63RD INTERNATIONAL CONGRESS OF NAVAL ARCHITECTURE, MARINE ENGINEERING AND MARITIME INDUSTRY

Concluding on the potentials for Ammonia, Biofuel, Hydrogen and WAPS as green solution in shipping.

René Sejer Laursen / Director Global Sustainability
Madrid, 24th of April /2024

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EMSA project overview

Key Numbers

- **6** Alternative Fuels / Power
- **3** Partners + Industry/Authorities
  Shell, DFDS, Port of Rotterdam, Bureau Veritas, Stena, Minerva, Wartsila, Carnival, Interferry, SWS, CSSC COSCO, MARIC, MAN ABC etc.
- **20** Team members
- **12** Dedicated HAZID workshops

Tasks

Task 1 – State of Play
Production pathways, scalability, availability, sustainability, suitability, cost analysis

Task 2 – Standards/Regulations/Guidelines
IMO, IGF code, SOLAS, IACS, ISO, ISM, Regional Regs, Guidelines, SIGGTO, SGMF
Regulatory Gap Analysis

Task 3 – Safety Assessment
Selected 3/4 Designs
HAZID workshops
Suggestions for improvement

Progress

2021/2022	Biofuels Ammonia	✓
2022/2023	Hydrogen	✓
2023	*WAPS*	✓
2023/2024	*E-fuels and Nuclear*	(in progress)

Latest News - Update on Potential of Biofuels for Shipping [updated] - EMSA - European Maritime Safety Agency (europa.eu)
Latest News - Potential of Ammonia as Fuel in Shipping [updated] - EMSA - European Maritime Safety Agency (europa.eu)
Latest News - New report: the potential of hydrogen as a fuel in shipping - EMSA - European Maritime Safety Agency (europa.eu)
Publications - Potential of wind-assisted propulsion for shipping - EMSA - European Maritime Safety Agency (europa.eu)

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Biofuels production pathways – TRLs

- There are many pathways available
- The current more developed pathways tend to provide less GHG reduction potential
- Promising pathways still require further development

Fuel category	End product	Production pathway	Fuel production	
			TRL 2019	TRL 2030
Biodiesels	FAME	Transesterification	10	10
	HVO	Hydrotreatment	10	10
	HVO (from wood)	Wood extractives pulping/ catalytic upgrading	8/9	8/10
	HVO (from algae)	Algae/oil extraction / catalytic upgrading	4/5	4/5
	FT diesel	FT synthesis	6/8	8/9
	DME	Lignocellulosic Gasification	6/8	8/9
Bio-alchohols	Bioethanol	Fermentation	10	10
		Waste based	8/9	10
		Lignocellulosic hydrolysis	8/9	9/10
		Waste based	8/9	10
	Bio-methanol	Black liquor gasification	6/8	8/9
		Lignocellulosic gasification	6/8	8/9
Biocrudes	SVO		10	10
	Pyrolysis oil	Lignocellulosic Pyrolysis/ catalysed upgrading	5/6	6/8
	HTL biocrude	Lignocellulosic Hydrothermal liquefaction/ catalytic refining	2/4	4/5
	Solvolysis oil	Lignocellulosic hydrolysis / solvolysis	4/5	6/8
Gaseous biofuels	Liquefied biomethane	Sludge/maize/manure/residues Fermentation / digestion	10	10
	Liquefied biomethane	Lignocellulosic Gasification	6/8	8/9

Suitablility - biofuels

Note: Bio-methane and bio-methanol are chemical identical with methane and methanol – no change

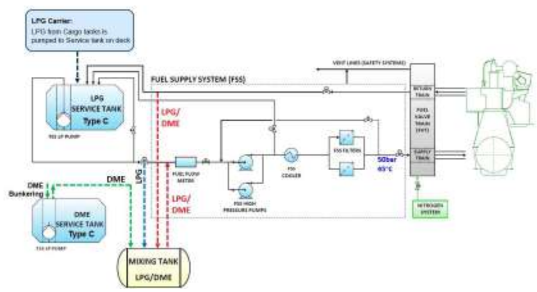
Bio-fuels

Fuel Property	Units	MGO – Diesel (Petroleum based)	FAME (Biodiesel)	HVO (Renewable Diesel)
Cetane Number	-	40 – 55	50 – 65	80 – 99
Density at 15°C	Kg/m³	0.82-0.85	0.88	0.77-0.78
Kinematic viscosity at 40°C	mm²/s	2.5-4.5	4.5	2.5-3.5
LHV	MJ/Kg	42-44	37-38	34-44
Oxygen content	%	0	11	0
Sulphur content	ppm	< 10	< 10	< 10
NOx Emissions (from combustion)	%	Baseline	+10%	-10% to 0
Lubricity	-	Baseline	Good	Poor (may require additives)
Oxidative Stability / Storage stability	-	Baseline	Poor (Antioxidants to increase storage life or stability, or frequent bunkering is more likely)	Good
Cold Flow Properties	-	Baseline	Poor	Good (only with isomerisation)

FAME and HVO: can be used in exsisting marine engines with a few pre-caution.

Fuel Property	Units	MGO – Diesel (Petroleum based)	DME	LPG	
				Propane	Butane
Cetane Number	-	40 – 55	55 – 60	42-45	42-45
Density at 15°C	Kg/m³	0.82-0.85	0.66	0.5	0.61
Kinematic viscosity at 40°C	mm²/s	2.5 – 4.5	0.12–0.15	0.2	0.2
LHV	MJ/Kg	42-44	28	46	45
Oxygen content	%	0	34.8	0	
Sulphur content	ppm	< 10	0	0.01	
Expected NOx Emissions (from combustion)	%	Baseline	- 20%	- 10% to 15%	
Lubricity	-	Baseline	Poor	Between Baseline and Poor	

DME similar to LPG, but LHV is lower - new engine development is required



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Drop-in biofuels

- Fully drop-in
  - FAME
  - HVO
  - FT Diesel
  - Bio-methanol
  - Bio-ethanol
  - Bio-methane
- Not fully drop-in
  - DME
  - SVO
  - HTL Biocrude
  - Pyrolysis oil
  - Solvolysis oil

Biofuel	Replaced fossil fuel	Drop in properties/blend %	Remarks
FAME	Distillates	Up to 100% v/v	Subject to confirmation by Engine Designer for blends above 7% v/v FAME
HVO	Distillates	Up to 100% v/v	Subject to confirmation by Engine Designer
FT diesel	Distillates	Up to 100% v/v	Subject to confirmation by Engine Designer
DME	Distillates – LPG in dual fuel engines	Up to 20-30% v/v – up to 100% v/v	Subject to confirmation by Engine Designer
Bio-methanol	Methanol	Up to 100% v/v	For Methanol DF Engines and Fuel Supply System
Bio-ethanol	Distillates in Otto engines – Methanol in dual fuel 2-stroke engines.	Up to 100% v/v	Not enough information about use in marine engines – probably doable by introducing minor modification to the methanol fuel injection system
SVO	Fuel oil	Up to a limited share	Subject to confirmation by engine Designer
Pyrolysis oil	Fuel oil	Not a drop-in fuel	Properties vary widely and change with ageing. Acidic and corrosive. Can be upgraded to a drop-in fuel.
HTL biocrude	Fuel oil	Up to a limited share	Little information about use in blends in marine engines. Can be upgraded to a drop-in fuel.
Solvolysis oil	Fuel oil	Up to a limited share	Little information about use in blends in marine engines. Can be upgraded to a drop-in fuel.
Liquefied biomethane	LNG	Up to 100% v/v	For DF and Gas Engines, and Fuel Gas Supply System

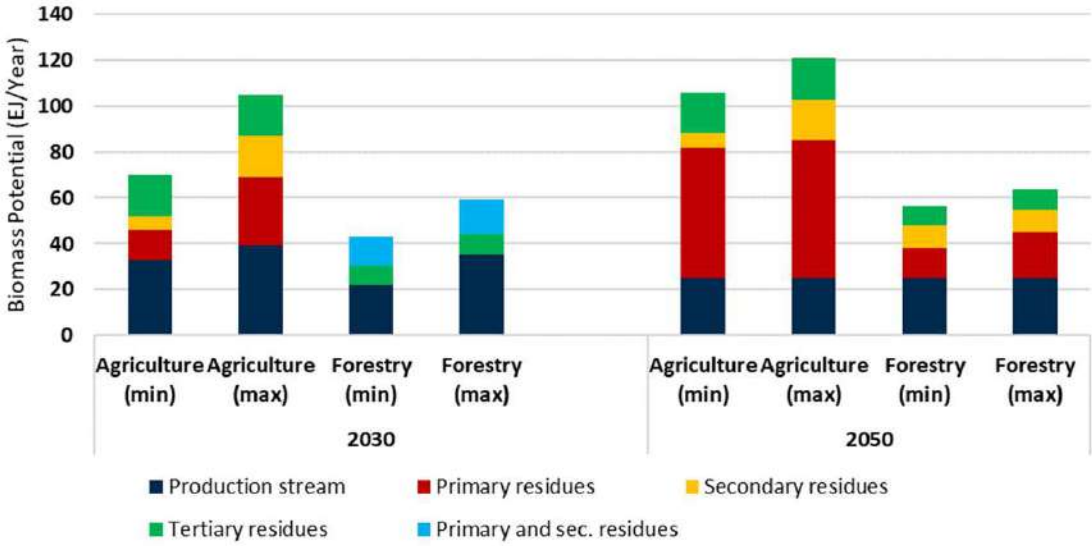
Biofuels availability and scalability

- Biofuel availability for the maritime sector is determined by
  - The availability of feedstocks; and
  - Competition with other sectors.

  - The availability of feedstocks depend on:
    - Sustainability criteria;
    - Type of feedstock: lignocellulosic / algae / carbohydrates / bio oils & fats.

  - Competition with other sectors depends on:
    - Alternative sources; and
    - Policy measures.

Global sustainable biomass potential



Energy demand from shipping: 18 EJ in 2018

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Conclusions

Bio

Ranking was performed based on:
- Fuel production costs developments
- Production maturity
- GHG reduction potential
- Feedstock availability
- Suitability of engines

1. Bio-methanol, FT diesel, biomethane from digestion of waste and residues and DME arrive very close
2. FAME from FOGs, biomethane from gasification
3. FAME from vegetable oils, HVO from FOGs and from vegetable oils arrive

Main conclusions:
- **<u>We do not see major bottlenecks (Safety aspects)</u>**
- **<u>Regulatory (ship-related) bottlenecks are minor or resolvable</u>**
- **<u>Need for common and harmonized sustainability criteria and LCA guidelines:</u>**
  - International & cross-industry

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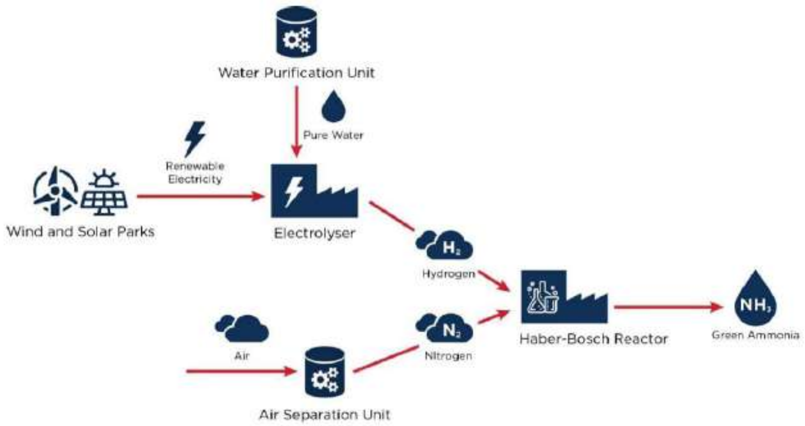
Ammonia Availability and Scalability

NH_3 HB is the most mature process



Process Type	Expected Efficiency [up to]
Pathway 1 Electrolysis and Haber-Bosch synthesis	~72%
Pathway 2 Direct solar hydrogen production	9% [up 70%]
Pathway 3 Biogenic hydrogen production	~57%
Pathway 4 Non-thermal plasma synthesis	12-37% [up to 45%]
Pathway 5 Electrochemical ammonia synthesis	14-62% [up to 90%]

Grey NH3 Production

235 Mtons/year

2019

Green NH3 Announced

>133 Mtons/year

*annouced blue and green ammonia production

What are the challenges ?

- Many sectors will have demand for green or blue ammonia.
- Green electricity will also be in high demand
- Demand depends on policy, many of which are not yet confirmed
- Green production needs to be efficient, utlized at maximum capacity and this poses challenges:
  - Location, pipelines, access to ports
  - Connection to grid (sustainable?)
  - Potentially oversized

Ammonia sustainability

NH_3

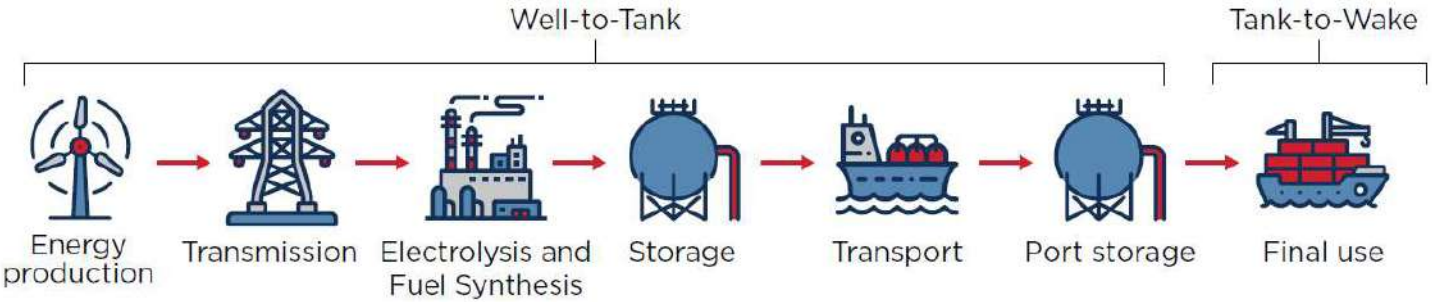
The challenge is green electricity

- Certification mechanisms
- If connected to the grid, need to ensure the source of that energy
- Transportation, if not decarbonised, may lead to increased footprint

Engine still under development

- NOx & N2O slip uncertain
- Pilot fuel usage

Pollutant	HFO, MGO	LNG	Ammonia (combusted in engines)
SO_2 and metals	Present	Not present	Not present
Carbon monoxide and hydrocarbons	Present	Present or increased	Not present
VOCs and PAHs	Present	Reduced	Not present
NO_x **	Needs SCR for Emission Control Area	Otto engines meet Emission Control Area without SCR	Needs SCR for Emission Control Area
Direct particulate matter	Present	Reduced	Reduced
Ammonia (NH_3) ***	Low	Not present	Unknown
N_2O	Present	Present	Present or increased****
CH_4	Low	Present at Otto engines	Not present
CO_2*****	Present	Present	Not present



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Ammonia sustainability

NH_3

Other Environmental Impacts (production of Ammonia)

- Production of hydrogen requires pure, deionized water. The amount of (fresh) water can increase water scarcity. Desalination and rejection of brines can be detrimental to ocean biodiversity and marine life
- Generating green electricity will require land (solar or onshore wind)
- Production of Solar should avoid using land used for crops

Where Solar ?

- Northern Chile
- Western Australia
- Northeast Brazil
- Northern Africa
- Pats of US and China

Where Wind ?

- Avoid land used for crops (Australia, Chile, etc)
- Using offshore may be an option in Western Europe and USA

- Inland transportation has been ongoing for many decades. Accidents happened and handling of ammonia is known.
- Ammonia spills can be harmful for marine life, need for further evaluation

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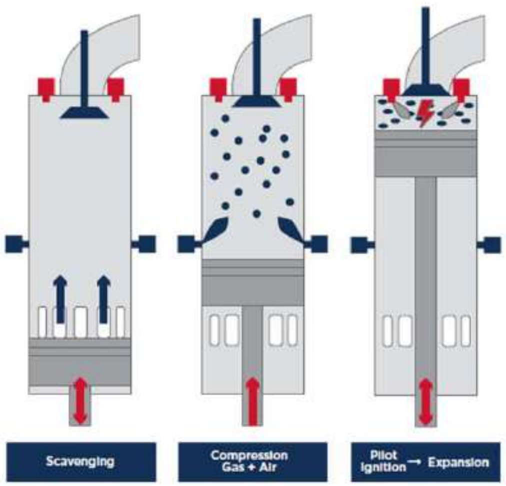
Suitability: Engine Technology – burning ammonia

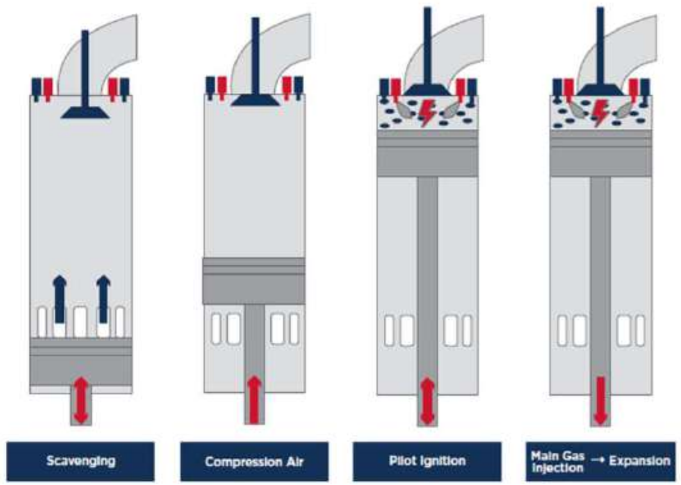
NH_3

Ammonia is resistant to autoignition, it requires an ignition source through out the period where it burns

Low Pressure Gas Injection



High Pressure Gas Injection



Conclusions

NH_3 **Ammonia as a fuel is likely to take place. It presents a series of advantages and is a promising fuel:**

- Known and well-estabilished production process
- Naturally carbon-free, although attention is to be given to NOx, N2O and Pilot fuel and trully green production pathways
- It is known to shipping as a cargo (IGC covers it), and poses many challenges to be used as a fuel
- There are challenges to overcome to handle its corrosivity and toxicity: bunkering, engine, fuel supply systems.
- However, it has been used for many decades and there is substantial knowledge available

Main challenges:

- Ensure availability of green energy and competition with other sectors
- High costs associated with green ammonia production
- Safety and Regulations concerns: need to accelerate awareness and regulatory framework developments
- Need more knowledge on spillage and other environmental aspects
- IMO Guidelines to be ready by 2025

Hydrogen Suitability - Storage

H_2

FUEL	Fuel Properties							Storage	FGSS/FSS
	Storage Conditions (liquid state)		Specific Energy (MJ/kg)	Energy Density (MJ/L)	Carbon Content	C_F (t-CO_2/t-Fuel)	kg CO_2/kWh	Fuel Tank Volume Compared to MGO (not including insulation etc)	Supply Pressure (bar)
	Temperature	Pressure							
MGO	atm	atm	42.7	38.4	0.8744	3.206	0.2701	1	8
LNG	-162C	atm (or pressurised ~5-10 bar)	48	21.6	0.75	2.75	0.2061	1.8	300 (Diesel) 5 ~ 13(Otto)
Ethane	-89C	atm (or semi-ref ~ 5 bar)	47.8	27.2	0.7989	2.927	0.2205	1.4	380 (Diesel) ~ 5 (Otto)
Methanol	atm	atm	19.9	15.7	0.375	1.375	0.2486	2.4	10-15
LPG	-48C (Propane)	atm (or fully pressurised up to 18 bar)	46.3 (Propane) 45.7 (Butane)	23.2 27.4	0.8182 0.8264	3.00 3.03	0.2331 0.2385	1.7 1.4	50
Ammonia	-33C	atm (or fully pressurised up to~ 18 bar)	18.6	12.9	0.0*	0.0*	0.0*	3.0	83
Hydrogen	-253C	atm (or pressurised ~100-300 bar)	120.0	8.5	0.0*	0.0*	0.0*	Liquid > 4.5 Pressure (25- 700 bar) > 8	3-10 bar (Otto)

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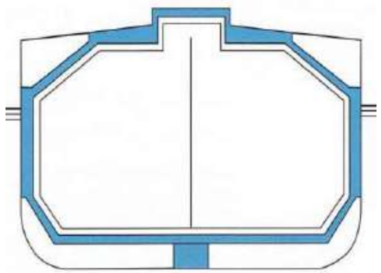
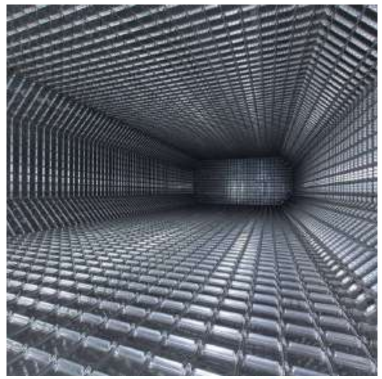
Suitability - LH_2 Containment Systems

Independent Tanks			Integral Tanks
Type A	**Type B**	**Type C**	**Membrane**
(P <700mbar) Full Secondary Barrier	(P <700mbar) Partial Secondary Barrier Designs not in use	(P >2000mbar) No Secondary Barrier Designs already in use	(P <700mbar) Full Secondary Barrier Designs not in use
	Candidates for Liquefied Hydrogen		


Source: Sea-Man.org


Source: Kawasaki Kisen Kaisha


Source: Wartsila


Source: Conrad Shipyard & GTT

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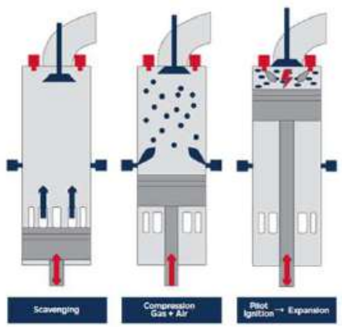
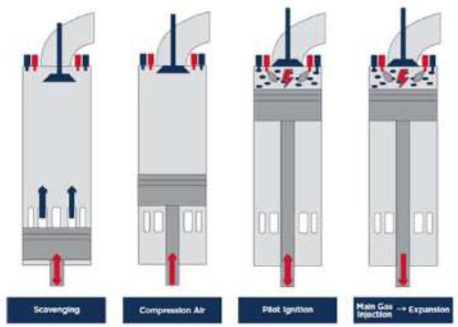
Suitability: Engine Technology – burning hydrogen

	Low-Pressure (LP)		High-Pressure (HP)	
Gas mode cycle type	Otto		Diesel	
Gas injection / Combustion principles- methane and hydrogen	LP gas-admission valves located on the cylinder for pre-mixed gas/air and in-cylinder compression (diesel pilot fuel required for start of combustion)		HP gas-injection valves located on the cylinder cover for direct gas injection into the cylinder for diffusion combustion (diesel pilot fuel required for start of combustion)	
Fuel	Methane gas	Hydrogen (guid. values)	Methane	Hydrogen (guid. values)
Fuel-supply pressure	~5 bar (4-stroke) <13-16 bar (2-stroke)	3-16 bar	300 bar	~300 bar
Injection pressure	Same as supply pressure	Same as supply pressure	Same as supply pressure	Same as supply pressure
Liquid pilot % @MCR	0.5 – 1.0	0.5 – 15%	0.5 – 1.5	0.5-5
BMEP [bar]	17.3	~17	21.0	21.0
Min load for DF mode [%]	~5	~5	~5	~5
IMO NOx Compliance	Tier II (oil mode) Tier III (gas mode)	Tier II (oil mode) Tier II (hydrogen mode)	Tier II (oil mode) Tier II (gas mode)	Tier II (oil mode) Tier II (hydrogen mode)
Fuel Quality Sensitive	Yes - Requirement for Methane Number	Yes	No	No
Fuel Slip	Yes	Insignificant	Insignificant	Insignificant
Knock/Misfire Sensitive	Yes	Yes, however the risk of misfire is low	No	No
Load response	reduced	reduced	unchanged	unchanged

Low Pressure Gas Injection

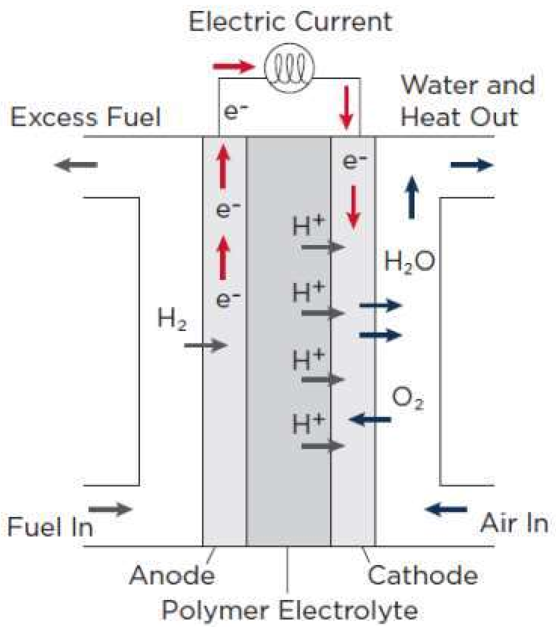


High Pressure Gas Injection



Suitability – Hydrogen fuel cell

H_2



Type	Operating Temperature	Electrical efficiency*	Applications
Proton Exchange Membrane (PEM)	30-120 °C	50-60%	Vehicles and mobile applications and lower power Combined Heat and Power (CHP) systems
Alkaline Fuel Cell (AFC)	100-250 °C	50-60%	Used in space vehicles
Phosphoric Acid Fuel Cell (PAFC)	150-220 °C	40%	Large numbers of 200 kW CHP systems in use
Molten Carbonate Fuel Cell (MCFC)	600-700 °C	50%	Suitable for medium to large scale systems
Solid Oxide Fuel Cell (SOFC)	650-1,000 °C	60%	Suitable for all sizes of systems

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Conclusions

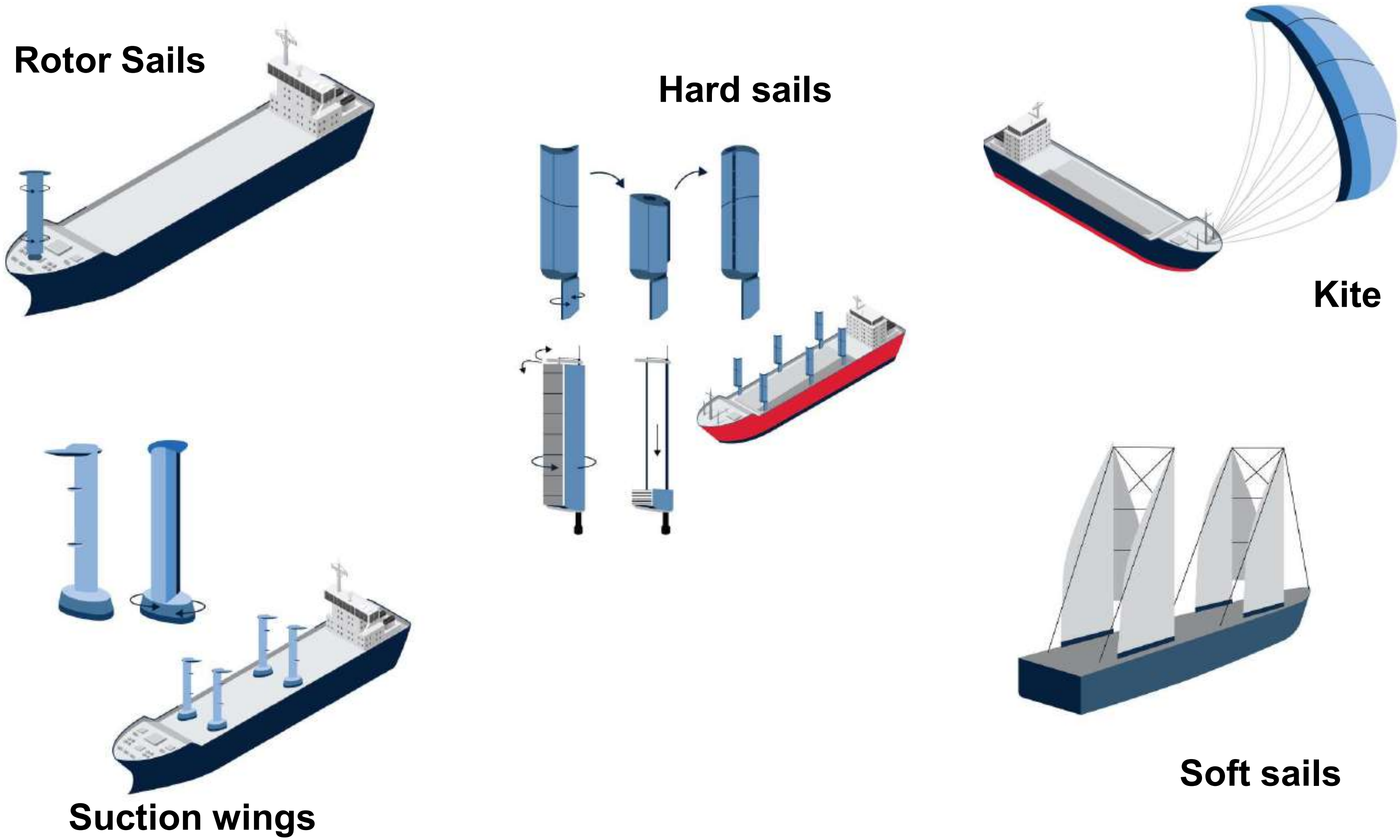
Hydrogen presents a series of advantages :

- Naturally carbon-free, although attention is to be given to NOx, and trully green production pathways
- Known production process

Main challenges:

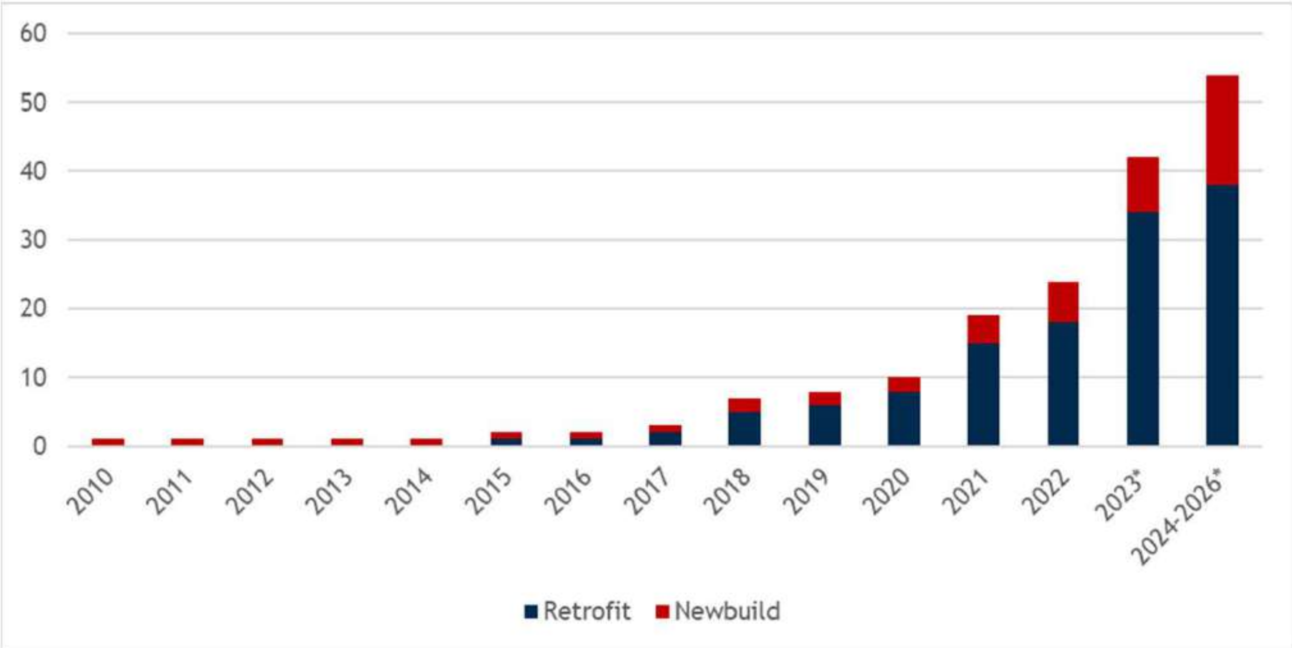
- Ensure availability of green energy and competition with other sectors
- High costs associated with green hydrogen production and transpotation
- Safety and Regulations concerns: need to accelerate awareness and regulatory framework developments
- Volumefactor is 4.5 times bigger than for fuel oil. Liquid at -253^{o}C.
- Small molecule which difficult to contain and it is an indirect GHG , 5-11 times more potent than CO_2
- Infrastructure of hydrogen is not established and it is cost intensive.

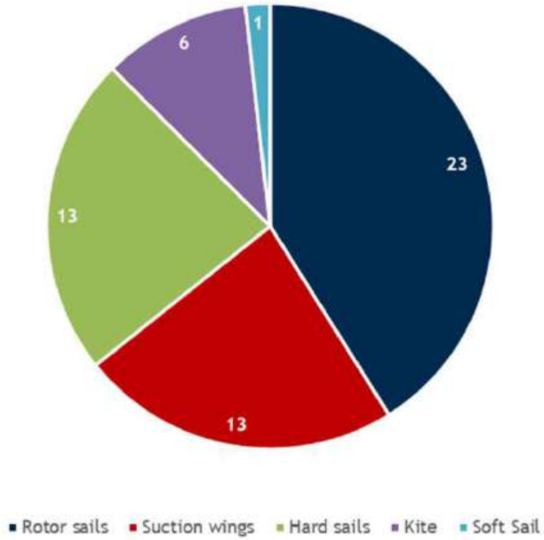
WAPS Overview of systems



WAPS Overview of installations

Number of ships (*planned to be) equipped with a wind propulsion system





Number of realised and planned installation of systems per technology.

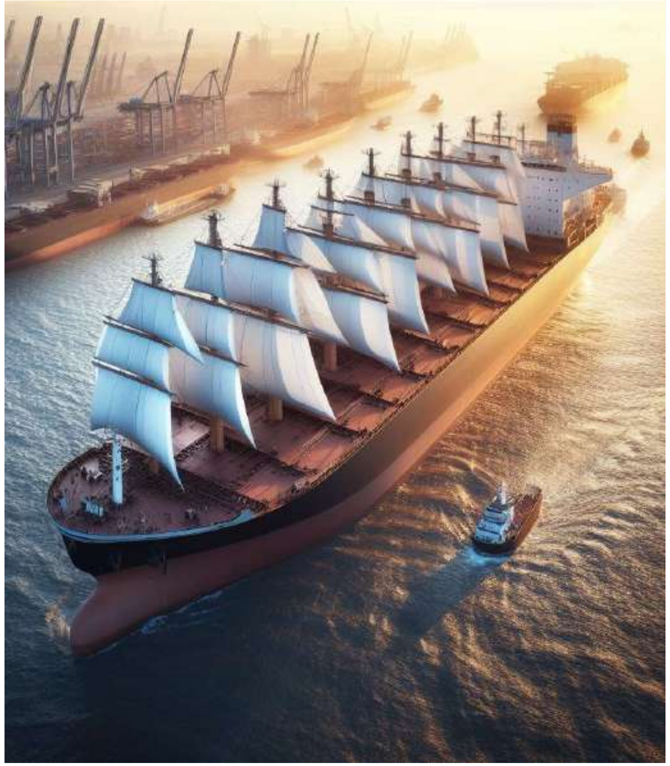
Wind HAZID – General Findings

- WAPS may impact vessel manoeuvrability and controllability
- Equipment number could be affected (mooring equipment)
- Stability type issues – e.g. heeling moments with regulatory requirements for intact and damage stability not sufficiently adapted
- Motions/weather conditions beyond design limits of WAPS or the vessel
- Fire related issues – increase in fire load on deck, escape routes

Courtesy of IWSA

Wind HAZID – Common Findings

- Structural issues – vibration, fatigue, green water, extreme environmental
- Interference with deck operations
- Obstructions – bridge visibility, radar, navigation lights, cargo handling equipment, helicopter winching
- Significant change in air draft – documentation needs to be updated + crew awareness
- WAPS to be evaluated for dropped object potential/impacts, prevention/mitigation
- Working at height risks in the event this is required



Microsoft Bing Image Creator

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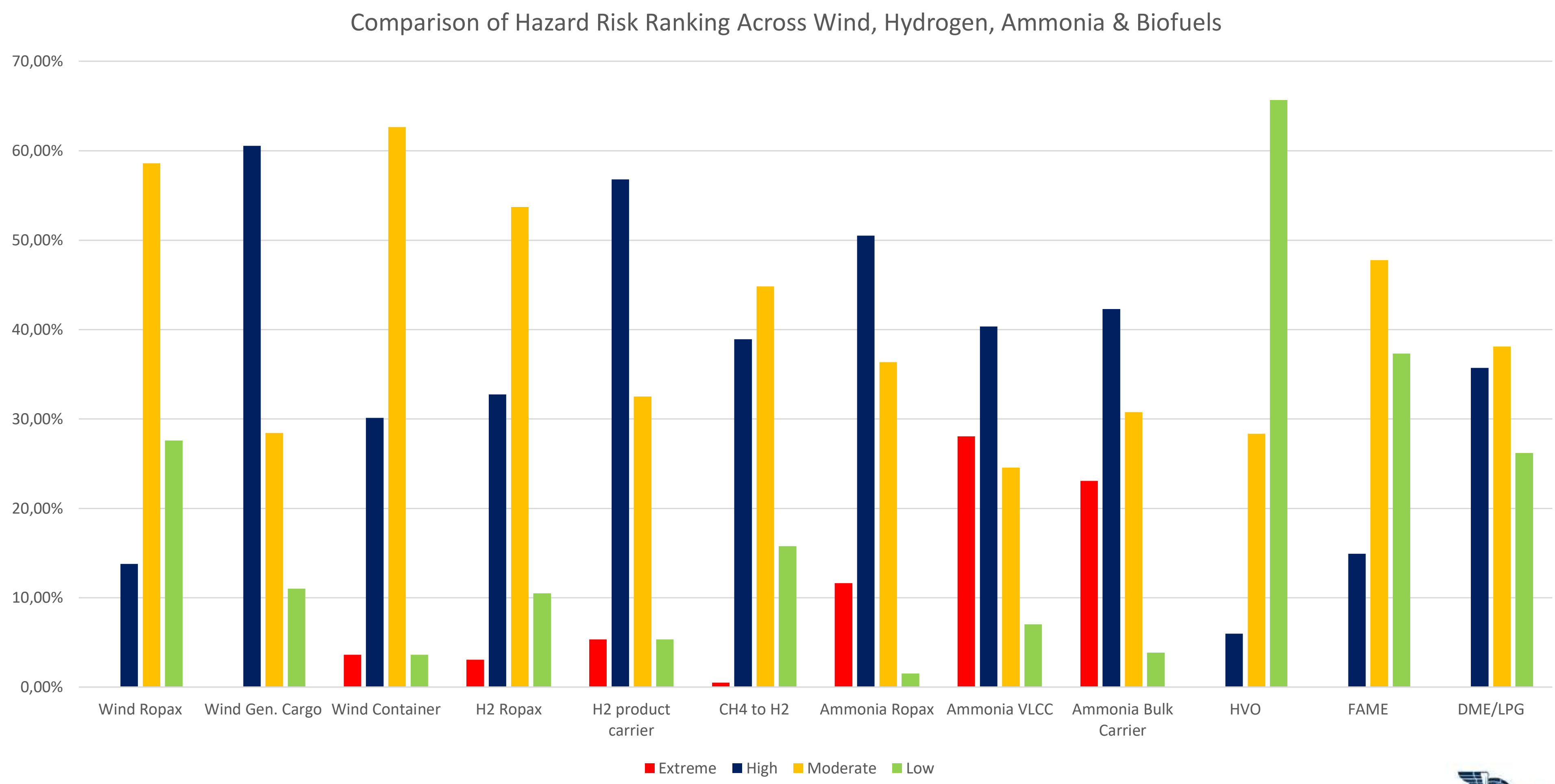
12 HAZID's – Conclusions



Thank You

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