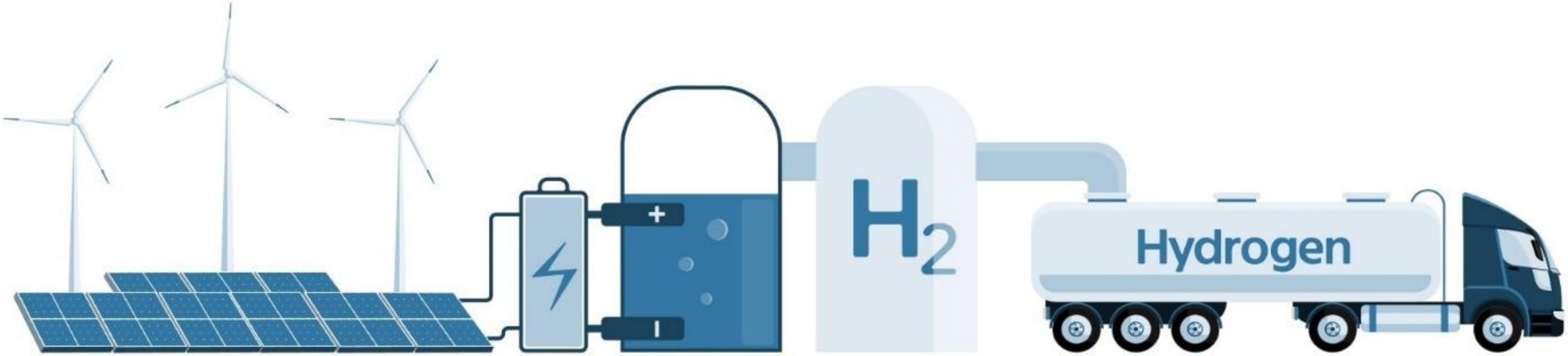
HYDROGEN FUEL CELLS FOR MOBILITY

Mobility spectrum of hydrogen energy

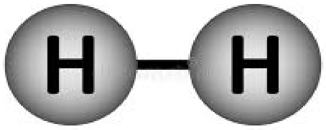


Professor K. K. Pant

Director IITR

Prof. Chemical Engg. Deptt IIT Delhi

Why hydrogen economy

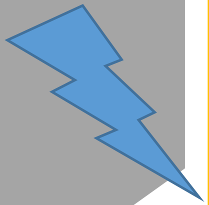


Zero Carbon footprint

- Water as combustion byproduct

High energy density

- 120 MJ/kg
- Twice as compared to gasoline



Best energy carrier

- Liquid/gaseous transport over large distance

Availability

- Most abundantly available material in the universe

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

- 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 NM^3 CNG.

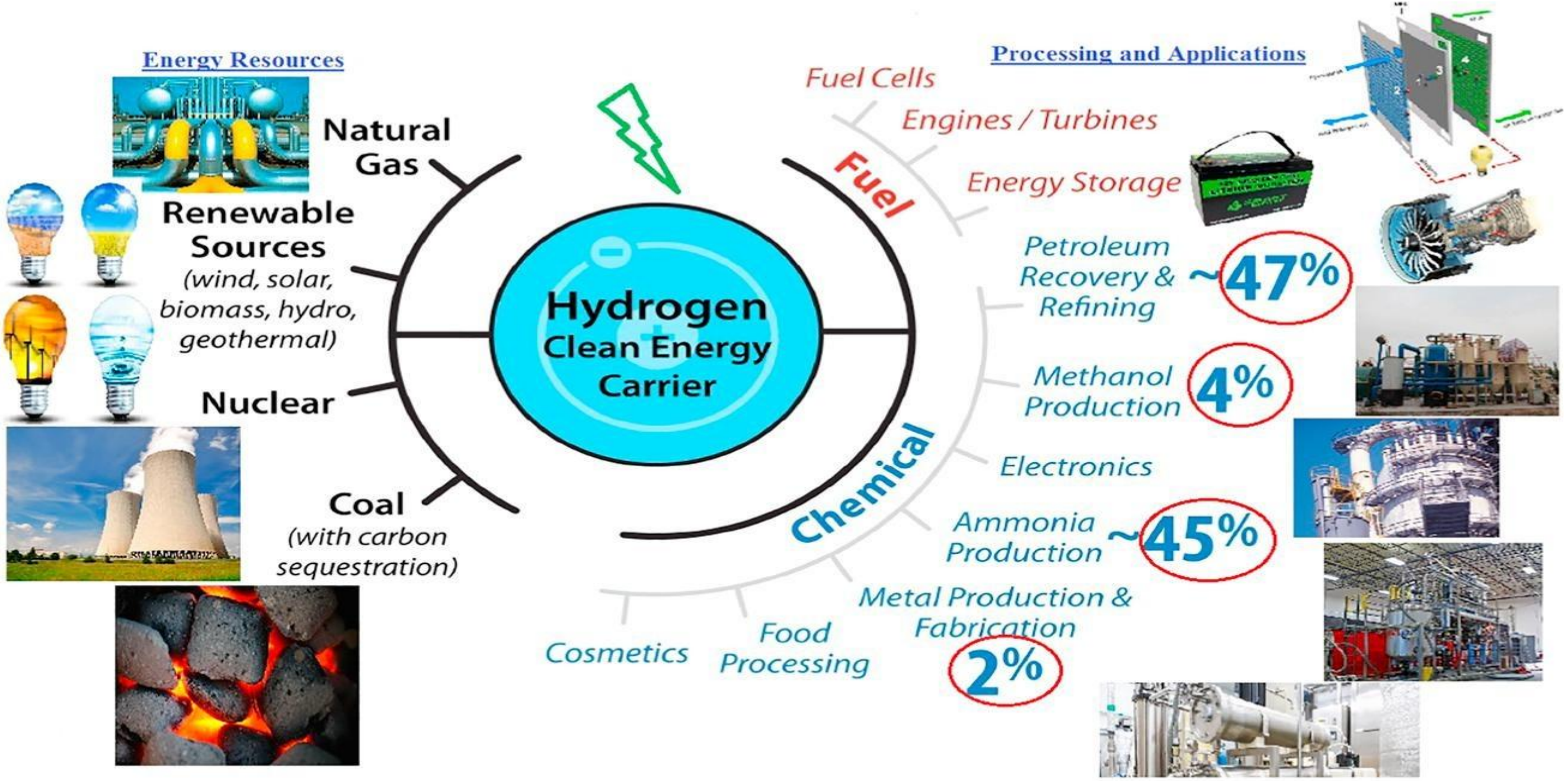
➢ Low energy per unit volume 0.09 kg/m^3 @ ambient condition

➢ Required higher storage tank surface area

➢ H_2 embrittlement

➢ Reacts with impurities :For example: H_2S Corrode storage/ transmission lines

Hydrogen: A Clean Energy Carrier



Hydrogen clean energy carrier as one of most essential clean and sustainable resource with main applications in both research and industry diverse.

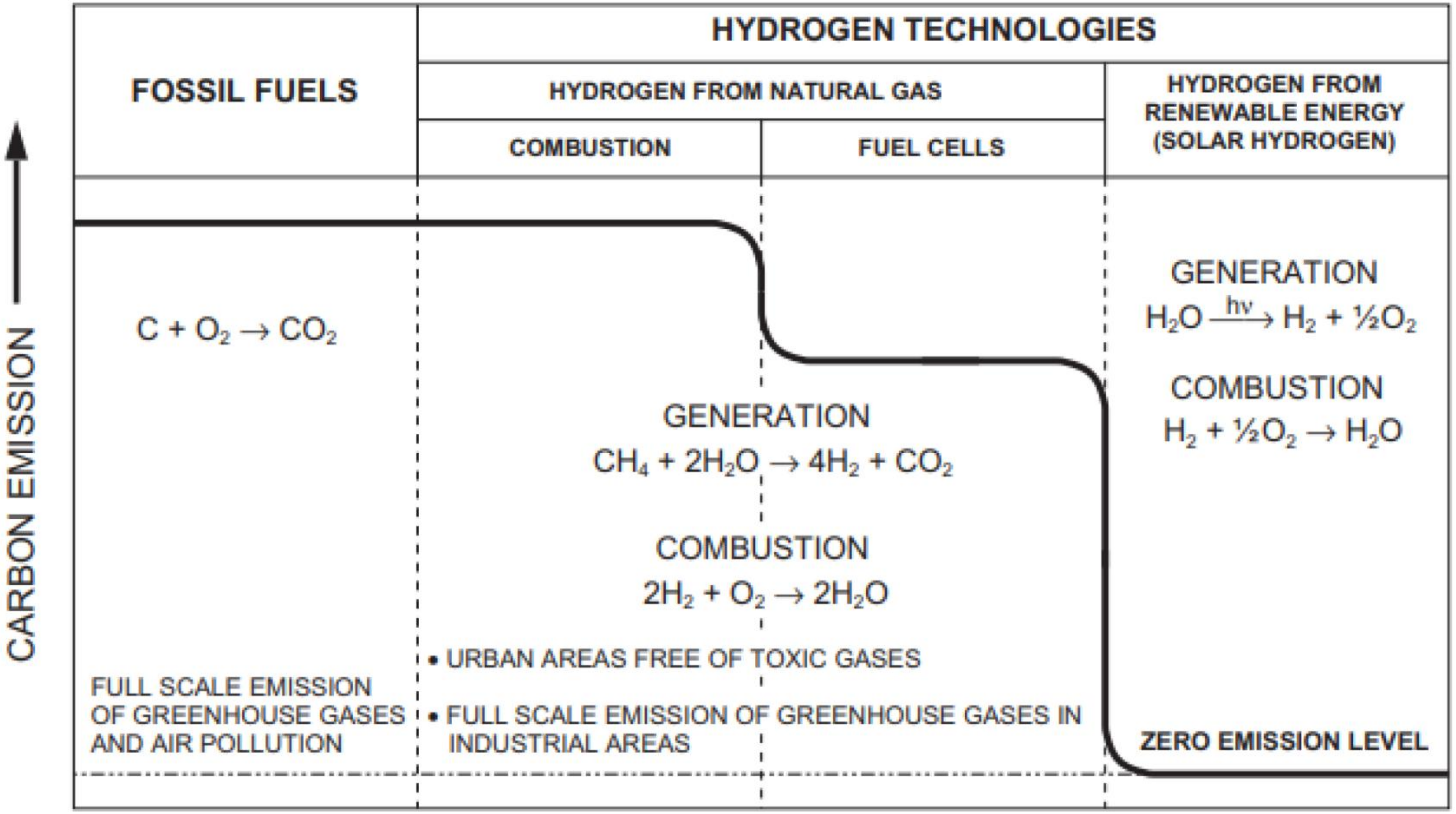
Why is Hydrogen Important as a Future Mobility and Transportation Solution?

- Efforts for decarbonization of mobility have progress regarding e-mobiity resulted in an increased enthusiasm around hydrogen-powered vehicles.
- Green hydrogen is promising to provide sustainable mobility applications, whether by powering fuel-cell electric vehicles (FCEVs), a hydrogen combustion engine (H2-ICE) or as element for synthetic fuels.
- Especially regarding heavy-duty transportation by means of trucks, buses, and trains hydrogen vehicle solutions are likely to shape the future of mobility.

Until 2030 the emissions of cars should be reduced by 55% and for trucks by 50% and until 2023 emission-free new cars should be released.

=> Hydrogen will play a crucial role in achieving climate goals, especially in public transportation and mobility

Comparison of fossil fuels and hydrogen combustion on carbon emission



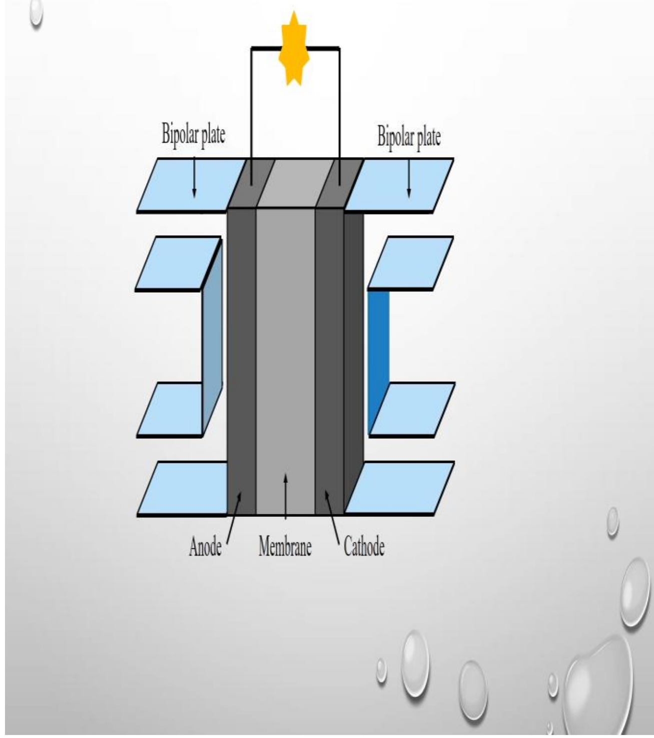
Comparison of fossil fuels and hydrogen combustion on carbon emission

- Using hydrogen produced from conventional methods can reduce the carbon emission by almost 20% when used in fuel cells.

- A significant reduction in carbon emission, i.e., a zero-emission level can be achieved by producing hydrogen using renewable sources of energy.

Energies **2021**, *14*, 7389.

Overview of Hydrogen fuel cell technology



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.

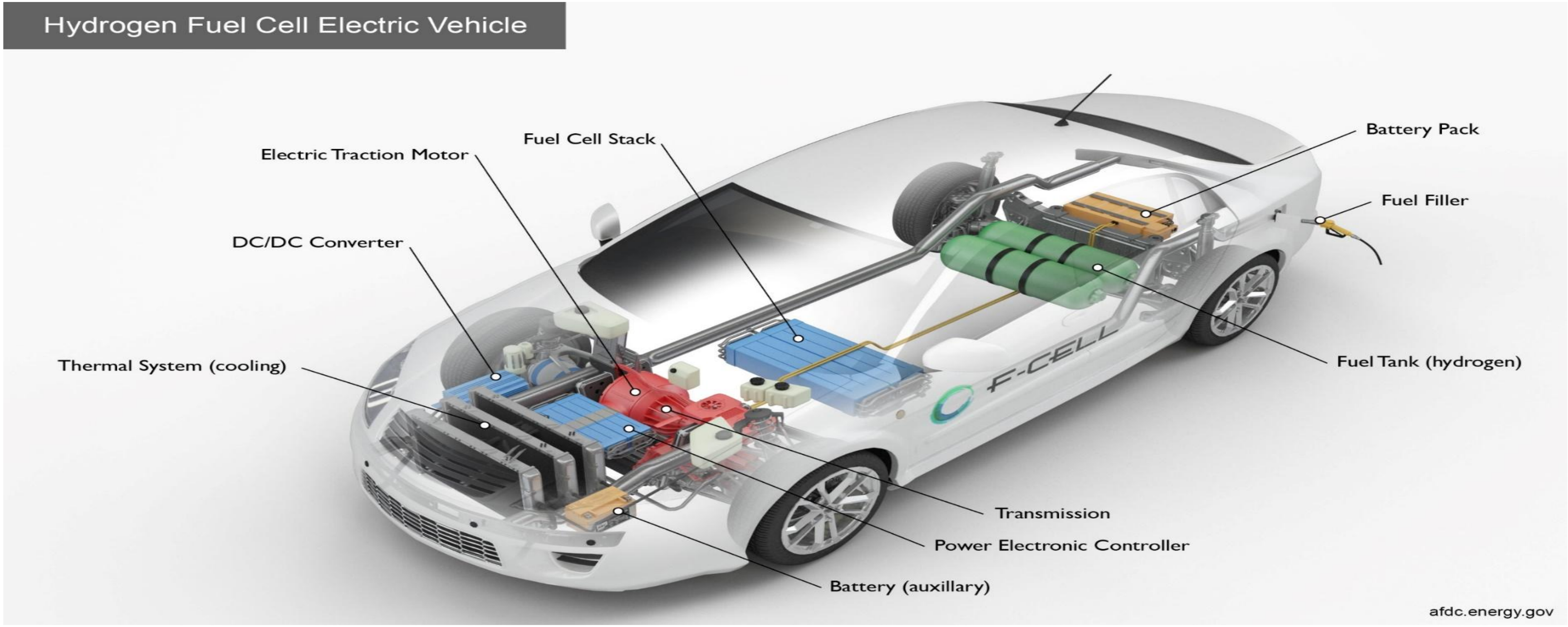
5. **Power generation:** The electric current produced by the flow of electrons powers the vehicle’s electric motor and other auxiliary systems such as the headlights, heating, and air conditioning.

Different types of Fuel Cells

	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

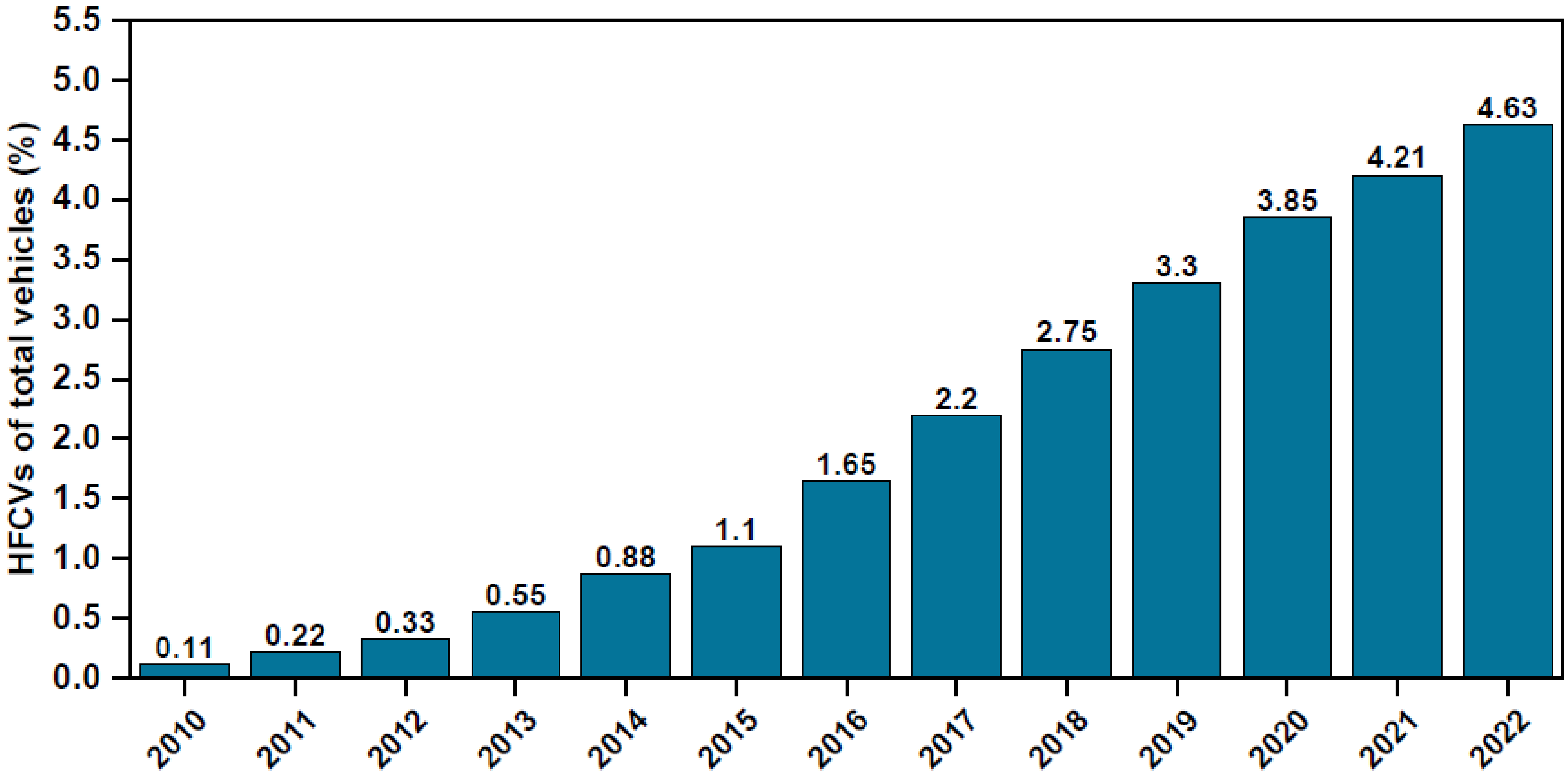
Ref: https://techetch.com/

Hydrogen Economy: Generation → Storage → Usage



http://dx.doi.org/10.3390/app9112296

The Global HFCVs as a Percentage of the Total Vehicles



Scope for Research & Development

Fabrication of stable/ durable/ low-cost/ robust

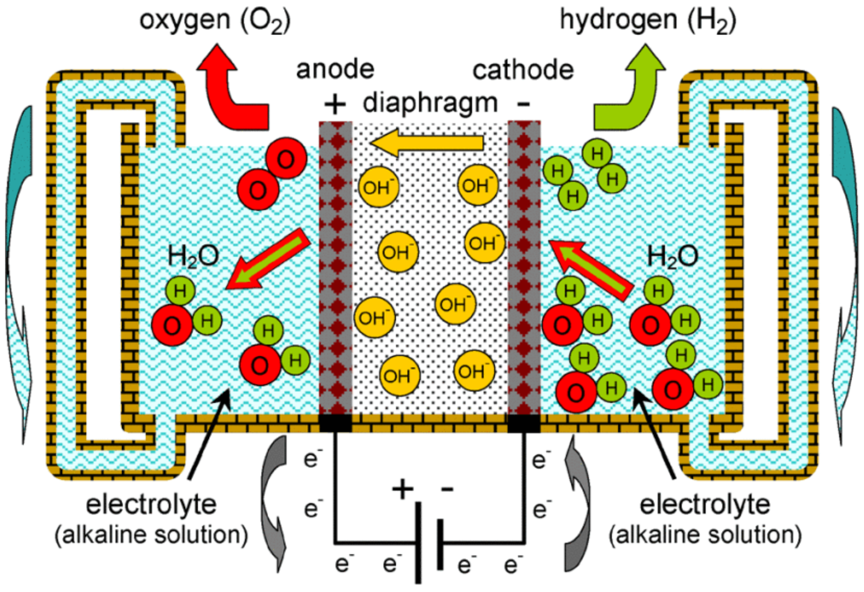
For H_2 generation

- Electrodes: PGM Free catalysts for PEM
- Membranes: Perfluorinated membranes and titanium current collectors are complex and expensive
- Hight performance electrolyte
- Fuel cell

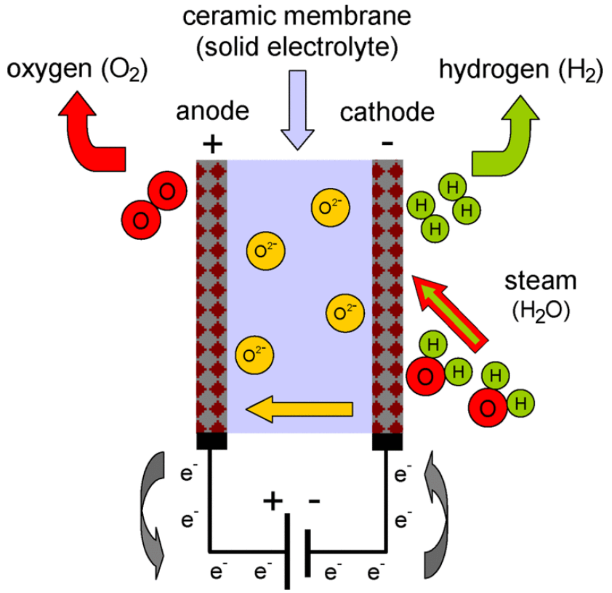
For H_2 transportation/ storage

- ✓ H_2 cylinders
- ✓ Pipeline to avoid hydrogen embrittlement
- ✓ Storing in form chemical bond such Metal hydride, NH_3 etc
- ✓ Packing material

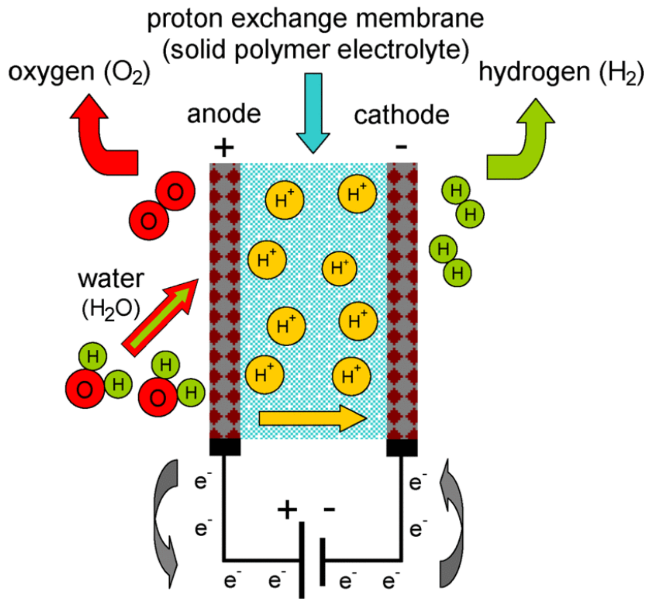
Water Electrolysis



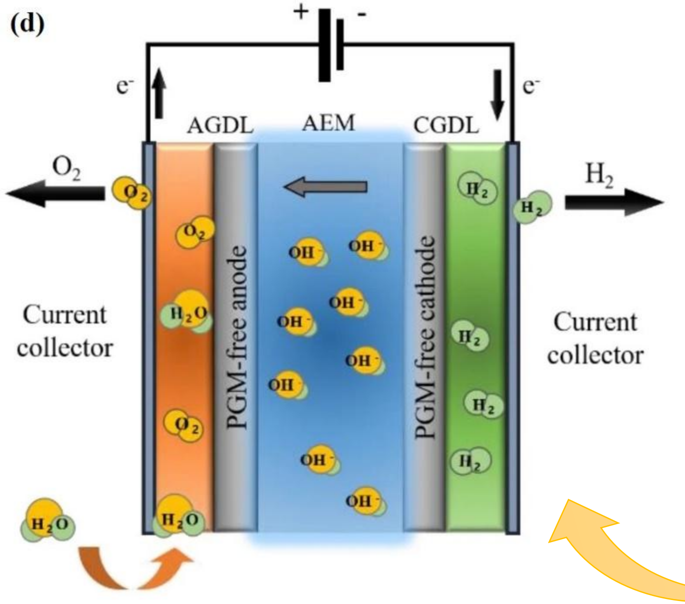
(a) Alkaline Electrolysis



(b) Solid Oxide Electrolysis



(c) PEM Electrolysis



(d) AEM (Pt-group metal free) Electrolysis

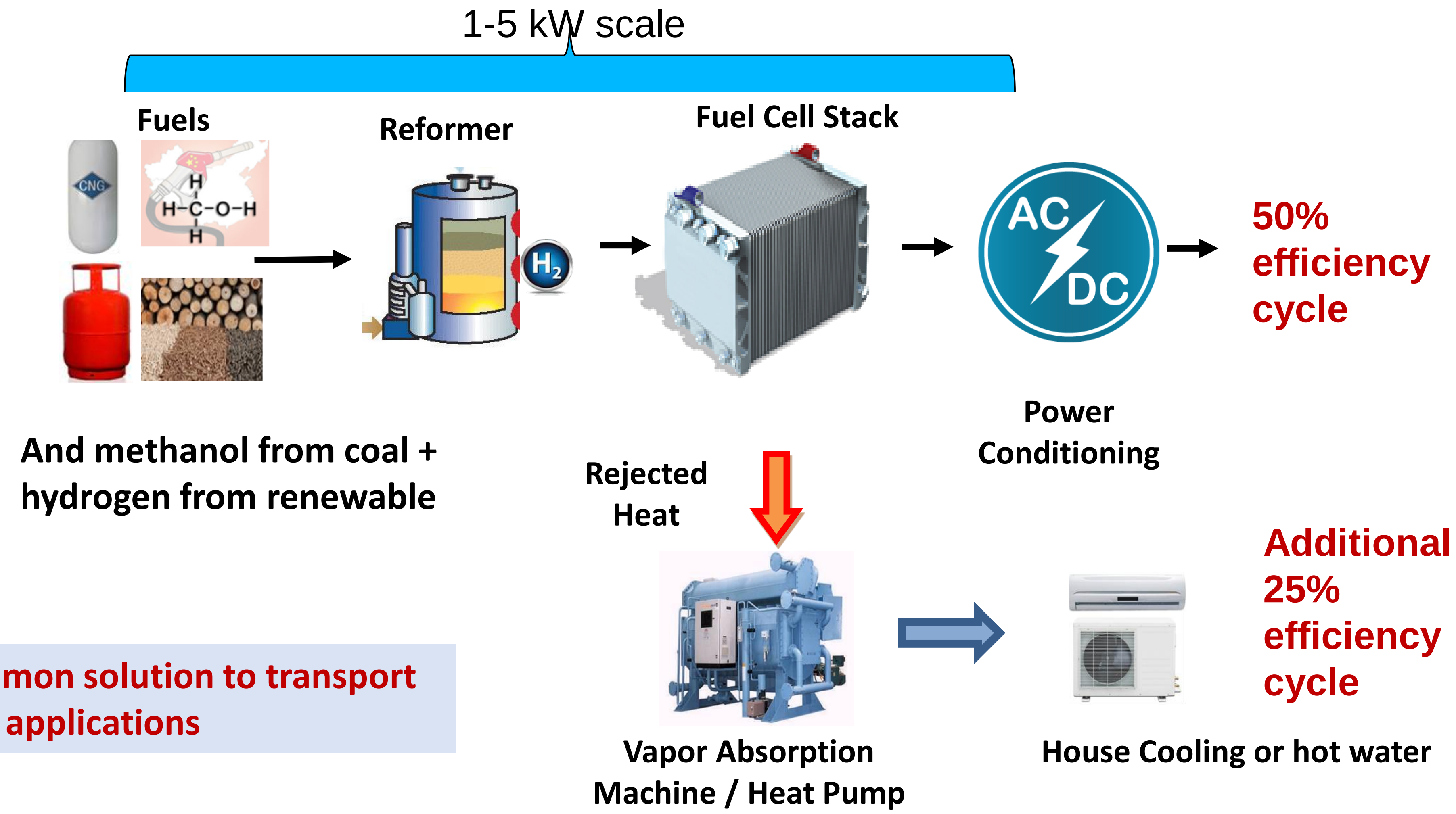
- **Water electrolysis produces 3,80,000 kg H_2 per year, consumption rate of 53.4 kWh/kg H_2**
- **Electricity costs: >62% of overall costs on a big scale (1000 kg/day), capital costs approaching 30%.**
- **For small-scale (10 kg/day) operations, capital costs account for ~62% of total costs, power costs accounting for 20%**

*Sci Rep **11**, 293 (2021)*

Proceedings of the IEEE, vol. 100, no. 2, pp. 410-426, Feb. 2012

HYDROGEN FUEL CELLS DELIVERING HIGHEST EFFICIENCY FROM FOSSIL

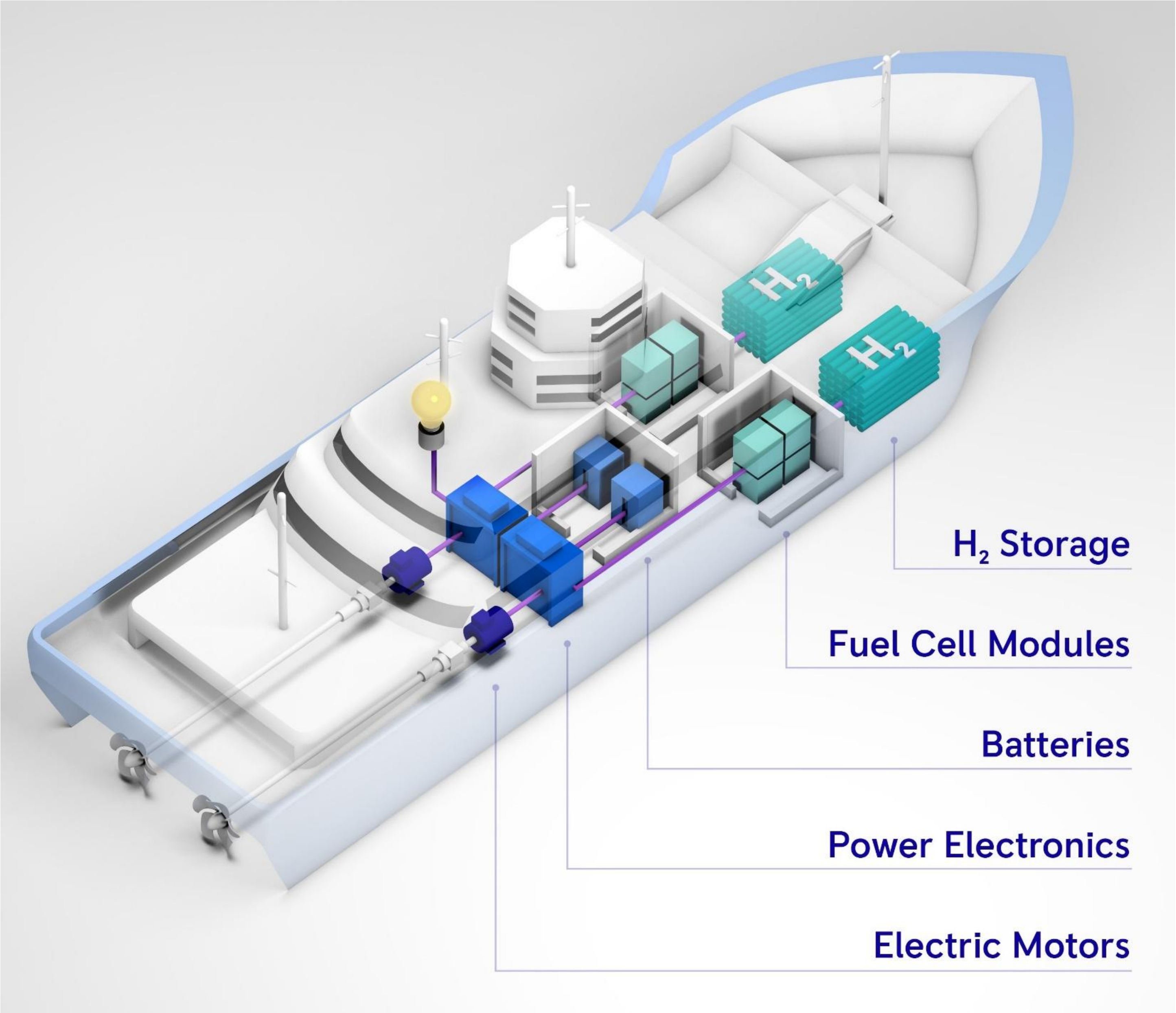
Hydrogen (from renewable + fossil + biomass) will power the home at 1-5 kW scale with 50% fuel cell efficiency boosted to 75% efficiency system.



This is a common solution to transport & stationary applications

Hydrogen Economy: Generation → Storage → **Usage**

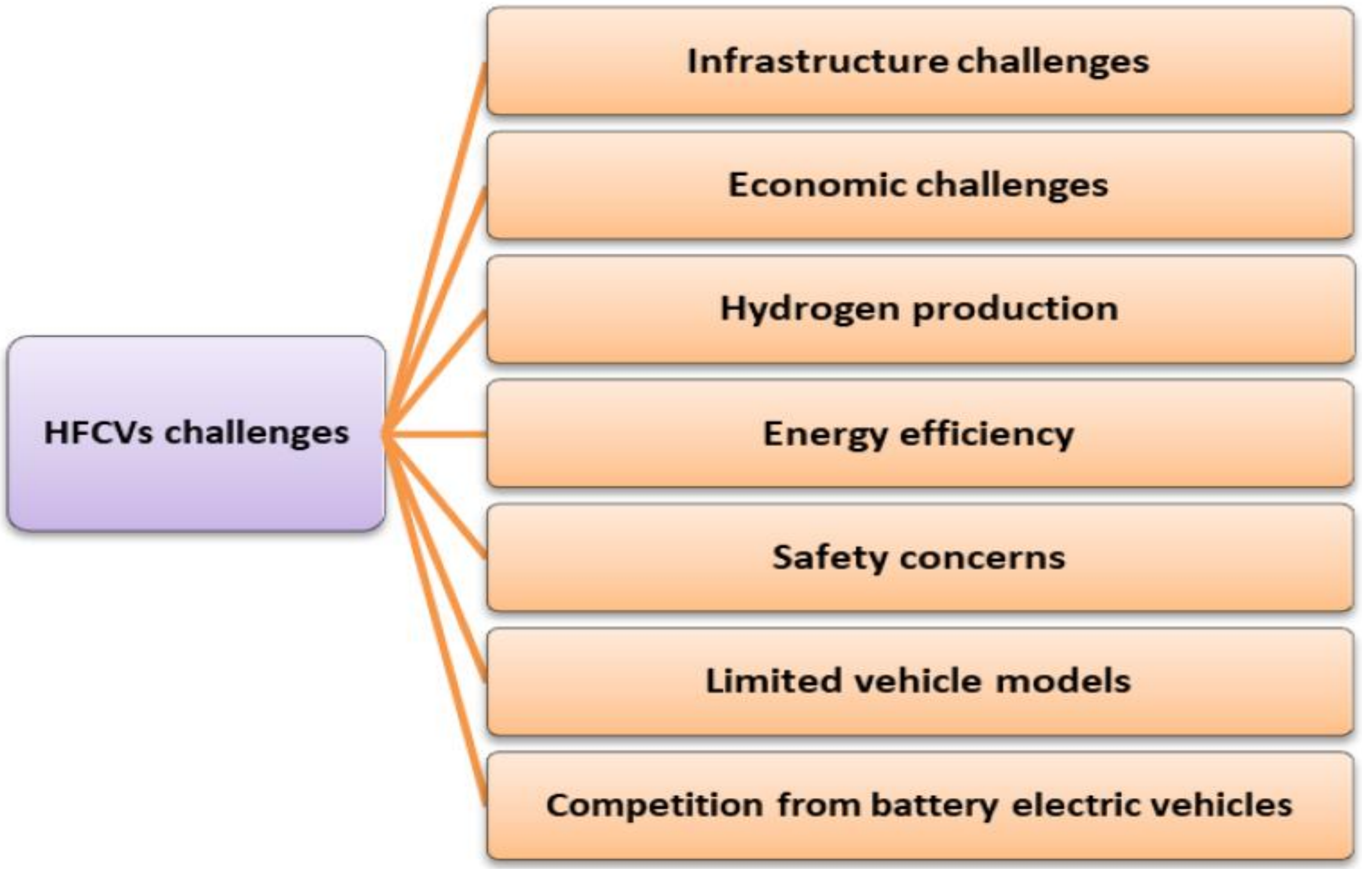
Maritime Applications

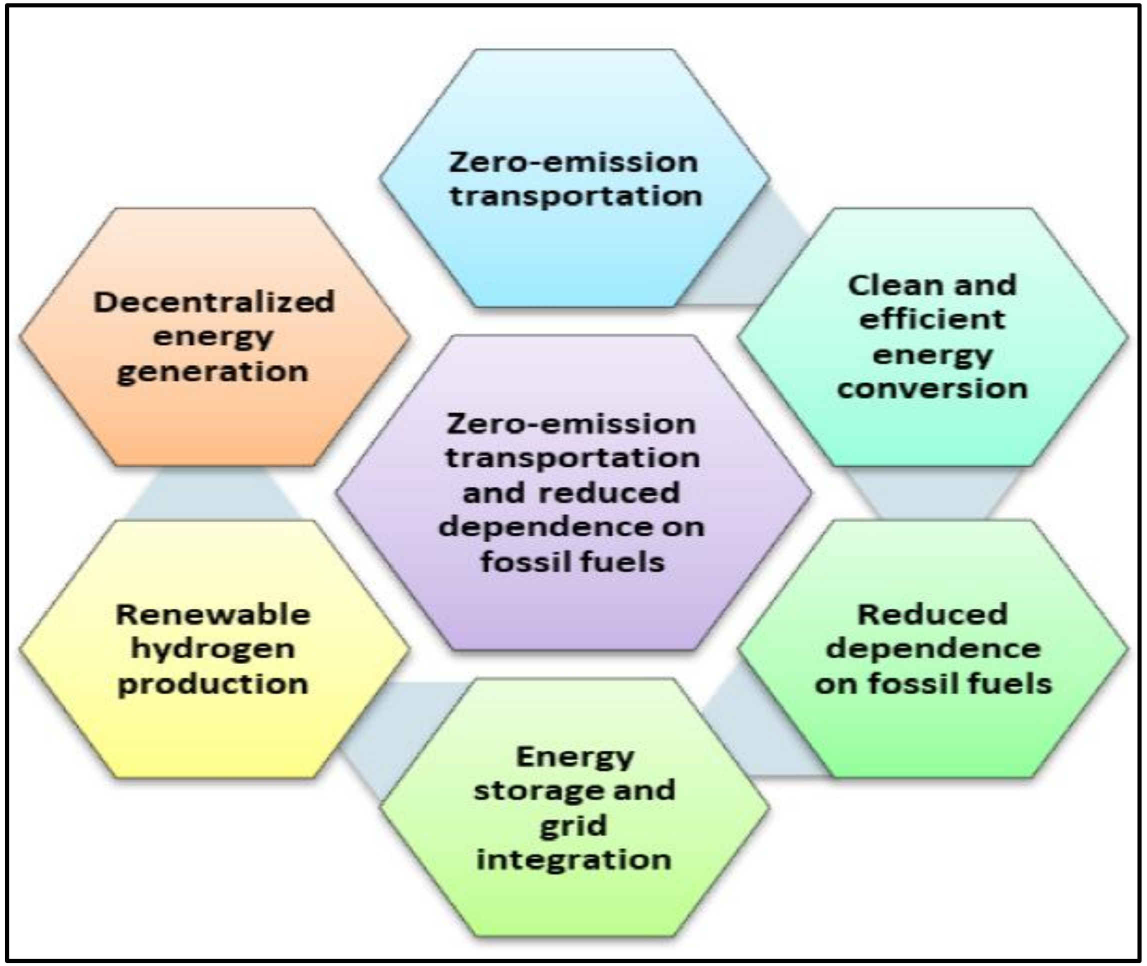


- Mitigating fuel price hike, studies with feasible of alternative energy sources found.
- Substitution of marine diesel fuels found in a gaseous state (e.g., propane, natural gas and hydrogen) or liquid state(e.g., methanol, ethanol, biodiesel and bio-oils).
- Two forms of hydrogen - used in maritime applications i.e. hydrogen employed for internal combustion engines and hydrogen fuel cells.
- Total GHG emissions per ton-km of hydrogen as dual fuel (with heavy fuel oils) decreases by 40%.

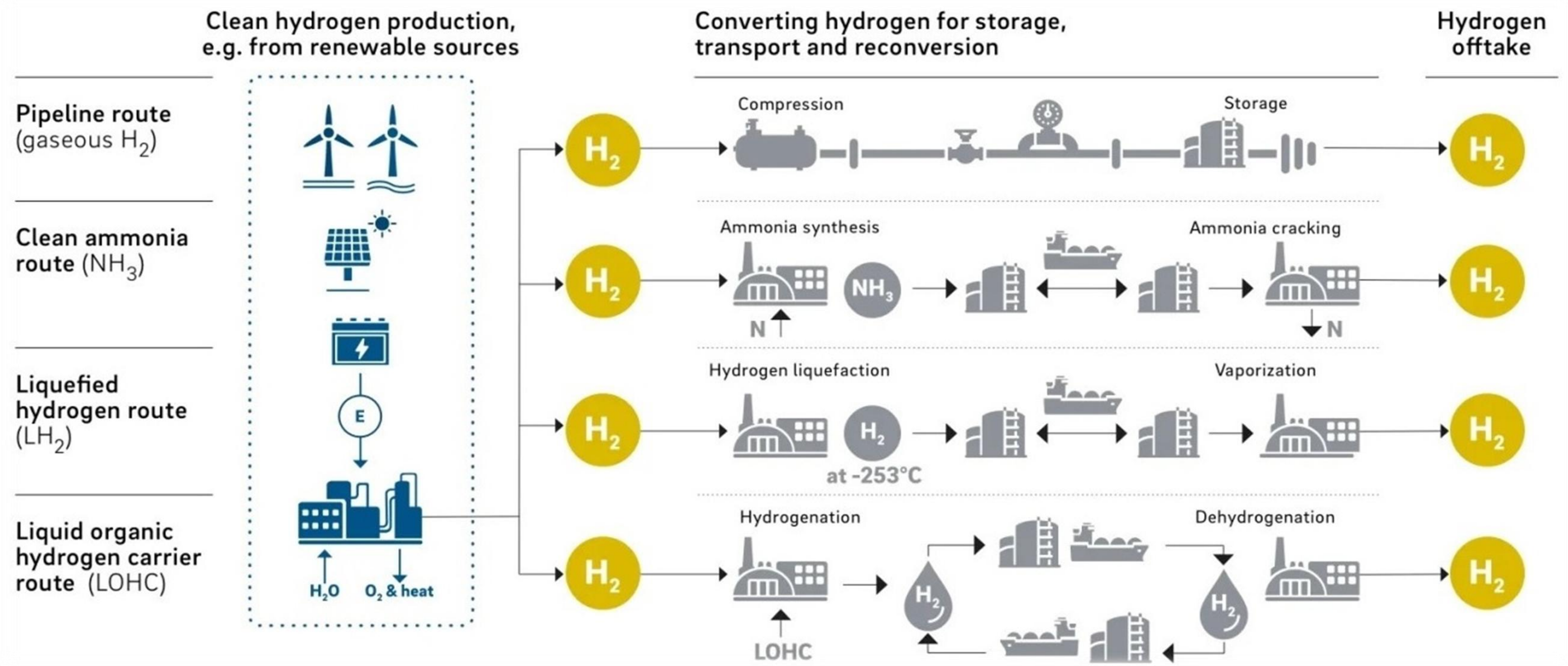
MTU-A Rolls-Royce solution

HFCV Challenges & Potentials for Zero Energy Transmission





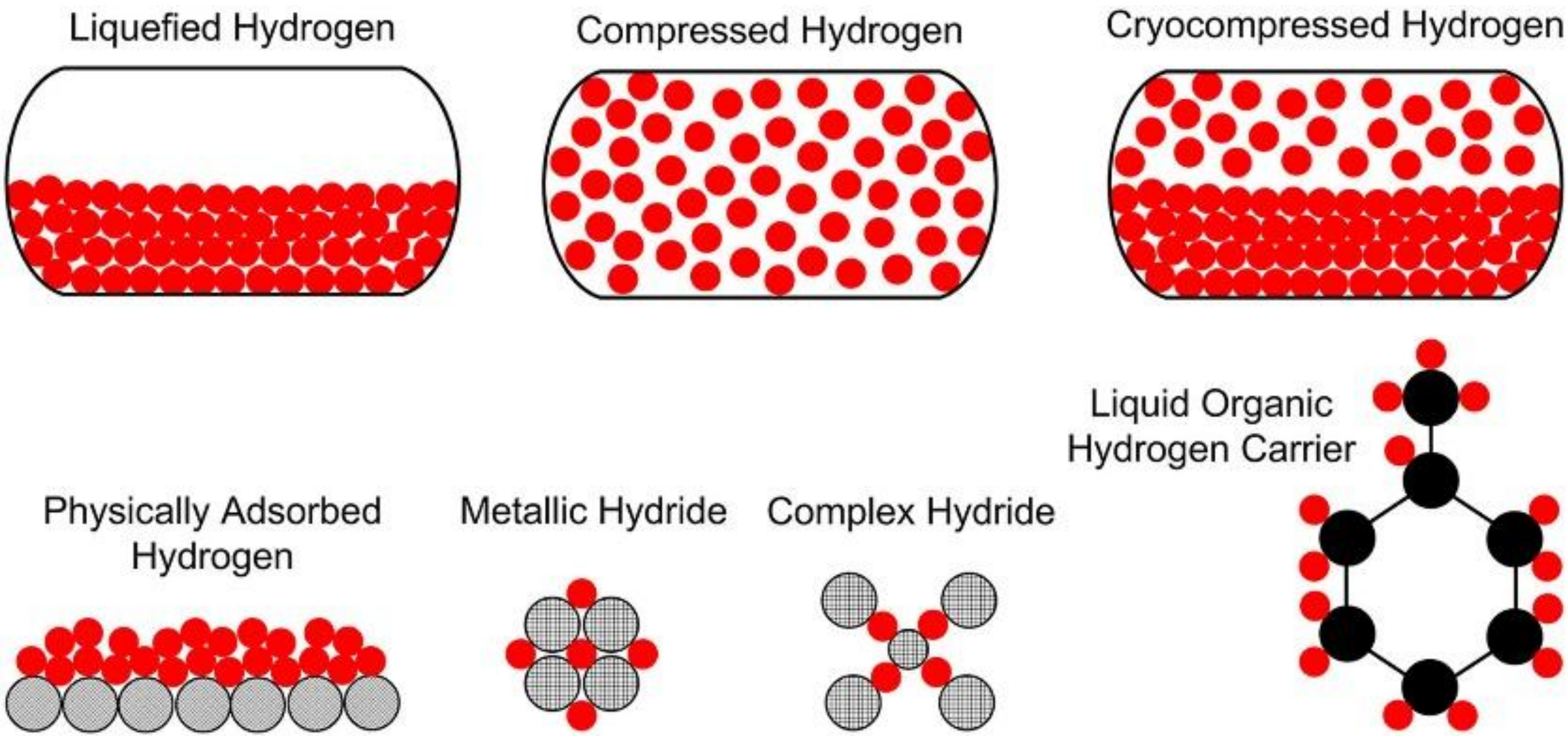
Trends in Hydrogen Transportation



- Obtaining hydrogen from the production sites to the end users at lowest possible cost will be the key to the success of Green Economy.
- Static pipeline infrastructure, is used to transport gaseous hydrogen to end consumers who are connected to the gas grid.
- Existing NG pipelines need to be upgraded to carry volatile H_2.

Source: Roland Berger

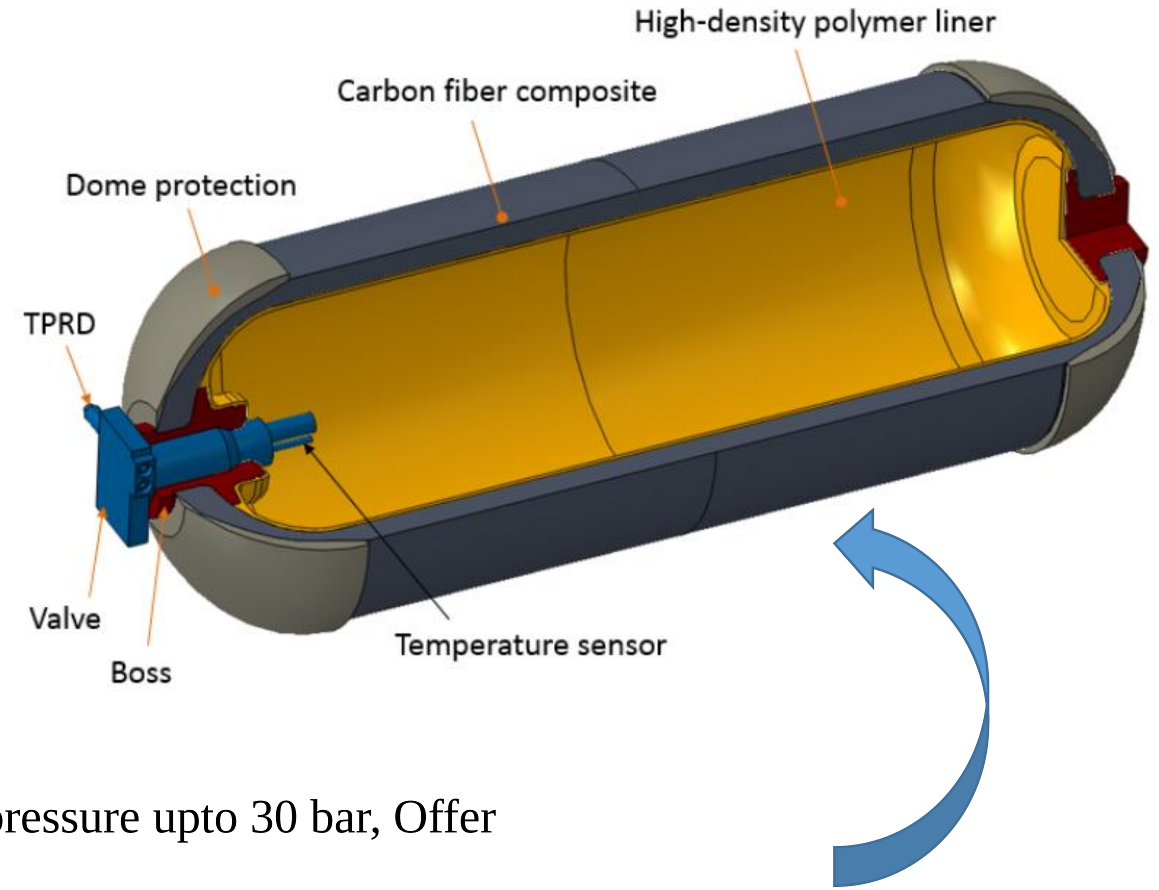
Challenges :Hydrogen Storage Methods



Renewable and Sustainable Energy Reviews, *167*, 112743.

Compressed Hydrogen Storage system

Storage Method	Hydrogen content (wt%)	Volumetric Density (g/L)	Volumetric Energy Density (MJ/L)
cH_2			
1 bar, RT	100	0.0814	0.01
350 bar, RT	100	24.5	2.94
700 bar, RT	100	41.4	4.97
700 bar, RT, (incl. Type IV tank)	5.7	40.8	4.9



Five types of Vessels for storing **Compressed Hydrogen** gas:

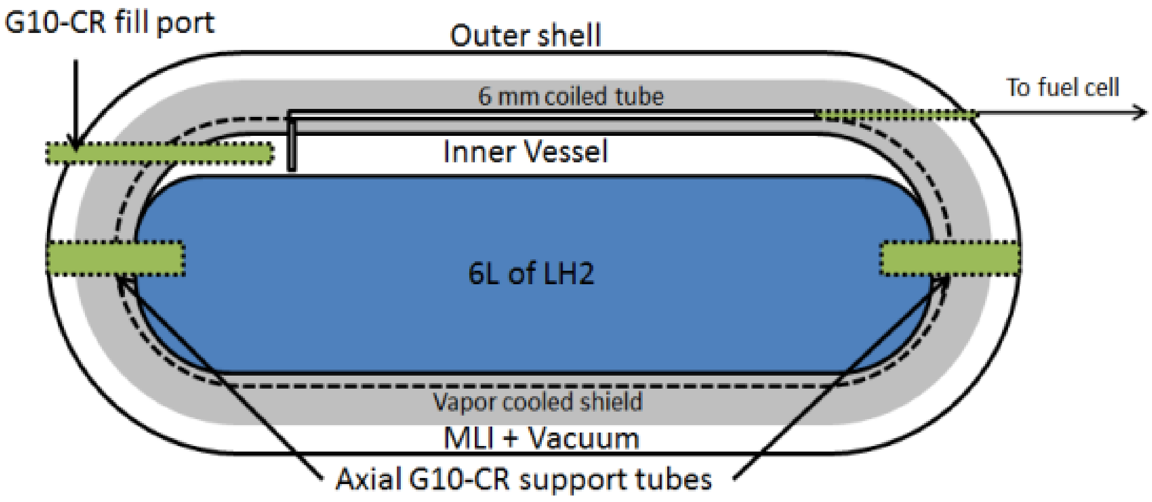
- Type I: Made up of Steel or Alluminium Alloy, Cheapest, Withstand pressure upto 30 bar, Offer extremely low gravimetric energy desnsity.
- Type II: Metallic wall wrapped with fiber resin composite, 30-40% lighter and 50% costlier than Type I.
- Type III: Made of Carbon Fibre Reinforced Plastic (CFRP) lined with Al, stronger, lighter, low thermal conductivity.
- Type IV: Similar to Type III, but the liner is mostly polymeric (HDPE), handle Pr upto 700 bar.
- Type V-VI: Under development, not available commercially.

TPRD = Thermally Activated Pressure Relief Device

Renewable and Sustainable Energy Reviews, 167, 112743.

Liquid Hydrogen Storage

Storage Method	Hydrogen content (wt%)	Volumetric Density (g/L)	Volumetric Energy Density (MJ/L)
LH_2			
1 bar, -253^{o}C	100	70.8	8.5
1 bar, -253^{o}C (incl. tank)	14	51	6.12



Liquid Hydrogen tank of 6L

- 4 cylinders of LH_2 are equivalent to 1 gasoline tank.
- Releases hydrogen at high rate and offer low adiabatic expansion energy at cryogenic condition.
- Smaller tank size is required as density is 1.5-2 times as that of CH_2
- Non-corrosive in nature.
- Expensive as high energy is required for liquefaction.
- Boil-off phenomenon – 1.5-3% of H_2 vaporizes per day, require more open space.

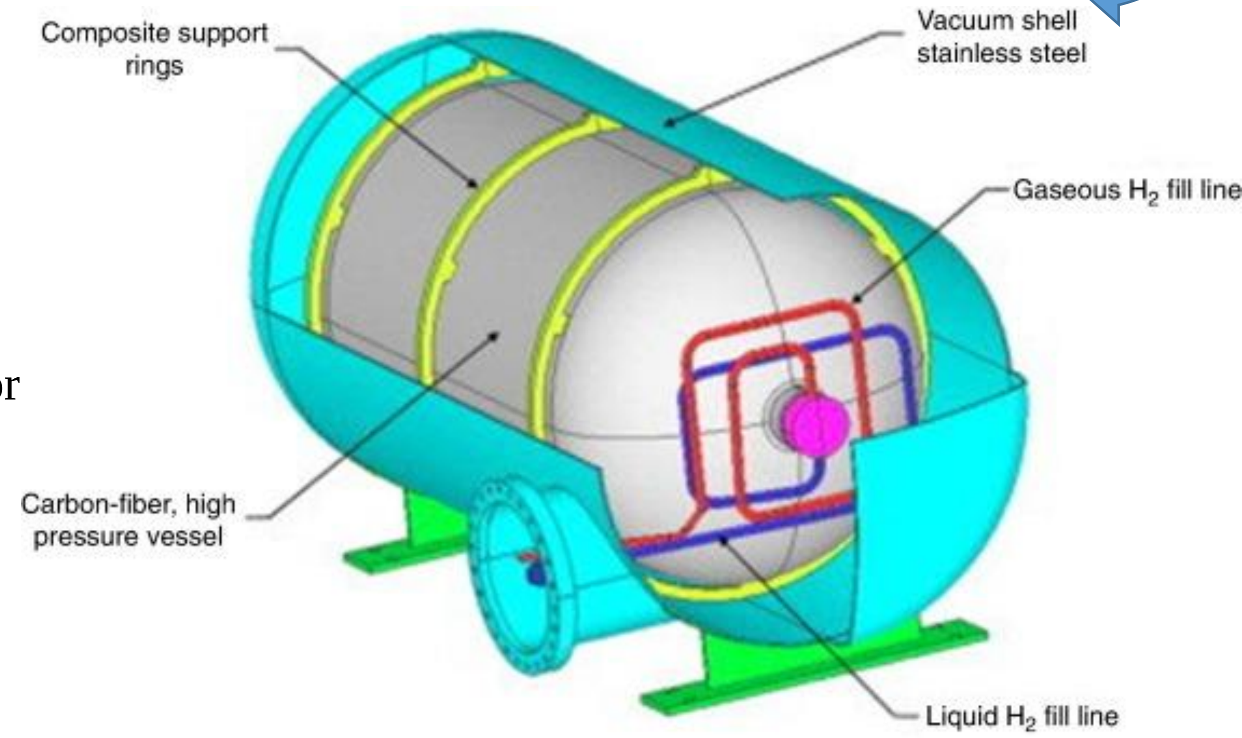
Renewable and Sustainable Energy Reviews, 167, 112743.

Cryo-Compressed Hydrogen Storage

CcH_2			
Storage Method	Hydrogen content (wt%)	Volumetric Density (g/L)	Volumetric Energy Density (MJ/L)
350 bar, -253^{o}C	100	80	9.6

<u>CcH_2 storage tank</u>

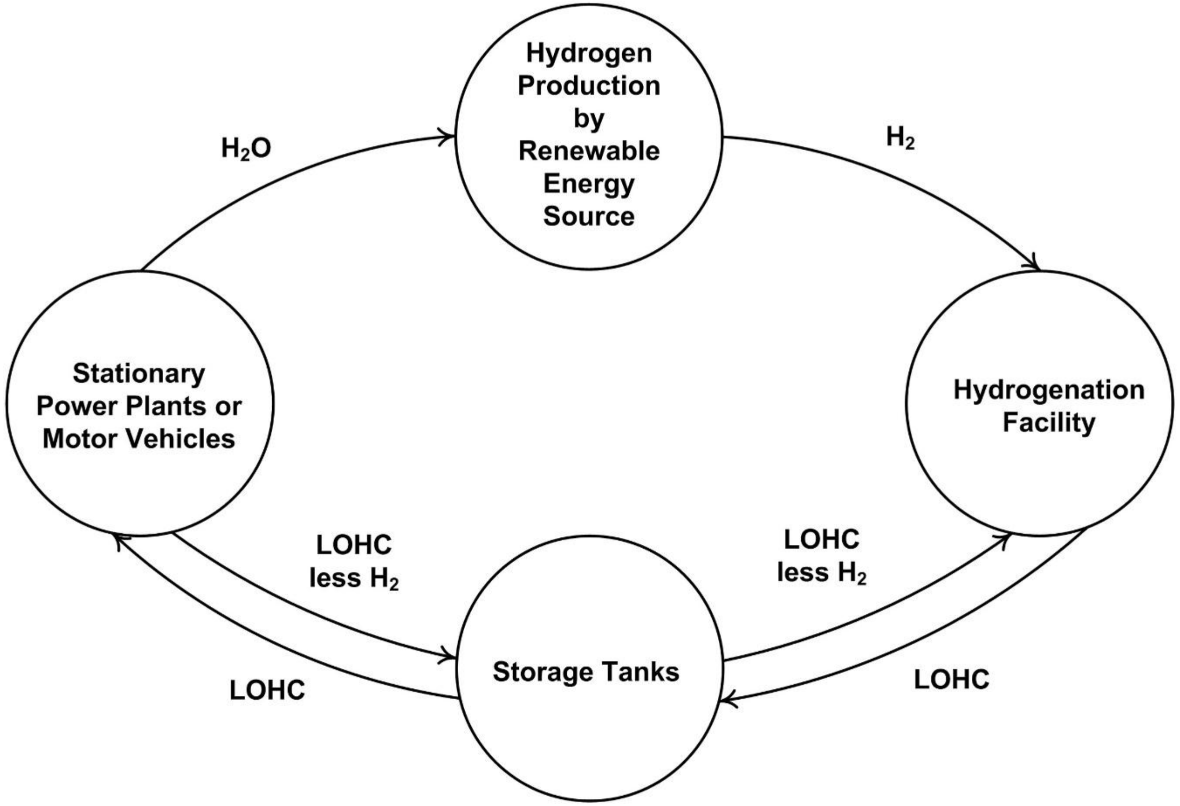
- Aspects of both compressed gaseous H_2 and the cryogenic hydrogen are combined.
- cCH_2 offers nearly 10g/L higher density than that of LH_2.
- Greatly reduces Boil-off losses.
- Dormancy period is around 7 days while filled to 85%.
- More expensive double walled Type III vessel is required for stor
- Rate of H_2 release and refuelling the tanks is fast.



Renewable and Sustainable Energy Reviews, 167, 112743.

Liquid Organic Hydrogen Carrier (LOHC) Storage System

LOHC			
Storage Method	Hydrogen content (wt%)	Volumetric Density (g/L)	Volumetric Energy Density (MJ/L)
Methyl-cyclohexane / Toluene/H_2 (MTH)	6.2	47.3	5.68
Perhydro-benzyltoluene / benzyltoluene	6.2	56.0	6.72

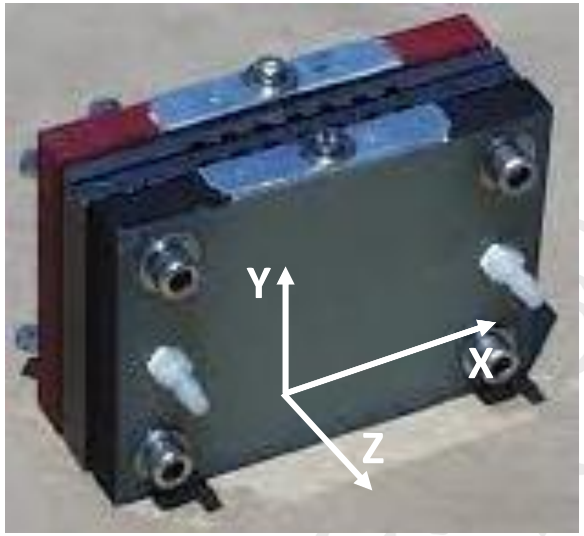


LOHC Cycle

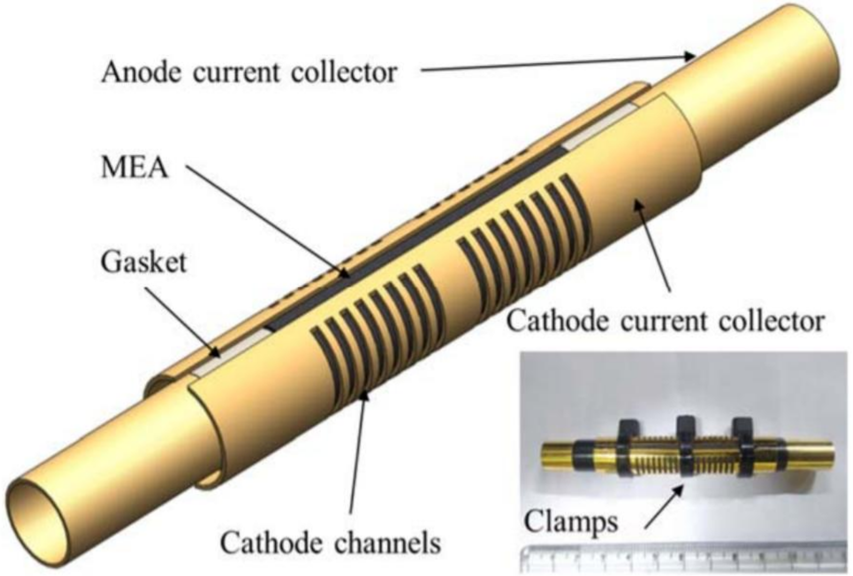
- In a liquid organic hydrogen carrier (LOHC) or liquid organic hydride, hydrogen is stored chemically by reacting with a hydrogen deficient organic molecule.
- The organic hydride is dehydrogenated in the reactor and the necessary hydrogen is released for the power production either in a stationary power plant or in an on-vehicle application.
- The dehydrogenated product is removed at the filling station and the organic hydride is recharged.
- The dehydrogenated organic hydride is trans-ported to an off-site hydrogenation facility and hydrogenated and theorganic hydride is finally conveyed to the filling station

Renewable and Sustainable Energy Reviews, 167, 112743.

Significance of cylindrical fuel cells (Cy-PEMFCs)



Planar cell



Cylindrical fuel cell

Cy-PEMFCs are meant to deliver higher power wrt weight and volume compared to planar cells as evident from power density comparisons.

They can be preferred choices for ones that need more power per unit weight and volume viz. drones and aviation industries etc.

Appx. Weight = 1500 g
Appx volume = 10*10*10 cm^3
Power delivered = 2 W
Cost = 15,000/-
Volumetric power density = **0.014 W/cm3**
Gravimetric power density = **0.001 W/g**

Appx. Weight = 50 g
Appx volume = 0.78*1*8 cm^3
Power delivered = 1.6 W
Cost = 5,000/-
Volumetric power density = **0.657 W/cm3**
Gravimetric power density = **0.863 W/g**

Challenges in Hydrogen Mobility Need To Be Solved for the Future Of M

As a manufacturer, supplier, or system integrator : Must bring hydrogen mobility products safely to the market.

- Compliance to existing regulations play an important role.
- Regulatory conformity is required to gain legal permission to access global markets, and in many cases government regulations and customer requirements become stricter.
- Fueling a hydrogen car : Needs aligning the heavy nozzle and sealing it properly so the car and pump can communicate electronically can require some practice.
- The infrastructure for supplying hydrogen FCEV to retail outlets is very thin. Today's stations can often only fuel two to five vehicles before they go offline for up to half an hour to repressurize.
- Best-selling hydrogen car in the U.S., is rated at 90 kW (120 horsepower). But that's not enough to accelerate onto a fast-moving highway, so Toyota and other HFCV makers adds in a high-voltage low-capacity battery, very similar to those used in [gasoline-electric hybrid vehicles].

Way Forward

- Advancements in catalysts, membrane materials, and flow field designs leading to higher efficiency, durability, and cost reduction.
- The high costs associated with vehicle production and hydrogen fuel cell technology, a lack of refueling infrastructure, and concerns about the efficiency and environmental footprint of hydrogen production. Need to be addressed
- Advancements in technology, economies of scale, and significant R&D investments may likely help overcome these obstacles in the future.
- While the pathway toward a broad HFCV adoption is lined with both technical and infrastructural challenges, the potential benefits it offers in our fight against climate change make these obstacles worth tackling.
- Collaborate with energy companies and governments to develop a comprehensive hydrogen refueling infrastructure.
- Allocate resources and establish partnerships to expand the network of hydrogen refueling stations.
- Promote consumer awareness and education
- Invest in marketing and educational campaigns to raise awareness about thebenefits of HFCVs and address misconceptions.
- Implement supportive policies, incentives, and subsidies to encourage HFCV adoption and reduce market barriers.

Thank You…!!!