Hydrogen Developments at CMB Technologies

March 2019

CMB
Technologies

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- Why focus on Hydrogen?
- Why hydrogen combustion engines?
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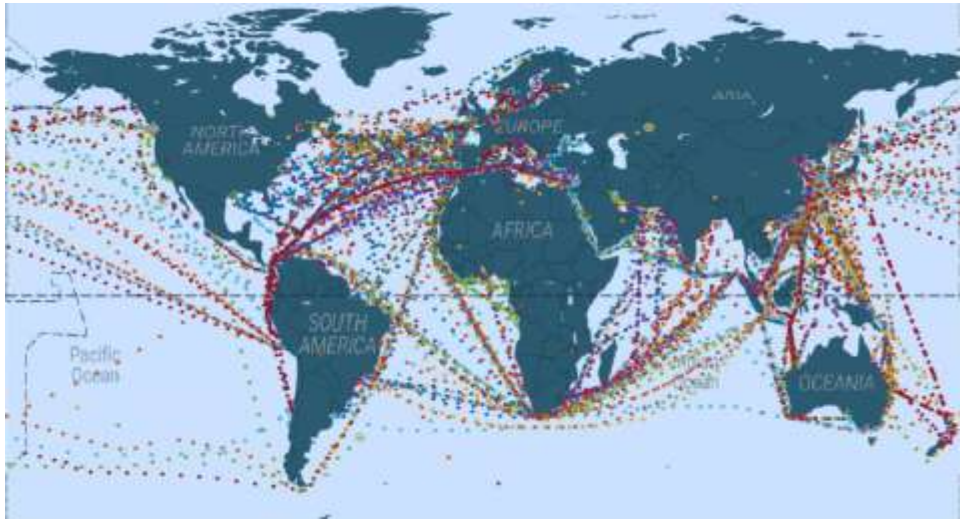
CMB (Compagnie Maritime Belge) owns/operates 90 ships

- CMB is a maritime group with its registered office in Antwerp and was founded in 1895.
- The group consists of 4 divisions:
  - ➢ Bocimar: active in dry bulk shipping
  - ➢ Delphis: container fleet, mainly ice classed
  - ➢ Bochem: chemical tanker fleet
  - ➢ CMB Technologies

CMB Technologies

CMB Technologies is the Innovation & Development division of CMB

- The division focusses on:
    - ➢ Fleet Performance Monitoring
    - ➢ Weather routing software
    - ➢ On-board battery pack to reduce emissions for redundancy power
    - ➢ Hydrogen technology
    - ➢ Waste heat recuperation
- Goals:
    - ➢ Implementation of cost saving technologies
    - ➢ Improvement of the operational performance
    - ➢ Reduction of emissions
    - ➢ Assure that the new builds are future proof



To achieve 'green shipping', Hydrogen technology is the way forward

- Batteries: Ships require a large energy buffer, resulting in a battery size which is too large, too heavy and too expensive. There are no means to charge this battery during port call;
- Photo-Voltaic panels: the ship's surface is not big enough to even provide 10% of the required power;
- Wind energy: more interesting for slow sailing vessels. Deck space is challenging, but with a projected saving of 10-30% the IMO limit of 50% GHG reduction can not be reached;
- Nuclear: too expensive, not insurable, requires too much personnel;
- Bio fuel: not enough biomass available;
- E-fuels:
    - Ammonia: toxic, ADR complexity and produces more NOx during combustion;
    - Methanol: interesting fuel but emits CO_2 during combustion and it will be difficult to prove that original CO_2 was captured from the air;
    - DME: same as methanol, it still emits carbon.

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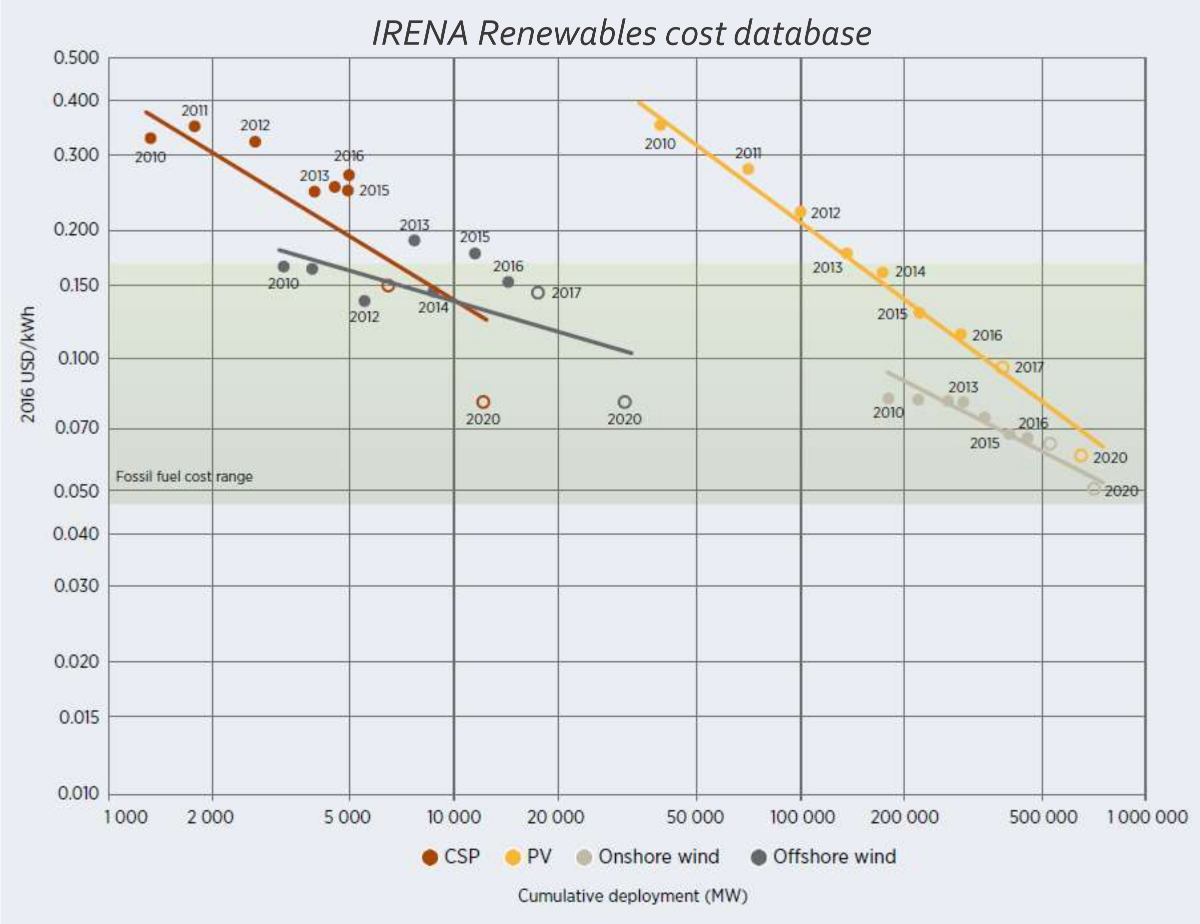
Price of green Hydrogen is dropping every year

- The more renewables such as wind and photovoltaic energy are installed, the more need there will be for a grid stabilizing/storage technology.
- Batteries are too expensive to be used for seasonal storage of energy. By far H_2 is the cheapest way of storing energy. We need to store as molecule not as electron.
- Price of renewables is dropping every year and the hydrogen electrolyser are following the same trend.
- Nowadays, once can already produce green hydrogen in Australia/Chile with existing technology which is cheaper than diesel!



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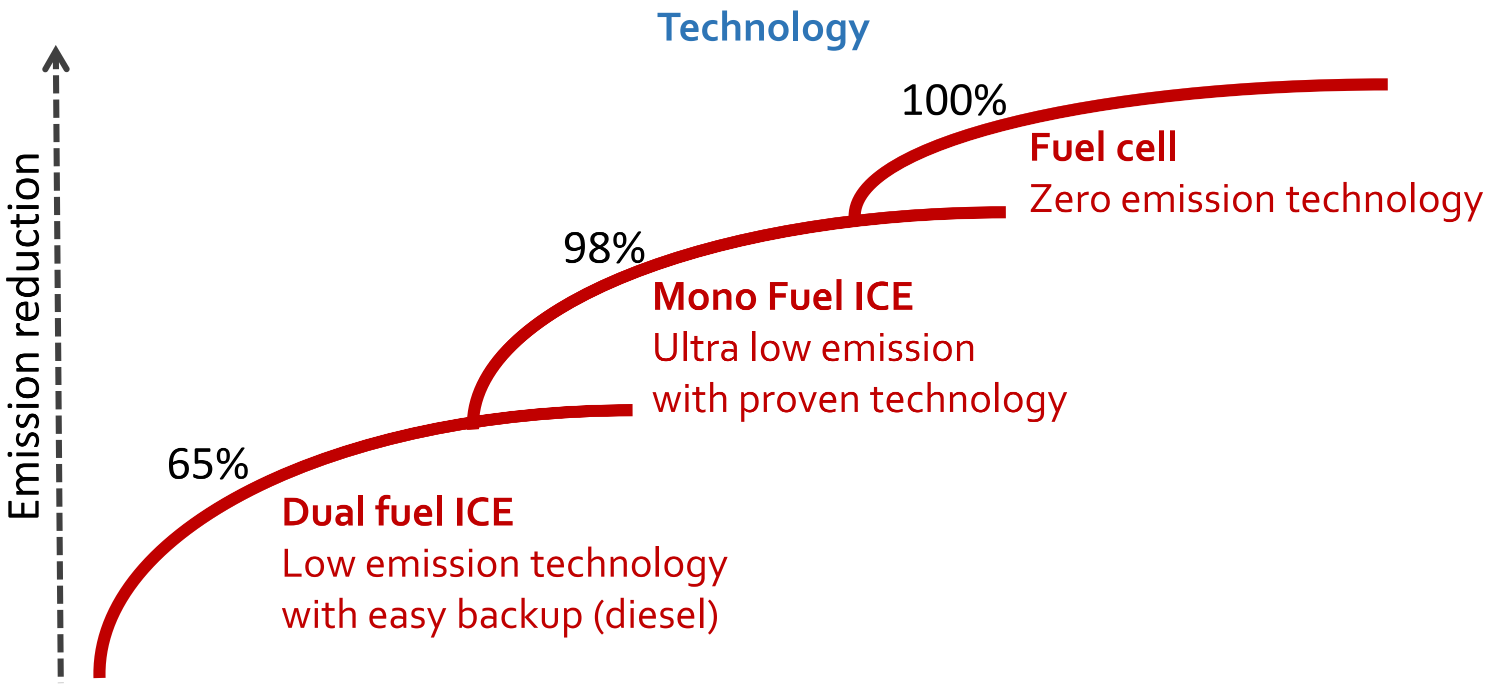
Before 'zero emission technology' can be used widely, one needs a 'low emission technology' as kick starter

- Zero emission applications require innovations at 3 domains:
  - Hydrogen <u>supply</u>: H_2 purity of 99,995% is required. Also the refuelling/bunkering station must be operational (in reality only 70-98% uptime)
  - Proven H2 <u>storage</u> system: large enough to have a realistic autonomy with some backup fuel quantity
  - Hydrogen <u>Fuel Cell</u>: FCs are still novel technology and are not yet proven in the demanding transport industry (salt, dust, degradation & lifetime issues)
- Innovation on 3 domains implies risks, which restrain fleet owners to invest massively in this technology. A dual fuel combustion technology can mitigate these risks.
- Dual fuel technology is the transition technology enabling the H_2 supply and the H_2 storage technology to mature and to create a market for hydrogen as a fuel.
- Dual fuel hydrogen diesel combustion engines are a low carbon technology. Without hardware modifications to the engine (so only software tuning for the hydrogen combustion), reductions of 65% up to 85% can be achieved.

Heavy industries (such as shipping) require incremental innovation instead of disruptive innovation

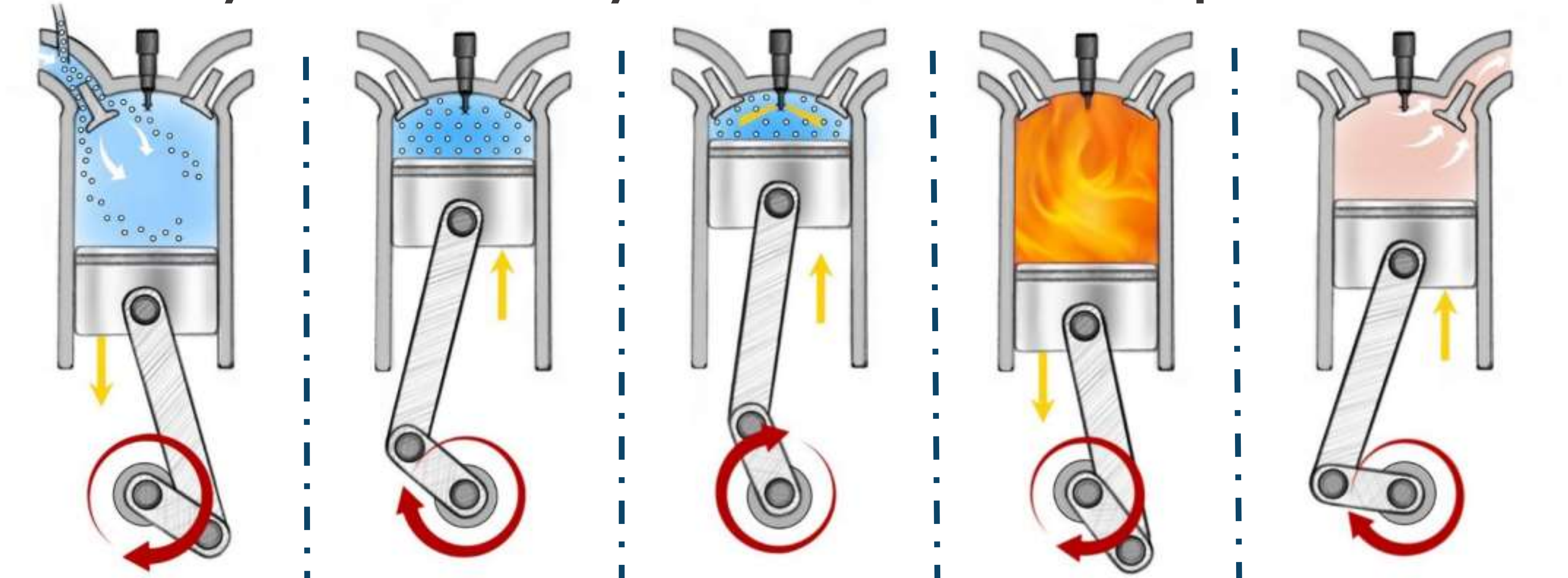
- Most people are convinced that hydrogen is the future solution to make the energy transition happen, but how to get there is still unclear for heavy industries.



Power	H_2 source	Storage/refuelling
M/E + A/Es	Green H_2 99,99% pure	High availability
A/Es		Widely spread H_2 refuelling options + high reliability
A/E	Chemical waste H_2	H_2 storage to cover >90% of all voyages

➔Dual fuel technology is the first step towards the zero emission goal, while the service can be guaranteed as one always can rely on diesel

Hydrogen-Diesel co-combustion: ability to combine fuel flexibility and efficiency with environmental performance



1. Hydrogen is injected at the port and aspirated in the cylinder during intake stroke
2. Hydrogen mixes further into a uniform and homogeneous mixture during the compression stroke
3. A small amount of pilot fuel (diesel) is injected into the chamber just before top dead centre
4. Diesel auto-ignites (due to high temperature and pressure) and co-combusts with all the H_2, forcing the piston down during the power stroke
5. The cylinder is cleaned during the exhaust stroke, having lower NO_x and CO_2 emission in the exhaust gas

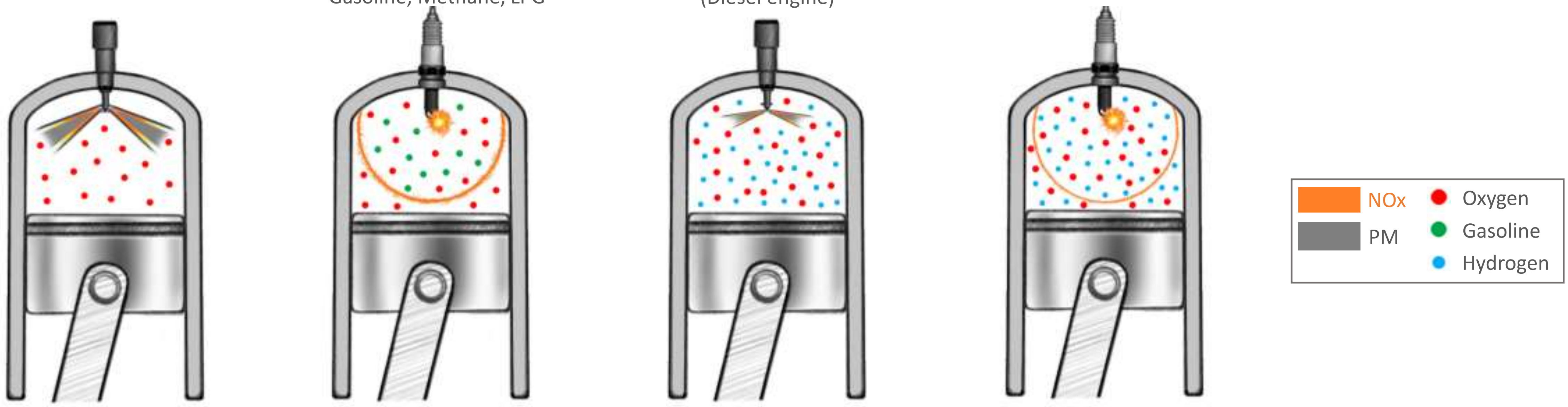
Mono fuel H_2ICE is already tested successfully

Compression ignition
(Diesel cycle)

Spark ignition
(Otto cycle)
Gasoline, Methane, LPG

Co-combustion
Hydrogen – diesel
(Diesel engine)

Hydrogen Mono-fuel
Spark ignition



High efficiency
but more **NO_x** and **PM**

Less soot & NO_x
But **lower efficiency** due to throttling losses (➔more GHG emissions) due to lower compression ratio to avoid knocking

High efficiency with low emissions
Diffusion rate of H_2 is higher than with other gases so it mixes naturally into a homogeneous mix
Very lean combustion (lambda>2)
Higher thermal efficiency due to smoother combustion

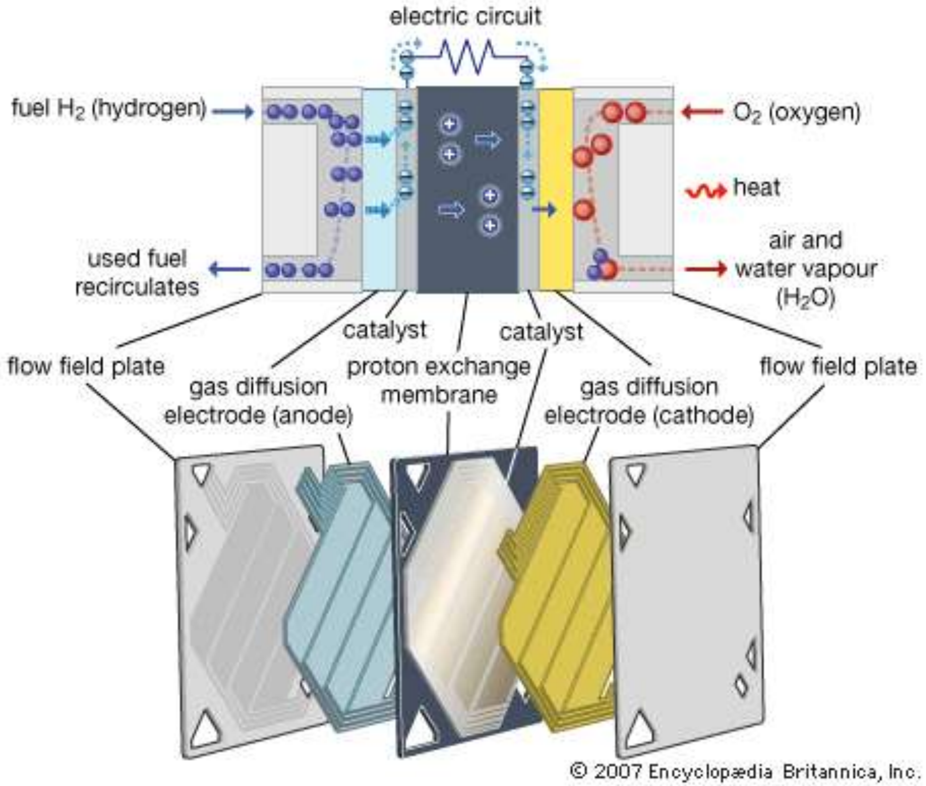
Nearly **Zero-emission**
High lambda value for low NO_x and high efficiency of diesel engine. But larger engine size required due to reduced power output

2 new types of hydrogen engines are currently being developed

- Volvo Penta D13-1000hp (2300RPM):
  - ➢ Suitable for crew transfer vessels, patrol boats, gen-sets, trucks, heavy duty (mining) vehicles, etc.
  - ➢ D13 has a yearly production volume of 85.000 pieces and has the newest injection technology with a twin turbo and steel pistons.
- Medium speed engine (1000RPM):
  - ➢ Joint Venture between ABC Engines and CMB;
  - ➢ Due to low rotation speed, high efficiency is obtained;
  - ➢ Lifetime of >150.000h with low maintenance cost;
  - ➢ Power range of 0,8–3MW (L6→ V16);
  - ➢ Available as dual fuel as well as mono fuel
  - ➢ Mono fuel has NO_x emissions less than 1/10th of IMO Tier III

A Fuel Cell is better at lower loads, but a hydrogen combustion engine performs better at higher loads

- Although the FC stack has a high efficiency, the system losses due to auxiliary components decreases the overall efficiency.
- The larger the FC, the higher the losses and the more complex the system becomes. Combustion engines show the opposite trend, the larger the more efficient (>50% efficiency for a large 2 stroke marine engine).
- A combustion engine just uses larger cylinders, while a FC can't scale up without having the complexity to explode.
- FCs tends to degrade in performance over time.
- FCs are sensitive to impurities (salt, dust) in the air which is needed in the core for a reaction with H_2



Hydroville Showcase Project

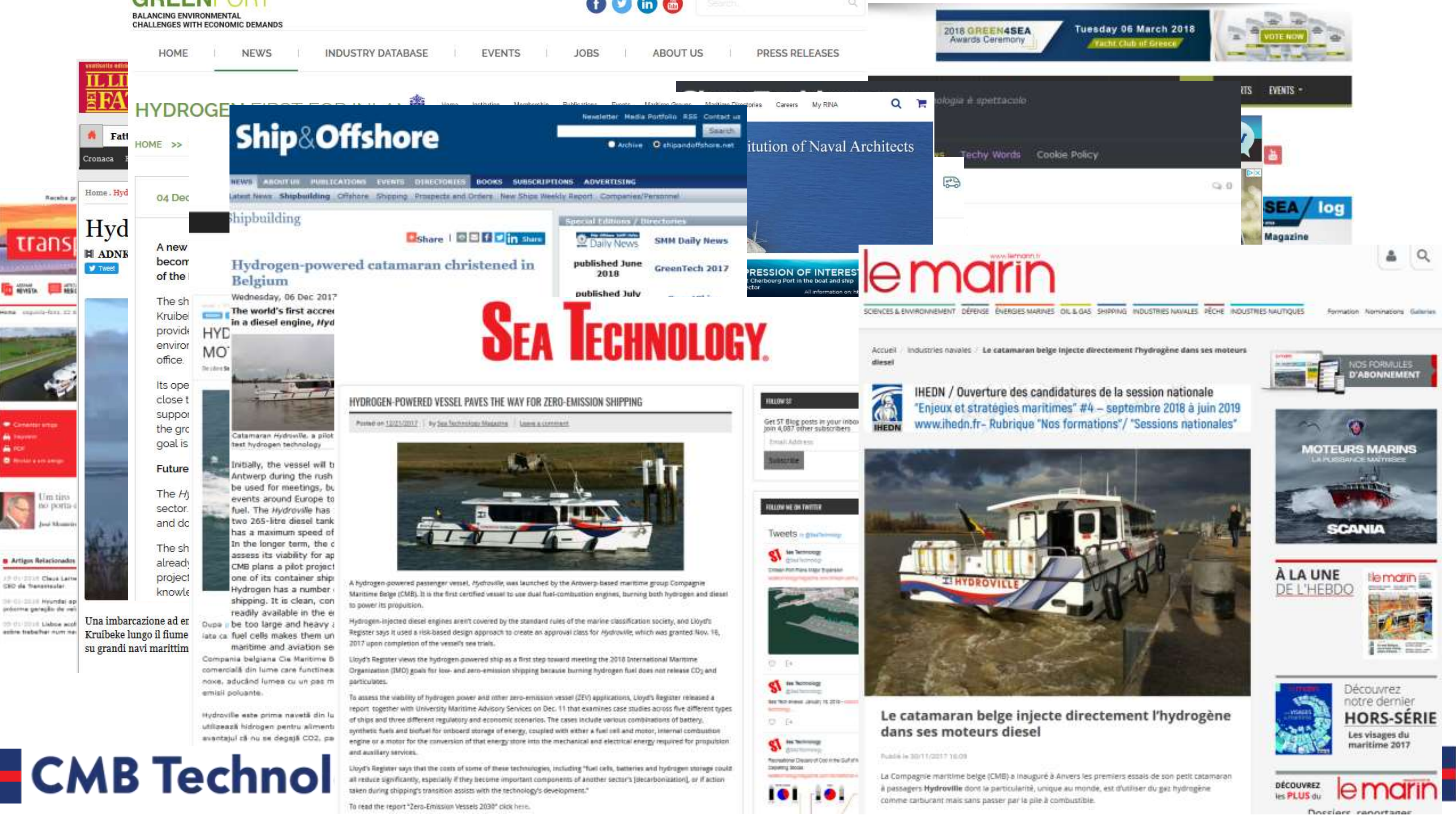
HYDROVILLE

https://www.youtube.com/watch?v=5kNxUqClDno

The complete project was realized within a timeframe of 1.5 year

- First ideas of the project were generated in June 2016
- By December 2016 the building contract was signed with the ship yard
- Plan approval by Lloyd's Register (hull & machinery)
- The vessel was christened in Antwerp on 29th of November 2017

https://www.youtube.com/watch?v=HkOSvV-UvBg



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HYDROGEN-POWERED VESSEL PAVES THE WAY FOR ZERO-EMISSION SHIPPING
A hydrogen-powered passenger vessel, Hydroville, was launched by the Antwerp-based maritime group Compagnie Maritime Belge (CMB). It is the first certified vessel to use dual fuel-combustion engines, burning both hydrogen and diesel to power its propulsion.
le marin
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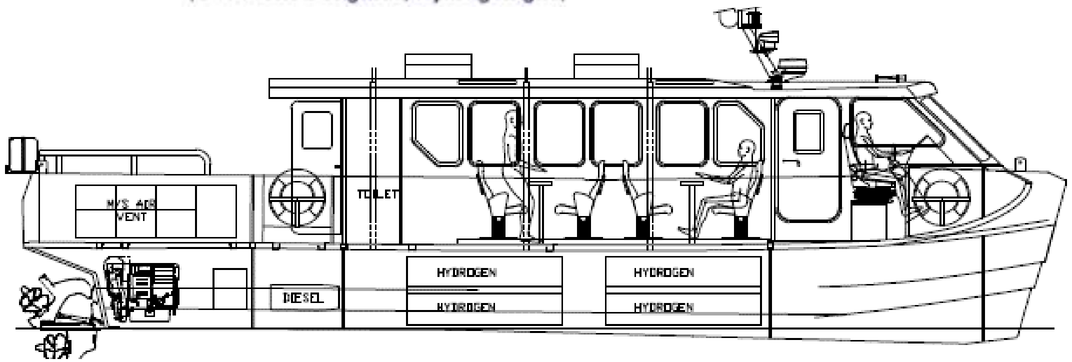
Le catamaran belge injecte directement l'hydrogène dans ses moteurs diesel
La Compagnie maritime belge (CMB) a inauguré à Anvers les premiers essais de son petit catamaran à passagers Hydroville dont la particularité, unique au monde, est d'utiliser du gaz hydrogène comme carburant mais sans passer par la pile à combustible.
HYDROVILLE
Una imbarcazione ad er
Kruibeke lungo il fiume
su grandi navi marittim
CMB Technol

Hydroville: Hydrogen Powered Catamaran (hi-speed with non-planing hull)

GENERAL SPECIFICATIONS

Passenger shuttle

Length	14 m
# of passengers	16
Beam	4.2 m
Max Draft	0.65 m
Displacement at full load	14 ton
Lightweight	12 ton
Propulsion	2x dual fuel (diesel and hydrogen) internal combustion engines (H2ICED) with a total shaft power of 441kW
Fuel	12 hydrogen tanks (205 liter @ 220bar or 36kg of useable hydrogen) and 2 diesel fuel tanks (2x265 liter) as pilot/backup fuel
Max speed	27 kn
Cruise speed	22 kn
Classification notation	Lloyd's Register ✠100A1 Special Service Craft, Crewboat, Catamaran, High Speed Craft, G2, MCH Descriptive note for Low Flash Point Fuels (Gas fuelled engines, Hydrogen gas)

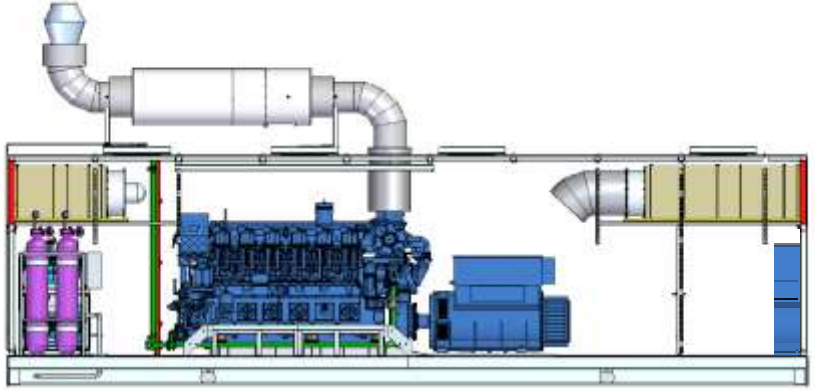


SPECIFICATIONS H_2 TANKS

Cylinder life	20 years
Weight	66kg (35kg aluminium liner, 31kg composite laminate)
Water volume	205 liter
Service pressure	200 bar
Max. developed pressure	260 bar
Test pressure	300 bar
Min. burst pressure	558.4 bar
Working temperature	-40°c to +82°c
Hydrogen Cylinders Frame Structure	Stainless steel 316L
Supported frame accelerations	Forward 12g, afterwards 2g, transverse 2g, vertical 2g

Ongoing Hydrogen projects

Cold ironing with clean technology



- Marine gen-set delivers automatically at correct Voltage/Frequency next to the vessel ➔ no expensive power converters required.
- Mobile & safe solution, available as mono fuel as well as dual fuel.
- Up to 2,5 MW power available.
- 1x 40ft container can hold up to 1ton of H_2, enough to run for 24h on 100% pure hydrogen at 700kW hotel load avoiding **10 tons of CO_2 a day** while all **soot, SO_x and 95% of the NO_x** are saved from the port location.
- Low pressure H_2 piping can provide fuel for the cold ironing gen set.

A hydrogen powered container can also be placed within the cell guides of a container vessel

- With 10 skids of compressed hydrogen storage, the engine could save 65 tons of CO_2 on a weekly basis (=~ 735 cars).
- The H_2 gen set will be connected to the onboard cold ironing system, the water cooling and MGO supply.
- Easy and fast way to gather experience with this promising technology, without investing in an expensive and time consuming retrofit.

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A Hydrogen auxiliary engine on a bulk carrier can save up to 135 ton CO2 per voyage

- The aft deck can hold up to 24 FEU low cost containers with pressurized hydrogen which can be used to power the A/Es during a 2 weeks voyage.
- Novel H_2 storage technologies are being tested and will be applicable within 3y time, but we can already start with compressed H_2 today.

A new Hydrocat is being developed to be operated at an offshore wind park at the North Sea

- Dual fuel capability diesel – hydrogen
- Daily hydrogen refuelling of 170kg @350bar

Other industrial applications with H_2 combustion engines can be envisaged to obtain the scale up effect

Hydrogen powered gen-set of 40kW, saving up to 500kg of CO_2 a day

Iron ore freight trains running on dual fuel H_2 can save up to 35ton CO_2 per train per day

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Currently, Port of Antwerp already produces 36,000 tons of Hydrogen a year

- Hydrogen is a base element for the chemical industry
- Often, it is produced as a waste gas:
    - ➢ Chloralkali process (Inovyn)
    - ➢ Recently accounced 4,5B€ investment by Borealis & INEOS for the dehydrogenation of propane
- Chemical industry has 50y of experience
- Hydrogen is used for:
    - ➢ Fertilizer production
    - ➢ Steel making
    - ➢ Glass industry
    - ➢ Food industry
- Already 1600km of H_2 pipelines in BeNeLux

1MW PEM electrolyser and refuelling station is already ordered and will be installed during fall 2019

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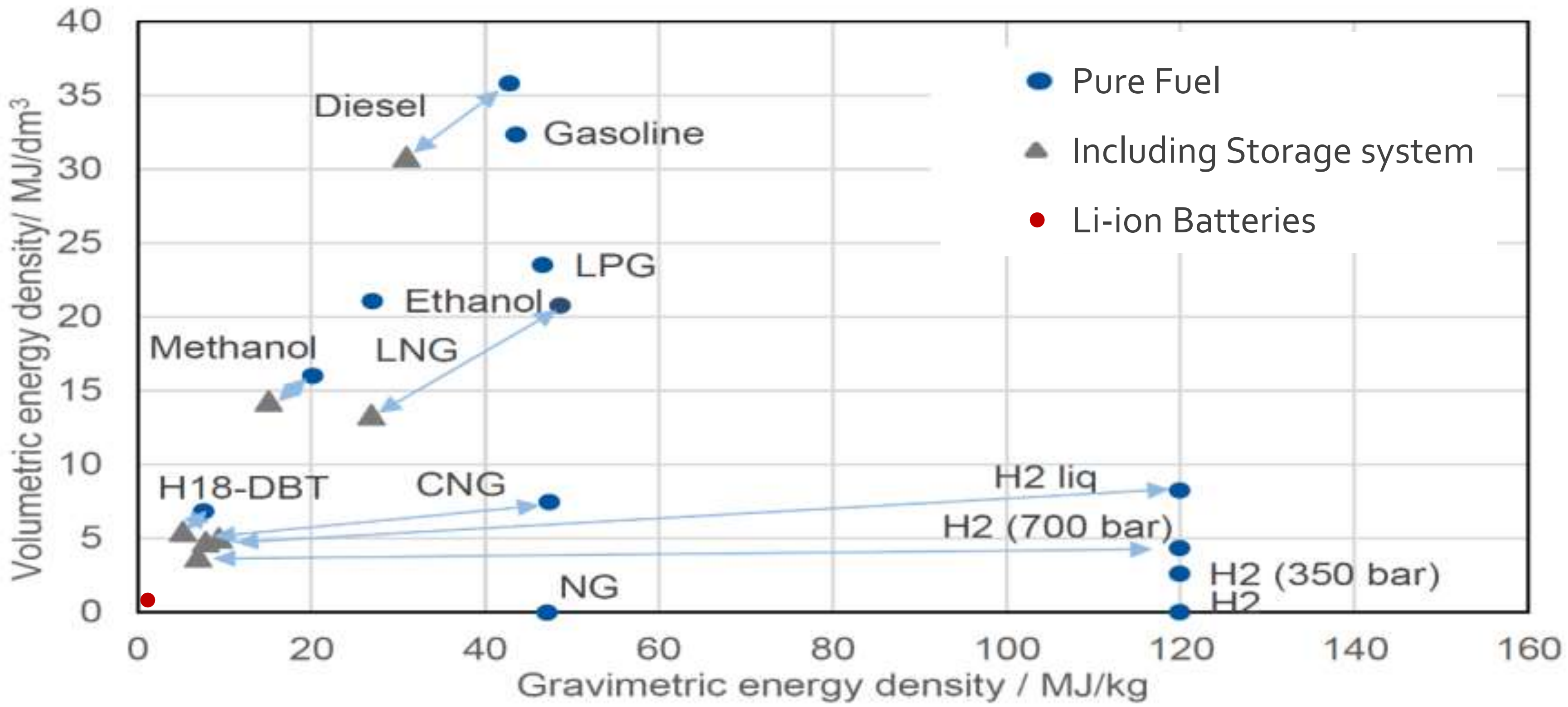
For shipping, storage of Hydrogen is the main challenge

- Deep sea going vessels are high consumers of energy.
- Up to 700ton of MGO is consumed for a single trip of a capesize bulk carrier. This covers up to 95% of all voyages.
- Storage tanks up to 4000 ton are not uncommon for these ships.
- If we need to use a low carbon fuel, the autonomy of the vessel will be reduced or we have to increase the fuel storage
- Liquid and compressed H_2 is not favoured
- LOHC (Liquid Organic Hydrogen Carrier) seems the most promising technology

Fuel Type	Net weight [ton]	Gross weight [ton]	Net Volume [m³]
MGO	700	749	777
LNG	568	965	1,351
Methanol	1,599	1,791	2,015
H_2 (300bar)	233	13,000	11,650
H_2 liquid	233	420	3,281
LOHC (6,5wt%)	3,590	3841	3,985
Ammonia	1,694	NA	2,320

We have to accept that we never will match the properties of Diesel

- Liquid hydrogen has a low density (14 times lower than water)
- 1kg of hydrogen contains 237x the energy within 1kg of Li-ion batteries



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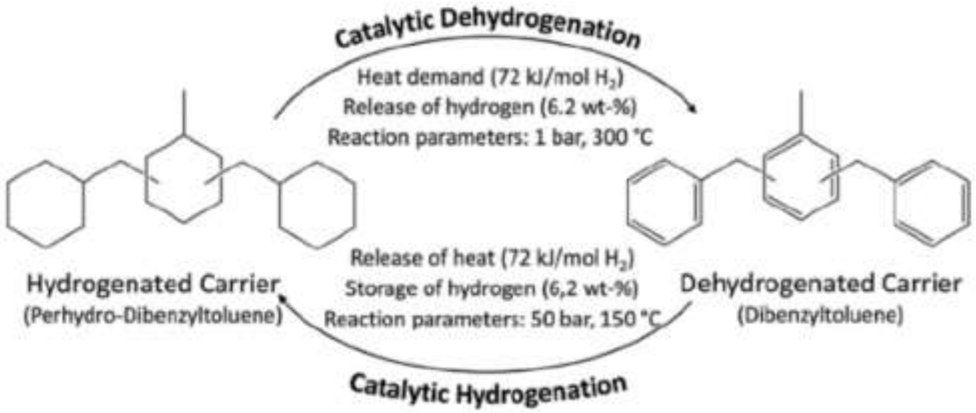
Liquid Organic Hydrogen Carrier (LOHC) is a promising solution for ships

- LOHC is **compatible with existing infrastructure**
- Dibenzyltoluene can store/release hydrogen up to 6.2% of its weight
- Suitable for long term storage, safe transport, non ADR (United Nations treaty that governs transnational transport of hazardous materials), non toxic, high flash point
- A liquid can be **stored inside structural strength holds** (=no loss of cargo space)
- A liquid can be **pumped easily** in high volume with a bunker barge alongside (no special bunkering movement required)
- Exothermic reaction of the hydrogenation can be valorised for district heating, so the marine engines can have efficiency up to 70%
- Proven technology which needs to be scaled up to be fitted on a vessel



Besides H_2 combustion engines, CMB can provide key knowledge

- CMB technologies can also offer:
  - Key knowlegdge about hydrogen technology
  - A supplier network for components, valves, pipes, sensors, etc
  - Assistance during risk analysis and risk mitigation:
    - HAZID (Hazard Identification)
    - HAZOP (Hazard and Operability Analysis)
  - Field experience with the technology
  - Project management for hydrogen projects
- Our knowledge assures that the project can be run at limited costs within the agreed time frame.

Q&A

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