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Making Hydrogen work



The missing piece in the global hydrogen puzzle

2023

H2FUEL's Distinguished Proposition as First Mover in Solid Hydrogen

1 Opportunity to Tap Into **Soaring Hydrogen Market…**

Hydrogen is expected to become a **key driving force** for **cornerstone sectors of economy**, incl. Mobility, Power, Iron & Steel and Buildings, **satisfying 12% of global energy demand** in 2050, as well as a feedstock for multiple industrial products, **replacing fossil alternatives**

7x **expected increase in end-user demand, 2020-2050**

2 …via **Solving the Key Pain Point** of Hydrogen Economy…

Disconnect between production and consumption hubs is expected to give rise to global-scale transportation of hydrogen, **making efficient technology for hydrogen storage and transportation essential**

c.40% **end-to-end cost reduction compared to ammonia**[1]

3 ...through a **Breakthrough and Truly Circular** Solution…

Solid hydrogen is a powder at ambient conditions**,** has a **higher energy density**, is **safer** and **cheaper to handle** than ammonia, LOHC or LH2 and can be stored for many years without losing its energy

2-3x **higher energy density**

- **Non-flammable**
- **Non-toxic**
- **No loss in storage**

4 …with **Unique and Cost-Efficient** Technology

High full cycle efficiency including transport and storage and **direct and full hydrogen release** without adding further energy and circular

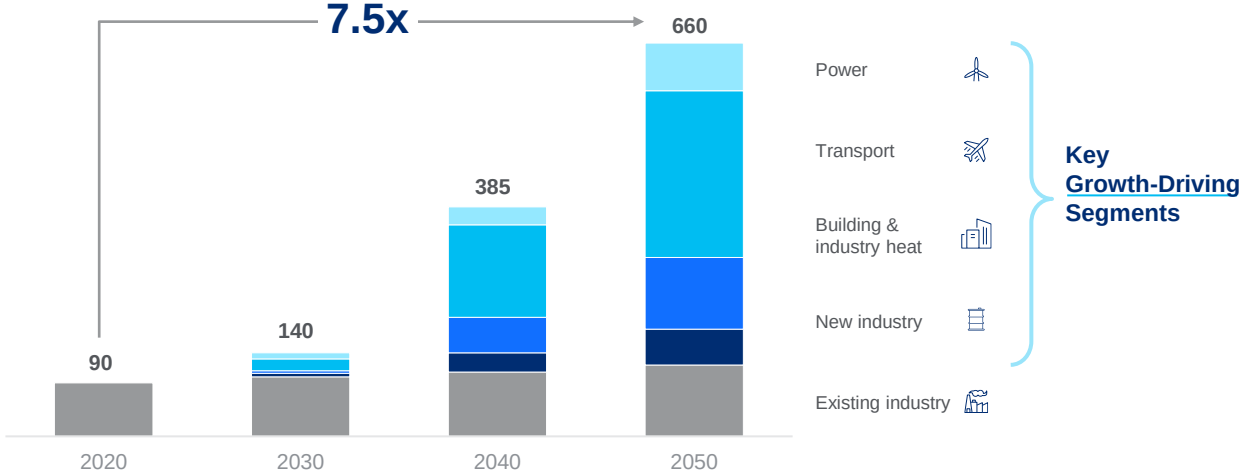
- **Release process proven**
- **Regeneration process advanced**

Source: McKinsey Energy Insights Global Energy Perspective; Hydrogen Council; McKinsey Hydrogen Insights; IHS Markit (Global Supply and Demand Trade Flow of Green Ammonia), Company data.
Notes: **1.** Exemplary route from Saudi to Germany.

Hydrogen is Essential to Decarbonization yet Constrained by Technology

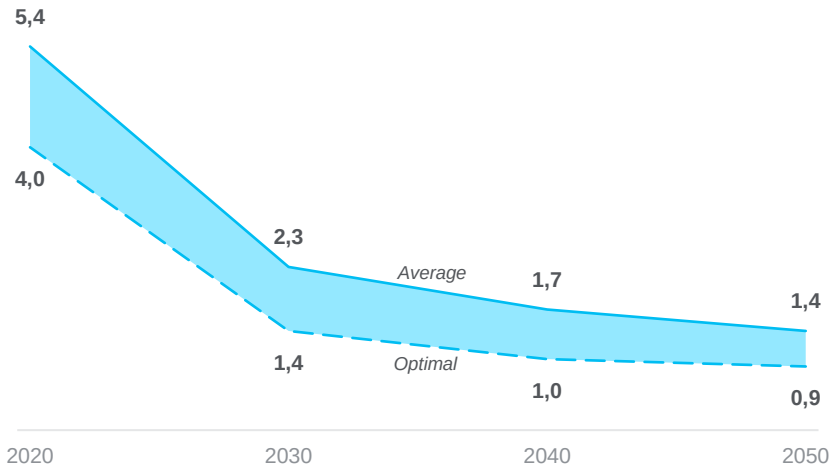
Green Hydrogen is a High Growth Market

hydrogen end-use demand by segment, million ton per annum (MT p.a.)



Supported by Diminishing Green Hydrogen Cost

production cost of green hydrogen (USD/kg)[1]



$2.00
Cost price at which green hydrogen **could become cost competitive**

>2.5x
Factor between markets with lowest and highest hydrogen production costs in 2050

33%
Of hydrogen produced at **< $1.00/kg** in 2050

However, There are Still Pain Points to its Scale-up

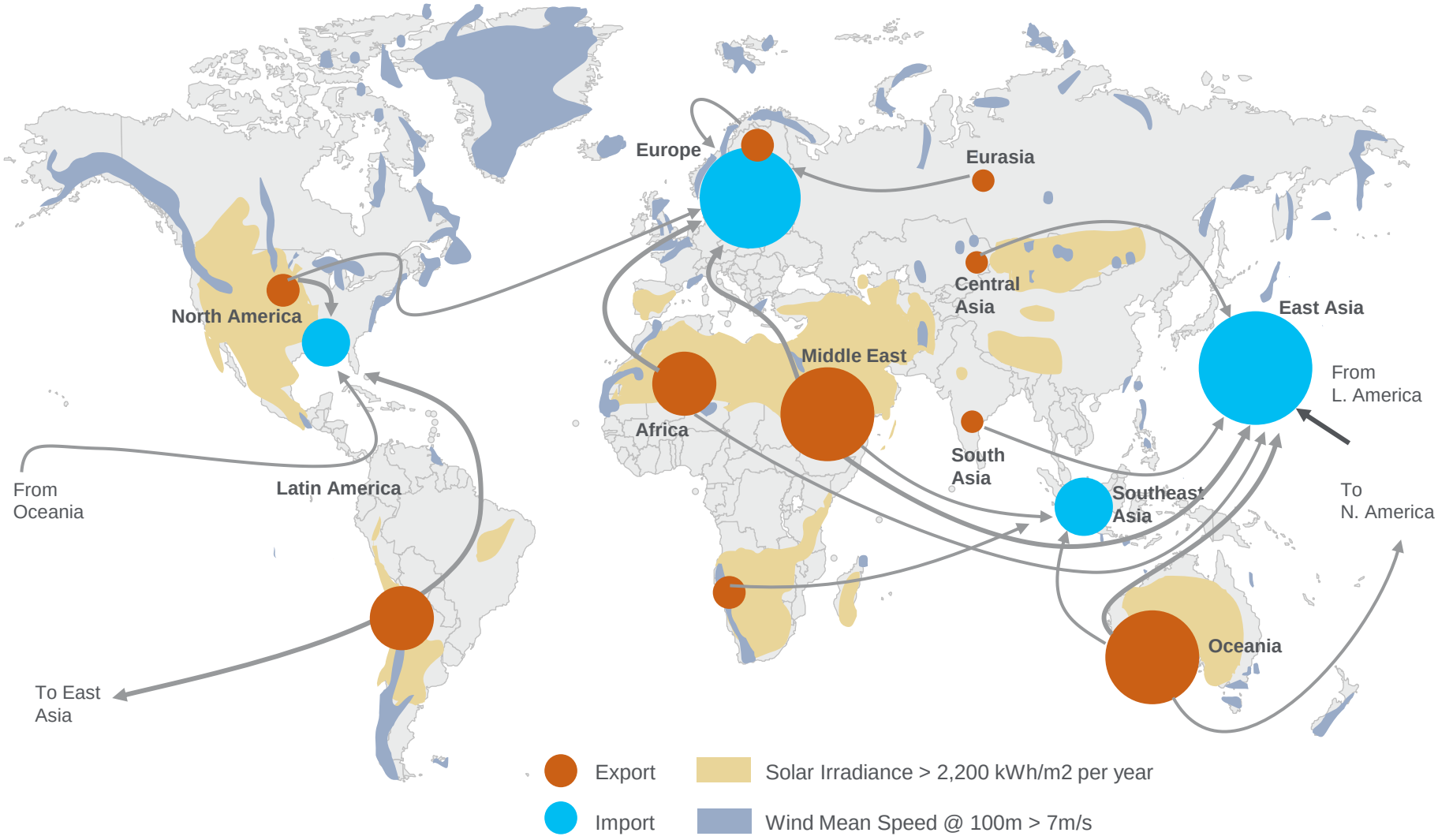
1. **Disconnect between production locations of cheap hydrogen ($1.5/kg) and consumption hubs driven by high transportation costs**
2. **Lack of hydrogen storage (particularly long-term) and distribution infrastructure**
3. **Low energy density of hydrogen and main carriers obstructs international trade**
4. **Safety concerns on storage and distribution**

Source: McKinsey Energy Insights Global Energy Perspective; Hydrogen Council; McKinsey Hydrogen Insights; McKinsey Sustainability.
Notes: **1.** Based on alkaline size classes of respectively 2 MW (2020), 20 MW (2025), and 80 MW (> 2030), and levelized energy costs ($/MWh) of 25–73 (2020), 13–37 (2030), and 7–25 (2050).

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Efficient Transportation is a Key to Unlock the Global Hydrogen Economy

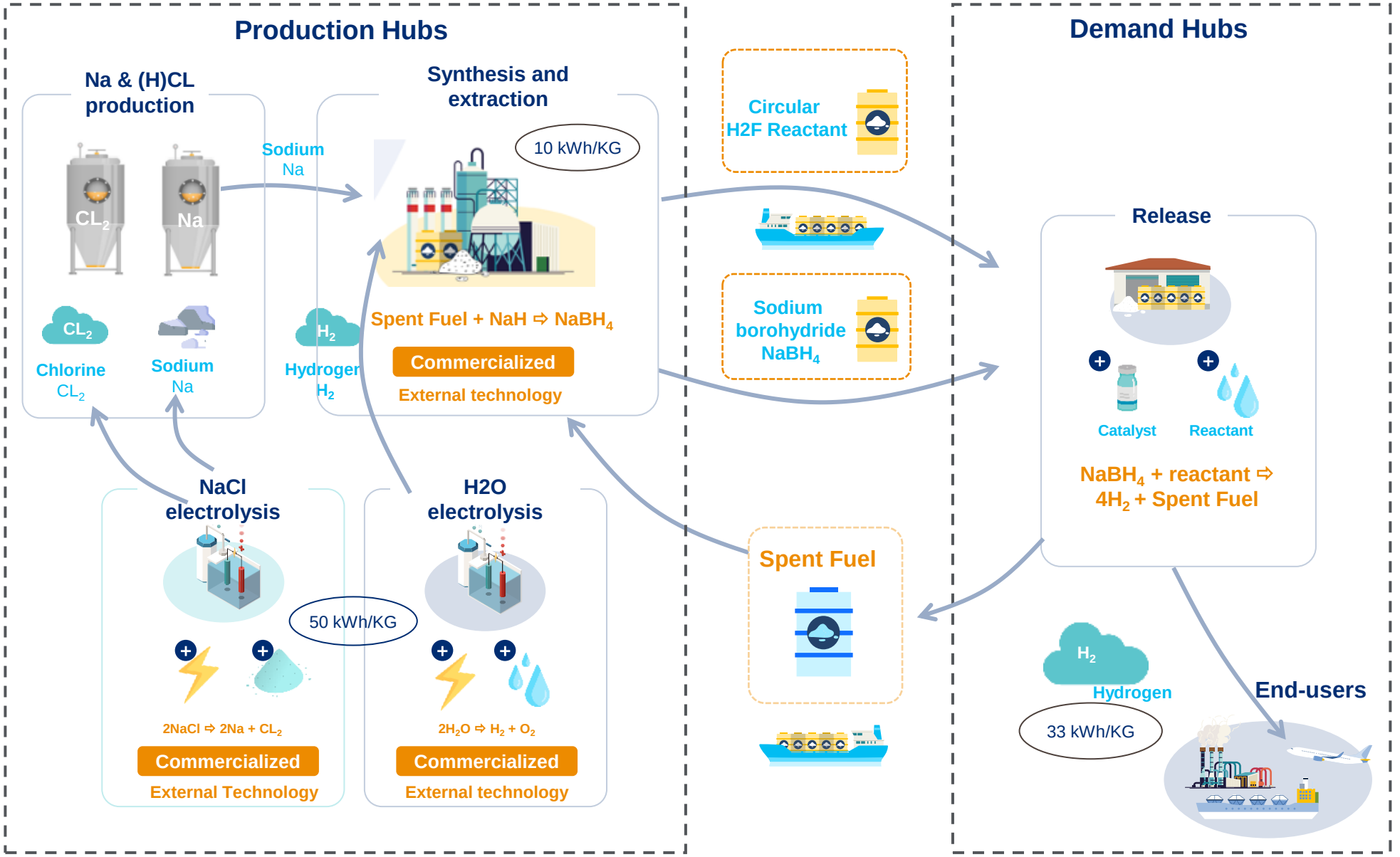
Disconnect between Consumption and Production Hubs due to Differing Availability of Renewables



Source: McKinsey Energy Insights Global Energy Perspective; Hydrogen Council; McKinsey Hydrogen Insights; IHS Markit (Global Supply and Demand Trade Flow of Green Ammonia).

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H2FUEL Developed Breakthrough and Truly Circular Technology



Source: University of Amsterdam research.

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H2FUEL Developed Breakthrough and Truly Circular Technology



The missing piece in the Hydrogen puzzle:

SOLID HYDROGEN

Transporting and storing hydrogen safely and economically

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Practical manageability

Safety/Calamaties:
- ✓ Non-explosive
- ✓ Non-flammable
- ✓ Non-toxic
- ✓ No leakage

High energy density:
- ✓ 2 – 4x higher than alternatives (Ammonia LOHC, Liquid Hydrogen)
- ✓ Energy density close to energy density of Diesel

Transport & Storage:
- ✓ Under atomospheric conditions (dry storage)
- ✓ No need for additional legal requirements
- ✓ No evaporation



Solid hydrogen (energy-dense powder, easy to transport)

Economic feasibility

Cost competitiveness versus alternatives:
- ✓ 20 – 35% cheaper transport & distribtion
- ✓ 80 – 95% cheaper Storage
- ✓ ~50% cheaper well to wheel and back again

On demand release:
- ✓ Exothermic process
- ✓ High purity (99.8%)
- ✓ Release bonus: 1 KG hydrogen storage → 2 KG hydrogen release

Circular process:
- ✓ Re-use of residual (so called 'Spent Fuel')
- ✓ Cost effective

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H2FUEL Solves Key Challenges of Hydrogen Economy

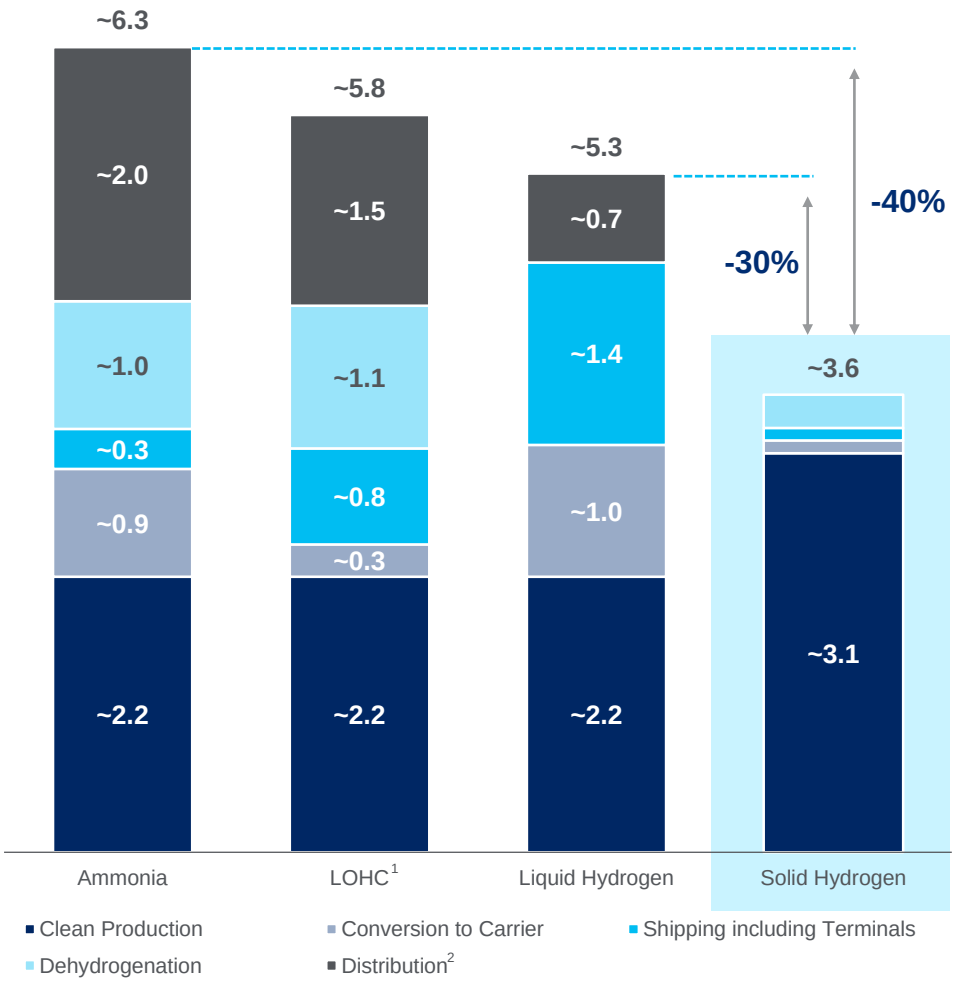
Key Challenges	H2FUEL Solution
1 High costs of transportation	• **virtually absent costs of transportation and distribution** compared to liquid hydrogen and ammonia • **the most competitive option** whenever there are no hydrogen pipelines in place
2 Expensive storage, particularly long-term	• **~85% lower long-term storage cost** compared to gaseous hydrogen • **short term storage ("firming") is cheaper than alternatives** whenever the end-user is not connected to a pipeline (nor close to cheap renewables)
3 Low energy density	• **2-3x higher energy density compared to other carriers** and similar to that of diesel
4 Safety considerations	• **not flammable, not corrosive, not toxic** hence requiring less safety considerations than alternative carriers • **comes in a powder form** as easy to transport and store as grain

Source: Company data.

Solid Hydrogen Offers a Solution to Handling Costs Problem

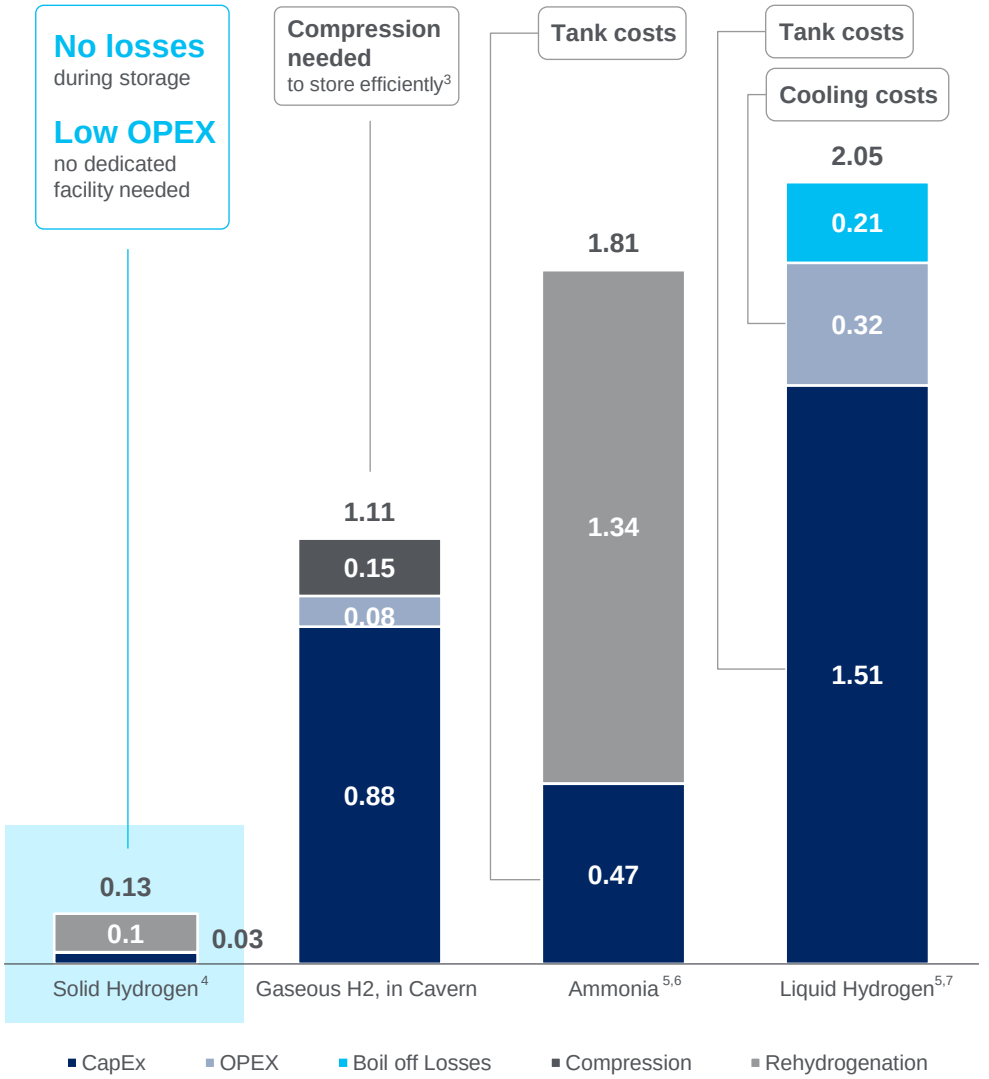
1 Solid H_2 End-to-End Costs are 30-40% Lower as Transportation Costs are Virtually Absent

2025 costs, exemplary route from Saudi to Germany (one-way), EUR/kg H_2



2 Storage Costs for Solid H_2 are Dramatically Lower

6 months storage costs in 2030, including rehydrogenation, EUR/kg H_2



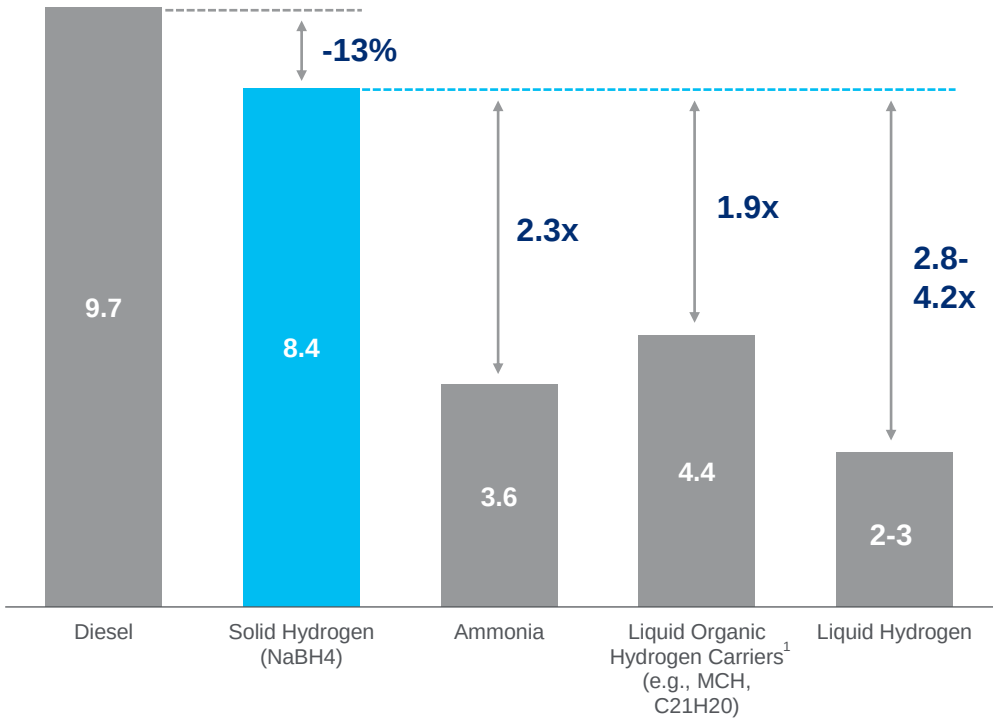
Source: Company data.
Notes: **1.** Liquid Organic Hydrogen Carriers. **2.** Assumes liquid (for liquid hydrogen, LOHC) or gaseous (for ammonia) distribution with truck for 300km at 500 bar, also includes: purification to FCEV standard using a PSA for LOHC and NH3, boil-off losses for liquid hydrogen, storage costs at port and HRS operating costs. **3.** Assuming cavern storage at 200 bar. **4.** Based on soy bean storage. **5.** Assuming 3.5 kt tank. **6.** Ammonia rehydrogenation includes cracking and purification. **7.** Not taking into account compression of hydrogen for liquefaction as part of the storage costs, as it is assumed the liquefaction will have happened prior to the storage.

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Unique Combination of High Energy Density and Usage Safety

3 Solid H_2 Allows to Carry More Energy than Other Alternatives

energy density, kWh/l



Solid hydrogen's high density is a **key advantage for use in the marine and aviation sectors**, where fuel's energy density is critical, and **contributes** to its **low cost of transport and storage**

4 Solid H_2 is a Safe and Stable Carrier

Solid Hydrogen

- ☑ **Non-flammable**[2], non-corrosive and **non-toxic**
- ☑ Can be transported **at atmospheric conditions**
- ☐ Need for tight/hermetic tankage as any water addition will cause hydrogen release

Ammonia

- ☒ Requires **special care**[3] as **explosive** and **highly toxic**[4]
- ☒ **Regulatory restrictions** related to handling and storage in residential areas
- ☒ **Limited options** for handling in ports and in-land distribution

Liquid Organic Carriers

- ☐ **Low toxicity**, hardly flammable or explosive
- ☑ **No loss** through evaporation
- ☑ Can use **existing industry-scale diesel infrastructure** without any additional safety regulations

Liquid Hydrogen

- ☐ **Explosive**, but not toxic
- ☒ **Hydrogen loss** during loading and shipping
- ☐ Requires **boil-off management** as evaporation starts after 14 days

Source: Hydrogen Council, JPMC risk assessment, expert interviews, scientific papers: "Review of Global Regulations for Anhydrous Ammonia Production, Use, and Storage", Mark Fecke et al, Hazards26, Symposium series n° 161, 2016; "Reversible ammonia-based and liquid organic hydrogen carriers for high-density hydrogen storage: Recent progress" Joshua W. Makepeace, et. al, International Journal of Hydrogen Energy, 2019.
Notes: **1.** Based on methanol. **2.** High auto-ignition temperature: 220°C, allowing for untroubled transportation under normal circumstances. **3.** High expansion foam system and extra insulation valves have been recommended in major hazard risk assessment of ammonia storage.
4. Can be fatal upon exposure to elevated concentrations.

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H2FUEL's advantages for Military purposes

1 100% CIRCULARITY

H2Fuel's patented circular technology enables the re-use of the residual materials of the hydrogen carrier (spent-fuel) after release of the hydrogen. This technology not only saves costs, but also allows for an unlimited availability of raw materials to combine with newly generated hydrogen in remote positions where re-supply of materials is unwanted or impossible.

2 GEOGRAPHICAL INDEPENDENCY

H2Fuel's hydrogen carrier can be (re)produced in all parts of the world and transported or distributed in large or smaller quantities, whenever and wherever required. Transportation and storage does not require special treatment. Put it a box, keep it dry and drop it off. Not only 100% of the amount of hydrogen originally stored in the carrier can be released on demand, but an extra amount will be released from the ultra-pure water used in H2Fuel's patented release process.

3 CALAMITIES

H2Fuel is non-toxic, non-flammable, non-explosive, has no leakage and consists of natural substances, so that the composition naturally breaks down into the original substances in the event of an emergency. Stored in H2Fuel's hydrogen carrier (whether newly produced or based on recirculated spent-fuel), its hydrogen can be kept ready for use indefinitely.

4 SAFETY

Since no gas formation occurs in the entire process up to release, H2Fuel is completely safe and therefore does not require impactful changes to existing fuel transportation or storage processes. Its hydrogen only becomes gaseous when it is released immediately before consumption, so that large gaseous storage is avoided. If anything, it will simplify such safety measures.

Source: McKinsey Energy Insights Global Energy Perspective; Hydrogen Council; McKinsey Hydrogen Insights; IHS Markit (Global Supply and Demand Trade Flow of Green Ammonia), Company data.
Notes: **1.** Exemplary route from Saudi to Germany.

H2FUEL's Proprietary Technology is Well Protected with Patents

Patents obtained for release and submitted for regeneration

Significant expansion of team in 2022 to move H2FUEL into next phase

2024

first commercial use targeted



First maritime commercial use

Neo Orbis boat is being developed for Port of Amsterdam and will be used to hold business and other official meetings

2008	2010	2020-2022	2021	2022E	2023E	2024E
H2FUEL founded by Rob de Kraa	First patent for **Release** stage received	2 test setups for **release stage** constructed at Port of Rotterdam	Patent application filed for **regeneration** stage (patent pending)	University of Amsterdam to test **regeneration** stage concept in a lab	**Test plant for regeneration and release** process to be built to proof the circular concept of H2FUEL	**Commercial use of solid hydrogen** by Neo Orbis boat

Technology partnerships

UNIVERSITY OF AMSTERDAM

H_2CiF **H2 Circular Fuel**

Source: Company data.