II. Chemical Sciences

Article 10

Green hydrogen: the fuel for the future

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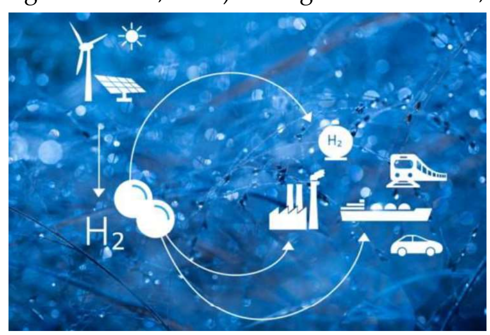
Hydrogen is known to be one of the most abundant elements in the universe. It is also the lightest element and most efficient energy carrier, with a high energy density estimated three times higher than gasoline (IEA, 2022; Hydrogen Council, 2022). NASA demonstrated the utility of hydrogen for propelling spacecraft and rockets in the 1970s (NASA, 1970). Hydrogen is a clean, renewable energy source that produces only water vapor when burned. Therefore, hydrogen as a fuel can be a feasible solution for future energy requirements worldwide in an environmentally friendly manner. That means that developing sustainable hydrogen production is a vital task for the future, as it is an essential support for establishing a sustainable society (IEA, 2022). The consideration is emphasized by reports from the International Energy Agency (IEA) and Hydrogen Council, predicting a hydrogen demand of 500 million tons with an overall revenue of about 3 trillion USD in 2050 (IEA, 2022; Hydrogen Council, 2022). Along the same lines, the International Maritime Organization (IMO) is pursuing drastic reductions in greenhouse gas (GHG) emissions by at least 50% by 2050 compared with 2008 to decrease the carbon dioxide (CO2) emissions per transport work by 40% in 2030 and 70% in 2050 with the target of eliminating all these emissions by 2100 (IMO, 2020).



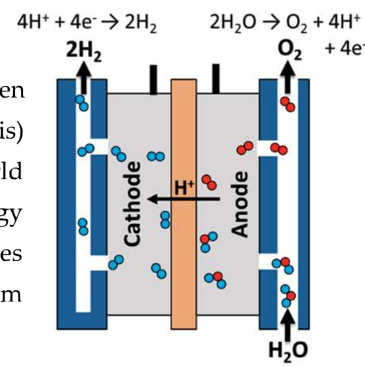
Decarbonizing the planet is one of the goals that countries all over the world have set for 2050. To achieve this, decarbonizing the coal and oil-based techniques for hydrogen production, giving rise to green hydrogen is one of the keys as this is currently responsible for more than 2% of global CO2 emissions. In the upcoming decades, we will be able to determine how this is achieved and its impact. Nevertheless, the daily life routine requires a gradual increase in energy consumption to function properly. According to the IEA's latest estimates, global energy demand will rise between 25% and 30% by 2040 due to the growing population and standard of living (IEA, 2022). This economy is dependent on fossil fuels, which means more CO2 emissions, exacerbating global climate change and environmental pollution. On the other hand, decarbonizing the planet suggests a different world in 2050 that is more accessible, efficient, sustainable, and driven by clean energies such as green hydrogen.

How can green hydrogen be obtained?

Electrolysis is a promising approach among many methods for producing eco-friendly and high-purity hydrogen (99.999%). This process uses electrical power to break down water molecules (H_2O) into oxygen (O_2) and hydrogen (H_2). The reaction takes place in an electrolyzer unit, where the water used must contain salts and minerals to conduct the electricity. Two electrodes are immersed in the water and connected to a power source and a direct current is applied. In the case of green hydrogen, the electricity comes from renewable sources such as wind turbines, solar panels, hydropower, or geothermal, so that the electrolysis process emits no carbon or harmful substances (IEA, 2022). Green hydrogen is thus regarded as a carbon-neutral fuel. The basic net reaction for its formation is explained by the following equation:

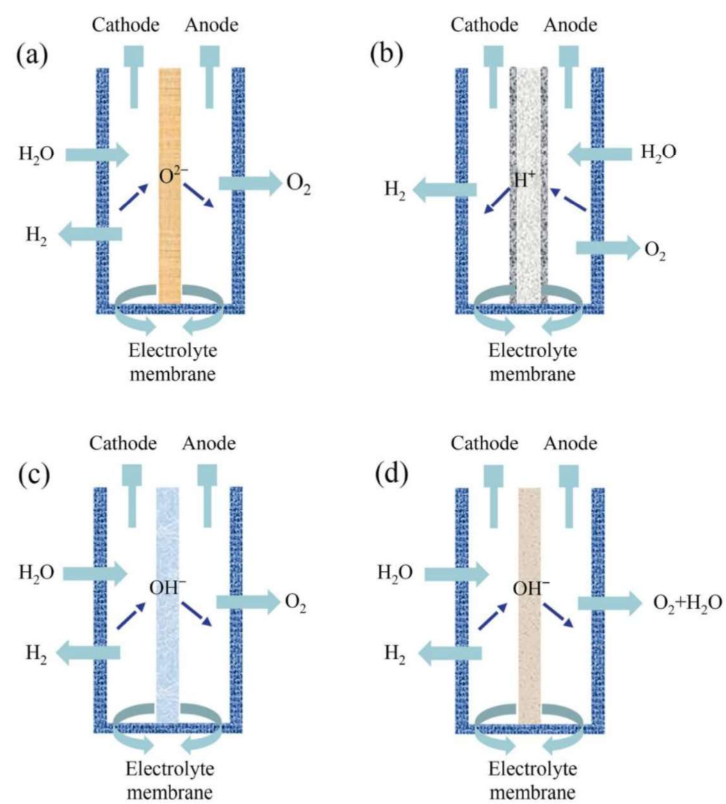
H_2O + Electricity (237.2 kJ/mol) + Heat (48.6 kJ/mol) = H_2 + ½ O_2 (Jones & Smith, 2021).

As the IEA points out, the demand for hydrogen as a fuel source has tripled since 1975, reaching 95 million tons per year in 2022. Switching to green hydrogen could save the world the annual emission of 830 million tons of carbon dioxide associated with fossil fuel-based hydrogen production. Likewise, replacing all grey hydrogen in the world would require 3,000 TWh/year from new renewables equivalent to the current demand in Europe. However, there are some questions about the viability of green hydrogen because of its high production cost, a reasonable doubt that will disappear as the decarbonization of the earth progresses and, consequently, the generation of renewable energy becomes cheaper. That is why the world's hydrogen production by electrolysis (mainly brine electrolysis) accounts for only approximately 4% of the total world production (IEA, 2022). This is mainly because the energy required to extract hydrogen from water is about four times larger than the energy required to extract hydrogen from methane, for example (IEA, 2022).

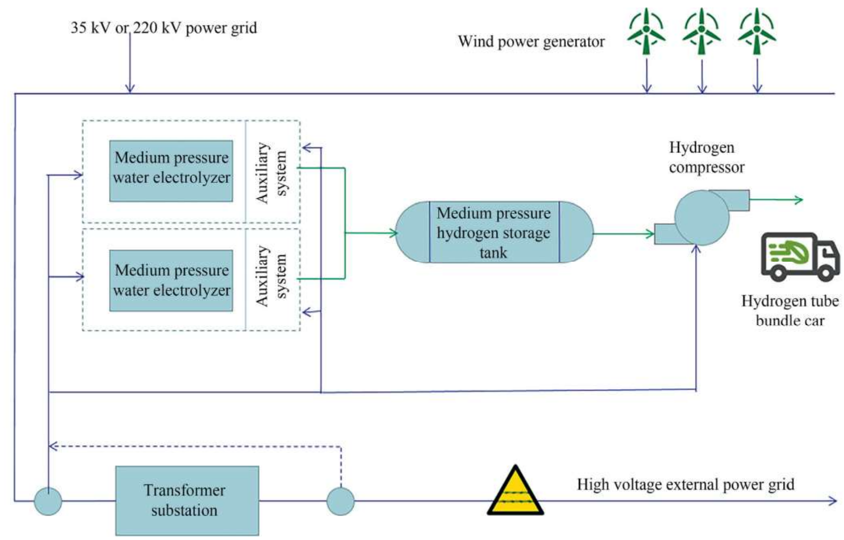


Over the last few years, proton-conducting polymer electrolyte membranes (PEM) water electrolysis has received a lot of attention. The technology now offers high efficiency at high current densities and low operating temperatures (<100 oC). Proton polymer electrolyte membrane water electrolysis was first developed by General Electric in the 1960s for space applications (IEA, 2022). Rapidly it established substantial advantages over alkaline water electrolysis. Some advantages include the use of non-corrosive electrolytes, significantly higher hydrogen production capacity, improved hydrogen purity, and enhanced efficiency at much higher current densities (Jones & Smith, 2021). Conducting polymer electrolyte membranes is the main component of the water electrolyzer. They act as cell electrolytes and cell separators to prevent the direct mixing of hydrogen and oxygen. Like fuel cells, electrolyzers consist of an anode and a cathode separated by an electrolyte. Different electrolyzers function in various ways, mainly due to the different types of electrolyte materials involved and the ionic species they conduct.

The process of producing hydrogen from water electrolysis is mainly composed of two half reactions, one is hydrogen evolution reaction (HER) at the cathode, and the other is oxygen evolution reaction (OER) at the anode. Nowadays, the application and research of this technology mostly includes 4 types, alkaline water electrolysis (AWE), proton exchange membranes (PEM), solid oxide electrolytic cells (SOE), and solid polymer anion exchange membrane (AEM). AWE electrolyzer, since the earliest industrialization time, is known to be reliable technology, low cost, and easy to operate, but the device occupies a large area (Smith & Johnson, 2020). The PEM technology is easy to integrate and has high conversion efficiency, but the cost is high. Furthermore, the catalyst cost is one of the big reasons causing this technology not applicable on a large scale. However, due to the small size of the electrolytic cell, it is easy to couple with wind energy and photovoltaics, so this technology can be adapted in the future. While SOE technology is subject to certain restrictions due to the high temperature as working conditions, the AEM technology is still in the research stage, and the development of both needs to be more advanced in related materials science (Smith & Johnson, 2020).



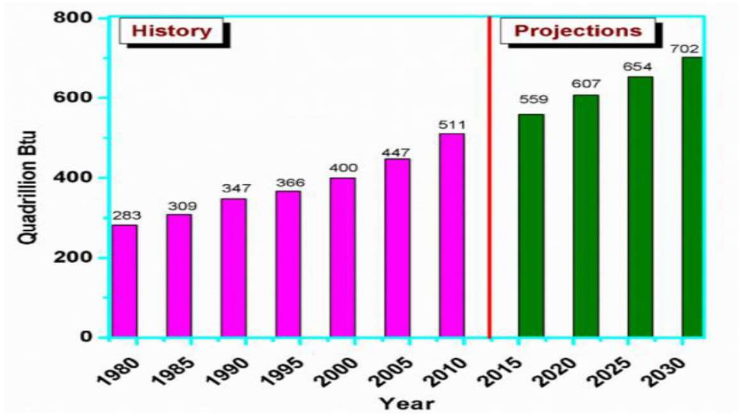
Schematic diagrams of the AWE (a), PEM (b), SOE (c), and AEM (d).



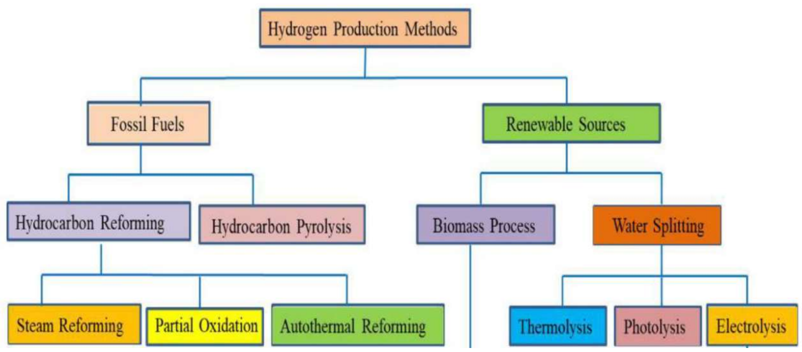
Schematic diagram of wind power hydrogen production for large-scale wind farms (Smith & Johnson, 2020).

After hydrogen production, the gas should be stored at high pressure, and this is done by the compressor. A major concern in hydrogen application is always safety. A diaphragm compressor is only allowed to trace leaks or not allowed to leak gas compression equipment. The diaphragm-type compressor has a small clearance volume, good cooling effect, and other characteristics. Also, it has a small size, high-pressure oil-free lubrication conditions with no pollution on the processed gas, particularly suitable for inflammable, explosive, toxic, and hazardous medium, therefore it is widely used in small flow pressurized systems (IEA, 2022).

The cost of hydrogen production remains an essential issue to be considered. Electrolysis produces pure hydrogen at the cost of 28 USD/million BTU, which is almost ~5 times more than natural gas (6 USD/million BTU). Thus, till today natural gas is the most favored option for hydrogen generation and utilization in industries (Brown et al., 2019). In the end, hydrogen generation using renewable sources such as water and solar light would need some important achievements concerning photocatalytic and photoelectron chemical hydrogen generation. The results from various studies in the literature show clearly that all renewable energy-based approaches for hydrogen production are more environmentally friendly than fossil fuel-based hydrogen generation approaches. However, the cost of hydrogen production using renewable energy needs to be further reduced to be applied on a large scale. Considering the H2-based energy source strategies, it is reasonable to conclude that providing the necessary incentives and interactions among countries, scientists, researchers, societies, and others is the most important scenario for encouraging the transition to a hydrogen economy and technologies and promoting an environmentally friendly H2-based energy source system.



Global energy consumption for the period 1980–2030 (Jones & Smith, 2021).



Different approaches for hydrogen production (Jones & Smith, 2021).

In this respect, Egypt is keen to offer the largest possible package of incentives and facilities for green hydrogen production projects. The country has made great progress in attracting foreign investments into this field so that Egypt becomes a transit route for clean energy to Europe. Provision of up to USD 80 million equity bridge loan to "Egypt Green Hydrogen S.A.E." (the Borrower), an Egypt-domiciled company established to develop and operate the first green hydrogen production facility in Egypt. The Loan will support funding the procurement and construction of a 100 MW electrolyzer facility together with the related facilities and civil works needed for the completion of the Project. The electrolyzer, which will be powered by renewable energy, will produce green hydrogen that will substitute some of the grey hydrogen used by the "Egyptian Fertilizer Company" and will be used as input to produce green ammonia, which will be exported to the international markets. Being the first project of its kind in Egypt, the Project will lead to a significant demonstration effect and will be an important milestone in the development of green hydrogen, as well as the ammonia industry in Egypt, which is a key step towards decarbonizing several industries, particularly fertilizers - a main consuming industry for ammonia.

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