GRÜNER WASSERSTOFF DURCH ELEKTROLYSE: WEGBEREITER DER ENERGIEWENDE IN ENERGIE, INDUSTRIE UND MOBILITÄT

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Abstract

To make our society sustainable and decarbonize it, we need to incorporate renewable hydrogen into our energy system. Hydrogen serves multiple purposes, ranging from energy storage for later use in industry applications and to fueling vehicles. The infrastructure must be customized according to its application, focusing on the hydrogen's quality, volume, and its state — whether it's pressurized or liquefied. Today, the most promising way to produce green hydrogen is via electrolysis supplied by green electricity. There are different basic principles how electrolysis can be performed. Based on the electrolyte, the following technologies will be discussed: proton exchange membrane electrolysis (PEMEL), anion exchange membrane electrolysis (AEMEL), alkaline electrolysis, (AEL or AEL-EL), high temperature electrolysis (HTEL); see Figure 1. The detail descriptions are necessary to understand the advantages of the technology and the application possibilities.

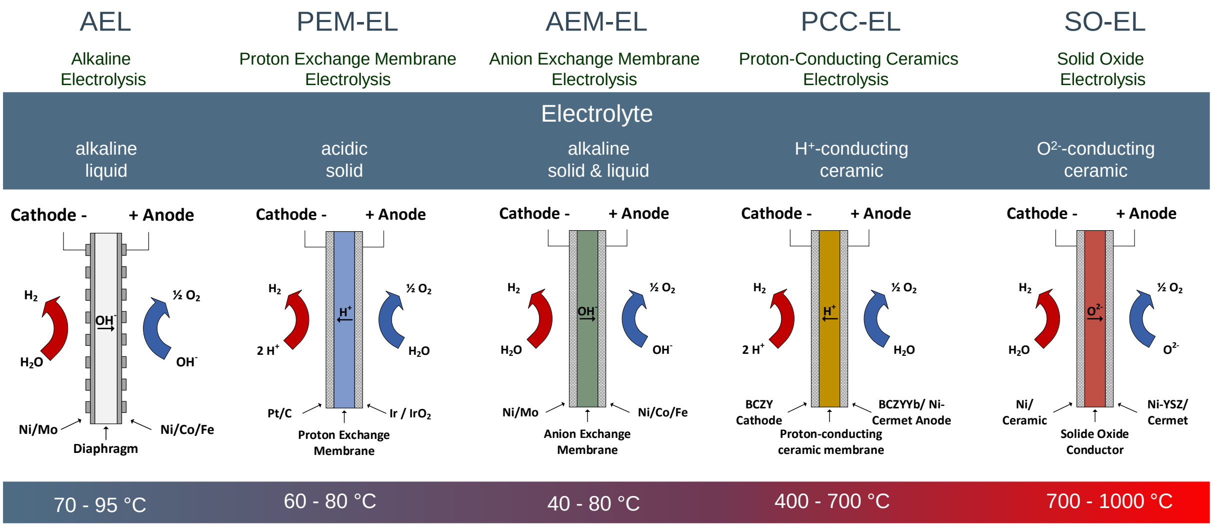

Figure 1: Overview of electrolysis technologies

1. Alkaline Electrolysis (AEL): Alkaline Electrolysis (AEL) technology, prevalent since the early 1900s, typically operates at pressures between 1-20 bars and achieves electrical efficiencies of 60-70% under standard conditions. AEL uses an alkaline solution of potassium or sodium hydroxide, and is known for its durability and scalability to multi-megawatt systems, highlighting its potential for large-scale hydrogen production. Despite its low current densities (up to 0.6 A/cm^2) and modest pressure levels, AEL's benefits include cost-effectiveness, longevity, and the lack of need for costly, scarce catalyst materials. Modern systems can operate at electric powers up to 100 MW. However, its electrolyte, a liquid potassium hydroxide solution, presents safety challenges due to its corrosive nature. Additionally, achieving the often-required hydrogen purity level of 5.0 for further use remains a challenge.

2. Proton Exchange Membrane Electrolyzers (PEM): PEM systems, crucial for energy system decarbonization, operate at pressures of 1-30 bar and temperatures of 50-80°C, featuring a solid polymer electrolyte core that efficiently conducts protons while blocking gases like hydrogen and oxygen. This unique property enables a more compact design than Alkaline Electrolysis (AEL) technologies. PEM electrolysis stands out for its dynamic response to energy demands, offering high

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current densities and stack efficiencies, and the ability to produce hydrogen at pressures suitable for applications such as fueling stations. Despite these advantages, PEM systems require expensive, rare metal catalysts like platinum and iridium, and there are ongoing concerns about their lifespan and scalability. Currently, commercial PEM systems achieve efficiencies up to 70% (based on lower calorific value) and current densities up to 4 A/cm^2, with stack sizes available up to 2.5 MW, highlighting their potential for modular expansion.

3. Solid Oxide Electrolysis Cells (SOEC): SOECs, operating at 700-850°C, can achieve efficiencies of up to 85% when heat integration is optimized, thanks to their use of solid ceramic electrolytes that withstand high temperatures. These high efficiencies are largely due to lower cell voltages and reduced activation energy, making SOECs a promising option for high-temperature electrolysis (HTEL). However, the technology, still in early development, faces challenges with material durability and long-term stability at high temperatures. Current commercial systems are available up to 150 kW with first demo plants in the MW range, but with current densities only reaching up to 1 A/cm^2. Additionally, the ceramics used cannot withstand high pressures at temperatures up to 1000 °C, presenting a significant limitation. The long warm-up times also restrict SOECs from applications requiring frequent start-stop operations, indicating a clear need for further research to overcome these obstacles.

4. Anion Exchange Membrane (AEM) Electrolyzers: AEM technology, still evolving, seeks to blend the environmental benefits of Proton Exchange Membrane (PEM) systems with the cost efficiencies of Alkaline Electrolysis (AEL). AEMs operate at slightly higher temperatures than PEMs, potentially enhancing both efficiency and durability. They aim to minimize the use of expensive noble metals, significantly reducing costs. Unlike PEM electrolysis, AEM electrolysis utilizes an alkaline membrane, offering advantages such as lower-cost catalysts which substantially decrease overall system expenses. However, AEMs currently face challenges like lower current densities and shorter lifespans (high membrane degradation) compared to PEM systems. Given its early development stage, there's potential for improvements in both current densities and durability. Presently, available systems are limited to several kW with efficiencies nearing 70%, and possible current densities of up to 3 A/cm^2 within an operating temperature range of 40–80°C.

5. Photochemical and Photoelectrochemical Cell Electrolysis (PCCE): These innovative systems utilize solar energy directly to split water into hydrogen and oxygen. Although still in the research phase, they represent a truly renewable approach to hydrogen production without the need for external electricity.

These technologies form the backbone of the emerging green hydrogen sector, each with distinct advantages, technical specifications, and developmental stages. Their continued development and integration into renewable energy networks are essential for achieving a sustainable and environmentally friendly energy future.

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