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GREEN HYDROGEN

WHAT IS GREEN HYDROGEN?

Green hydrogen is produced when **renewable energy is used to derive the hydrogen molecule from electrolysis of water**. Hydrogen as a fuel source has become a central building block for a sustainable, resilient, and low-to-zero carbon energy supply to industrial, public and private customers. Since hydrogen is the most abundant element in the universe, it plays an important role to aid in the transition to clean energy.

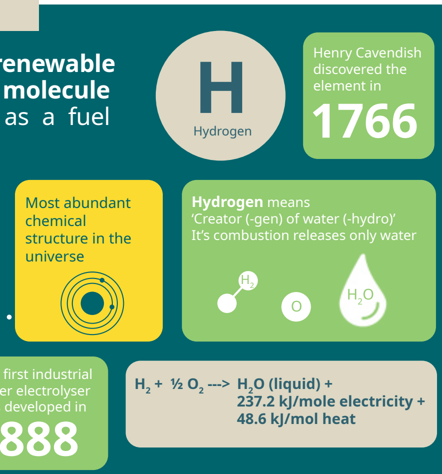

Figure 1: General Information about Hydrogen [6]

A CLOSER LOOK AT GREEN HYDROGEN

There are three ways to produce hydrogen: [1]

Grey Hydrogen

Obtained from fossil fuels. For example, natural gas is converted to hydrogen and carbon dioxide under heat through steam reforming. Approximately nine tons of carbon dioxide is generated to produce one ton of hydrogen from natural gas.

Green Hydrogen

Produced by water electrolysis. Water is split into H_2 and O_2 by an electric current with the help of an electrolyte. If the electrictiy required for electrolysis comes exclusively from CO_2-free sources, the renewable energy produced is completely CO_2-free.

Blue Hydrogen

Generated in a CO_2 neutral method from fossil fuels. The CO_2 is separated, stored or resused - Carbon Capture and Storage (CCS) or Carbon Capture Usage (CCU).

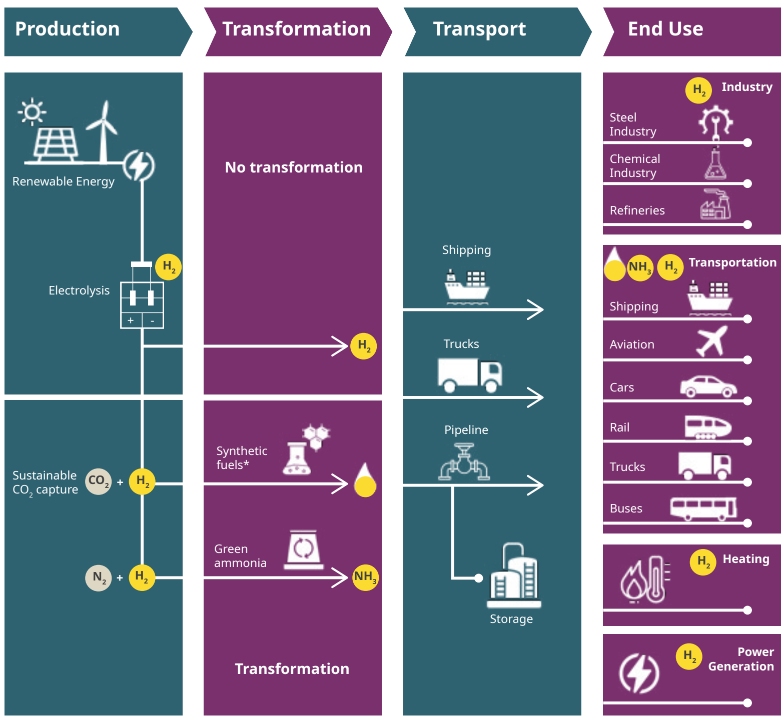

Figure 2: Green Hydrogen Economy

KEY FACTS

Around **120 MILLION TONS OF HYDROGEN** are generated annually worldwide, out of which **2/3 are pure hydrogen** and **1/3 is in mixture** with other gases [7].

55 MWh

Around 55 MWh of electrical energy is **required to generate one ton of hydrogen.**

Hydrogen supply costs are 1.5-5 times more than those of petroleum per unit of energy [5].

According to the International Energy Agency (IEA), **380-plus hydrogen refueling stations are open** to the public, and the global fuel cell electric vehicle **(FCEV) stock reached 11,200 units** at the end of 2018, with **sales of around 4,000** that year [3].

Fuel cell stacks are designed to last the **lifetime of a vehicle about 250,000-320,000 km**.

Pure hydrogen, as an energy source in pipelines, **has an almost comparable transport energy density as natural gas**. It can therefore provide the market with the required capacities for climate-neutral energy.

Hydrogen can be easily transported by trucks, pipelines to storage facilities or markets. Hydrogen can basically do **everything like petroleum WITHOUT THE CARBON EMISSIONS**.

ELECTROLYSERS

Electrolysers use electricity to break water into hydrogen and oxygen. The hydrogen obtained is ultra-pure (99.99%) and it is used in various forms namely, hydrogen injection into the gas grid, hydrogen fuel cells, energy storage, and synthetic fuel production.

Types	Alkaline Electrolyser	Proton exchange membrane (PEM) Electrolyser	Solid oxide Electrolyser	Anion exchange membrane (AEM)
Electrolyte	Potassium hydroxide	Polymer membrane	Zirconia oxide	Divinylbenzene
Operation Temperature	50-100 °C	80-100 °C	800-1000 °C	40-60 °C
Capacity	10-200 Nm³/h H_2	0.01-10 Nm³/h H_2	1-10 Nm³/h H_2	-
Efficiency	75-95%	80-90%	80-90%	60-70%
Operational life	15-20 yr	15-17 yr	-	<20 yr
Market maturity	Commercial (dominates in the market, especially in large scale projects.)	Commercial (more flexible and compatible with variable RE)	Research and Development (R&D)	R&D
Capital Cost Estimates for large stacks (>1MW) ($/kW)	270	400	<2000	-

Table 1: Characteristics Of Four Types of Electrolysers [2-3]

FUEL CELLS

Fuel cells are devices that use the chemical energy of hydrogen to produce clean energy. They resemble batteries in many aspects and supply electricity over a longer period of time. They are used in power plants, hospitals, hotels, offices along with many waste treatment plants that use fuel cells to generate power from methane gas. In Japan, USA, EU, fuel cell vehicles are being used in public transport.

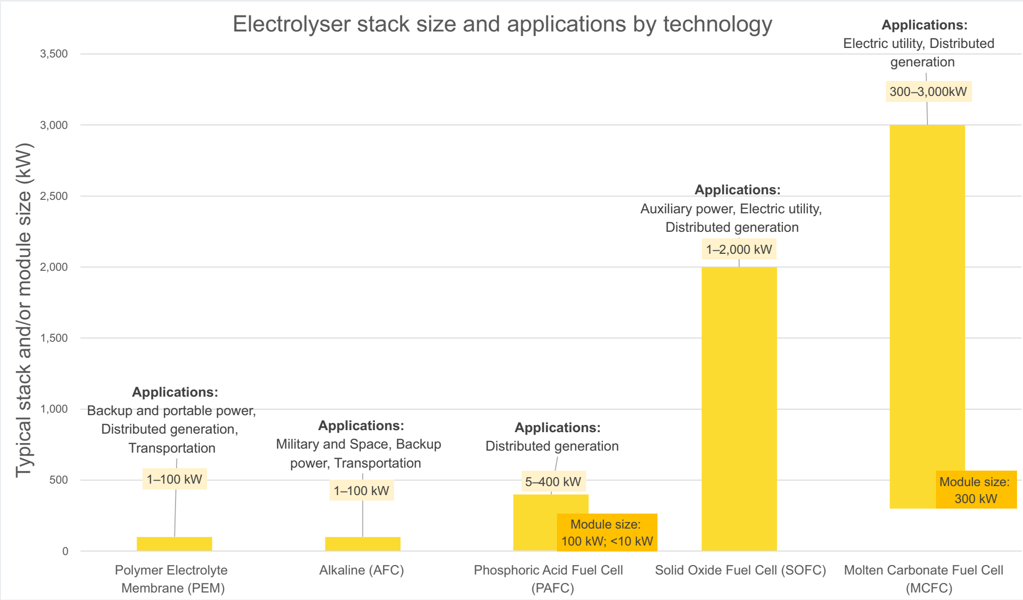

Figure 3: Fuel Cell stack size and application by technology

FINANCIAL FACTS

Electrolyser capacity is growing from MW to GW with advancement in technology. On an average, their cost is about 840 $/kW, while the price is expected to be halved by 2040-2050 [5]. With the decreasing costs of electrolysers, hydrogen costs have lowered to around 4 $/kg - 5 $/kg [6].

Due to the efficiency of the current process, any power cost that goes into the process translates into roughly 1.5 times this value in final production costs. This means that a power cost of 20 $/MWh results in around 31 $/MWh in the final cost of the hydrogen, or a figure slightly above 1 $/kg H_2 [7].

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Supported by:

Federal Ministry
for the Environment, Nature Conservation
and Nuclear Safety

based on a decision of the German Bundestag