Green Hydrogen: “Zero Emission” Fuel for Mobility

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Selling Points for A Hydrogen Economy

- Hydrogen has the highest gravimetric energy density of all known substances (~120 MJ/kg, compared with ~44MJ/kg for gasoline)
- Can store surplus renewables power when the grid cannot absorb
- Zero tailpipe emissions (No C-C bonds)
- Electricity cables can transport up to 1-2 GW but the average gas pipeline can carry 20 GW and is 10-20 times cheaper to build
- Can piggyback on the fossil fuel infrastructure e.g., pipelines, power plants, storage etc.
- Easy and fast to store and discharge large quantities of hydrogen
- Can help to de-carbonize hard-to-electrify sectors such as long distance transport and heavy industries
- Can replace fossil fuels as a zero-carbon feedstock in chemicals and synthetic fuels production

Where can we find the Hydrogen we need?

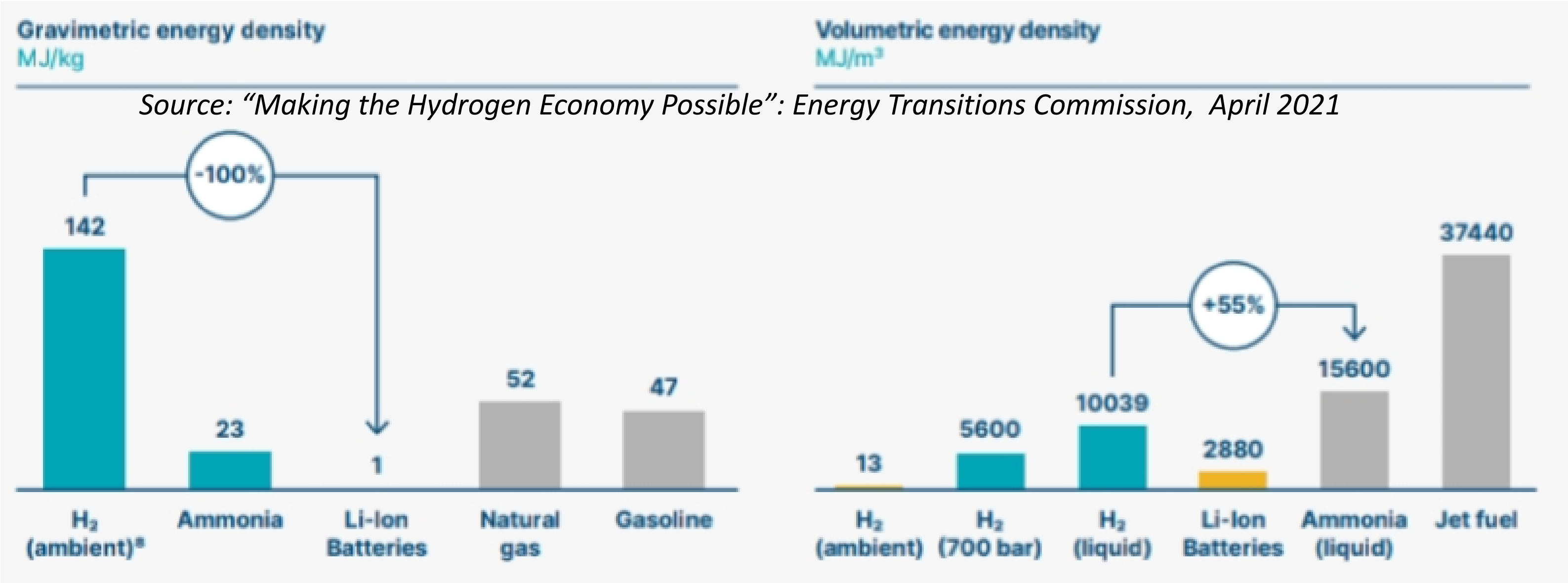
- ~74% H_2 content in the Universe, ~70.5% in the Solar System
- 0.14% in the Earth's Crust, **10.8% in the oceans**; pure H_2 not present in the Earth's atmosphere: water is the best possible source for H_2 on earth
- Rocks formed beneath the ocean floor may be a large and previously overlooked source of free hydrogen gas (Duke University, 2016)

Technology Imperatives – H_2 Production and Utilization

- Sustainable generation (Life Cycle Analysis)
- Affordability (Minimize production cost)
- Delivery (Minimize storage and transport cost and risks)
- Durability (Systems will be expensive – must be built to last with minimal down time and acceptable serviceability)

The Challenges Must Not Be Underestimated

How Much Energy can Hydrogen Store?

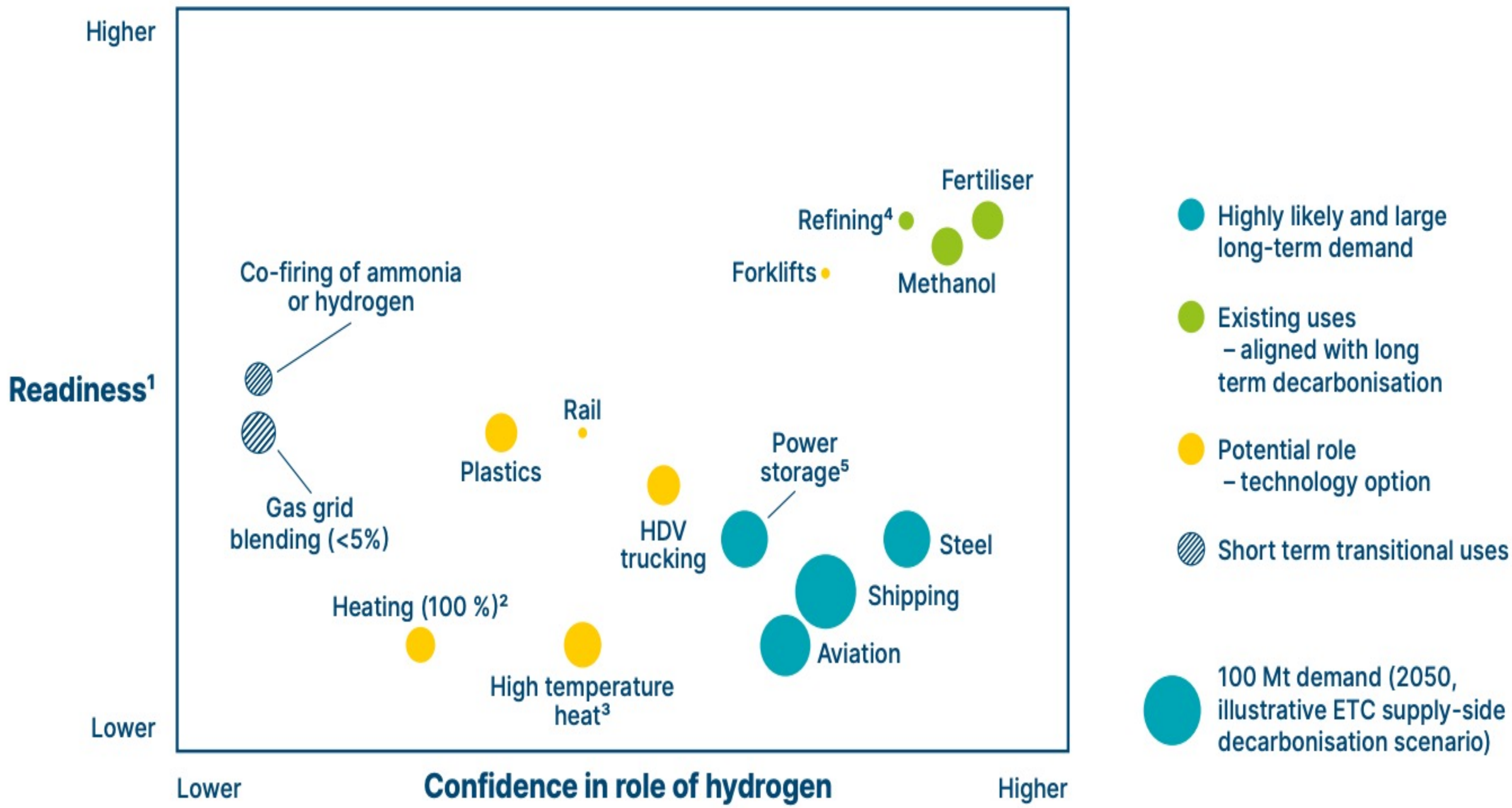


Source: "Making the Hydrogen Economy Possible": Energy Transitions Commission, April 2021

- How much of the available energy is lost in the storage cycle?
- Volumetric energy density is rather low. The gravimetric heating value of a ***fuel gas*** is less relevant for practical applications.
- In general, the volume available for fuel tanks is limited for automotive applications.
- Also, the diameter of pipelines cannot be increased at will

Generate-Store-Transport , or On-Site Generation?

How Ready Is Mobility for Hydrogen?



Source: "Making the Hydrogen Economy Possible": Energy Transitions Commission, April 2021

- For the automotive sector, volumetric energy density remains a challenge – therefore on-board production (FCV approach) continues to attract interest
- HCNG is a lower-hanging fruit and may be encouraged right away

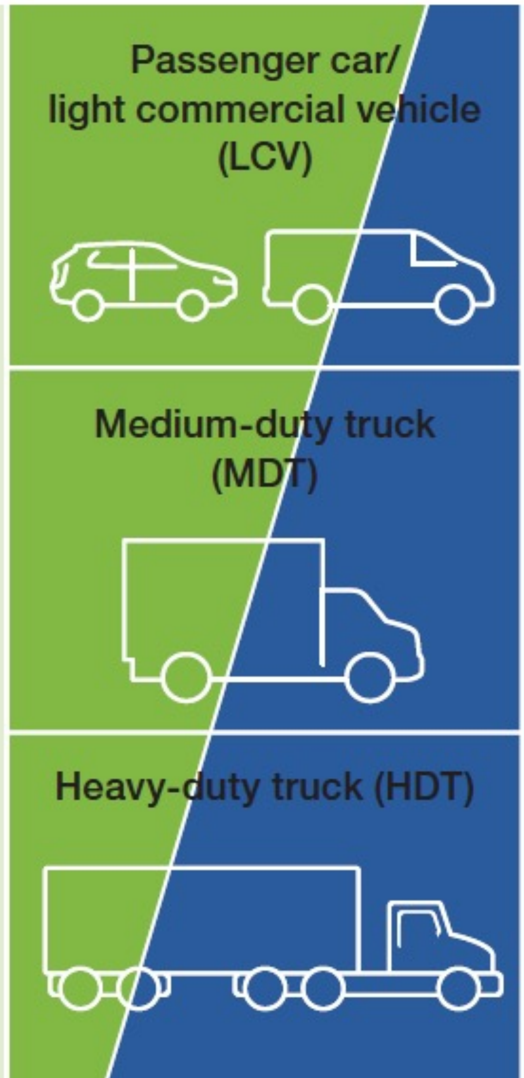
BEV and (not vs.) FCV

Battery (BEV)

BEVs are vital for enabling **fast decarbonisation** of transport and will become **mainstream** in **many use cases**

Relevance in segment

(illustrative)



Fuel cell (FCEV)

For **important segments** of road transport, **hydrogen** is the **best option.**

- Regions with **constrained renewables** or grid capacity in the mid to long term
- **Vehicle segments with high power** and **energy demands**
- Use cases and customer segments with a preference for **long-range capability and fast refuelling**

Roadmap towards zero emissions: The complementary role of BEVs and FCEVs Hydrogen Council September 2021

Indicative Estimated Total Cost of Ownership (TCO) for FCEB

- Capex : 0.35 Mn USD for 12 m AC bus (at scale)
- Travel length : 400 km/ day
- Bus life : 10 y
- Capex cost : 20 Rs/ km
- CGH2 cost : 4 $/ kg
- Fuel efficiency : 10 km/ kg
- Opex cost : 30 Rs/ km
- TCO : 50 Rs/ km (10% lower than ICE bus)

Capex is non-negligible component of TCO

→ Fuel cell stack is a large component of the capex

→ → Hence, need to maximize power density at operating stack voltage

The Sustainability Lens for Green Hydrogen

Energy Penalty per kg of H_2 produced by a water electrolyser

Four Situations Modelled

Case 1: Hydrogen produced by water electrolysis, compressed to 200 bars, transported through pipelines, stored at filling stations (at 60 bar) and delivered

Case 2: Hydrogen is produced by water electrolysis, compressed and stored at 200 bars, transported through road, stored in filling stations (at 60 bar) and delivered

Case 3: Hydrogen is produced by water electrolysis on site and delivered

Case 4: Hydrogen is produced by water electrolysis, liquefied & distributed by road

<u>Assumptions Made:</u>

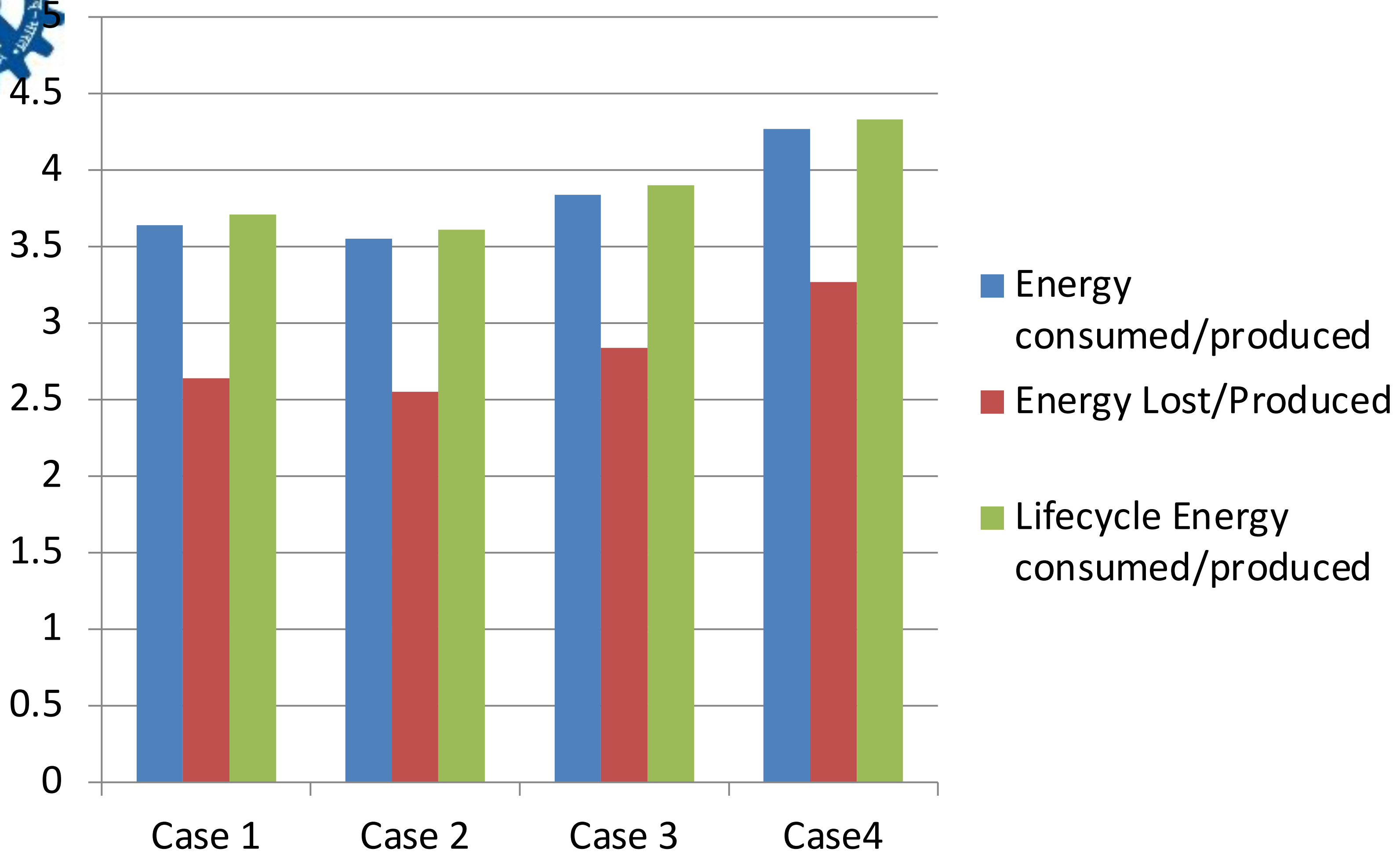
a) AC/DC conversion efficiency is 94%

b) Electrolyser energy efficiency taken to be 70%

c) The electrical energy for electrolysis, storage and transport is supplied externally and not derived from the hydrogen i.e., 1 kg of H_2 produced at the electrolyser is directly available as input to the Fuel Cell for power generation

d) End-of-life disposal or recycling energy costs are not considered

Life Cycle Energy Ratios: Hydrogen via Electrolysis



Case 1: Electrolysis – 200 Bar Storage – Road Transport

Case 2: Electrolysis – 200 Bar Storage – Pipeline Transport

Case 3: On site Electrolysis – 200 Bar Storage – Delivery

Case 4: Electrolysis – Liquefaction – Road Transport

All or substantial part of the input energy will have to be Renewable

CSIR's Hydrogen Program:
Across the Entire Value Chain

H_2

Generation	Storage	Utilization

Generation
- **Bio-Mass Gasification**
- **Coal-bed Methane Gasification**
- **Underground Coal Gasification**
- **PEM/AEM Electrolysers**
- **High Temperature Steam Electrolyzer**
- **Photochemical**
- **Electrochemical**
- **Photo-Electrochemical**
- **Photo-catalytic**
- **CO-PROX Converter**
- **Open Loop Thermochemical S-I Cycle**

Storage
- **Storage Materials**
- **Type IV Storage Tank**
- **Safety Valves**
- **Sensors & Detectors**
- **Organic Liquid Carriers**

Utilization
- **PEMFC stacks (HT, LT & Open Cathode)**
- **DMFC stacks**
- **SOFC stacks (MT & LT)**
- **FC components (MEA, Electrode, Catalyst, GDL, Membrane, Bipolar Plate, Fixtures, Humidity control...)**
- **FC Test Station**
- **Solar H_2 to Chemical**
- **Solar Hydrogen Cookstove**

Hydrogen Generation					Hydrogen Storage		Hydrogen Utilization	
Gasification	Electrolyzers	Photo/ Electrochemical	CO-PROX	Open Loop SI Cycle	Materials	Tanks/Valves/ Sensors	Fuel Cells	Solar Hydrogen Cookstove
CSIR-CIMFR	CSIR-CECRI CSIR-NCL CSIR-IMMT CSIR-AMPRI CSIR-CGCRI	CSIR-NCL CSIR-CECRI CSIR-IMMT CSIR-CSIO CSIR-CMERI CSIR-IIP	CSIR-NEERI	CSIR-IIP CSIR-CSMCRI	CSIR-CSMCRI CSIR-CMERI CSIR-AMPRI CSIR-CECRI	CSIR-CMERI CSIR-NIIST	CSIR-NCL CSIR-CECRI CSIR-NPL CSIR-CGCRI	CSIR-CSIO

In Summary

- Green Hydrogen for Mobility is making great strides, with HCNG as the bridging solution
- No silver bullet – all available sustainable mobility solutions must be deployed, and undistorted markets be allowed to determine winners
- Life Cycle Analysis and Net Energy Ratio tools must be rigorously used to ensure decarbonization objectives are met
- Input energy streams across the value chain for Green Hydrogen needs to be renewable as far as possible
- FCVs need sustained and significant R&D investments to maximize power density and durability

Thank You

Questions?