THE ANZ HYDROGEN HANDBOOK VOL II

ELECTROLYSERS

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A hydrogen electrolyser is a complex piece of equipment which uses an electrical current to convert water molecules (H_2O) into its composite parts – hydrogen (H_2) and oxygen (O_2). The oxygen is returned to the air and the hydrogen is stored in pipeline assets for use. When the electrical energy comes from a renewable source, the hydrogen has no carbon footprint and is considered green or clean hydrogen.

ELECTROLYSERS ENABLE THE USER TO NOT JUST GENERATE HYDROGEN, BUT TO ALSO MANAGE THE LOAD PLACED ON THE GRID.

Electrolysers enable the user to not just generate hydrogen, but to also manage/balance the load placed on the grid - essential to power and energy companies who need the intermittent renewable energy supply to match spikes in consumer demand.

In 2023, green hydrogen constituted around 1%[225] of global hydrogen production. However, Goldman Sachs estimates green hydrogen to supply up to 25% of the world's energy needs by 2050, which would make it a EUR€10 trillion market globally.[226]

According to the IEA, global hydrogen electrolyser capacity was almost 11GW in 2022[227], compared to 0.3GW in 2020.[228] If all projects currently in the pipeline are realised, electrolyser capacity would reach 170-365GW by 2030.

Production of electrolysers has ramped up significantly to meet the global demand for green hydrogen, albeit the growth rate slowed slightly in 2022. Electrolysers will play a central role in the further development and completion of the energy system transition.

TECHNOLOGIES

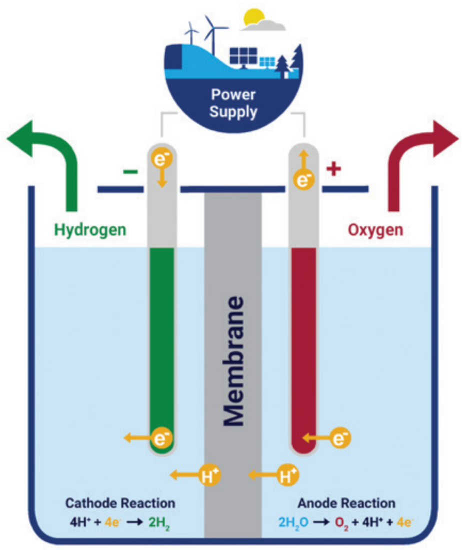
There are different types of electrolysers that support a wide range of solutions based on cost, capacity and application. The two main types include alkaline and PEM technologies.

ALKALINE

Alkaline electrolysers are the most commonly used hydrogen generators in the industry. In alkaline technology, the water is split into its constituents in the presence of a caustic electrolyte solution — frequently potassium hydroxide (KOH).[229]

A reaction occurs between two electrodes (cathode and anode) in the solution composed of water and caustic electrolyte. And when sufficient voltage is applied, water molecules take electrons to make OH^- ions and a hydrogen molecule. The OH^- ions travel through the solution toward the anode, where they combine and give up their extra electrons to make water, hydrogen, and oxygen.

Recombination of hydrogen and oxygen at this stage is prevented by means of an ion- exchange membrane. This was historically made of porous white asbestos, however recent technologies have developed membranes of highly resistant, inorganic materials (asbestos free to eliminate toxicity). The electrolyte remains in the system owing to a closed-loop, pump-free recirculation process.[230]

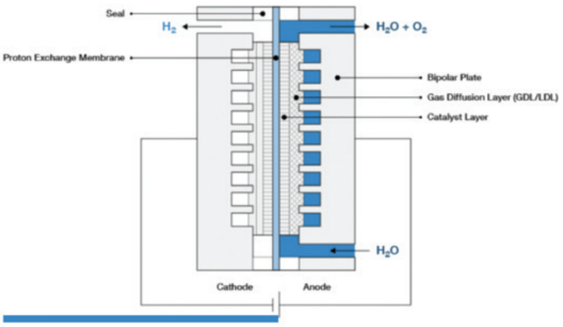


Alkaline electrolysis (Cummins.com)

PEM

Polymer Electrolyte Membrane (PEM) technology is the electrolysis of water in a cell equipped with a solid polymer electrolyte (SPE) to separate hydrogen and oxygen. PEM electrolysis creates a reaction using an ionically conductive solid polymer, rather than a liquid. When voltage is applied between two electrodes, negatively charged oxygen in the water molecules produces protons, electrons, and oxygen at the anode.

The H+ ions travel through polymer membrane towards the cathode, where they take an electron and combine to make hydrogen. The electrolyte and two electrodes are sandwiched between two bipolar plates, which transport water towards them/gases away from them, conduct electricity, and circulate a coolant fluid to cool down the process.[231]



PEM electrolysis (Cummins.com)

OTHER

Other emerging hydrogen electrolysis technologies, include anion exchange membrane (AEM), solid-oxide electrolyser cell (SOEC), protonic ceramic electrochemical cell (PCEC) and photoelectrochemical (PEC) water splitting.

COMPARISONS

Alkaline electrolysis is the more established technology and typically more affordable, as PEM electrolysers involve an acidic environment which require precious metals for the catalyst (as opposed to alkaline being able to use stainless steel and nickel). However, PEMs are often seen as a safer option since the membrane provides a physical barrier between the produced H_2 and O2.

PEM systems also overcome some of the fundamental limitations of traditional alkaline electrolysis in which it is more difficult to pressurise, and additional compression steps are required. Further, PEM is also a more compact machine which is better suited with renewables as they can operate dynamically using varying loads of electricity, allowing PEM electrolysers to be operated when renewable energy generation is cheapest.

SIZES

A typical required flow of hydrogen, and subsequently the size range that current technologies allow for in an individual electrolyser, varies between 0.25Nm^3/h (≈0.00125MW) in small scale generators and up to 4000Nm^3/h (≈20MW) in large scale plants for industrial applications.

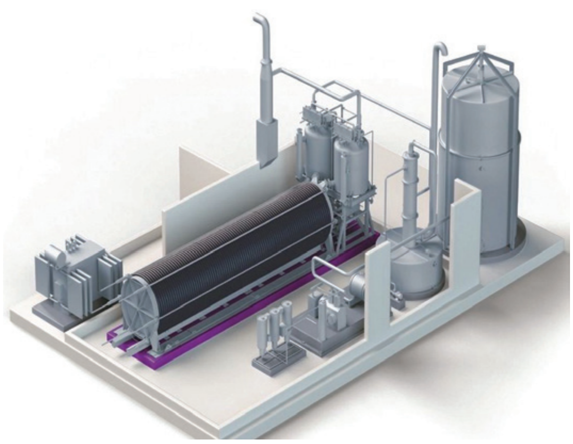
The world's largest electrolyser in operation today is a 150MW alkaline unit in China's Ningxia region by Ningzia Baofeng Energy Group, it is also the largest green hydrogen plant at present. The Baofeng plant is powered by a 200MW solar plant. However, competitors remain ambitious with their plans and Baofeng is unlikely to hold this record for long with several other competitors already in production.

Physical size dimensions can vary greatly, with an average of around ≈12x3x4m for containerised electrolysers, to ≈0.8x1x1.1m for compact scale hydrogen plants with minimal maintenance electrolyser technologies[232].

PRICES

The overall cost comprises the cost of the electrolyser, maintenance and replacement of worn-out membranes, the price of the electricity used for the process, and any subsequent costs for drying, purification, liquefaction, transport and compression of the gas.[233] The balance of plant/ storage is also a significant cost. Additionally, in many cases, including off grid, the renewables and transmission are part of the project directly and not just an operating cost for electricity.

Furthermore, production costs are also highly dependent on factors such as electricity taxes, grid fees and the capacity utilisation rates of electrolysers, which vary widely per region. The two main factors determining the cost of hydrogen production from electrolysis are the cost of electricity and the cost of electrolysers.



Hydrogen electrolyser sample diagram (rechargenews.com)

COST OF ELECTRICITY

Typical up-front capital costs for utility-scale solar PV installations fell by 85% between 2010 to 2020 and by 56% for onshore wind generators. This means lower average costs of generating electricity over the lifetime of assets, which is expected to continue as the energy transition endures. While 2022 saw supply chain issues impacting costs coming down further, the cost of electricity from solar PV still fell by 2% on annual global basis and onshore wind fell 5%.[234]

In the post-COVID era, levelised cost of electricity (LCOE) (measure of average electricity generation costs over the lifetime of a generating plant) has risen because of factors including freight and commodity costs. While that has now largely eased, the costs to finance have increased due to rising interest rates. The International Energy Agency (IEA) expect, in 2024, that the LCOE for onshore wind and solar PV will decline but remain above 2020 rates by 10-15%.[235] (Large scale solar PV installations costs in 2020 were A$41-77/MWh internationally.[236] The equivalent numbers for onshore wind were A$56-93/MWh.[237])

It is also important to note that for an electrolyser to operate at its highest capital efficiency, this will require the input of firm renewable energy to mitigate the risk of unpredictable H_2 production volumes impacted by variables such as weather.

COST OF ELECTROLYSERS

Electrolyser capital costs vary, however they have fallen from around A$3,700 per kW in 2020 to A$2,700 per kW in 2022. The CSIRO estimates costs will fall to around A$200 – A$800 per kW in 2050.[238] This is an average cost as alkaline costs are less than that of PEM electrolysers.

At present, it is believed that Chinese electrolyser manufacturers can produce and sell alkaline technology at well below the price of European competitors because of economies of scale. Further, the electrolyser industry has continuously dropped its capital costs, driven mainly by market need for larger systems and innovation in system design and manufacturing. Costs of hydrogen electrolysis capex is expected to drop further in the next decade, as national targets and pilot projects produce enough volume to realise substantial declines.

In 2021, Siemens Energy announced plans to produce green hydrogen at US$1.50/kg (≈A$2/kg) by 2025 "based on large-scale commercial projects in operation".[239] This target is in line with the Australian Government's target of A$2/kg to be competitive with non-renewable energy sources.[240] Currently, the projects are based on wind energy, with underlining assumptions of a cost of electricity at A$16/MWh through a 100MW PEM electrolyser, running a 16.4hrs/day on average.

Australia is well placed to achieve low-cost green hydrogen production due to its low-cost renewable energy supply and the potential to achieve large economies of scale. However, demand needs to be created to drive down costs, and a wide range of delivery infrastructure needs to be built, with the support of government targets and subsidies, to help achieve these future cost targets.

CHALLENGES

Challenges primarily related to green hydrogen electrolysis

MATURITY

Although electrolysis technology has been around for a long time, and is sound and market proven, it is still perceived by some to be new. Hydrogen's ability to combine with oxygen was actually first noted by Henry Cavendish in 1766, with the first electrolyser subsequently developed in 1800 by Nicholson and Carlisle. However, political, business and consumer comfort with the technology is continuously increasing, and due to the recent increased recognition of green hydrogen as a viable energy source, acceptance of electrolysers is at an all-time high. Both PEM and solid oxide technology is rapidly evolving and it is unclear what is required moving forward as the future scale is unprecedented.

COSTS

Green hydrogen can cost more than double than generating blue hydrogen (SMR with carbon capture and storage), however this is diminishing with rise in demand; in no industry has green hydrogen been found to be cheaper than grey hydrogen.[241]

Manufacturers are working hard to reduce the costs of components within electrolysers, by using product standardisation and repeat parts. Manufacturers are looking at how to improve gigawatt scale in a number of ways. Other major areas of development include membrane-coating techniques/simplifying membrane fabrication; optimising the porous transport layer; and reducing precious-metals content (which account for roughly 30-40% of total cost).

GEOGRAPHY

For consumers in areas that require hydrogen to be transported via methods such as tube trailers, liquefied tank trucks, or transported overseas in hydrogen carrier vessels, this can be a very inefficient and CO_2 intensive process. Since hydrogen is such a light molecule, transportation is constrained in terms of the amount of hydrogen a vessel can hold (whether liquefied or compressed). Furthermore, considerable losses can occur in the storage of hydrogen as a liquid.

Transport costs vary greatly depending on the method used and can prove to be a costly part of the hydrogen value chain. However, pricing outlooks show a rapid decline as the industry develops and demand increases.

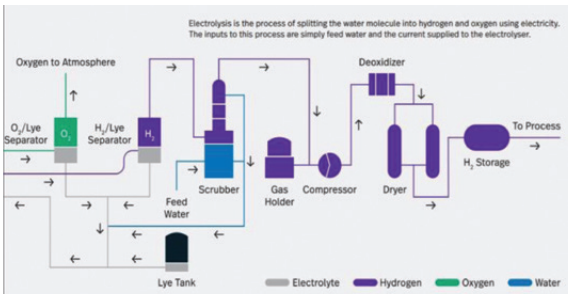
Further, electrolysers provide more efficiency at a lower cost than transporting hydrogen or buying an SMR unit, thus making on-site generation of hydrogen vastly attractive and more economically viable for many hydrogen consumers.

INPUTS

Hydrogen electrolysis specifically requires de-ionised water to be used as an input to production, however feedwater quality is currently an emerging area of research from manufacturers. Early-stage projects are investigating the ability to use dirty water or salt water as an input, as opposed to requiring high-purity water for electrolysis. The cost of this input can be significant and therefore is an important factor to consider. Water temperature must also be kept between 5°C to 40°C.

POST-PROCESSING

Although electrolysers have made strides in efficiency and cost, the produced hydrogen still often requires post-processing steps, such as compression, dehydration or purification. This is predominantly found within alkaline technology as a Potassium Hydroxide solution is used as a process fluid, and therefore traces may need to be removed from the produced hydrogen.



Post-processing of hydrogen from electrolysis (nelhydrogen.com)

TESTING

Safety, purity, flow and reliability are important factors in hydrogen electrolyser manufacturing. Systems must be designed and delivered in an automated manner to produce high purity hydrogen, with strict safety design standards that must conform to the country of installation.

Therefore, testing is of importance before transport for packing and shipping to customers, and service departments test each unit according to certain procedures (including pressure, flow, purity, alarms, visualisation and calibrations of sensors). There is also a two-day FAT (factory acceptance test) procedure which in some cases can be witnessed by customers and provides certainty of functioning ability of the electrolyser.[242]

JURISDICTIONS

China has remained the leader of the global markets for several years for both current and pipeline electrolysers with 40% of the global share.[243] However, many European-based companies are also leading the way on developing innovative technologies that better suit the production of green hydrogen through renewable energy. With the announcement from EU executives wanting at least 40GW of electrolysers installed in the EU by 2030 (producing up to 10 million tonnes of renewable hydrogen)[244],this outlook shows continued promising growth for the jurisdiction.

Globally, many organisations are developing sustainability and energy initiatives centred around hydrogen, including projects in the U.S., Canada, Saudi Arabia, Denmark, Austria, New Zealand, Australia, Singapore, Germany, Chile, Spain, China, Portugal and Japan.

ENVIRONMENTAL AND SOCIAL

As the industry rapidly evolves and grows, there are key environmental and social factors which need to be considered. Modern slavery in the supply chain must be consistently scrutinised as the cross-border nature of the industry means it may be difficult to regulate. Mining and processing of raw materials required for use in hydrogen technologies are also higher risk activities. There are large land requirements which require sizable stakeholder engagement as the impact on the wider environment and community may be impacted. The process of electrolysis can be energy intensive, with high demand for water and power usage. The competition for these resources must also be considered, particularly where these resources may be scarce.

USES VS SUPPLY

Development of uses and supply of hydrogen are occurring simultaneously, facing a 'chicken and the egg' scenario. Demand for hydrogen relies on availability and costs, and without demand, supply infrastructure is difficult to justify. As demand for hydrogen increases, the supply infrastructure will be built as cost declines, leaving the question of which comes first. The industry and regulators must consider how to put long term offtake agreements in place to help foster expansion within the industry and allow projects to continue being developed while these two aspects continue to become established concurrently.

REFERENCES

225 Wan, L., & Butterworth, P. (2023, February 24). *Energy from green hydrogen will be expensive, even in 2050.* Sustainability | CRU. https://sustainability.crugroup.com/article/energy-from-green-hydrogen-will-be-expensive-even-in-2050#:~:text=Green%20hydrogen%20uses%20green%20power,gas%20reformation%20or%20coal%20gasification

226 Gandolfi, A., Patel, A., et al. (2020, September 22). *Green Hydrogen: The next transformational driver of the Utilities Industry*. Goldman Sachs https://www.goldmansachs.com/insights/pages/gs-research/green-hydrogen/report.pdf

227 IEA. (n.d.). *Electrolysers*. https://www.iea.org/energy-system/low-emission-fuels/electrolysers

228 IEA. (2021, December 1). *Could the green hydrogen boom lead to additional renewable capacity by 2026?*. https://www.iea.org/articles/could-the-green-hydrogen-boom-lead-to-additional-renewable-capacity-by-2026

229 US Office of Energy Efficiency & Renewable Energy. (n.d.). *Hydrogen Production: Electrolysis*. https://www.energy.gov/eere/fuelcells/hydrogen-production-electrolysis

230 Cummins Inc. (n.d.). *Electrolysis*. https://www.cummins.com/new-power/applications/about-hydrogen/electrolysis

231 Cummins Inc. (n.d.). *Electrolysis*. https://www.cummins.com/new-power/applications/about-hydrogen/electrolysis

232 Nel Hydrogen. (n.d.). *Water Electrolysers/hydrogen generators.* https://nelhydrogen.com/water-electrolysers-hydrogen- generators/

233 Yin, I. (2021, December 06). *China scaling up electrolyser manufacturing base for domestic, export markets*. S&P Global. https://www.spglobal.com/platts/en/market-insights/latest-news/energy-transition/120621- china-scaling-up-electrolyzer-manufacturing-base-for-domestic-export-markets

234 IRENA. (2023). *Renewable power generation costs in 2022*. https://www.irena.org/Publications/2023/Aug/Renewable-Power-Generation-Costs-in-2022

235 IEA. (2023, June). *Will solar PV and wind costs finally begin to fall again in 2023 and 2024? – Renewable energy market update - June 2023 – Analysis.* https://www.iea.org/reports/renewable-energy-market-update-june-2023/will-solar-pv-and-wind-costs-finally-begin-to-fall-again-in-2023-and-2024

236 International Energy Agency (IEA). (2021, November 30). *LCOE of utility-scale solar PV and onshore in 2020 and in the* high commodity price scenario. https://www.iea.org/data-and-statistics/charts/lcoe-of-utility-scale-solar-pv- and-onshore-in-2020-and-in-the-high-commodity-price-scenario

237 International Energy Agency (IEA). (2021, November 30). LCOE of utility-scale solar PV and onshore in 2020 and in the high commodity price scenario. https://www.iea.org/data-and-statistics/charts/lcoe-of-utility-scale-solar-pv- and-onshore-in-2020-and-in-the-high-commodity-price-scenario

238 CSIRO. (2024, January 10). *GenCost: Annual electricity cost estimates for Australia.* Commonwealth Scientific and Industrial Research Organisation, Australian Government - CSIRO. https://www.csiro.au/en/research/technology-space/energy/energy-data-modelling/gencost

239 Franke, A. (2021, March 22). *Siemens Energy targets $1.50/kg renewable hydrogen cost by 2025. S&P Global*. https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/032221-siemens-energy- targets-150kg-renewable-hydrogen-cost-by-2025

240 CSIRO. (2022, June 20). ***T****echno-economic analysis of commercial hydrogen production in Australia*. HyResearch: Australian Hydrogen R&D Portal. https://research.csiro.au/hyresearch/techno-economic-analysis-of-commercial-hydrogen-production-in-australia/

241 Schelling, K. (2023, August 9). *Green hydrogen to undercut gray sibling by end of decade*. BloombergNEF. https://about.bnef.com/blog/green-hydrogen-to-undercut-gray-sibling-by-end-of-decade/

242 Ho, K. (2020, June 18). *How to build an electrolyser*. Energy Magazine. https://www.energymagazine.com.au/ the-future-of-hydrogen-how%E2%80%8C-%E2%80%8Cto%E2%80%8C-%E2%80%8Cbuild%E2%80%8C-% E2%80%8Can%E2%80%8C-%E2%80%8Celectrolyser/

243 IEA. (n.d.). *Electrolysers*. https://www.iea.org/energy-system/low-emission-fuels/electrolysers

244 European Commission. (2020, July 08). COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT. *A hydrogen strategy for a climate-neutral Europe*. Brussels, COM(2020) 301 Final. https://ec.europa.eu/energy/ sites/ener/files/hydrogen_strategy.pdf

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