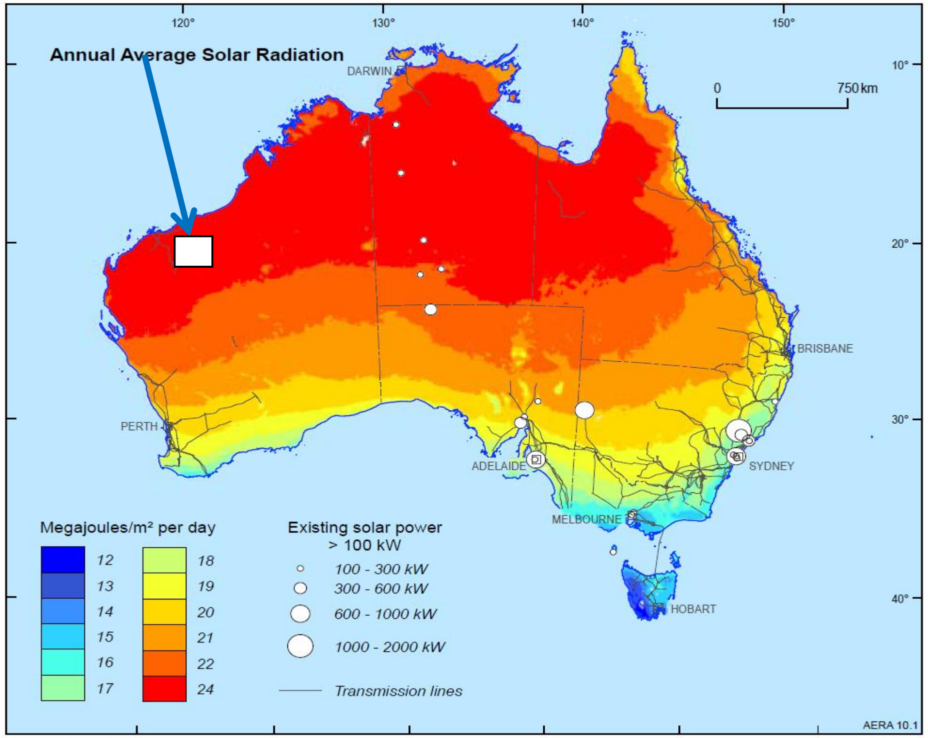


Figure 10.1 Annual average solar radiation (in MJ/m²) and currently installed solar power stations with a capacity of more than 10 kW

Source: Bureau of Meteorology 2009; Geoscience Australia

24 Megajoules/m2/day =

277 Watt average per day per m2

100 x 100 km = 2770 GW   Electrical power   55GkW

10 MW per unit at windspeeds > 10 m/s

SIEMENS Gamesa
RENEWABLE ENERGY

AMMON: Ammonia next generation marine engine

Establish fundament for making ordering of an ammonia-based marine powertrain possible

Conversion of renewable energy to ammonia	**Siemens Gamesa**, renewable power generation.
Bunkering of ammonia	**Yara**, producer of ammonia
Design of on-board handling system of ammonia	**Babcock LGE** (tank systems) **Eltronic** (Gas valve trains) **NGT International and Solvang ASA**, operators of ammonia ships
Classification and Regulation	**DNV/GL**, Classification society
Demonstration of engine operation	**MAN Energy Solutions**
End-use of technology	**APM-Maersk**, Operator/owner of a large fleet of container vessels **NGT International** and **Solvang ASA**, Two operators of ammonia ships
Universities	**Technical University of Denmark** **Lund University** **Politecnico Milano**

Horizon 2020, LC-MG-1-8-2019:

Retrofit Solutions and Next Generation Propulsion for Waterborne Transportation

Time line:

1. Deadline for stage 1 application: 2019-01-16
2. Answer from the EU – stage 1: March/April
3. Deadline of stage 2 application: Mid Sep
4. Answer from the EU – stage 2: Oct/Nov
5. Signing cooperation agreement: Nov/Dec
6. **Expected start of AMMON: 2020-01-01**

Gas carriers

Tank types and cargoes

Vessel type	Cargo tanks	Cargoes		
5.000 m3 Gas tanker Fully pressurized	Cylindrical Independent type C	Ammonia	Butane	Propane
20.000 m3 Gas carrier Semi refrigerated/pressurised	Bi-lobe x 4 Independent Type C (-48°C; 5.3 Bar)	Ammonia Propylene (pgm)	Butadiene Propane Propylene Ox.	Butane V.C.M.
20.000 m3 Gas carrier. Low temp for ethylene	Bi-lobe x 3 Independent Type C (-104°C; 4.16 Bar)	Ammonia Crude-C4 Propylene	Butadiene Butane- 1 Ethane Propane V.C.M.	Butane Ethylene
84.000 m3 Gas carrier Fully refrigerated ships	Independent Tanks x 3 Type A under deck (-48°C; 0.45 Bar in harbour/0.25 Bar at sea)	Ammonia Propylene	Butadiene LPG Mix(50/50) V.C.M.	Butane- 1 Propane

Marine decarbonization

CO2 from 300 mill fuel oil per year

Short term propulsion solutions :

- Lower ship speed
- New fuels with lower CO_2 emisson will be needed to meet EEDI
- To increase the efficiency; solutions like PTO, WHR will be more common

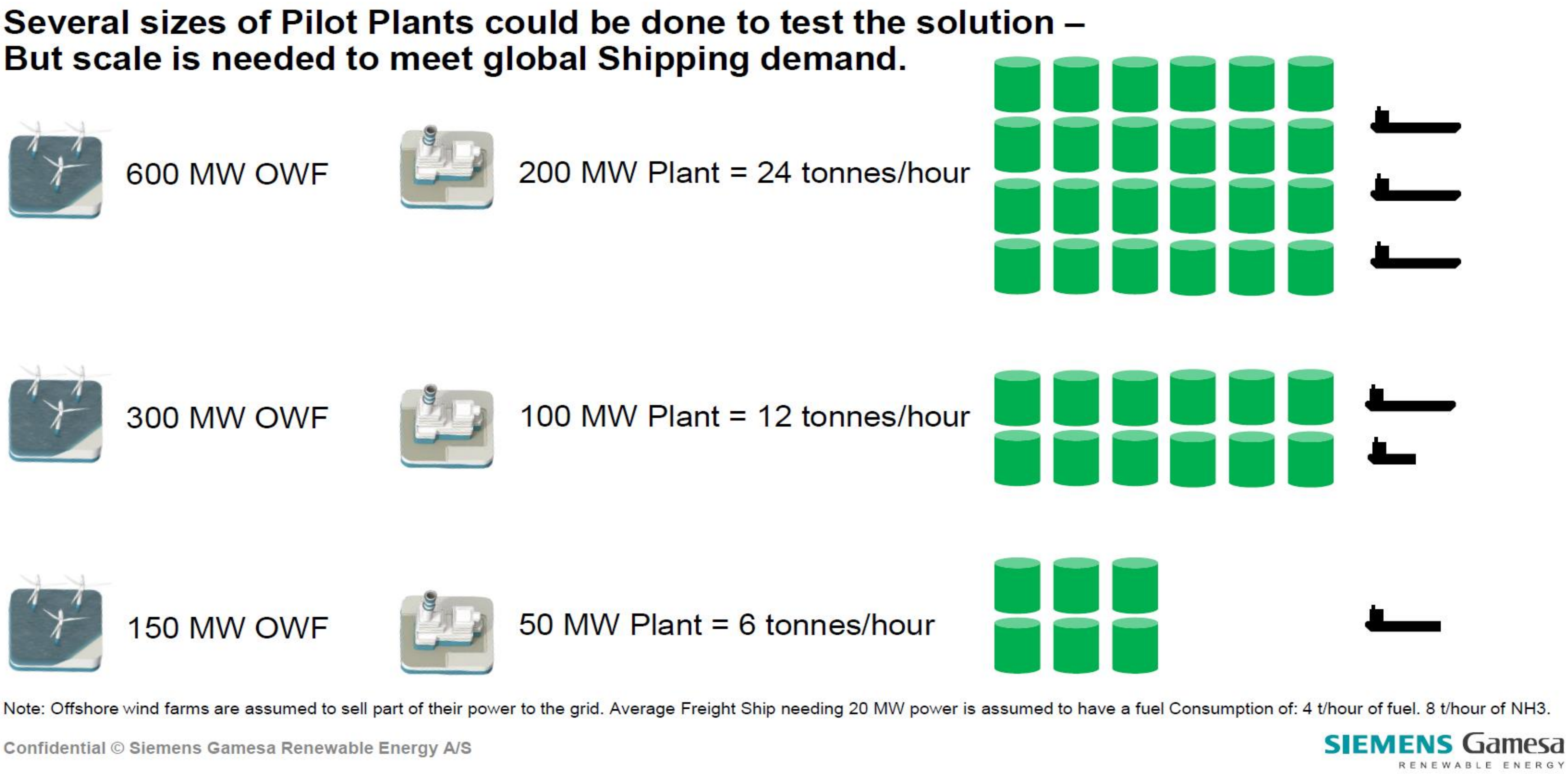
Long term propulsion solutions:

- 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:

- History shows that ammonia works as an engine fuel.
- Engine development will be done when the market comes.
- Development time is estimated to 2-3 years.

Ammonia plant sizing example



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Thank you very much!