Hydrogen Developments at CMB Technologies

March 2019
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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

![Map of CMB offices and headquarters](image)

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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 CO2 during combustion and it will be difficult to prove that original CO2 was captured from the air;
  - DME: same as methanol, it still emits carbon.
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 $\text{H}_2$ 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!
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 supply**: H₂ purity of 99.995% is required. Also the refuelling/bunkering station must be operational (in reality only 70-98% uptime)
  - **Proven H₂ storage system**: large enough to have a realistic autonomy with some backup fuel quantity
  - **Hydrogen Fuel Cell**: 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 H₂ supply and the H₂ 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.
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.

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

- 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.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Power</th>
<th>H₂ source</th>
<th>Storage/refuelling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel cell</td>
<td>M/E</td>
<td>Green H₂ 99,99% pure</td>
<td>High availability</td>
</tr>
<tr>
<td>Mono Fuel ICE</td>
<td>+ A/Es</td>
<td></td>
<td>Widely spread H₂ refuelling options + high reliability</td>
</tr>
<tr>
<td>Dual fuel ICE</td>
<td>A/E</td>
<td>Chemical waste H₂</td>
<td>H₂ storage to cover &gt;90% of all voyages</td>
</tr>
</tbody>
</table>
Hydrogen-Diesel co-combustion: ability to combine fuel flexibility and efficiency with environmental performance

Hydrogen is injected at the port and aspirated in the cylinder during intake stroke.

Hydrogen mixes further into a uniform and homogeneous mixture during the compression stroke.

A small amount of pilot fuel (diesel) is injected into the chamber just before top dead centre.

Diesel auto-ignites (due to high temperature and pressure) and co-combusts with all the H₂, forcing the piston down during the power stroke.

The cylinder is cleaned during the exhaust stroke, having lower NOₓ and CO₂ emission in the exhaust gas.
Mono fuel H₂ ICE is already tested successfully

**Compression ignition** (Diesel cycle)
- High efficiency but more NOx and PM

**Spark ignition** (Otto cycle)
- Gasoline, Methane, LPG
- Less soot & NOx, but lower efficiency due to throttling losses (more GHG emissions) due to lower compression ratio to avoid knocking

**Co-combustion**
- Hydrogen – diesel (Diesel engine)
- High efficiency with low emissions
  - Diffusion rate of H₂ 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

**Hydrogen Mono-fuel**
- Spark ignition
- Nearly Zero-emission
  - High lambda value for low NOx 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\textsubscript{x} emissions less than \(1/10\)th 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$_2$.
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
Le catamaran belge injecte directement l'hydrogène dans ses moteurs diesels

La Compagnie maritime belge (CMB) inaugure à Anvers les premières essais de son petit catamaran à passagers Hydronaute dont la particularité, unique au monde, est d'utiliser du gaz hydrogène comme combustible. Le navire belge est le premier du genre dans le monde de la marine commerciale et est l'aboutissement d'une collaboration entre l'Institut Naval Architects et le groupe de recherche CPMF (Comité de promotion de la marine marchande).
Hydroville: Hydrogen Powered Catamaran (hi-speed with non-planing hull)

**GENERAL SPECIFICATIONS**

**Passenger shuttle**

- Length: 14 m
- Number of passengers: 16
- Beam: 4.2 m
- Max Draft: 0.85 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 441 kW
- Fuel: 12 hydrogen tanks (205 liter @ 220 bar or 38kg of useable hydrogen) and 2 diesel fuel tanks (2x265 liter) as pile/backup fuel
- Max speed: 27 kn
- Cruise speed: 22 kn
- Classification notation: Lloyd’s Register 100A1 Special Service Craft, Crewboat, Catamaran, High Speed Craft, O2, MCH

*Descriptive note for Low Flash Point Fuels (Gas fuelled engines, Hydrogen gas)*

**SPECIFICATIONS H₂ TANKS**

- Cylinder life: 20 years
- Weight: 68kg (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

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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 H₂, enough to run for 24h on 100% pure hydrogen at 700kW hotel load avoiding 10 tons of CO₂ a day while all soot, SOₓ and 95% of the NOₓ are saved from the port location.
- Low pressure H₂ 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.
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 H₂ storage technologies are being tested and will be applicable within 3y time, but we can already start with compressed H₂ 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 H₂ combustion engines can be envisaged to obtain the scale up effect

Hydrogen powered gen-set of 40kW, saving up to 500kg of CO₂ a day

Iron ore freight trains running on dual fuel H₂ can save up to 35ton CO₂ per train per day
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 announced €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 H₂ pipelines in BeNeLux
1MW PEM electrolyser and refuelling station is already ordered and will be installed during fall 2019

1. 1MW PEM electrolyser
2. 30bar buffer tank
3. 4-stage 100bar compressor
4. 1 refilling station for cars (700bar)
5. 1 refilling station for buses and trucks (350bar)
6. Refilling station for 3 tube trailers (200bar)
7. Marine bunkering location (200 & 350bar)
For shipping, storage of Hydrogen is the main challenge

- Deep sea going vessels are high consumers of energy.
- Up to 700 ton 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 H₂ is not favoured.
- LOHC (Liquid Organic Hydrogen Carrier) seems the most promising technology.

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Net weight [ton]</th>
<th>Gross weight [ton]</th>
<th>Net Volume [m³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>MGO</td>
<td>700</td>
<td>749</td>
<td>777</td>
</tr>
<tr>
<td>LNG</td>
<td>568</td>
<td>965</td>
<td>1,351</td>
</tr>
<tr>
<td>Methanol</td>
<td>1,599</td>
<td>1,791</td>
<td>2,015</td>
</tr>
<tr>
<td>H₂ (300bar)</td>
<td>233</td>
<td>13,000</td>
<td>11,650</td>
</tr>
<tr>
<td>H₂ liquid</td>
<td>233</td>
<td>420</td>
<td>3,281</td>
</tr>
<tr>
<td>LOHC (6.5wt%)</td>
<td>3,590</td>
<td>3841</td>
<td>3,985</td>
</tr>
<tr>
<td>Ammonia</td>
<td>1,694</td>
<td>NA</td>
<td>2,320</td>
</tr>
</tbody>
</table>
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
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 \( \text{H}_2 \) combustion engines, CMB can provide key knowledge

- CMB technologies can also offer:
  - Key knowledge 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.