Ammonia = Hydrogen 2.0

Conference in Melbourne 22 - 23 August 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

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

1981: MAN Energy Solutions leaves MAN and becomes a subsidiary of VW

2007: Volkswagen AG becomes main shareholder of MAN AG

2011: MAN becomes part of the Volkswagen Group
Member of the Volkswagen group

MAN Energy Solutions is part of a brand family

<table>
<thead>
<tr>
<th>Passenger Cars Business Area</th>
<th>Commercial Vehicles Business Area</th>
<th>Power Engineering Business Area</th>
<th>Financial Services Division</th>
</tr>
</thead>
<tbody>
<tr>
<td>VW</td>
<td>VWN</td>
<td>MAN Energy Solutions</td>
<td>Dealer and customer financing</td>
</tr>
<tr>
<td>Audi</td>
<td>Scania</td>
<td>Renk</td>
<td>Leasing</td>
</tr>
<tr>
<td>Skoda</td>
<td>MAN Truck &amp; Bus</td>
<td></td>
<td>Direct bank</td>
</tr>
<tr>
<td>Seat</td>
<td></td>
<td></td>
<td>Insurance</td>
</tr>
<tr>
<td>Bentley</td>
<td></td>
<td></td>
<td>Fleet management</td>
</tr>
<tr>
<td>Porsche</td>
<td></td>
<td></td>
<td>Mobility offerings</td>
</tr>
<tr>
<td>Others</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NH3  -  H2 co-agency, Melbourne  22 Aug 2019
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
New Name

New Strategies

Decarbonization

calls for new technologies
- Limit global warming to below 2°C 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 Efficiency 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

<table>
<thead>
<tr>
<th>No. of engines</th>
<th>Engine type</th>
<th>Mb.</th>
<th>Gensets</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>S 90</td>
<td>10.5</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>G 90</td>
<td>9.5</td>
<td>10.5</td>
</tr>
<tr>
<td>4</td>
<td>S 80</td>
<td>9.5</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>S 70</td>
<td>7, 8.2, 10.5</td>
<td>6 x 9L28/32 DF</td>
</tr>
<tr>
<td>160</td>
<td>G 70</td>
<td>9.2, 9.5, 10.5</td>
<td>8 x 7L35/44 DF</td>
</tr>
<tr>
<td>5</td>
<td>L 70</td>
<td>8.2</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>S 60</td>
<td>10.5</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>S 50</td>
<td>8.2</td>
<td>9.5</td>
</tr>
<tr>
<td>5</td>
<td>G 50</td>
<td>9.5</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>G 45</td>
<td>9.5</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>G 50</td>
<td>9.3, 9.5, 10.5</td>
<td>4 x 5L23/30 DF / 8 x 8L23/30 DF</td>
</tr>
<tr>
<td>3</td>
<td>S 50</td>
<td>9.3</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>G 60</td>
<td>9.5</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>G 50</td>
<td>9.5</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>G 60</td>
<td>10.5, 9.2</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>S 60</td>
<td>10.5</td>
<td></td>
</tr>
</tbody>
</table>

**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, NH3 as green fuel produced with renewable energy

Ammonia is the logic option

NH3 advantages as green fuel:

• No carbon. Clean combustion without CO2 or carbon
• Can be produced 100% by electrical energy
• Can easily be reformed to H2 and N2
• Can be stored with high energy density at < 20 bar
• Low risk of fire. Relatively specific ratio of NH3 and air (15-25%) is required to sustain combustion
• (Toxic)
## Alternative fuels

### Properties

<table>
<thead>
<tr>
<th>Energy storage type</th>
<th>Specific energy MJ/kg</th>
<th>Energy density MJ/L</th>
<th>Required tank volume m³</th>
<th>Estimated PtX efficiency</th>
<th>Supply pressure bar</th>
<th>Injection pressure bar</th>
<th>Emission reduction compared to HFO Tier II</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFO</td>
<td>40,5</td>
<td>35</td>
<td>1000</td>
<td></td>
<td>07-aug</td>
<td>950</td>
<td>SOₓ</td>
</tr>
<tr>
<td>Liquefied natural gas (LNG -162 °C)</td>
<td>50</td>
<td>22</td>
<td>1590</td>
<td>0,56</td>
<td>300</td>
<td>300</td>
<td>90-99%</td>
</tr>
<tr>
<td>Methane</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>380 ETHANE</td>
<td>90-97%</td>
</tr>
<tr>
<td>LPG (including Propane / Butane)</td>
<td>42</td>
<td>26</td>
<td>1346</td>
<td></td>
<td>50</td>
<td>600-700</td>
<td>90-100%</td>
</tr>
<tr>
<td>Methanol</td>
<td>19,9</td>
<td>15</td>
<td>2333</td>
<td>0,54</td>
<td>10</td>
<td>500</td>
<td>90-97%</td>
</tr>
<tr>
<td>Ethanol</td>
<td>26</td>
<td>21</td>
<td>1750</td>
<td></td>
<td>10</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>Ammonia* (liquid -33 °C)</td>
<td>18,6</td>
<td>12,7</td>
<td>2755</td>
<td>0,65</td>
<td>50?</td>
<td>600-700</td>
<td></td>
</tr>
<tr>
<td>Hydrogen (liquid -253 °C)</td>
<td>120</td>
<td>8,5</td>
<td>4117</td>
<td>0,68</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marine battery market leader, Corvus, battery rack</td>
<td>0,29</td>
<td>0,33</td>
<td>106,060</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tesla model 3 battery Cell 2170*</td>
<td>0,8</td>
<td>2,5</td>
<td>14000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Given a 1000 m³ 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

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

Takasaki et al. CIMAC 2016

Marine gas oil
Methanol
Methane
Ethane

-15.0[deg. ASOI]
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 NH3

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

<table>
<thead>
<tr>
<th></th>
<th>Injection pressure</th>
<th>Supply pressure</th>
<th>Common rail</th>
</tr>
</thead>
<tbody>
<tr>
<td>ME-GI</td>
<td>200-380</td>
<td>200-380</td>
<td>Pressure booster valve</td>
</tr>
<tr>
<td>ME-LGI</td>
<td>600-800</td>
<td>8-50</td>
<td></td>
</tr>
</tbody>
</table>
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.

### 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.

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>2</td>
<td>L</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>3</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
</tr>
</tbody>
</table>

- 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.
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
### AMMON: Ammonia next generation marine engine

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

<table>
<thead>
<tr>
<th>Conversion of renewable energy to ammonia</th>
<th>Siemens Gamesa, renewable power generation.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunkering of ammonia</td>
<td>Yara, producer of ammonia</td>
</tr>
</tbody>
</table>
| 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

<table>
<thead>
<tr>
<th>Vessel type</th>
<th>Cargo tanks</th>
<th>Cargoes</th>
</tr>
</thead>
</table>
| 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  
Butadiene  
Propylene Ox.  
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  
Butadiene  
Butane-1  
Ethane  
Propane  
V.C.M.  
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  
Butadiene  
LPG Mix(50/50)  
Propane  
V.C.M.  
Butane-1 |
Marine decarbonization
CO2 from 300 mill fuel oil per year

**Short term propulsion solutions:**
- Lower ship speed
- New fuels with lower CO₂ emission 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

Several sizes of Pilot Plants could be done to test the solution –
But scale is needed to meet global Shipping demand.

600 MW OWF

200 MW Plant = 24 tonnes/hour

300 MW OWF

100 MW Plant = 12 tonnes/hour

150 MW OWF

50 MW Plant = 6 tonnes/hour

Note: Offshore wind farms are assumed to sell part of their power to the grid. Average Freight Ship needing 20 MW power is assumed to have a fuel Consumption of: 4 t/hour of fuel, 8 t/hour of NH3.
Disclaimer

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.
Thank you very much!