BioSolar Hydrogen for Green Transport

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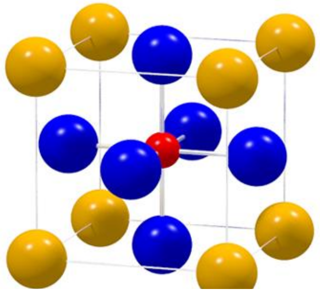
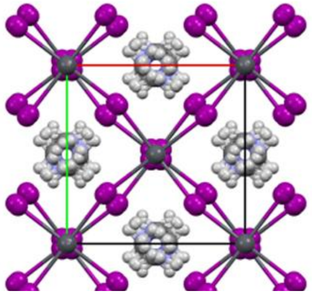
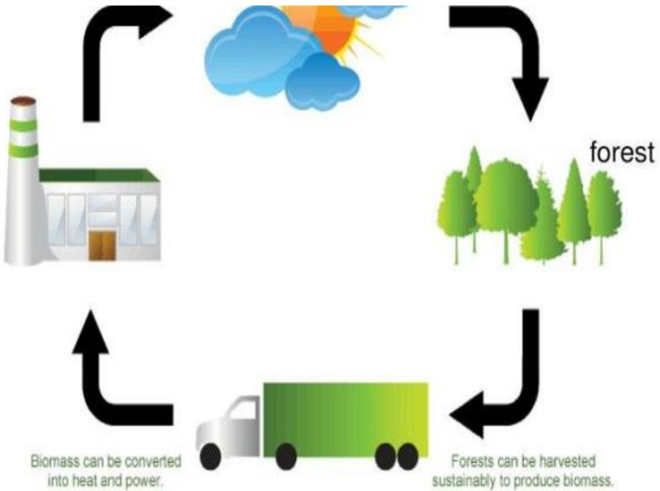






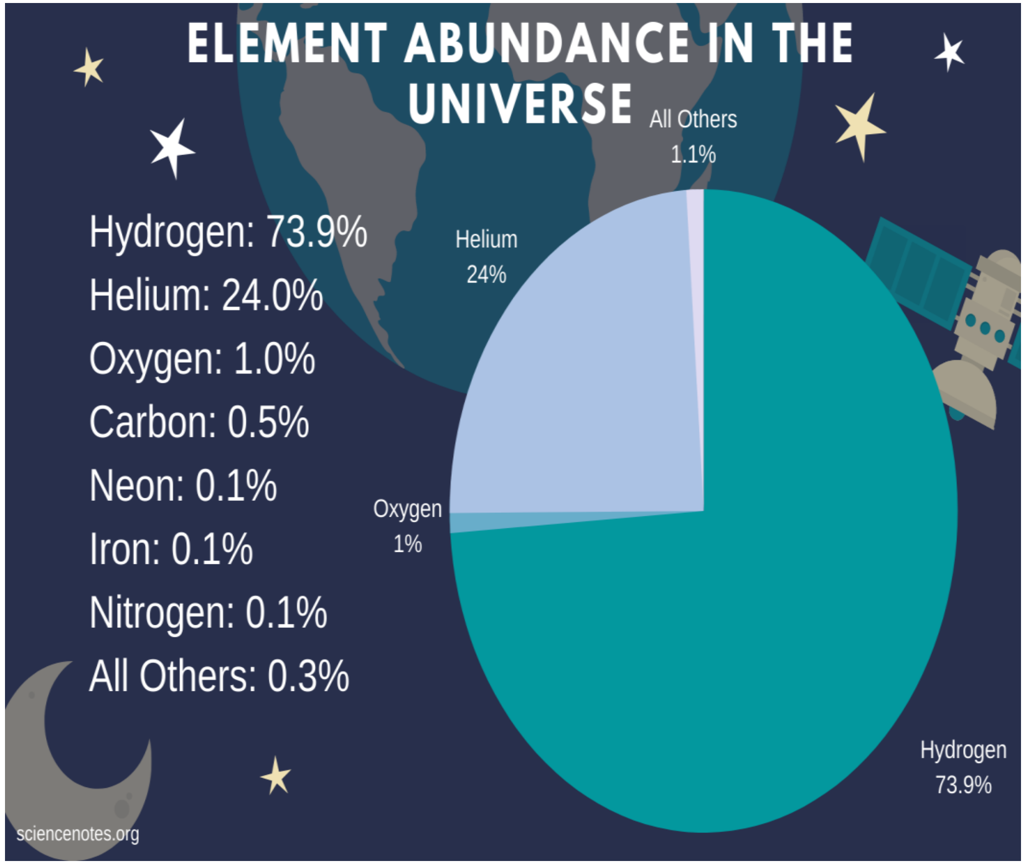
Scope and Objectives of the Presentation

- Understanding of **green hydrogen production, storage, and transportation**.
- Exploration of **technologies, efficiency, cost, and environmental impact**.
- Insight into **the current market, future trends, and potential growth areas**.
- **Case studies** illustrating practical applications and impact on sustainability goals.
- **Project** brief

Overview

Hydrogen Energy Overview

- **Hydrogen:** simplest and most abundant molecule in the universe.
- **High energy content per unit weight**, approximately three times higher than fossil fuels.
- Produces water vapor when combusted, **emitting no greenhouse gases**.
- Can be used **in fuel cells for electricity** or **directly as fuel** for heat and transportation.
- **A kg of hydrogen** has energy equivalent to **7-8 kg of coal** equivalent without associated carbon of coal and **3 kg of natural gas** or 42 NM3 CNG.



- Hydrogen has the **highest carbon free energy**
- 33.2 kWhr (**30,000 Kcal/kg**) energy compared to any other energy resource.

Green Hydrogen

Green Hydrogen in Sustainable Energy

- Produced using **renewable energy sources**, unlike gray or blue hydrogen.
- **Zero emissions** through electrolysis powered by wind, solar, or hydroelectric power.
- Significant role in **decarbonizing heavy industry and long-haul transportation.**
- **Promising solution** for energy storage, absorbing excess renewable energy and providing energy during high demand.

Hydrogen Production

Green Hydrogen Production Methods

- **Water Electrolysis:** Decomposition of water into hydrogen and oxygen using electricity from renewable sources.
- **Alkaline Electrolysis:** Uses a solution of water and a strong electrolyte, facilitated by metal electrodes.
- **Proton Exchange Membrane (PEM) Electrolysis:** Uses a solid polymer as an electrolyte, operates at high current densities.
- **Solid Oxide Electrolysis:** Uses a solid ceramic material as an electrolyte, works at high temperatures and efficiencies.
- **Biological Methods:** Includes photosynthetic water splitting, enzymatic hydrogen production, and microbial electrolysis.

Cost and Efficiency Analysis of Hydrogen Production

- **High costs** due to electrolysis equipment and energy requirements.
- **Efficiency varies**: Alkaline, PEM, Solid Oxide (over 80% under certain conditions).
- **Technological advancements and economies of scale** expected to reduce costs, making green hydrogen competitive.

	Alkaline	PEM	SOE	AEM
Electrolyte	Aqueous potassium hydroxide	PFSA membranes (e.g., Nafion)	Yttria Stabilises Zirconia (YSZ)	Anion exchange ionomer
Cathode	Nickel, Nickel - Molybdenum alloy	Platinum, Platinum - Palladium alloy	Nickel/YSZ	Nickel and Nickel alloys
Anode	Nickel, Nickel - Cobalt alloys	Ruthenium oxide, Iridium oxide	YSZ	Nickel, Ferrous, Cobalt oxides
Operating Temperature (℃)	60-80	50-80	500-850	50-60
Operating Pressure (Bar)	30	70	1-25	1-30
Stack Lifetime (h)	60-100k	20-60k	<10k	-
Technology Readiness	Matured	Commercialised	Demonstration	Large prototype
Cost	USD 500-1400/kW	USD 1100-1800/kW	USD 2800-5600/kW	

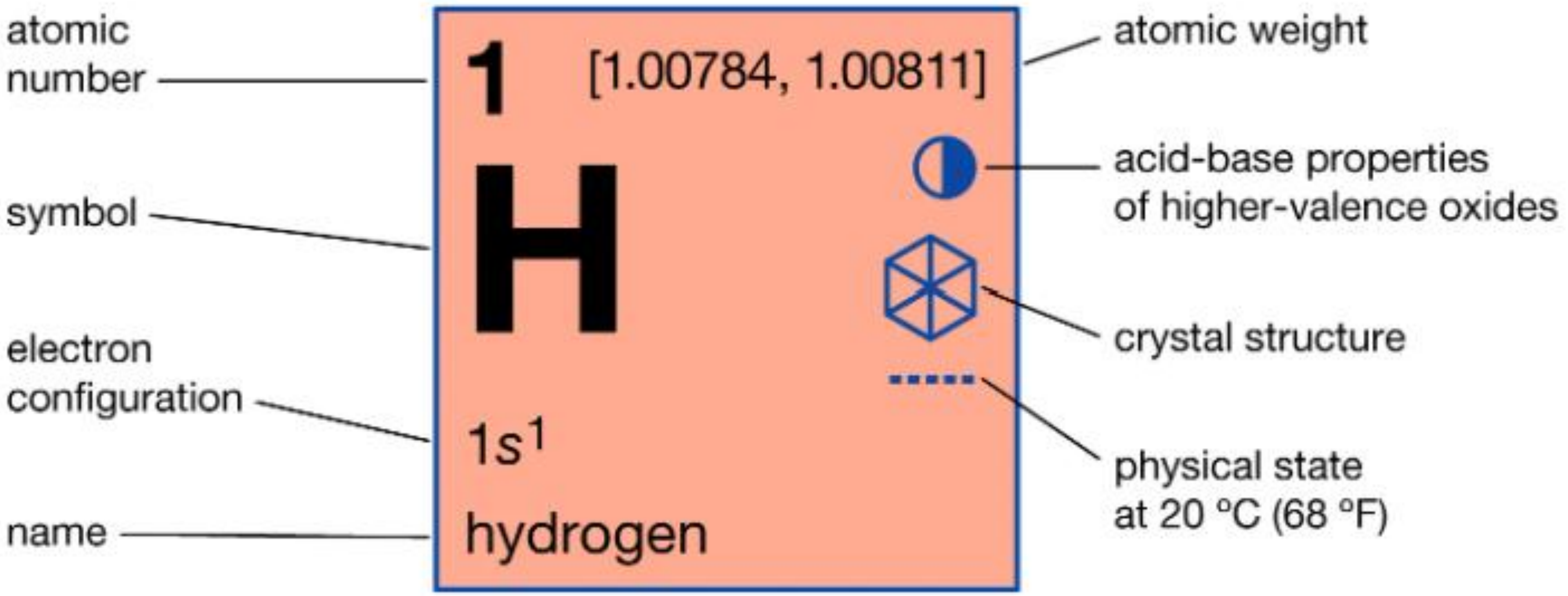
Efficiency Analysis of Hydrogen Production

	Polymer Electrolyte Membrane (PEM)	Molten Carbonate (MCFC)	Direct Methanol (DMFC)	Phosphoric Acid (PAFC)	Alkaline (AFC)	Solid oxide (SOFC)
Electrolyte	Polymer membrane	Molten Carbonate	Methanol	Phosphoric salt	KOH	Yttria-Stabilized Zirconia (YSZ
Type	Solid/liquid	Solid	liquid	Liquid	Liquid	solid
Anode	Platinum	Ceramic	Metal	Platinum	Carbon	Steel/ Nickel
Product	H_2	Methanol, H_2	Methanol/H_2	H_2/ Methanol	NH_3/H_2	Methanol/ H_2
Efficiency (%)	30-40	~ 50	30-40	40-50	60-70	60
Suitable for	Mobility	Mobility	Potable device	Buildings	Mobility	Power plant

Hydrogen Storage

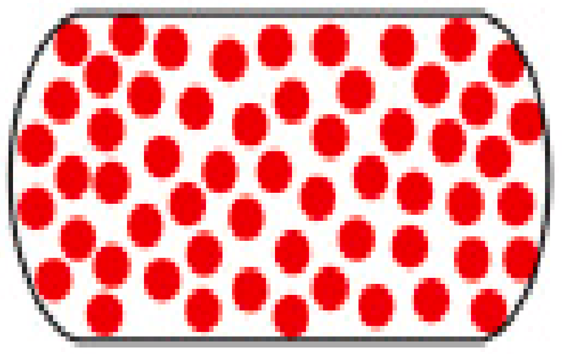
Storage of Green Hydrogen

- Important to **utilize hydrogen's potential** as an energy carrier.
- Address unique challenges posed by **hydrogen's properties**.
- Ensures energy availability **when needed**.
- Enables transportation of hydrogen **from production to use sites**.

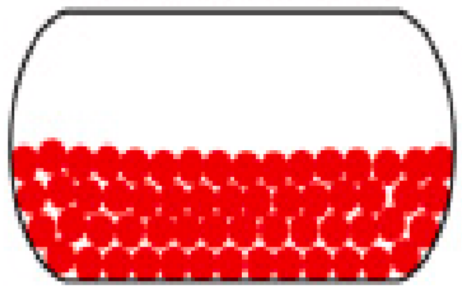


Physical Storage Methods

- **Compressed Hydrogen Storage**:
  - Hydrogen gas stored under high pressure (350-700 bars) in specially designed tanks.
  - Widely used, especially in hydrogen-fueled vehicles.

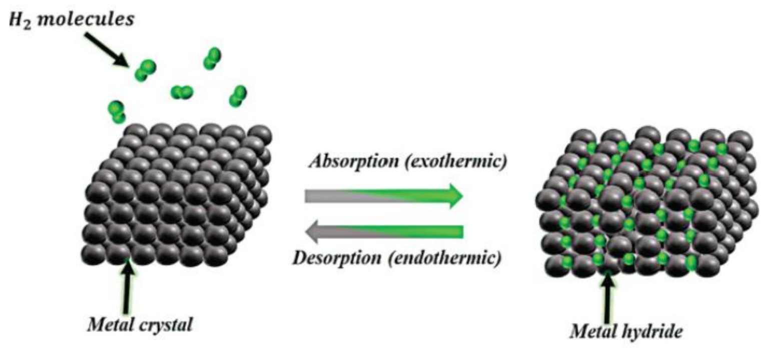


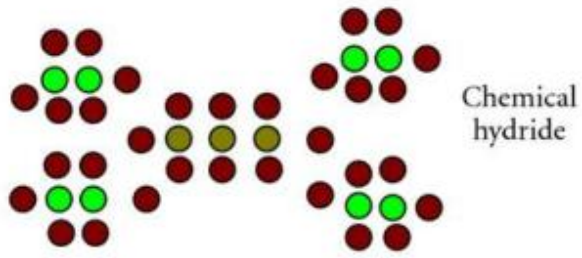
- **Liquid Hydrogen Storage**:
  - Hydrogen gas cooled to -253°C to become liquid.
  - Stored in insulated tanks, allowing for denser storage but requires significant energy for cooling.

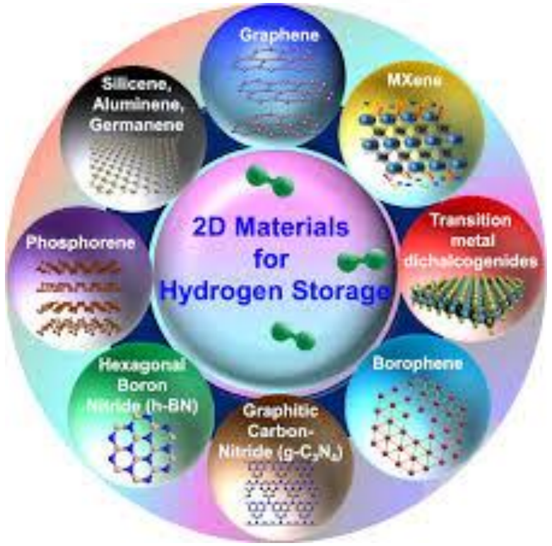


Material-Based Storage Methods

- **Metal Hydrides:**
  - Hydrogen stored in metal alloys, released when heated.
  - Safe and compact but energy-intensive.
- **Chemical Hydrides:**
  - Hydrogen stored within chemical compounds, released by reacting with water or heat.
  - Compact storage but can be expensive and energy-intensive.
- **Carbon-Based Materials:**
  - Hydrogen adsorbed onto surfaces of materials like activated carbon and graphene.
  - Promising for high-density, low-pressure storage, still in research phase.







Safety, and Efficiency Analysis of Storage

TECHNICAL COMPARISON OF H_2 STORAGE METHODS

PHYSICAL STORAGE

CHEMICAL STORAGE

METHOD	VOLUMETRIC DENSITY	MASS	PRESSURE	TEMPERATURE	NOTE
Compressed Gas	<33 kgH_2m^{-3}	13 mass%	350-800 bar	>298 K	-High cost -safety concerns -low vol. density -high space req. -high pressure
Liquid H_2	~71 kgH_2m^{-3}	100 mass%	1 bar	21 K	-high energy req. –low temp. req. -high cost –liquid boil-off losses
Adsorbent	20-50 kgH_2m^{-3}	4 mass%	70 bar	>65 K	-packing limitations(Chahine's rule) –weak adsorption enthalpies -low temp. req –large van der Waals dimension
Liquid Organic	40-60 kgH_2m^{-3}	7 mass%	50 bar	>298 K	-expensive catalyst development -boil off –additional solvent research necessary
Interstitial Hydride	100-150 kgH_2m^{-3}	2 mass%	1 bar	>298 K	-low gravimetric density -slow/complex desorption kinetics -early stage
Complex Hydride	150 kgH_2m^{-3}	18 mass%	1 bar	>298 K	-difficult activation -reversibility/desorption kinetics need improvement -large hysteresis
Chemical H_2	>100 kgH_2m^{-3}	14 mass%	1 bar	>298 K	-higher temperature needed for release -complex dehydrogenation pathway

Safety, and Efficiency Analysis of Storage

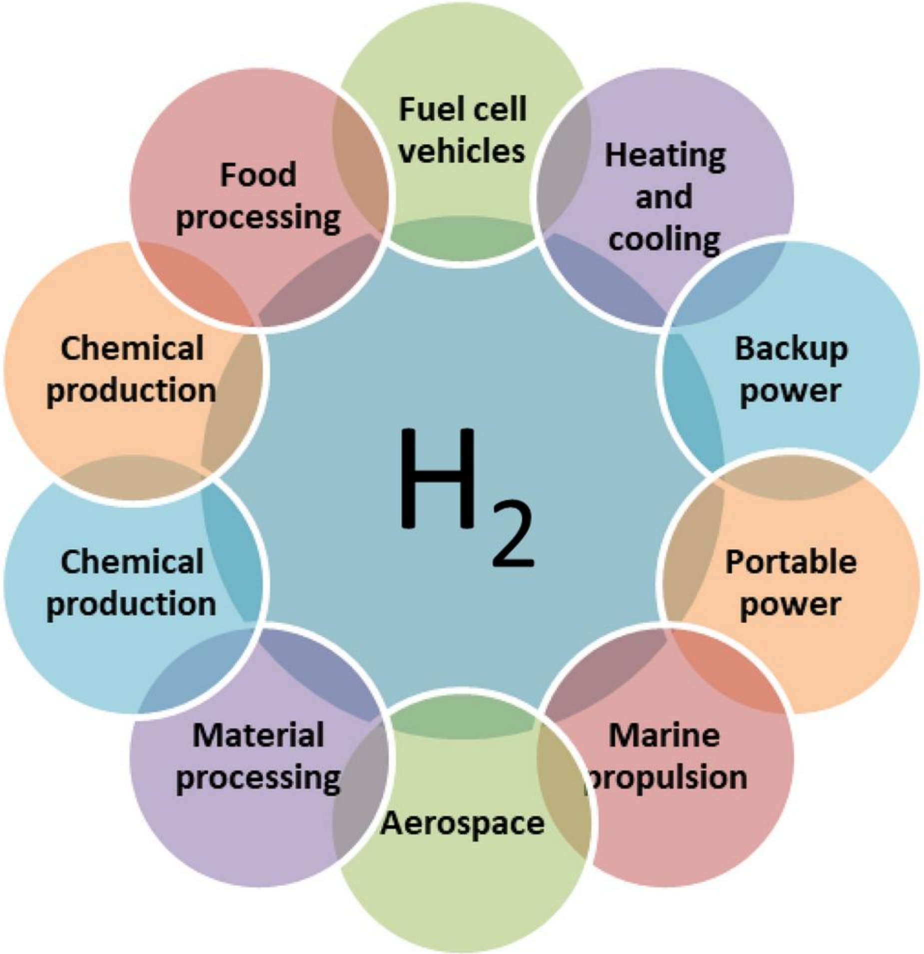
- **Compressed Gas:**
  - Cheapest but requires large, heavy tanks and has safety concerns due to high pressure.
- **Liquid Hydrogen:**
  - More compact but less efficient due to high energy cooling requirements.
- **Material-Based Methods:**
  - Compact and safe but can be expensive and energy-intensive.

- **Future research aims to improve safety, cost, and efficiency of hydrogen storage methods.**

Hydrogen Transportation

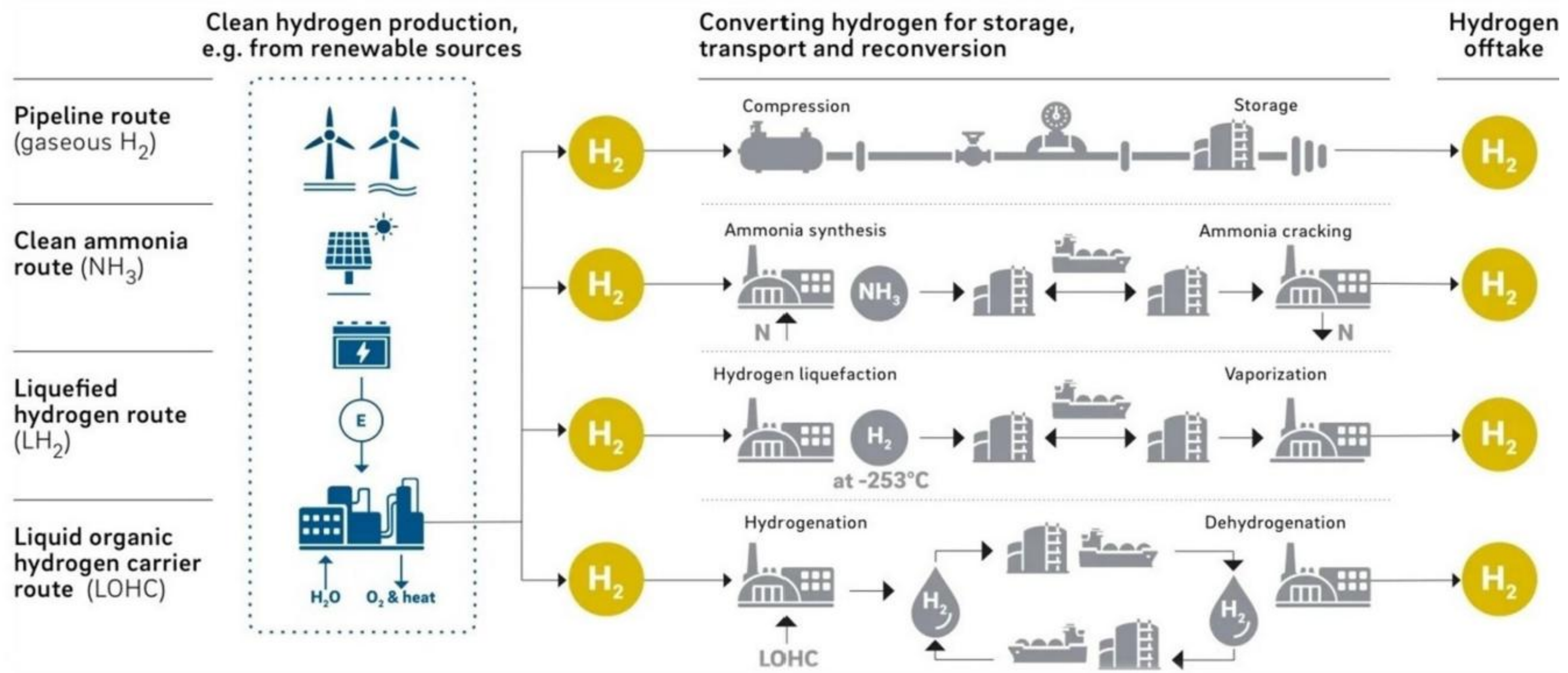
Transportation of Green Hydrogen

- Essential for moving hydrogen from production to use sites.
- **Pipelines:**
  - Common for short to medium distances, made from materials resistant to hydrogen embrittlement.
- **Compressed Hydrogen in Tanks:**
  - Transported in high-pressure tanks via trucks or trains, common for fueling stations.
- **Liquid Hydrogen in Cryogenic Tanks:**
  - Cooled to liquid form, transported by ships, trucks, or trains.
  - Energy-intensive but efficient for long distances.
- **Liquid Organic Hydrogen Carriers (LOHC):**
  - Hydrogen chemically bound to a carrier, transported in stable, non-pressurized state.
  - Released from the carrier at the use site, still under development.



Cost and Safety Analysis of Transportation

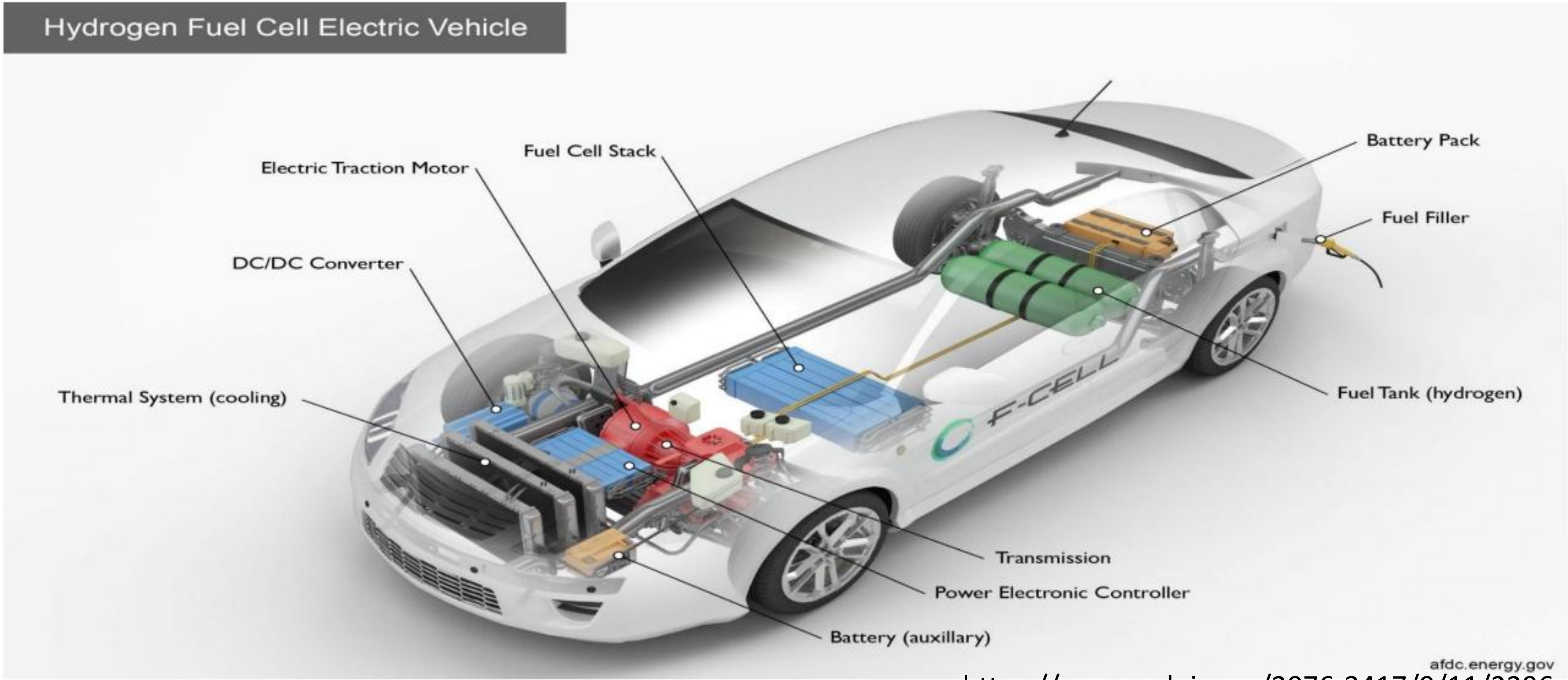
- Cost depends on **method and distance**.
- **Pipelines** cheapest for short distances; liquefaction and LOHCs more cost-effective for long distances.
- Safety concerns due to **hydrogen's flammability and material embrittlement**.
- **Technological advancements** expected to reduce costs and improve safety.



An example application

Example: Transportation Sector

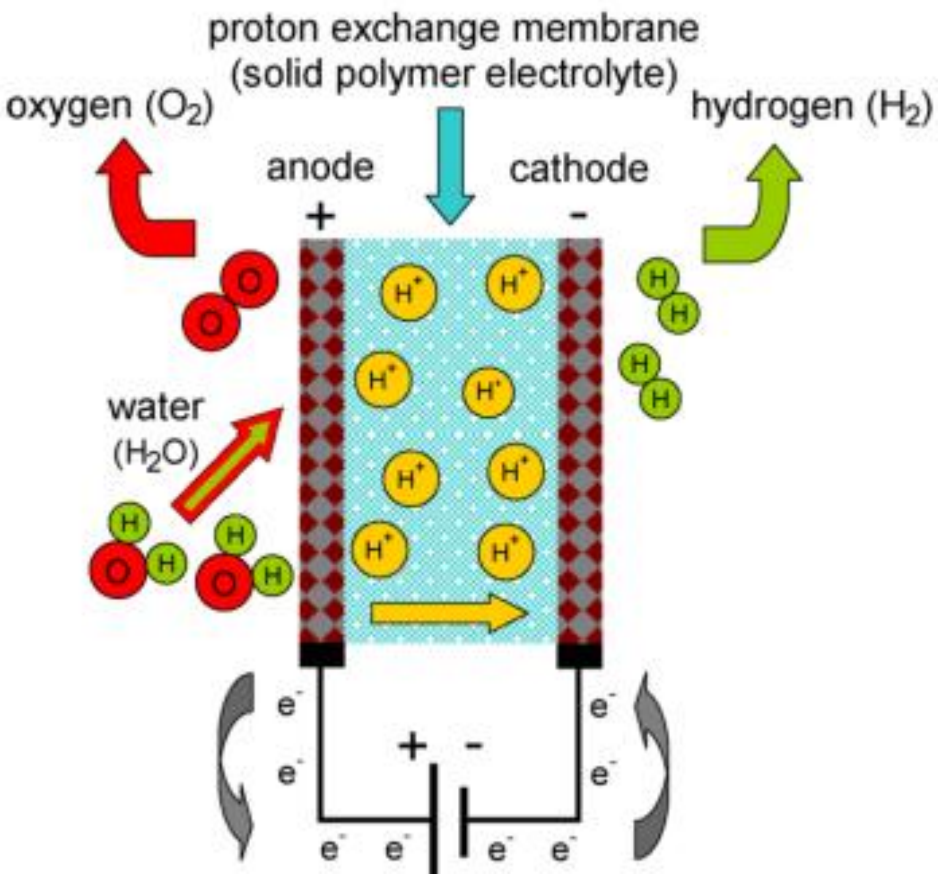
Fuel Cell Technology using PEM



https://www.mdpi.com/2076-3417/9/11/2296

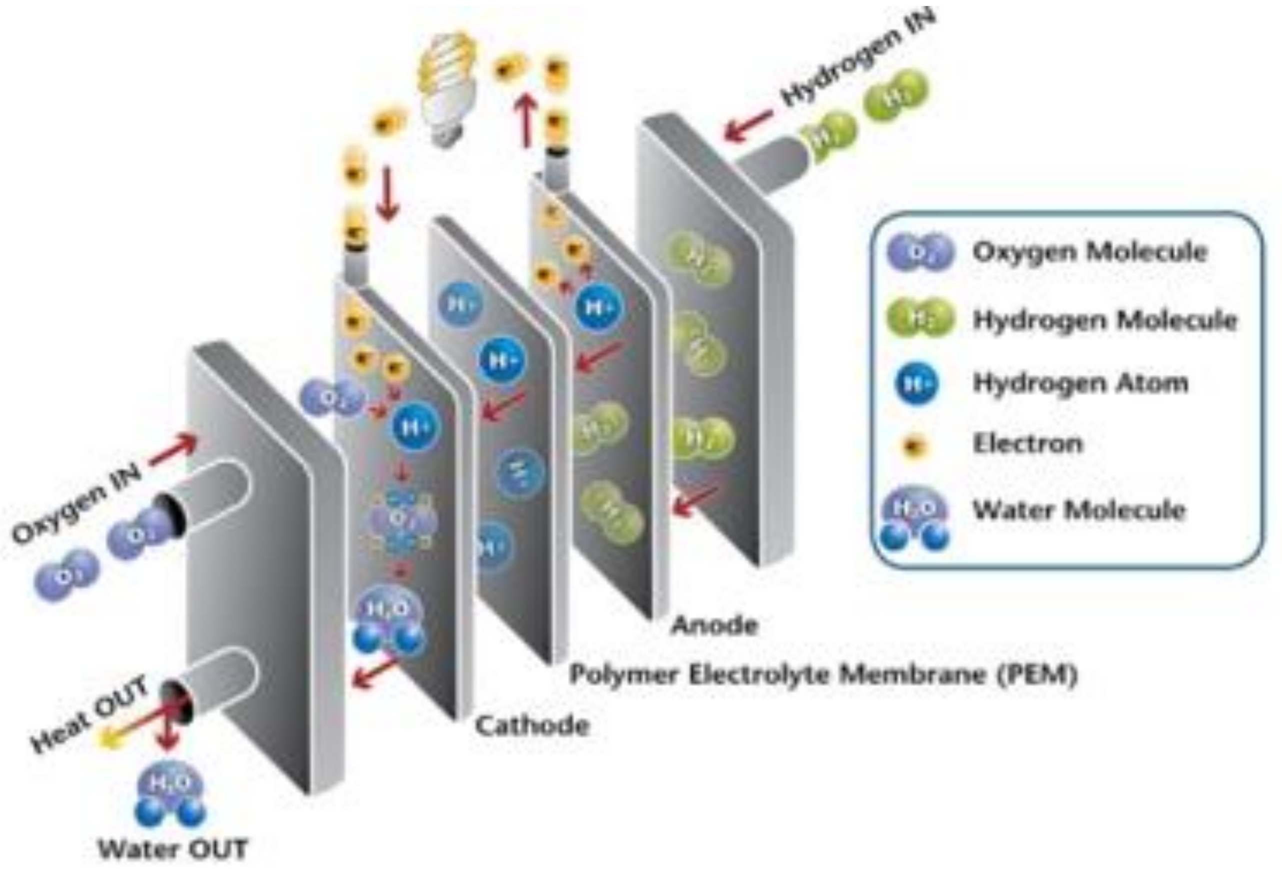
Example: Fuel Cell Technology using PEM

1. **Hydrogen supply:** Stored in high-pressure tanks within the vehicle, hydrogen gas is delivered to the anode of the fuel cell stack.
2. **Hydrogen ionization:** Once at the anode, a platinum catalyst assists in the ionization of hydrogen molecules, splitting each into two hydrogen ions (protons) and two electrons.
3. **Ion and electron separation:** The electrolyte, commonly a proton exchange membrane (PEM), permits only the positively charged hydrogen ions to move through to the cathode. This forces the electrons to travel via an external circuit to reach the cathode, thereby generating an electric current.
4. **Oxygen reduction and water formation:** At the cathode, oxygen from the ambient air is reduced and merges with the incoming hydrogen ions and electrons to generate water—the technology's sole exhaust product.
5. **Power generation:** The electric current produced by the flow of electrons powers the vehicle's electric motor and other auxiliary systems.



Converts hydrogen into electron

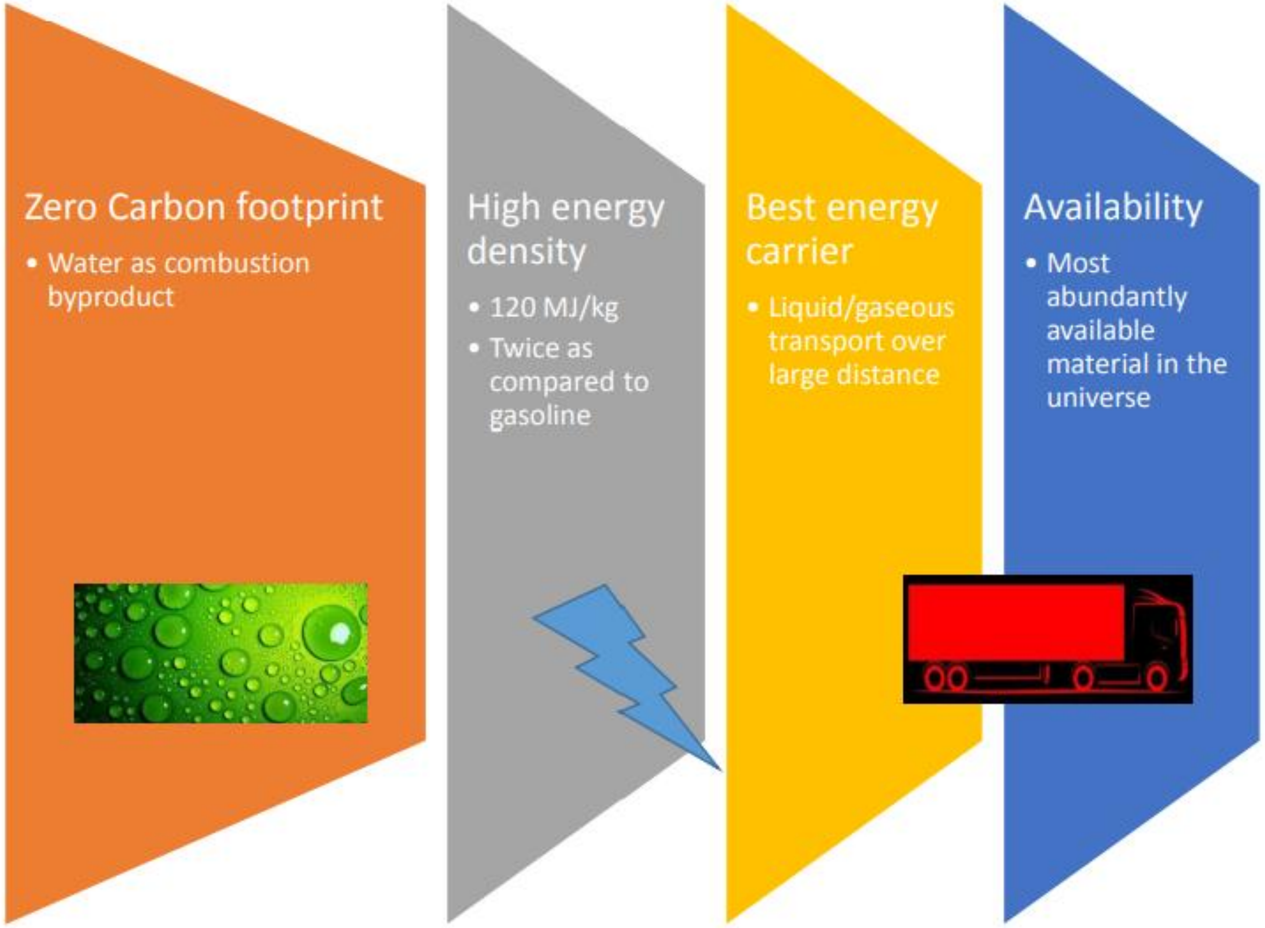
Fuel Cell and Stack



Hydrogen Market
(Fuel of Future)

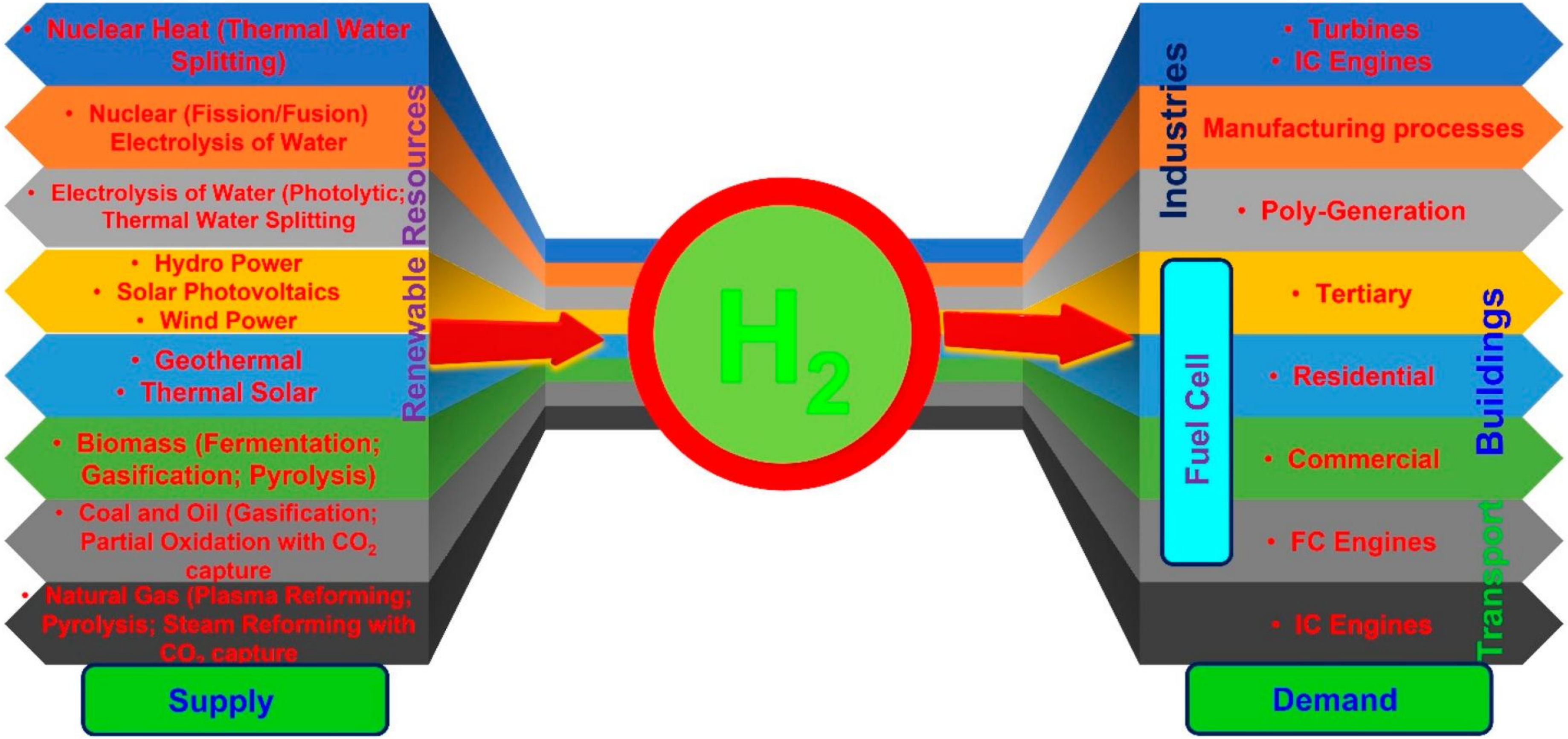
Market for Green Hydrogen

- Critical for **global transition** to a low-carbon economy.
- Current market is **emerging**.
- Majority of current hydrogen production is **gray or blue**; **green hydrogen production** expected to rise.
- Used in some **industries and transportation sector**, with numerous pilot projects in other sectors.
- **Potential markets** in many application sectors in the future.



Future Potential of Hydrogen: Fuel of the future

- Hydrogen could meet **24% of the world's energy needs by 2050** **(European commission)**.
- Potential market worth **trillions of dollars**.
- Projections **depend on** technological advancements, cost reductions, and supportive policies.

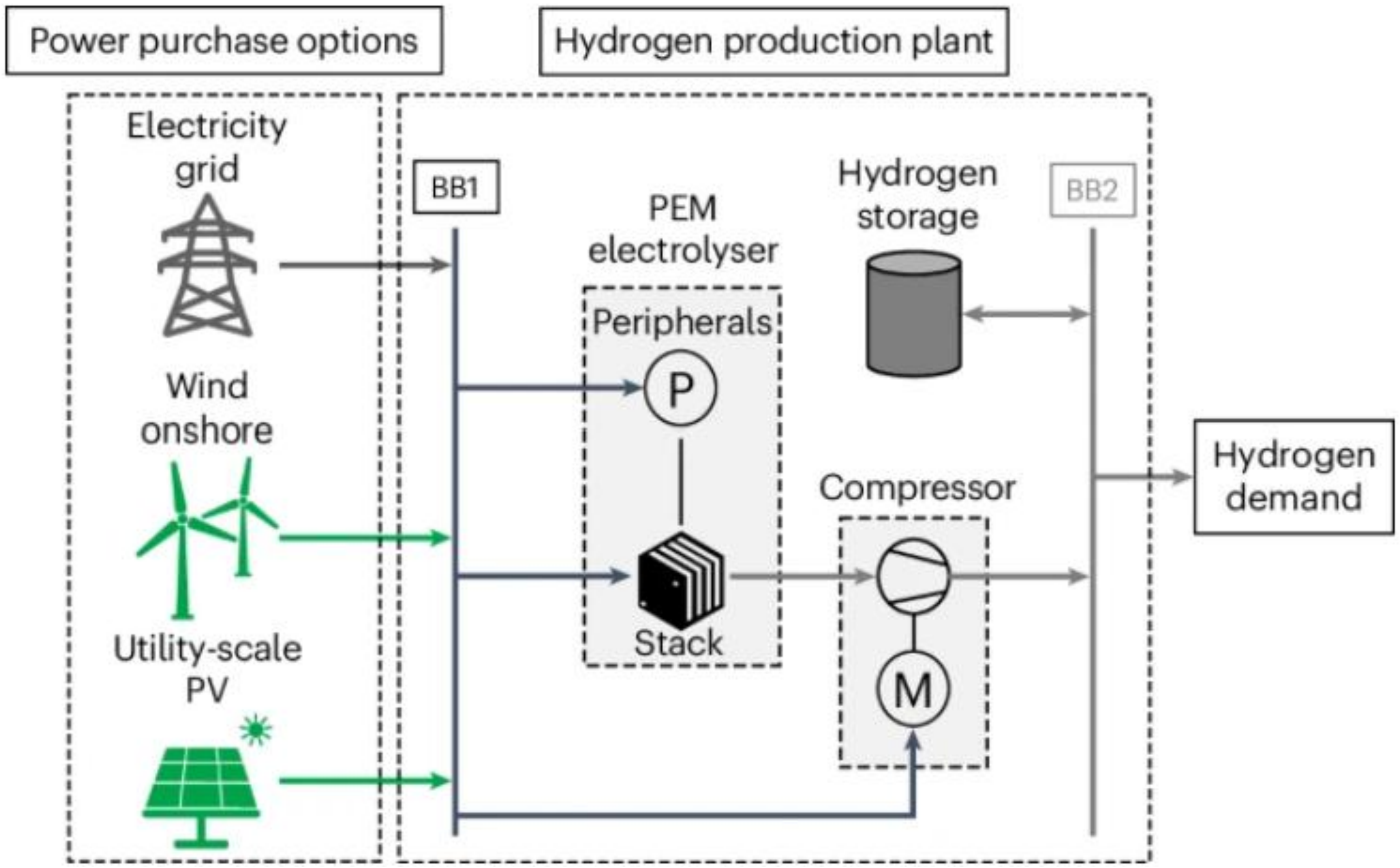


https://ec.europa.eu/commission/presscorner/detail/en/qanda_20_1257

Policies and Regulations

Policy and Regulation Influence

- **Supportive policies** (e.g., subsidies, renewable hydrogen requirements) **drive demand and reduce costs**.
- **Regulatory barriers** can **slow market development**.
- Governments recognizing **green hydrogen's potential**, including it in climate and energy strategies.
- Example: EU's target to install at least **40 GW of electrolyzers by 2030**;
- Many **national hydrogen strategies**: Germany, France, South Korea, India, and China.



Key Players

Key Players in the Green Hydrogen Market/Economy

Generation Storage Usage

- **Stakeholders include electrolyzer manufacturers, renewable energy providers, industrial hydrogen users, hydrogen fuel cell manufacturers, logistics and transportation companies**.
- **Notable companies:** Siemens, ITM Power, Nel Hydrogen, Plug Power, Ballard Power Systems, Toyota, Hyundai, BMW, Tata etc.
- **Maritime industry:** Two forms of hydrogen - used in maritime applications i.e. hydrogen employed for internal combustion engines and hydrogen fuel cells.
- Total **GHG emissions per ton-km** of hydrogen as dual fuel: emission can **decrease by 40%.**

Case studies brief

Case Studies of Green Hydrogen Projects

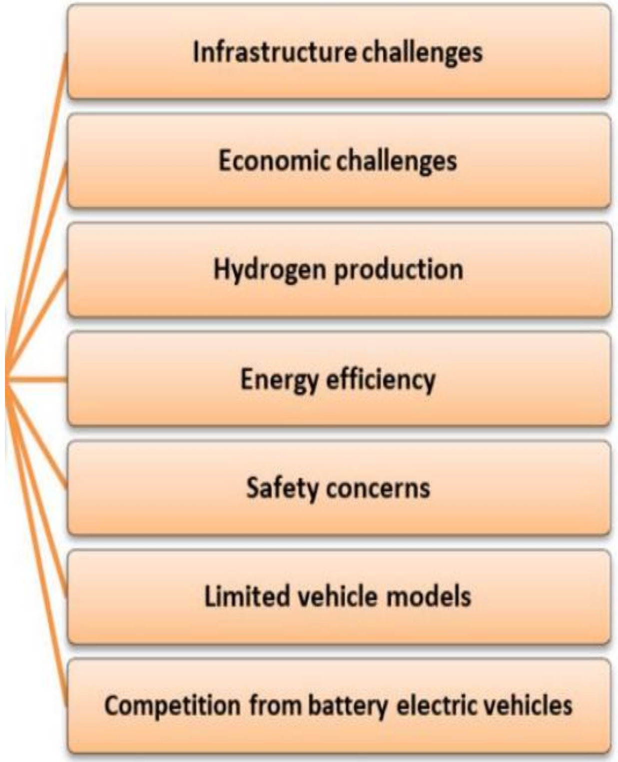
- **Ørsted's Green Hydrogen Projects:** Developing a 10 MW electrolyzer facility to produce green hydrogen from offshore wind power for use in buses, trucks, and potentially airplanes.
- **Orkney Islands, Scotland:** Converting excess wind and tidal power into green hydrogen for vehicles and heating.
- **California's Hydrogen Fueling Stations:** Using tube trailers to deliver hydrogen to fueling stations, addressing infrastructure challenges.
- **Germany's National Hydrogen Strategy:** Investing in offshore wind farms, considering importing green hydrogen, and forming international partnerships to secure supply chains.

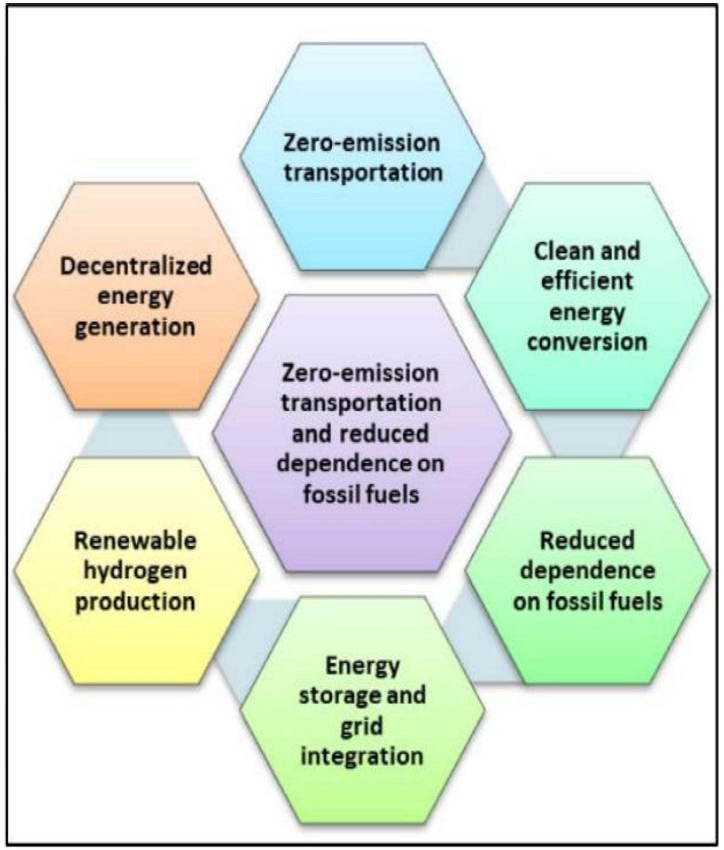
Challenges and Opportunities

Challenges and Opportunities in Green Hydrogen

Current Challenges:

- **High production costs** due to expensive electrolyzers and significant energy requirements.
- Energy requirement: Electrolysis **needs significant renewable energy.**
- **Storage and transportation difficulties** due to hydrogen's low density and material embrittlement.
- Infrastructure: Existing systems are set up for fossil fuels**, requiring significant modifications for hydrogen**.
- Market development**: Need for increased demand** and **regulatory frameworks to ensure safety and encourage investment**.





Future Opportunities

- **Technological advancements** in electrolysis efficiency and cost reductions.
- **Hydrogen-powered vehicles** with similar range and refueling times as conventional cars but no tailpipe emissions.
- **Renewable energy storage** to address intermittency of solar and wind power.
- **Decarbonizing industrial processes** like steel and cement production.
- **Government policies** supporting green hydrogen development.
- **International collaborations** to align standards, share best practices, and invest in green hydrogen projects.

Thank You !