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Hydrogen as marine fuel

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Global market leader, Sustainable shipping

Bureau Veritas Marine & Offshore

Hydrogen-as-marine fuel : **Current Market**

14 ships delivered with Hydrogen, ~30 ships in the orderbook

Silver Nova, Royal Caribbean.
LNG fuel. 4 MW fuel cell.

Viking Neptune, Viking.
Diesel fuel. 100 kW fuel cell.

MF Hydra, Norled.
Liquid Hydrogen (4T, 56 m^3). 2x200 kW fuel cell.

ZEUS = Zero Emission Ultimate Ship

Zeus, Fincantieri
144 kW Fuel Cell, 50 kg hydrogen

San Xia Qing Zhou 1 Hao (Three Gorges Hydrogen Boat 1), China Yangtze Power.
500 kW Fuel cell.

Hydrotug 1, CMB.TECH.
2 MW Engine.
400 kg hydrogen.

Sea Change, Switch maritime.
360 kW fuel cell, 242 kg, 250 bar.

Dredger “Hydromer”.
200 kW fuel cell

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Hydrogen-as-marine fuel : **Drivers**

Drivers for the use of hydrogen as marine fuel, today:

- Demonstrators: understanding the challenges
- Maturing the technologies : fuel cell and engines
- Local regulations for air quality : river, port (zero emission)
- GHG reduction

Applications

- Cruise ships : Hotel load (constant power demand)
- Small mobility : frequent bunkering and/or small power demand

Hydrogen : **some figures**

Energy density : interesting in mass, not so in volume

1 kg Hydrogen represents:

- 11 m^3 @ ambient temperature & pressure
- 25 litres @ 700 bar
- 15 litres @ -253°C
- 16 kWh produced by a Fuel Cell (PEM)

Exemple for a car

- 1 litre of gasoline = 7 litres Hydrogen @700 bar
- 1 litre of gasoline = 4 litres Hydrogen @-253°C
- 1 kg H_2 / 100km versus 7 litres gasoline / 100km

Property	Hydrogen	Comparison
Density (gaseous)	0.089 kg/m^3 (0°C, 1 bar)	1/10 of natural gas
Density (liquid)	70.79 kg/m^3 (-253°C, 1 bar)	1/6 of natural gas
Boiling point	-252.76°C (1 bar)	90°C below LNG
Energy per unit of mass (LHV)	120.1 MJ/kg	3x that of gasoline
Energy density (ambient cond., LHV)	0.01 MJ/L	1/3 of natural gas
Specific energy (liquefied, LHV)	8.5 MJ/L	1/3 of LNG
Flame velocity	346 cm/s	8x methane
Ignition range	4–77% in air by volume	6x wider than methane
Autoignition temperature	585°C	220°C for gasoline
Ignition energy	0.02 MJ	1/10 of methane

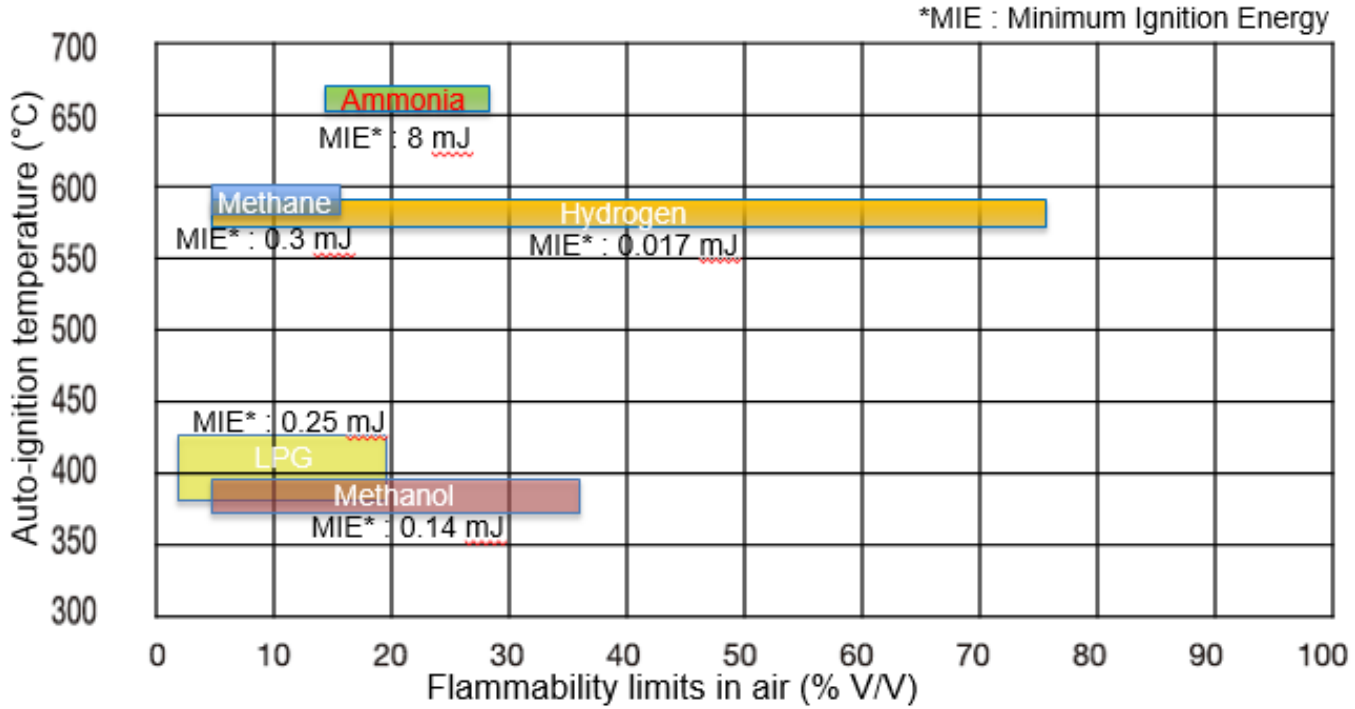
Notes: cm/s = centimetre per second; kg/m^3 = kilograms per cubic metre; LHV = lower heating value; MJ = megajoule; MJ/kg = megajoules per kilogram; MJ/L = megajoules per litre.

The Future of Hydrogen, IEA, 2019

Hydrogen : **safety**

A **safety** challenge

- Small molecule with very low viscosity (challenging prevention of leaks)
- Wide flammability range
- Low ignition energy (small sparks may ignite)
- Rapid burning rate and invisible flame (2,045°C)
- Explosive range (from 8%, 11% for detonation)



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Hydrogen as marine fuel - **Emissions**

Hydrogen leakage may lead to indirect radiative forcing, as highlighted in a recent UK government study which estimated a GWP of 11 ± 5 over 100 years.

Highlights the absolute need to limit leakage, even for non-direct GHG like hydrogen

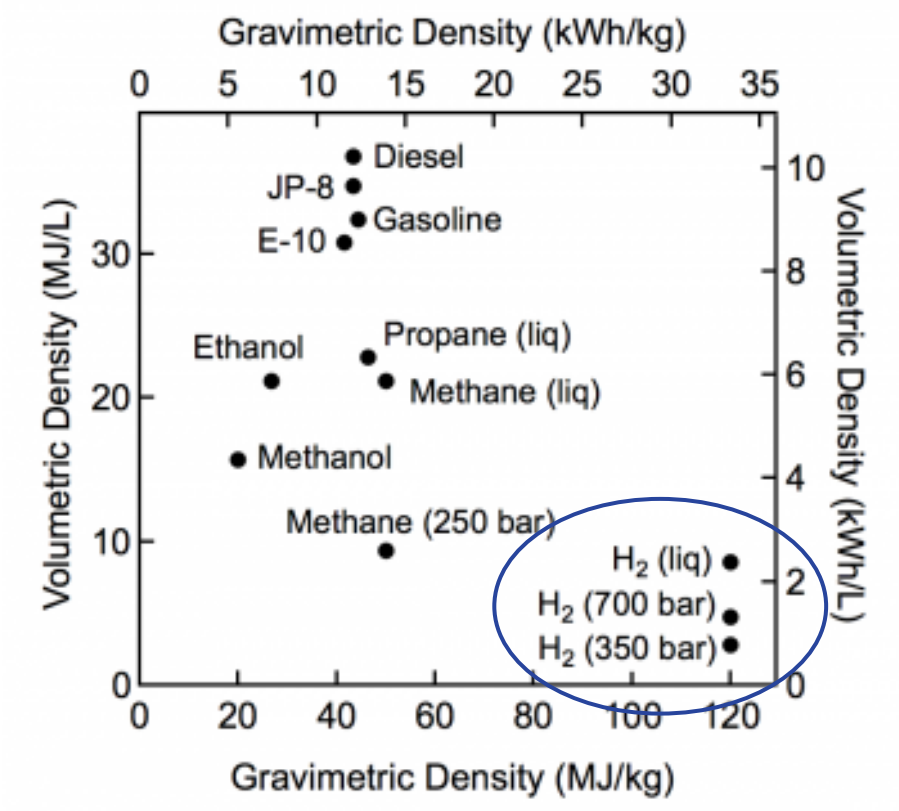
Name	Formula	20-year GWP	100-year GWP
Carbon dioxide	CO_2	1	1
Methane	CH_4	81.2	27.9
Nitrous oxide	N_2O	273	273
Hydrogen	H_2	33	11

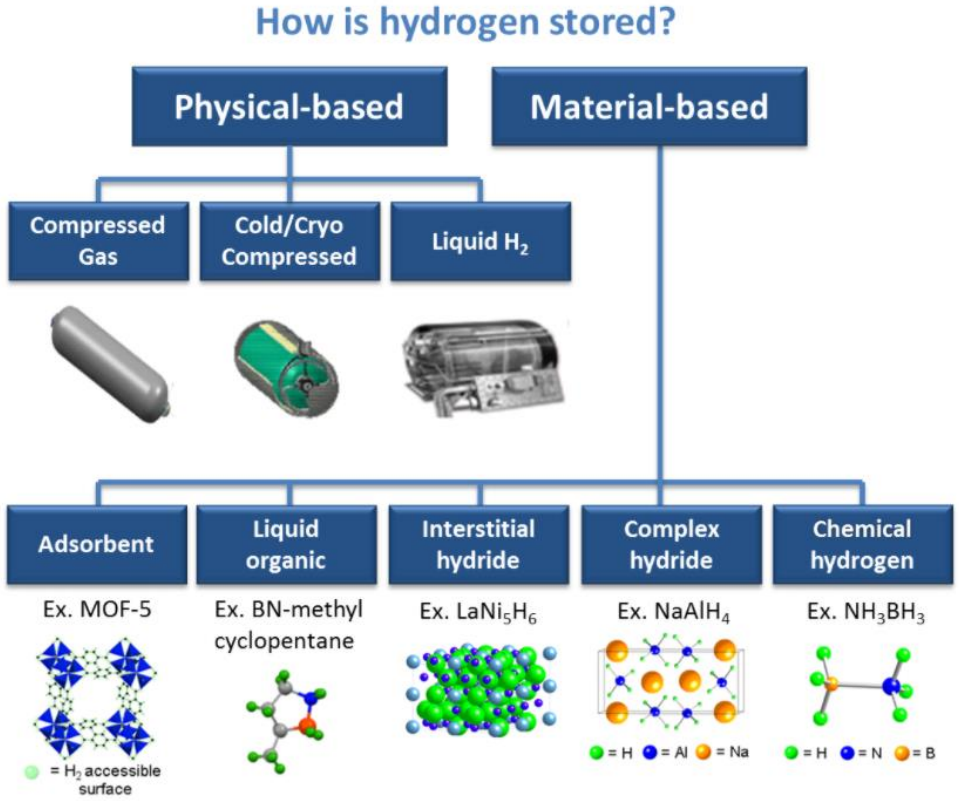
Note: Global warming potential taken from IPCC AR6 and for hydrogen from Warwick et al "Atmospheric implications of increased Hydrogen Use", 2022 report for the UK Government

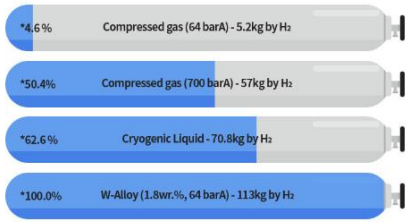
Graphical credit SGMF

Hydrogen **storage**

- Compressed Hydrogen (≤ 700 bars) or Liquid Hydrogen (-253°C) are ready
- Energy density is an issue







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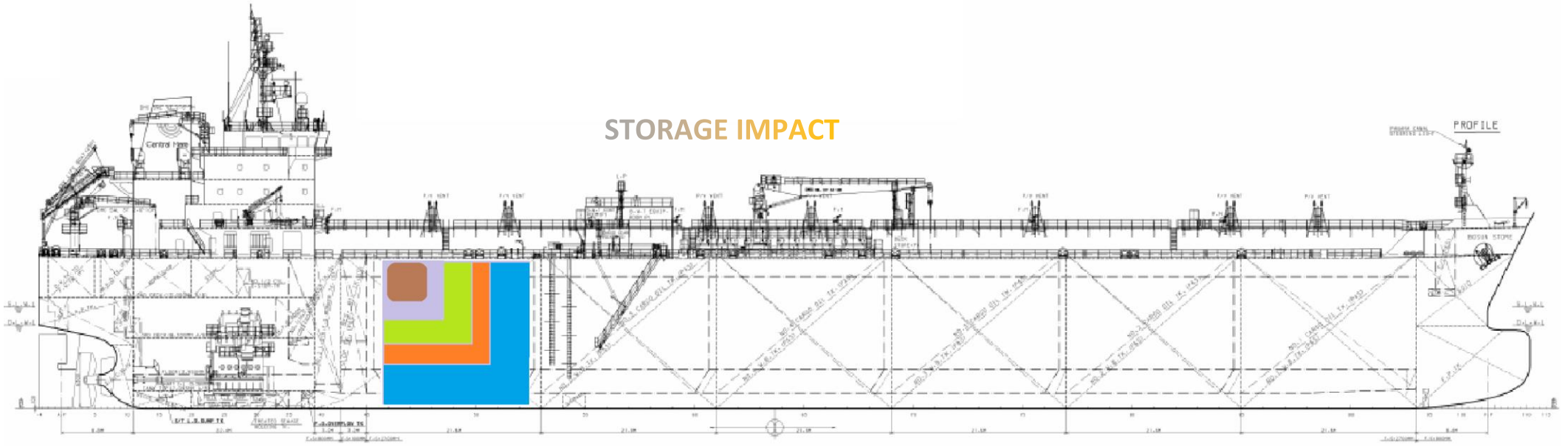
Storage of hydrogen onboard



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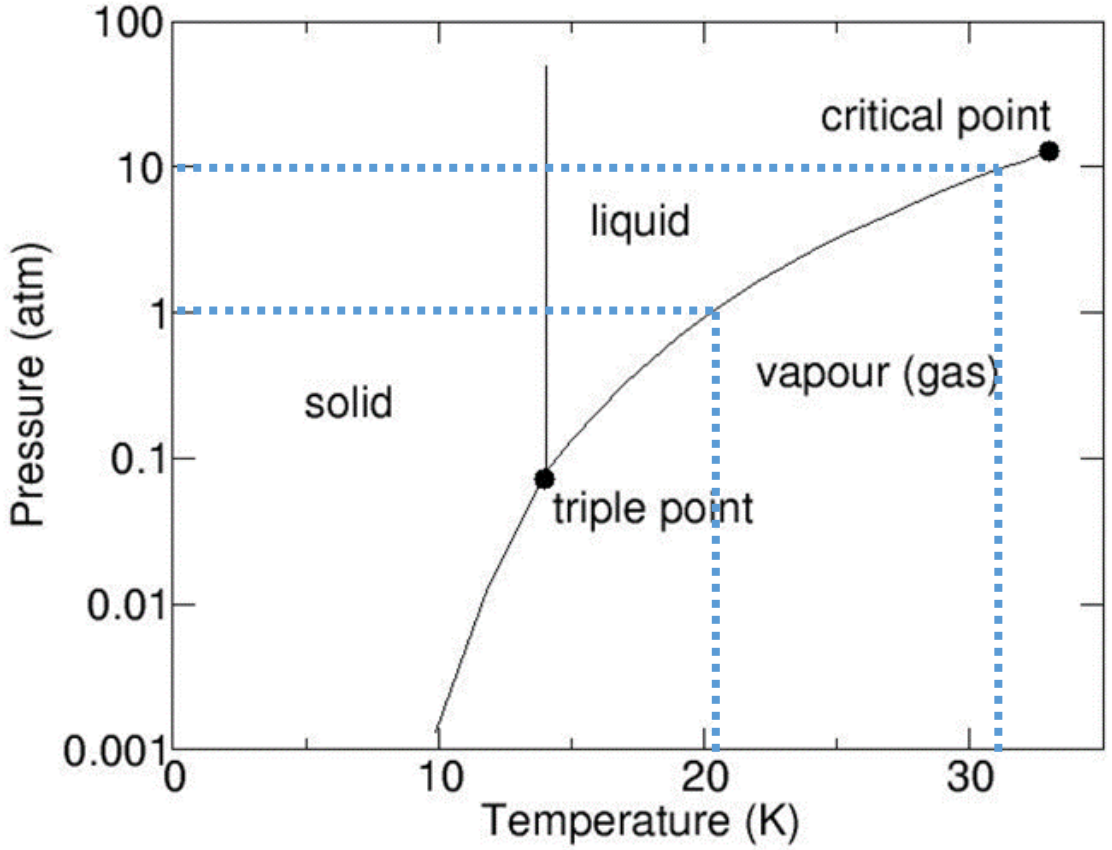
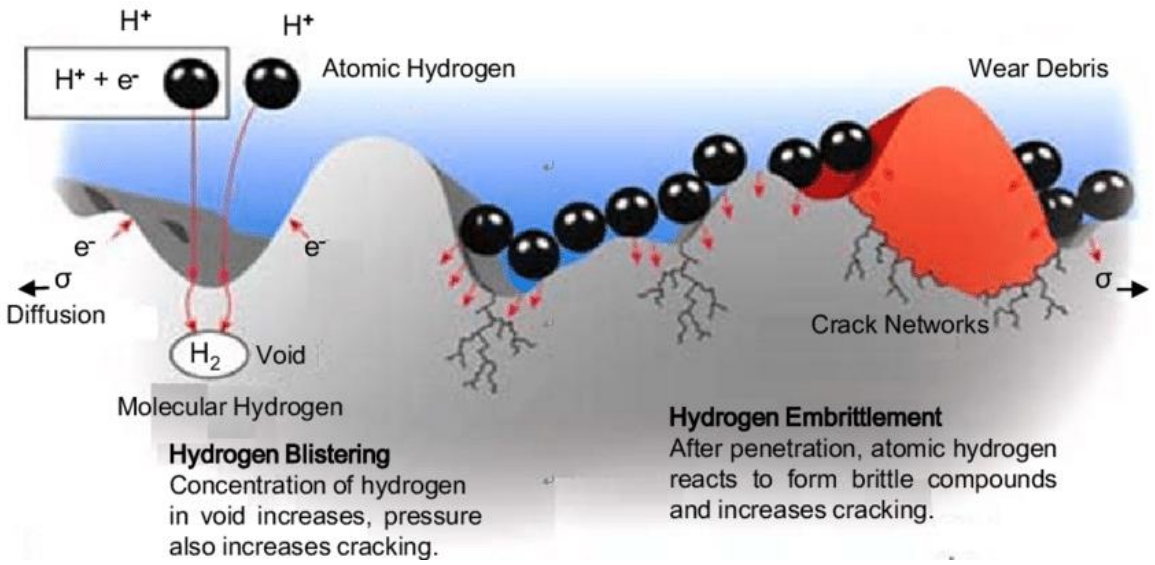
Hydrogen transport



- Conditions for transport : Pressure / Temperature diagram
- 10 degrees increase -> 10 atm increase

Hydrogen embrittlement : small molecules can easily diffuse in material

- Metallic materials and equipment may suffer from hydrogen embrittlement.
- Hydrogen embrittlement is the penetration of hydrogen causing loss of ductility and tensile strength.
- It may lead to micro-cracks, brittle fractures and eventually leakages.
- Careful selection of materials based on their properties and appropriate thickness.
- Special surface treatment and coatings can be used to protect against hydrogen absorption.
- **Stainless steels, aluminium and copper** are generally less susceptible to hydrogen embrittlement.



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Hydrogen technology : **Engine and Fuel Cell**

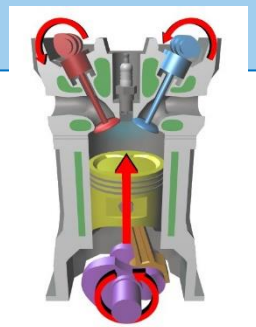
Internal combustion engine

Dual fuel engines

- Claimed increased efficiency and emission reduction
- TRL 8

Full Hydrogen engine

- Expected high level of emission reduction and increased engine efficiency
- TRL 4-5

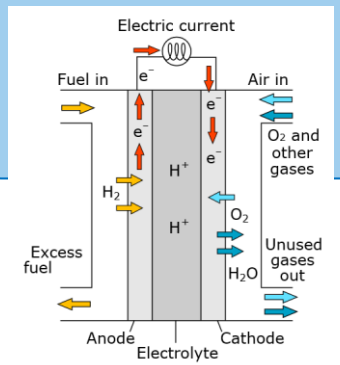


Fuel cell

PEMFC and SOFC are most likely to be used

onboard ships

- PEMFC: up to 1 MW, flexible in transient
- SOFC: more power output and fuel flexibility but long start up & limited shut down



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Hydrogen technology: **regulations development and main safety considerations**

Understand Hydrogen characteristics to mitigate the risk by design

- Eliminate potential ignition sources
- Ventilate as much as possible

Consider Hydrogen compatibility at the different operating condition for material selection

- Very low temperature and wide range of temperature are to be considered

Arrange piping in a way that reduce leakage and allow for easy detection

- Prefer butt-welded pipes

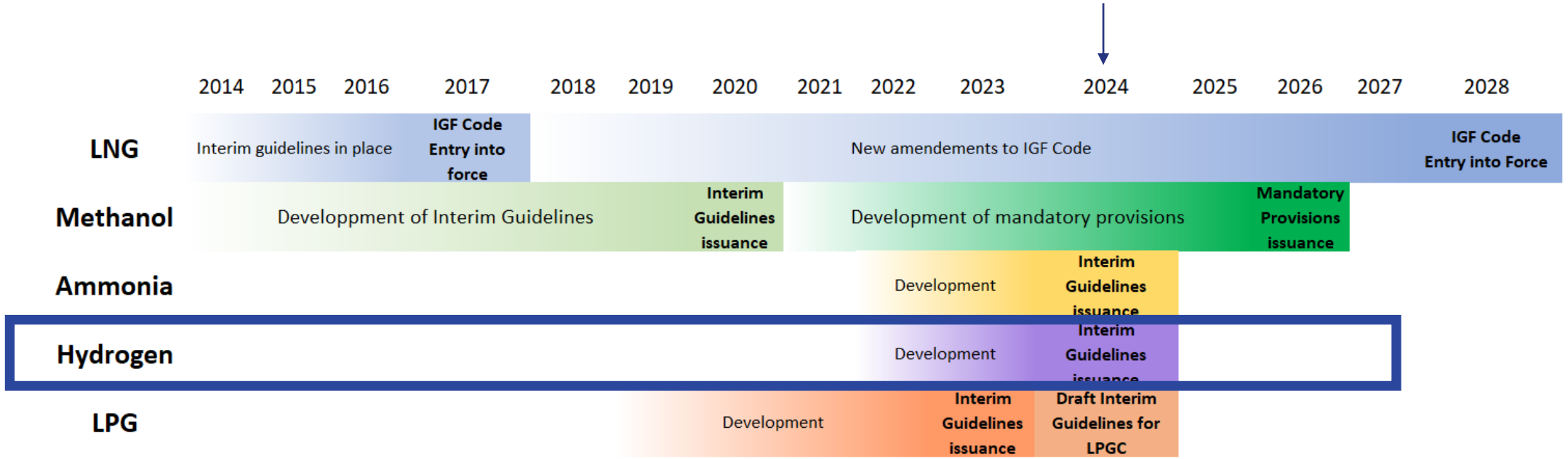
Control and monitoring is key

Specific safety aspects

- Compressed Hydrogen leakage at very high pressure
- Liquefied Hydrogen: Clogging, Oxygen stratification, boil-off management

IMO – Alternative fuels

IMO Sub-Committee on Carriage of Cargoes and Containers ("CCC") *(caretaker of IGF and IGC Codes)*
IMO Maritime Safety Committee (MSC)



TODAY, all new fuels
(LPG, Methanol, Hydrogen, Ammonia), except LNG,
are under "Alternative Design" scheme of IGF Code,
Before "Interim" becomes "Mandatory"
Meaning "Flag" will matter !

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Hydrogen as fuel – Bureau Veritas rules

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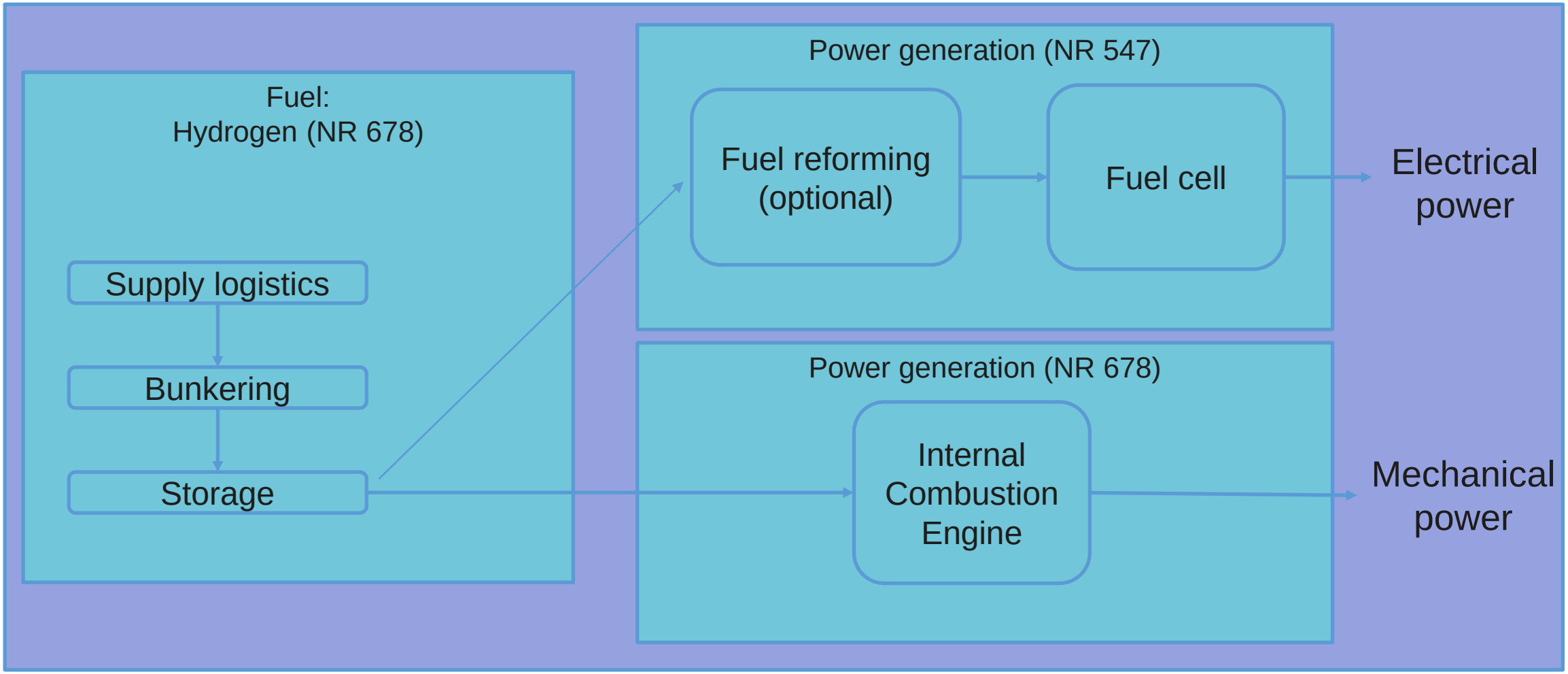
Hydrogen as fuel – Bureau Veritas rules



Bureau Veritas work in hydrogen as fuel and fuel cells

Approval In Principle

- OEM Fuel Cell : Approval-in-Principles delivered
- More OEM Fuel Cell (ongoing, confidential)

Ship concepts : Tug boat, Patrol, Pax ship, Cruise ship, LNG carrier

Classification - 7 projects Hydrogen + 2 projects reforming Hydrogen:

- Dredger “Hydromer” 70m : ONGOING
- Inland vessel “Zulu 06”, 55m : ONGOING
- Coastal vessels “Bastia school” and “Lorient Rade ” : ONGOING
- Containership 200m 2,000 TEU : ONGOING
- Buoy layer 54m : ONGOING
- Deckship Penguin Tenacity (retrofit) ONGOING
- Cruise ship “MSC World Europa” (LNG)
- Bulk carrier (retrofit, methanol) ADVENT
- Chemical tanker (retrofit, methanol) TECO2030

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Take aways – Hydrogen as marine fuel

Hydrogen is an interesting candidate marine fuel as:

- The molecule contains no carbon and can be produced with low GHG emissions
- It can be used in both fuel cells and internal combustion engine

The Challenges and Hazards are identified

Thank you

Rules and Standards are available from Class and in development at IMO level

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