Challenges in Developing Hydrogen Supply Chains
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**HYDROGEN SUPPLY CHAINS and MARKETS**

- **Coal Gasification + CCS**
- **Gas Reforming + CCS**
- **Bio Reforming (+CCS?)**
- **Electrolysis**
- **Transport**
  - **LH$_2$/NH$_3$/LOHC**
- **Mobility**
  - Passenger
  - Freight
- **Power**
- **Industry**
- **Buildings**
  - Power
  - Heat
- **Aviation & Marine**

**Unique CVP**
- High efficiency
- Higher range than BeV (500 vs. 250km)
- Easily blended in gas turbine
- No need for CCS at plant
- Only real clean fuel solution
- Distributed power/heat, limiting electricity grid investments
- Clean
- High efficiency
H2 MOBILITY’S UNIQUE CVP

- Hydrogen Fuel Cell Electric has a clear range advantage, but Battery Electric is improving fast…

And a Premium Outlet


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Future Energy Transport: LH2

Import needs future energies

Source: Ecofys

[Graph showing energy demand by region and source, with categories for Ocean, Wind, Solar (Distributed), Solar (Centralised), Geothermal, Hydro-electricity, and Biofuels.]

[Images of solar panels, ship, and cityscape]
LH2 AN ATTRACTIVE OPTION FOR H2 TRANSPORT & STORAGE

Supply Chain: Green/Clean Prod (Middle East) → H2 → Storage → NH3/LH2/LOHC → Shipping (Cargo as fuel) → H2

Dehydrogenation energy “loss” gives away all the upstream advantages for NH3 & LOHC

Notes:
1. Production from NG + CCS or from large scale electrolysis using renewable energy, at a future assumed cost of 2 $/kg
2. Shipping costs similar for Ammonia, LOHC and LH2 as dominated by fuel costs (lighter cargo & high ship speed for LH2)
3. Dehydrogenation represents thermodynamic energy loss due to cracking, and is applicable also for the cases of direct use applications
BUT MANY CHALLENGES TO BE SOLVED IN SUPPLY CHAIN

### H₂ Liquefaction

- Bigger cold box & novel turbo machinery design for ultra-low temp & large scale production
- New refrigerants (He/Ne cycle) & efficient catalysis for ortho/para conversion

<table>
<thead>
<tr>
<th>Capital Intensity ($M/TPD)</th>
<th>Energy Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference (LNG)</td>
<td>$0.3</td>
</tr>
<tr>
<td>Incumbent</td>
<td>$0.7</td>
</tr>
<tr>
<td>Aspired (new cycle)</td>
<td>$0.5</td>
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</table>

### Bulk LH₂ Shipping

- Cargo containment systems to serve extreme Cryogenics & minimize boil-off product loss via H₂ propulsion
- Safe operation of loading, transit & offloading
- LH₂ Standards & Regulation

<table>
<thead>
<tr>
<th>Capital Cost ($MM)</th>
<th>Cargo (mT)</th>
<th>Cargo (mT LNG equiv)</th>
<th>Daily boiloff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference (QMAX)</td>
<td>$300 - $350</td>
<td>120,000</td>
<td>120,000</td>
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<tr>
<td>Aspired Design</td>
<td>$400</td>
<td>20,000</td>
<td>60,000</td>
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</tbody>
</table>

### H₂ Utilization (Demand)

- H₂ Mobility – Significant Retail Infrastructure CAPEX & Complexity
- H₂ Power – H₂/NG blend turbines (0 - 100%)
- H₂ Industry – Supply Infrastructure
- H₂ Buildings – Supply Infrastructure & Systems development needed
- H₂ Aviation/Marine – Reliability, testing

Most importantly, demand needs to be created in all these sectors globally so supply chain development investments can deliver on promise.