Green Hydrogen for Carbon Neutral Society: Opportunity, Challenges and Levelized Cost of Production

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Climate change

Climate change refers to long-term shifts in temperatures and weather patterns. These shifts may be natural, such as through variations in the solar cycle. But since the 1800s, human activities have been the main driver of climate change, primarily due to burning fossil fuels like coal, oil and gas.

Hydrogen and concept of Green hydrogen

Concept of green hydrogen was 1st mentioned by British scientist J.B.S Haldane in 1923. Only in 1990 that prediction came true when hydrogen was produced from solar energy in a German pilot plant.

What is Green Hydrogen?

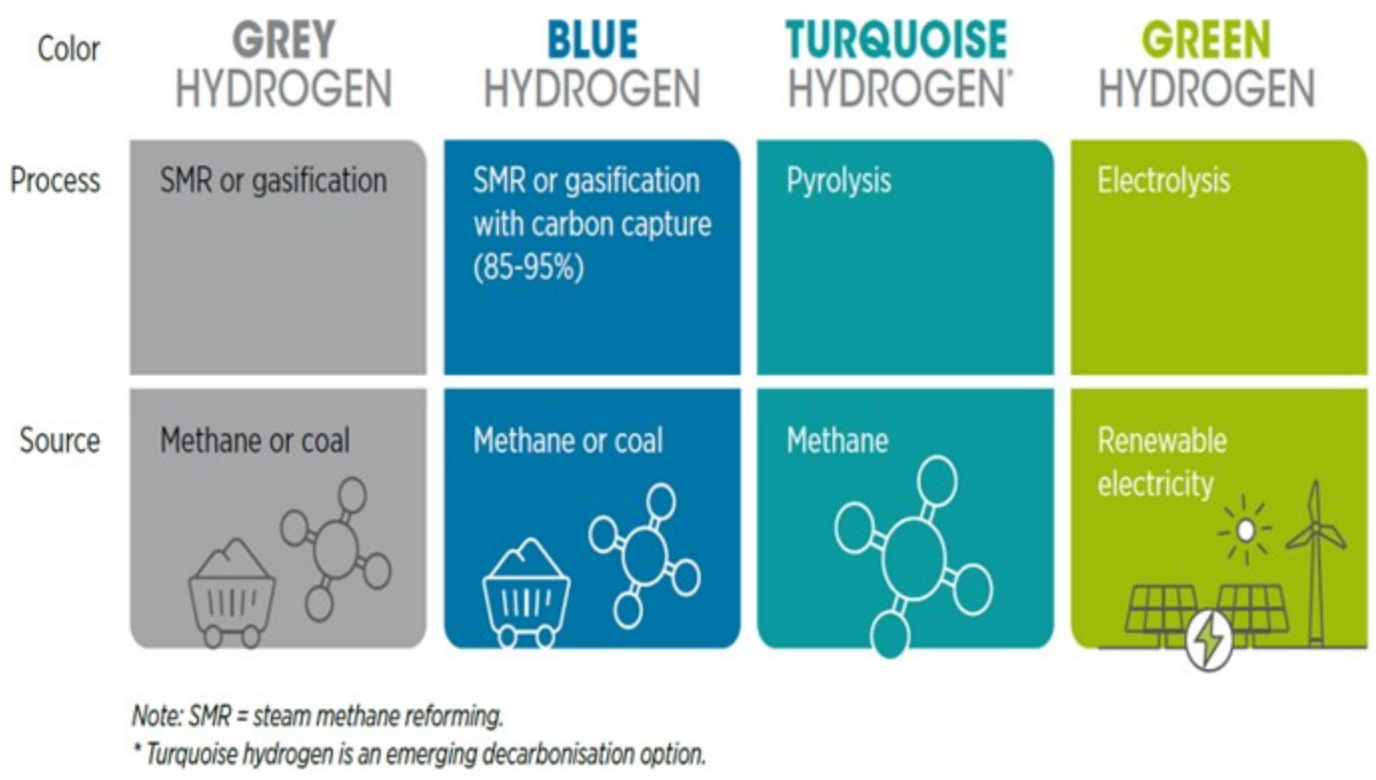


Figure 3: Different shades of hydrogen [14].

According to European CertifHy project Green hydrogen is

- Produced by renewal energy and
- Process carbon emission produced should be 60% less than that of Gray hydrogen

Carbon neutral by 2050

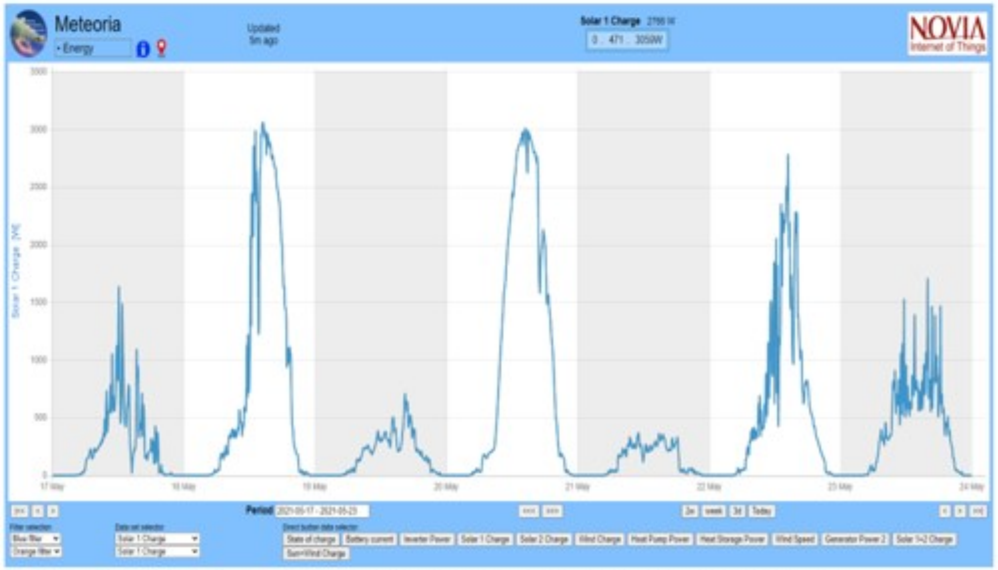


Figure 2: Solar Energy production fluctuation during the period 17.05.2021 and 23.05.2021 [6].

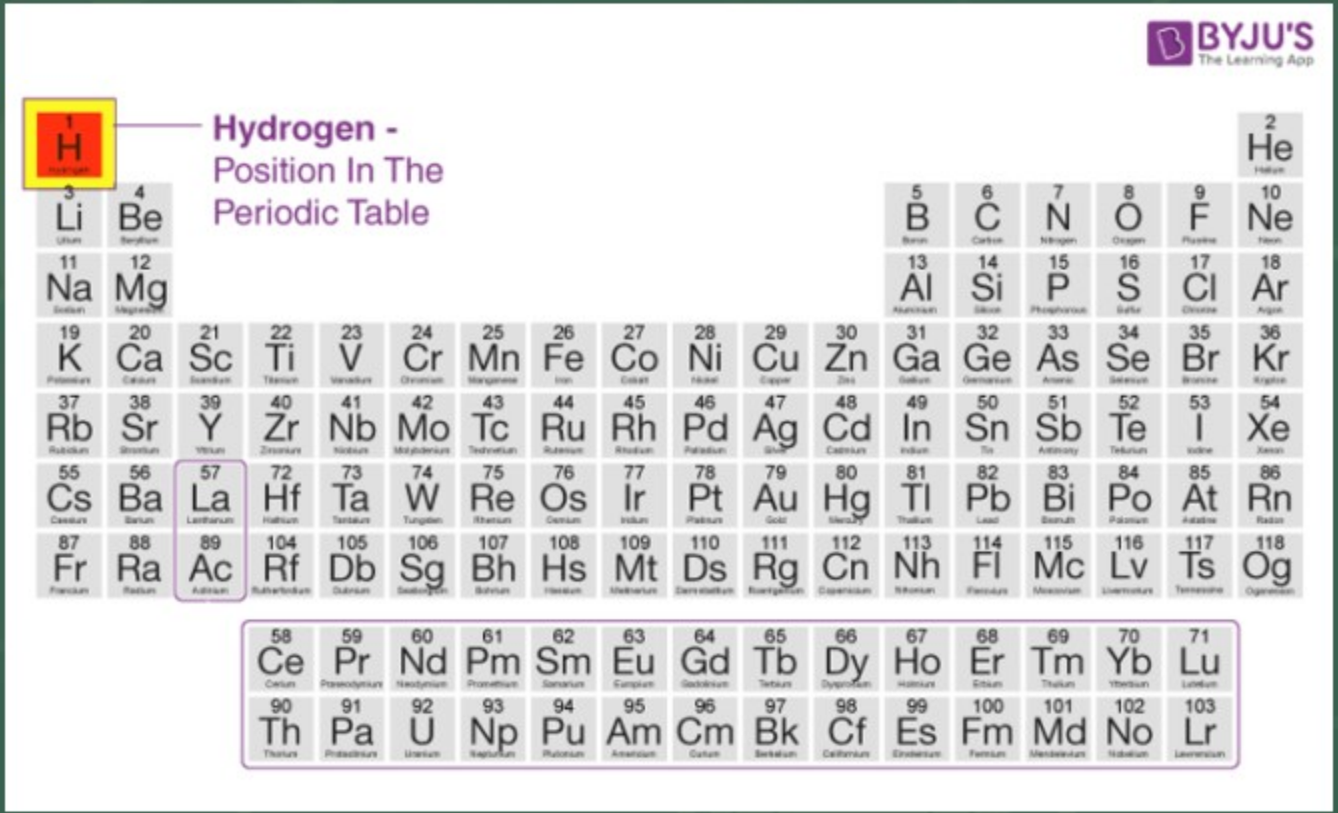
Figure 1: Wind Energy production fluctuation during the period 17.05.2021 and 23.05.2021 [5].

- No choice but using hydrogen
- Renewal energy can only get us so far and it has its own problems such as wind not blowing always and sun not shining at nights and winter.
- Hydrogen can help us to decarbonize range of sectors that have been hard to clean up in the past such as chemical, iron and steel industries as well as transport especially heavy and long transport sectors. Hydrogen can also be used to power and heat our home and store renewable energy.

So, What is the catch?

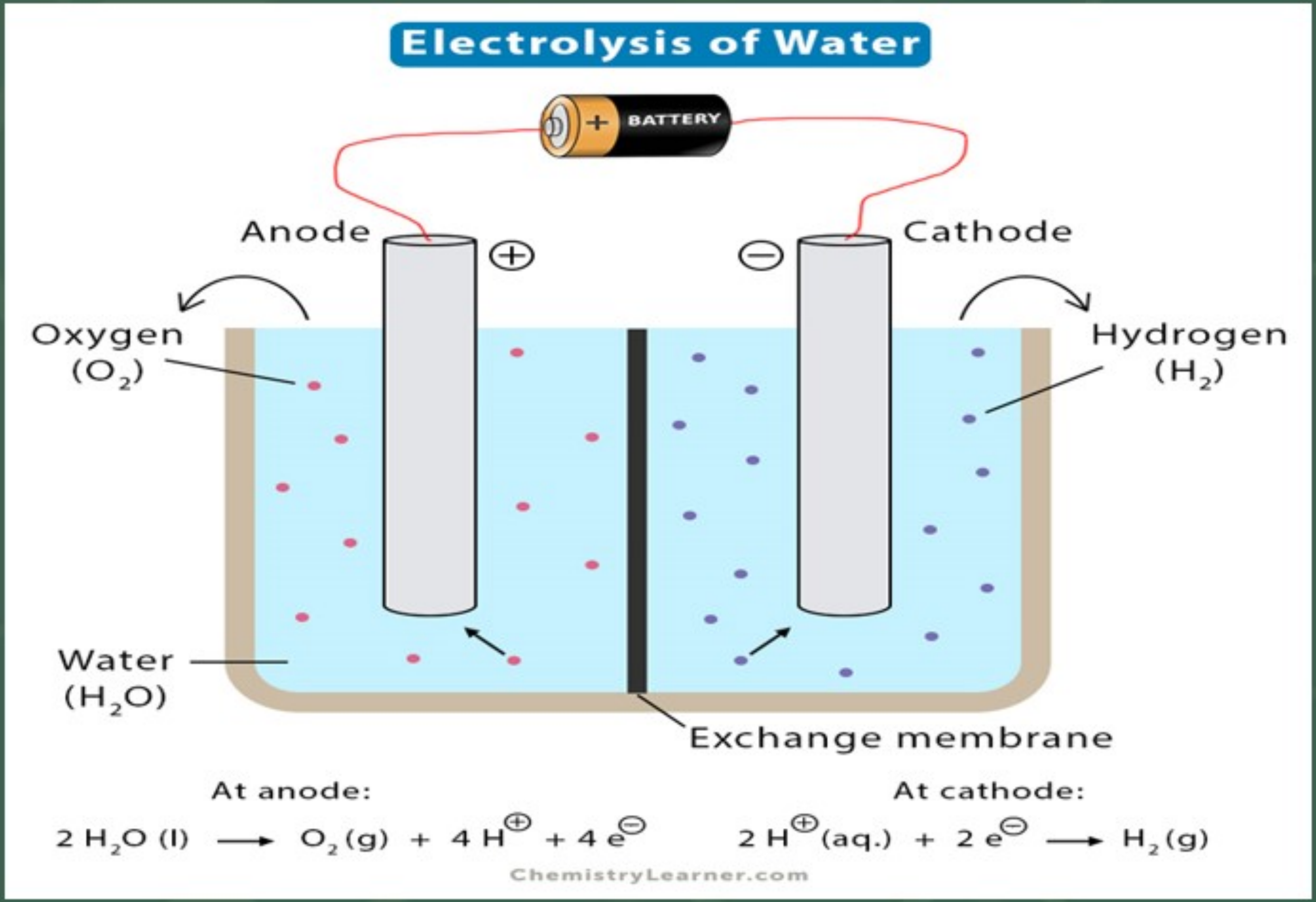
- Everything looks great right?
- why are we still not seeing hydrogen everywhere ?

Let's start with some basics



- Hydrogen is the most abundant element in the universe and also the first element in the periodic table.
- Hydrogen is very reactive, so it is not found freely in nature and only exists combined with other elements such as water.
- So, to produce hydrogen you must extract hydrogen form its naturally occurring compounds like methane or water. It is an energy intensive process.

Electrolysis of water



- It is a process in which we use electricity to break down a water compound into its component molecules hydrogen and oxygen.

Alkaline Electrolysis

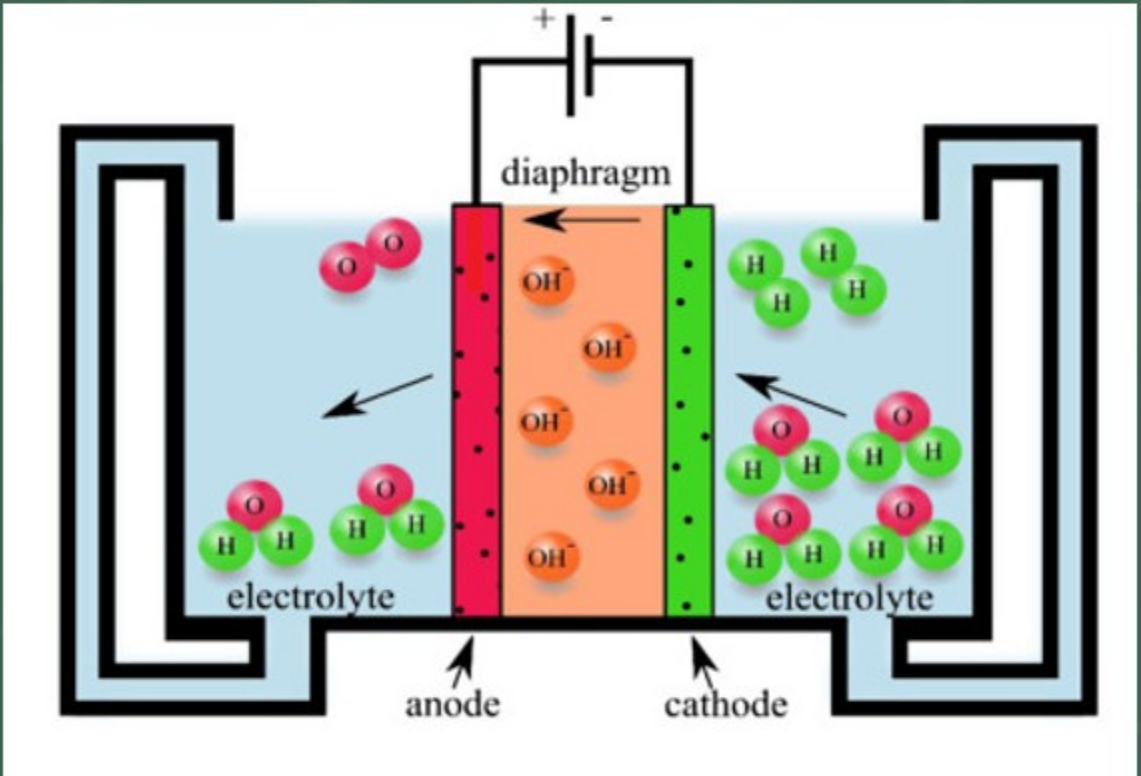


Figure 7: Operating principle of an alkaline electrolysis cell [23]

- The principle of alkaline water electrolysis is simple. Oxygen and hydrogen are separated from water when direct current is applied to the water.

PEM Electrolysis

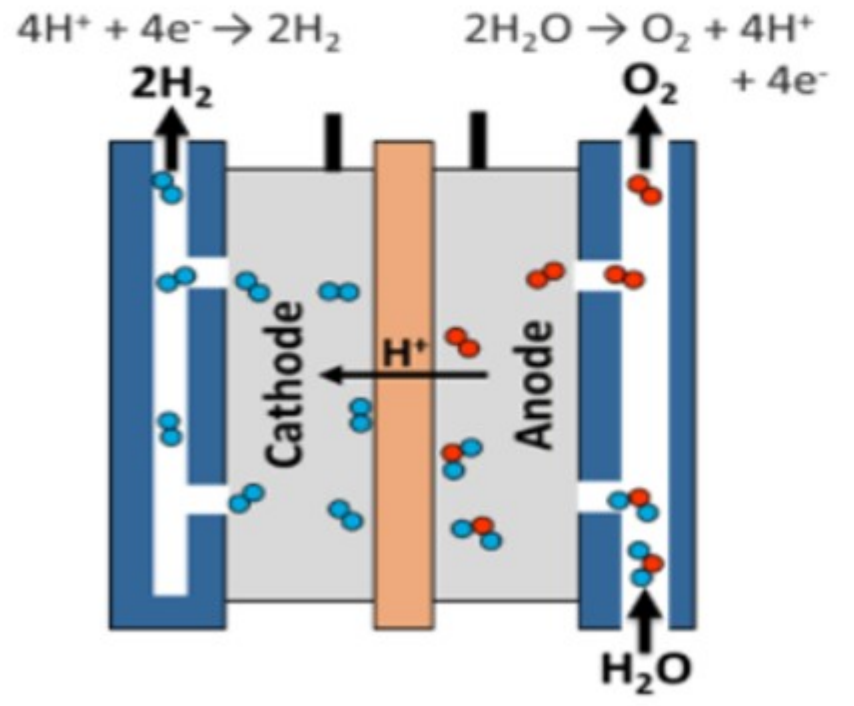


Figure 8: Operating principle of PEM electrolysis cell [24].

- According to the literature PEM water electrolysis cells can reach an efficiency of 80% at 1 A cm-2, a value that is commonly good practice at least at the lab scale but hard to find outside lab.
- When voltage is applied, water is oxidized at the anode to make hydrogen ions, electrons, and oxygen. The hydrogen ions move through the conductive polymer membrane to the cathode, where they are reduced to form hydrogen gas.

High Temperature Electrolysis

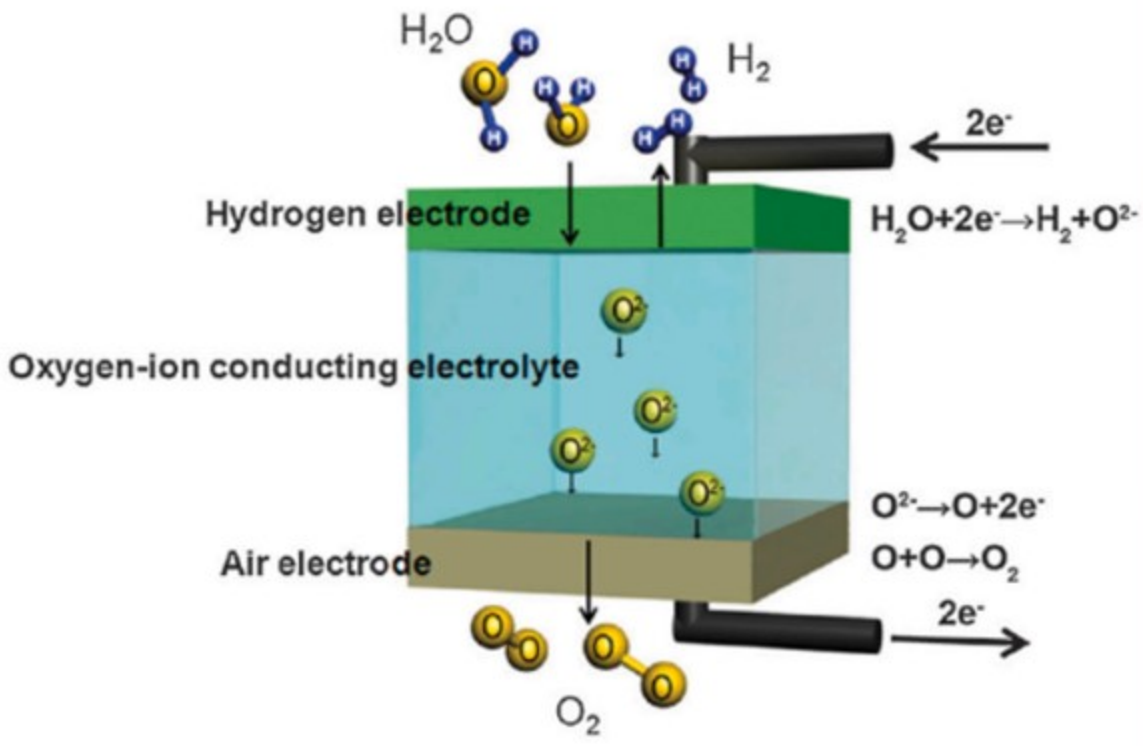


Figure 9: Solid oxide electrolysis cell principle for hydrogen production from water [25].

- A typical technology for high temperature electrolysis is the solid oxide electrolysis cells (SOEC). Solid oxide electrolyzers (SOE) are a less mature technology that uses a solid ceramic material as the electrolyte.
- The main advantage of this technology is that a substantial part of the energy required for electrolysis is added in form of heat, which is much cheaper than electricity.

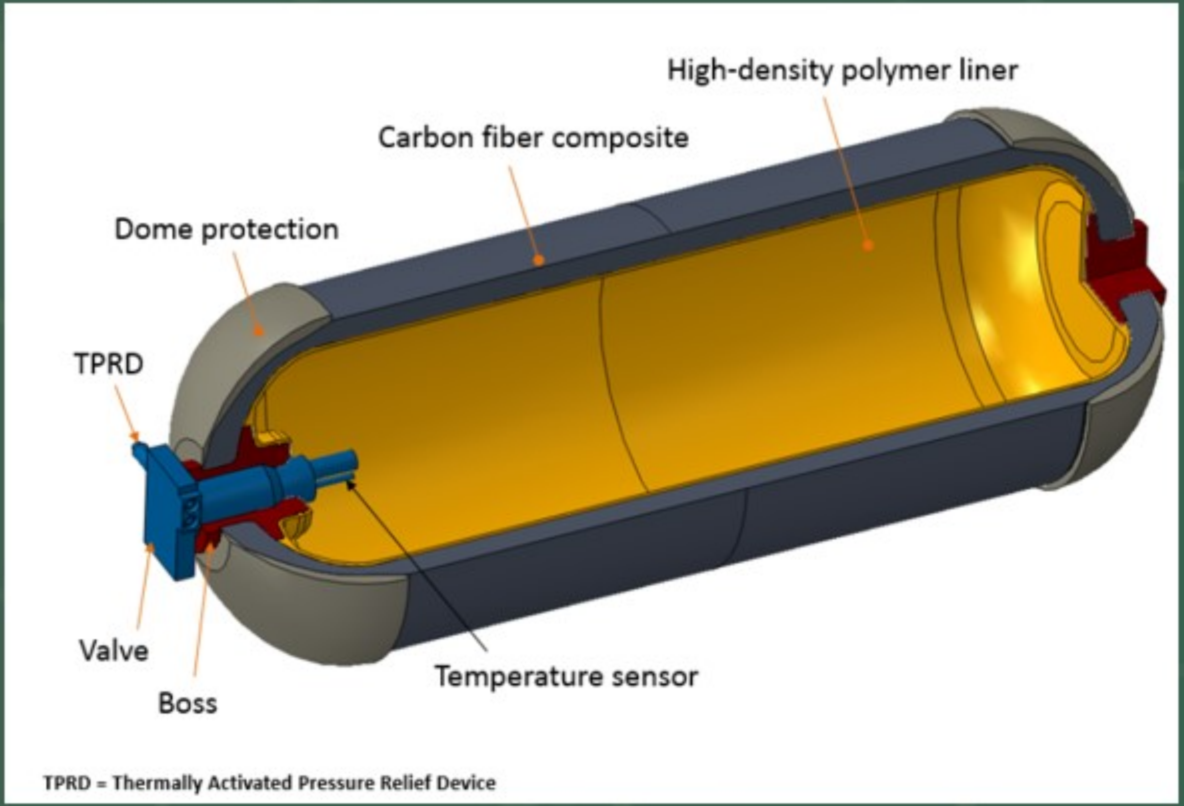
Hydrogen Storage and Distribution

Once hydrogen gas is produced and processed, it needs to be distributed and stored safely.

Commercially viable hydrogen storage is regarded as one of the most technically challenging key barriers for its widespread application as an effective energy carrier and feedstock. There are many ways to store hydrogen such as:

- High pressure gas cylinders up to 800 bar.
- Liquid hydrogen in cryogenic tanks at 21 K.
- Chemically bonded in covalent and ionic compounds at ambient pressure.
- Through oxidation of reactive metals such as lithium, sodium, magnesium, with water.

Hydrogen Storage and Distribution



Most proven, tested and commercially available hydrogen storage is in compressed gaseous form or in liquid form

Green Hydrogen Cost

- The market price of hydrogen generally depends on the required parameters for example its purity.
- In addition, the price also depends on the customer's location, that determines how the hydrogen is delivered. Distribution, transport, and storage are important when green hydrogen is produced on a large scale that determines the final price for the customer.
- Green hydrogen production cost is mainly influenced by the capital expenditure (CAPEX), the operating expenses (OPEX), Lifetime and efficiency.

Life cycle costing(LCC) and Levelized cost of hydrogen(LCOH)

LCC is a method to evaluate the total cost of a product or a system over its lifetime.

Even though there are many different methods for LCC, the many of the main steps are similar

- Define the cost elements
- Define the cost structure
- Establish cost estimating relationships
- Establish the method of LCC formulation.

The main drawback of this method comes from the fact that it includes a future estimation and can lead to uncertain results.

Life cycle costing(LCC) and Levelized cost of hydrogen(LCOH)

- The LCOH is a measure of the average total cost to build and operate a power plant over its lifetime divided by the total energy output over the lifetime of the plant.
- LCOH allows one to calculate the minimum price necessary to sell energy in order to meet a certain hurdle rate – the hurdle rate can be defined as the minimum rate of return on a project or investment.

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Hydrogen Costs breakdown

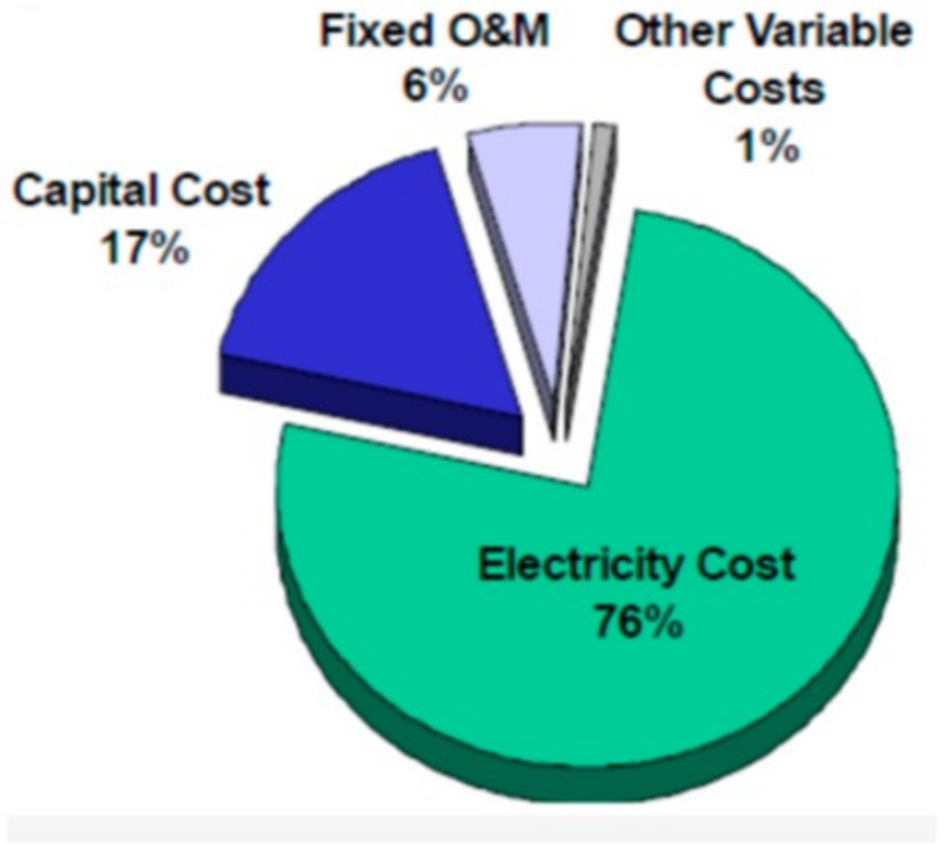

Figure 15: Hydrogen production, cost breakdown [38].

Components costs

Parameters	Assumptions	Lowest Cost (Euros)	Average Cost (Euros)	Highest Cost (Euros)	Comment
Electrolyzer cost (AEL)	1 MW	400,000	600,000	800,000	
Electrolyzer cost (PEM)	1 MW	600,000	800,000	1,000,000	
Electrolyzer cost (SOC)	1 MW	2,000,000	4,000,000	6,000,000	
Hydrogen Production (AEL)	300 kg/24 h				Assumed at 100% capacity factor
Hydrogen Production (PEM)	400 kg/24 h				Assumed at 100% capacity factor
Hydrogen Production (SOC)	500 kg/24 h				Assumed at 100% capacity factor
Compressor cost		100,000	200,000	300,000	
Storage cost (short term)		200,000	300,000	400,000	For 1 MW nominal power
Stack replacement cost/maintenance	25% of capital cost every 5 years in lifetime				

Costs

Parameters	Assumptions	Lowest Cost (Euros)	Average Cost (Euros)	Highest Cost (Euros)	Comment
Stack replacement cost/maintenance	25% of capital cost every 5 years in lifetime				
Compressor maintenance	6 % of compressor cost	6,000	12,000	18,000	
Service contract		100,000	100,000	100,000	Maintaining facilities etc
Electricity price Per MWh		x	x	x	
Water costs		1741	1741	1741	1.59 euro/m^3 for average household. Assuming 10 L of water is needed for 1kg hydrogen production Would be much lower for industry than for household in real world
Miscellaneous costs	1% of investment cost	7000	11,000	15000	
Discount rate	7%				
Lifetime years	20				

LCOH from different Scenarios

Table 8: LCOH from three Scenarios.

Scenario	Technology	Lowest Cost Euro per kg	Average Cost Euro per kg	Highest Cost Euro per kg
1	AEL	6.32	6.82	7.32
	PEM	4.93	5.30	5.68
	SOC	4.98	6.61	8.24
2	AEL	7.56	8.42	9.29
	PEM	6.00	6.65	7.30
	SOC	6.65	9.54	12.43
3	AEL	13.03	16.35	19.66
	PEM	11.04	13.53	16.02
	SOC	15.92	27.03	38.14

LCOH from different Scenarios

- From the result it can be noticed that capacity factor in which electrolyzer is producing hydrogen through its lifetime as well as efficiency of electrolyzer plays significant role just like other costs such as electricity to reduce the end price of hydrogen which is not discussed in literature very often.

Thank you!

Follow the project

www.h2ecosystem.org

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