

# Green Hydrogen Production and its Role in Decarbonisation

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## Introduction

Climate change, driven predominantly by greenhouse gas (GHG) emissions, represents one of the most critical challenges of the 21<sup>st</sup> century. The Intergovernmental Panel on Climate Change (IPCC), under the aegis of the United Nations, provides irrefutable evidence of the accelerating impacts of global warming. In response, nations and international organisations are implementing robust strategies to reduce emissions of carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and other greenhouse gases. These initiatives, collectively termed decarbonisation strategies, are pivotal in combating the climate crisis.

A cornerstone of decarbonisation strategies is the deployment of green hydrogen - a clean energy vector that complements renewable electricity sources like solar, wind, and hydropower. Produced sustainably, green hydrogen is poised to play a transformative role in the transition to a low carbon economy.

## What is Green Hydrogen?

Hydrogen, the most abundant element in the universe, is a versatile energy carrier with applications across transport, heavy industry, heating, and energy storage. While hydrogen can be produced via various methods, the environmental impact of these methods varies significantly.

Green hydrogen refers to hydrogen generated through the electrolysis of water powered by renewable electricity, such as solar or wind energy. Unlike 'grey hydrogen' (derived from natural gas) and 'blue hydrogen' (produced using natural gas with carbon capture and storage (CCS) technology), green hydrogen has zero greenhouse gas emissions across its production cycle.

## The Green Hydrogen Production Process

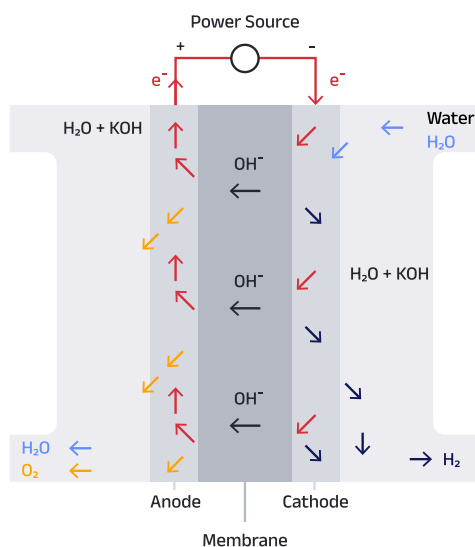
Green hydrogen production relies on water electrolysis, a process that uses electricity to split water molecules (H<sub>2</sub>O) into hydrogen (H<sub>2</sub>) and oxygen (O<sub>2</sub>). This process occurs in an electrolyzer, a device that facilitates the reactions:

- At the **cathode**, hydrogen ions (H<sup>+</sup>) gain electrons to form molecular hydrogen (H<sub>2</sub>).
- At the **anode**, hydroxide ions (OH<sup>-</sup>) lose electrons, resulting in oxygen gas (O<sub>2</sub>).

Different Electrolyzer technologies are employed, each with unique characteristics:

- **Alkaline Electrolysis (AEL or AWE).**

Alkaline electrolysis is the oldest and most established technology, characterised by relatively low capital and operating costs. Alkaline electrolyzers operate in an aqueous medium with the addition of alkaline electrolytes such as potassium hydroxide (KOH) or sodium hydroxide (NaOH). While this technology is slightly less efficient compared to some competing alternatives, it offers the advantage of utilising safe, proven solutions that have been refined over decades, thereby reducing the risks of project failure. Modern pressurised alkaline electrolyzers are capable of approaching the operational performance of PEM electrolyzers.



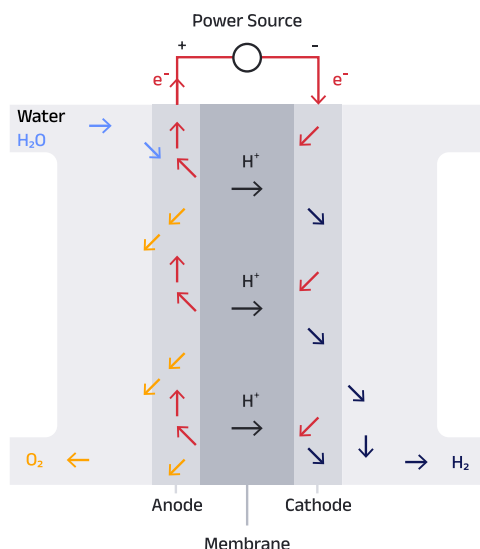
**Figure 1: Technical Cross-Section of an Alkaline Electrolyzer**

The diagram highlights the internal structure of an alkaline electrolyzer, showing the electrodes, the potassium hydroxide (KOH) electrolyte, and the separator membrane.

Own source – Rockfin R & D department

- **Polymer Electrolyte Membrane (PEM) Electrolysis**

Proton Exchange Membrane (PEM) electrolysis employs thin polymer membranes that act as proton conductors, enabling the separation of hydrogen from oxygen. This technology is generally more energy efficient than alkaline electrolysis and operates at higher pressures, facilitating easier hydrogen storage. PEM electrolyzers are also highly dynamic, making them particularly well-suited to integration with variable renewable energy sources (RES). Additionally, PEM systems require significantly less physical space compared to their alkaline counterparts. However, a key drawback is the higher cost of electrolyzers, primarily due to the expense of producing membranes and the catalysts required, such as platinum. Furthermore, this technology is currently available in a narrower power range compared to alkaline electrolyzers.



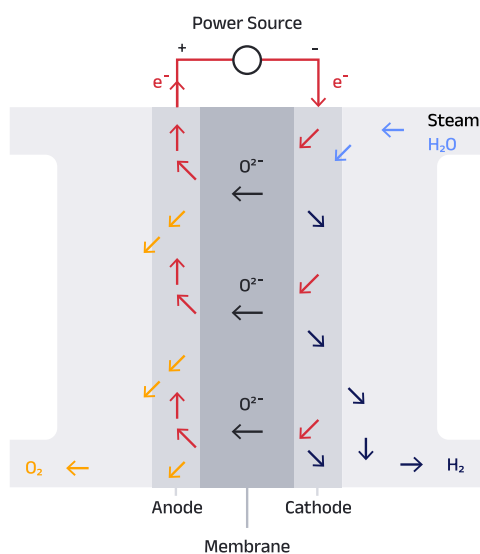
**Figure 2: Schematic of a Proton Exchange Membrane (PEM) Electrolyzer**

This schematic demonstrates the operation of a PEM electrolyzer, emphasising the proton-conductive membrane, catalytic electrodes, and the hydrogen and oxygen outputs.

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- **Solid Oxide Electrolysis (SOE)**

Solid oxide electrolysis operates at high temperatures (typically between 700–900 °C), which significantly enhances efficiency and making it the most efficient of the listed technologies. The high operating temperatures also allow for integration into industrial processes that generate waste heat, further improving overall system efficiency. However, this technology remains in the research and development phase, with commercial-scale deployment requiring substantial investment. It is anticipated that in the future, SOE electrolyzers will play a role in applications such as chemical plants (e.g., for producing artificial fertilisers) and nuclear reactors settings where high-temperature steam is readily available.



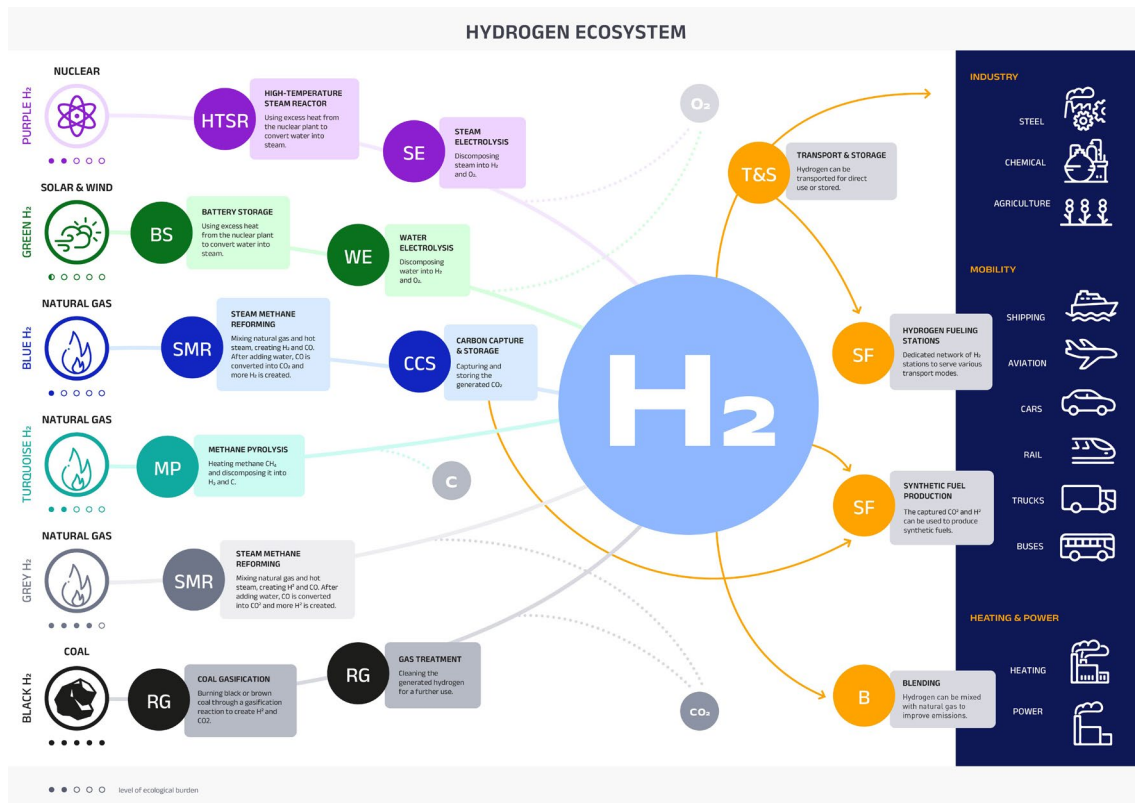
**Figure 3: Solid Oxide Electrolysis Cell (SOEC) System Diagram**

The figure depicts an SOEC system, showcasing its high-temperature operation, ceramic oxygen-ion conductive materials, and integration with industrial heat sources.

Own source – Rockfin R & D department

## The Role of Green Hydrogen in Decarbonisation

Green hydrogen holds immense potential to decarbonise critical sectors of the global economy. Key areas of impact include:



### Transport

Green hydrogen can serve as an alternative fuel for heavy duty vehicles, buses, trains, ships, and aircraft. Hydrogen fuel cells generate electricity by combining hydrogen with oxygen, emitting only water vapour as a by-product. Compared to battery-electric vehicles, hydrogen-powered vehicles offer advantages such as longer ranges, reduced refuelling times, and suitability for long-haul applications.

### Industry

Energy-intensive industries, such as steelmaking, cement production, and petrochemical manufacturing, are significant contributors to CO<sub>2</sub> emissions. Green hydrogen can replace fossil fuels as a feedstock and reducing agent, particularly in processes like ammonia synthesis and steel production, enabling substantial emission reductions.

#### Energy Storage and Grid Balancing

Hydrogen enables large-scale storage of surplus electricity generated by renewable sources. Stored hydrogen can be reconverted into electricity during periods of low renewable generation, enhancing grid reliability and stability.

#### Heating and District Energy

Hydrogen can be combusted in specialised boilers for district heating. Moreover, blending green hydrogen into existing natural gas networks can incrementally reduce the carbon footprint of heating systems while leveraging existing infrastructure.

## Challenges to Scaling Green Hydrogen

While green hydrogen offers transformative potential, several challenges and barriers must be addressed to unlock its full benefits:

- **High Production Costs**

One of the primary challenges associated with green hydrogen is the high cost of its production. Water electrolysis is currently a more expensive method of hydrogen generation compared to the traditional production of grey hydrogen via steam methane reforming (SMR). The cost of producing green hydrogen is directly tied to the price of electricity sourced from renewables and the capital expenditure required for infrastructure development. To make green hydrogen competitive, it is essential to further reduce the costs of electrolysis technologies and accelerate the expansion of renewable energy infrastructure. Additionally, in the initial stages of green hydrogen deployment, some production costs can be offset through subsidies and grants provided at both national and European levels.

- **Infrastructure Development**

The infrastructure necessary for the production, storage, and distribution of green hydrogen remains in its infancy. Developing large scale electrolyzers, hydrogen storage systems, and distribution networks demands substantial financial investment and international coordination. Furthermore, there is an urgent need to establish technical standards and regulatory frameworks that guarantee the safety, reliability, and efficiency of hydrogen systems. Addressing these gaps is critical to enabling the widespread adoption of green hydrogen technologies.

- **Technological Innovation**

Hydrogen production technologies, particularly solid oxide electrolysis (SOE) and, to a lesser extent, Proton Exchange Membrane (PEM) electrolysis, require significant ongoing investment in

research and development. Enhancing the durability and efficiency of electrolyzers, especially under prolonged operational conditions, is vital to ensuring the economic viability of green hydrogen projects. Innovations in hydrogen storage and transportation technologies are equally important, as current solutions remain costly and technically complex.

- **Environmental Considerations**

While the production of green hydrogen itself generates no direct CO<sub>2</sub> emissions, the entire lifecycle of hydrogen—encompassing production, transport, and storage—must be carefully evaluated for environmental impacts. For green hydrogen to genuinely contribute to decarbonisation goals, it is essential to monitor and mitigate these impacts. This includes addressing emissions and resource usage associated with the production of equipment, renewable electricity generation, and any auxiliary processes involved in the hydrogen supply chain.

## Future Perspectives and Recommendations

Despite the challenges, green hydrogen has the potential to play a key role in the world's future low-carbon economy. Thanks to its versatility, it can be used in many sectors, from transport to industry to energy, contributing to a significant reduction in CO<sub>2</sub> emissions.

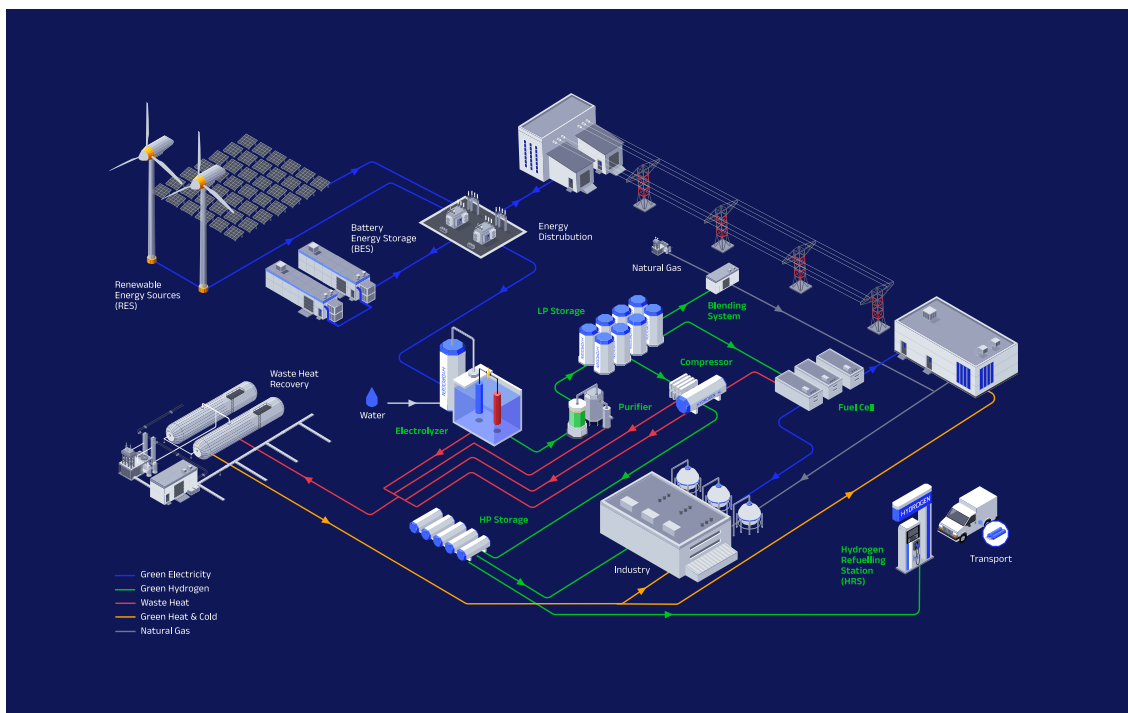
- **Policy Support:** Governments must implement supportive policies, including subsidies, tax incentives, and regulatory frameworks, to encourage investment in green hydrogen technologies.
- **Research and Development:** Increased funding for R & D is needed to enhance Electrolyzer performance, reduce costs, and develop innovative storage and transportation solutions.
- **International Collaboration:** Cross-border cooperation is essential to establish standards, share best practices, and coordinate large-scale hydrogen projects.

**Public Awareness:** Raising awareness about the benefits and applications of green hydrogen will foster public acceptance and encourage adoption.

## Conclusion

Green hydrogen represents a cornerstone of the low carbon transition, offering a pathway to decarbonise hard-to-abate sectors and enhance energy security. While challenges remain, strategic investments, technological advancements, and policy alignment can accelerate its adoption.

By embracing green hydrogen, countries can position themselves at the forefront of the emerging green economy, ensuring a sustainable future for generations to come.



## Disclaimer and Acknowledgement

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