# To PEM or not to PEM

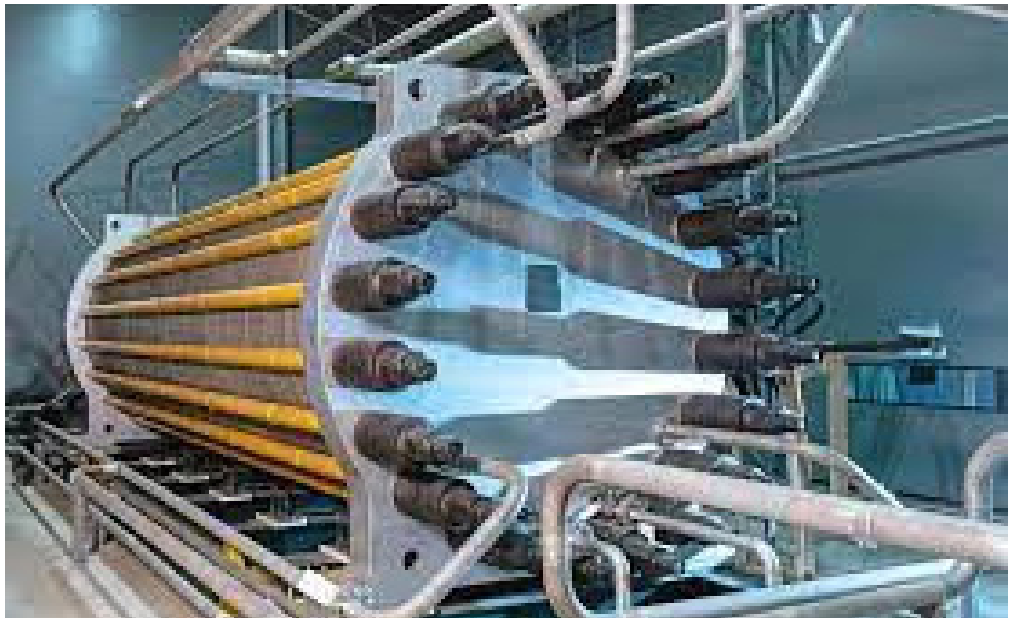
## INTRODUCTION

**Taking a quotation from William Shakespeare's Hamlet "To be, or not to be, that is the question" is a strange way to start a document on electrolyser technologies. However just as in this soliloquy Hamlet is pondering which path to take, just as many hydrogen projects globally are at a crossroads and are deciding which electrolysis technology is best to decide upon.**

There is a global vision for an innovative, low-carbon, affordable and safe hydrogen industry that would be the catalyst to combat climate change, restrict global warming, Many researchers and projects are accelerating the process of developing innovative solutions to produce, store and transport hydrogen. One of the key technical components in the production of hydrogen is the electrolyser.

There are many different types and technologies available with ongoing research investigating the use of cheaper, abundant raw materials to make electrolysers more efficient, cheaper and scalable up to market needs. As in many sectors there is not a one size fits all application. The scale of this work is evidenced by the fact that there were 10 894 patent families related to the electrolysis of water published worldwide between 2005 to 2020 with an average annual increase of 18%.[1]

As more countries foster deep decarbonisation strategies, green hydrogen produced from renewables via water electrolysis is expected to be at the very heart of energy transition as a key piece of the clean energy puzzle. IRENA's 1.5°C scenario projects that hydrogen and derivatives will account for up to 12% of final energy consumption by 2050.[2]





[1] **Patent Insight Report -** Innovation trends in electrolysers for hydrogen production. European Patent Office (EPO) and International Renewable Energy Agency (IRENA) accessed 21st September 2023.

[2] **IRENA (2022) -** World Energy Transitions Outlook: 1.5°C Pathway, International Renewable Energy Agency, Abu Dhabi

## BACKGROUND

**Many project developers are debating which type of electrolyser is best to utilise. Proton Exchange Membrane (PEM), Alkaline, Solid Oxide Electrolyser Cell (SOEC) or the latest hot tech? Developers have a myriad of factors to examine as they weigh up the pros and cons of each type of electrolysis.**

As a basic introduction, in order to produce green hydrogen H2 from renewable electricity we need to use an electrolyser to split water molecules into hydrogen and oxygen. Those are different types of electrolysers PEM (proton-exchange membrane) and SOE (solid oxide), Anion Exchange Membrane (AEM), alkaline and new technologies in their infancies.

The task all project developers face is deciding which type of electrolyser should be used for a particular project and this is a level of complexity that few have championed because the goal posts keep moving.

It is more than just weighing up the pros and cons of the technologies and costs, supply chain time frames, technology maturity, adaptation, technology saleability & flexibility, system integration and much more add to the decision-making process.

As we read the headlines, that proclaim all the wonderful inherent advantages of speed, scale and opportunity.

- Sunfire, a global leader in the development and production of industrial electrolysers, has secured €109 million...These new funds will allow Sunfire to bring its advanced pressurized alkaline and game-changing solid oxide (SOEC) electrolysis technologies to industrial scale, building the first in a series of production gigafactories, creating both meaningful electrolysis capacity for our customers and attractive returns for our investors." Nils Aldag, Co-Founder and CEO of Sunfire €1bn.[3]

- John Cockerill has announced a multi-gigawatt deployment of the leading pressurized alkaline technology in France, Belgium, India, USA, China and Morocco.

- Nel announces new 4GW hydrogen electrolyser gigafactory in Michigan, costing up to $400m. The plant, which will be one of the largest in the world, will use automated technology to produce both alkaline and PEM machines.[4]

- **'World's largest PEM green hydrogen project'** announced in China, backed by $4.5bn of investment. Nation can produce cheap alkaline electrolysers but is behind the West when it comes to proton-exchange-membrane machines.[5]



[3] https://www.sunfire.de/en/news/detail/sunfire-secures-landmark-investment-to-accelerate-growth-of-its-green-hydrogen-technologies
[4] https://www.hydrogeninsight.com/electrolysers/nel-announces-new-4gw-hydrogen-electrolyser-gigafactory-in-michigan-costing-up-to-400m/2-1-1445800
[5] https://www.hydrogeninsight.com/production/worlds-largest-pem-green-hydrogen-project-announced-in-china-backed-by-4-5bn-of-investment/2-1-1479258

## PURCHASE COST

**Whilst alkaline technology is well proven and has a circa 100-year history on purchase cost alone it is approximately half that of PEM.**

Alkaline electrolysers are known for being one of the oldest and most mature electrolysis technologies with no noble expensive material, which has contributed to their relatively lower capital costs compared to some other electrolysis technologies. It is forecast that with technology acceleration, automation and digitisation that the cost of PEM will come down further despite an inherent higher cost due to the use of noble material such as iridium and platinum.

The initial capital investment and operating costs of SOEC systems can be higher than other electrolysis technologies. However, advancements in materials and manufacturing processes are working to reduce these costs.

PEM electrolysers offer several advantages over alkaline electrolysers, such as flexible operation, higher output pressure and small size, but are associated with higher investment costs and shorter lifetimes[6]. A high upfront cost driven by the use of precious materials is certainly one of the major barriers to the wider deployment of PEM electrolysers.

## INTERMITTENCY RESPONSE

**The intermittency or renewables in the equation also brings challenges. If the proposed project us geographically remote and does not have a back up grid connection it means that the electrolyser will have to be turned off and will require 'cold start up' time which is a challenge for alkaline.**

Compared to PEM they lack the ability to start up from a cold start very quickly. Alkaline electrolysers can take up to 50 minutes to get up to full operating speed, compared to less than five minutes for PEM or pressurized alkaline if maintained in a hot state. Atmospheric [alkaline] electrolysers find it difficult to deal with intermittent power however pressurised alkaline is well suited for intermittent power.

Constantine Levoyannis, head of EU affairs at Norwegian manufacturer Nel states:

*'I think that the flexibility of both alkaline and PEM stacks is sufficient to follow fluctuations in wind and solar … everything depends on how your project is - built up … including the portfolio of renewable electricity feeding into the project, the use of the grid to provide back-up power, and access to energy storage.'*



[6] **Gielen, D. (2021) -** Critical minerals for the energy transition, International Renewable Energy Agency, Abu Dhabi

## FLEXIBILITY

### PEM electrolysers are available in various sizes, making them adaptable to both small-scale and larger-scale hydrogen production needs

However with a larger number of stacks compared to alkaline electrolysers which offer the solution of choice for large-scale hydrogen production. SOECs can operate in both electrolysis mode (converting water into hydrogen and oxygen) and fuel cell mode (converting hydrogen and oxygen back into water to generate electricity), offering flexibility for energy storage and conversion.

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## EFFICIENCY

### SOECs can achieve high conversion efficiencies in splitting water into hydrogen and oxygen.

They can operate at elevated temperatures, which can improve their efficiency compared to some other electrolysis methods. PEM and pressurised Alkaline electrolysers are known for their relatively high efficiency in converting electrical energy into hydrogen gas. They can respond quickly to changes in input power, making them suitable for applications that require dynamic response.

## LOCATION DYNAMICS

### Location dynamics also bring challenges for project planners.

However, given considerations on weight, ease of access and replaceability of components must also be considered. Accessing remote sites with heavy equipment to replace the electrolyser stacks will require detailed operational planning that will become a factor in equipment choice also. Some PEM installations will possibly entail dealing with multiple small stacks, maybe 1MW or 1.5MW, and run times indicative of between or 80,000 hours to 120,000 hours.

Then you need to replace them, and this takes time, space and access. PEM electrolysers are smaller and less heavy than alkaline, it may provide project advantage if you are dealing with fewer stacks with a higher capacity. Alkaline through larger stack installations reduces mechanical and may result in an overall ease of maintenance for large production facilities.

## APPLICATION SUITABILITY

**Alkaline electrolysers typically operate at lower temperatures and pressures compared to some other electrolysis technologies, which can simplify system design and maintenance.**

SOECs are particularly well-suited for applications that require large-scale hydrogen production, industrial processes, and grid-scale energy storage. Their high-temperature operation might not be ideal for all scenarios. PEM electrolysers operate at relatively low temperatures and pressures, which can simplify system design and reduce maintenance requirements. The modular design of PEM electrolysers allows for scalability and easier integration into different systems and applications.

## DURABILITY

**The durability of PEM electrolysers can be influenced by factors such as membrane life and electrode stability.**

Advances in materials and manufacturing techniques have improved the overall durability of these systems. The durability of alkaline electrolysers can be influenced by factors such as electrode degradation and membrane performance. Advances in materials and design have improved their overall durability. SOECs stability and durability at high temperatures are areas of ongoing research and development.

## SOE, AEM, CFE, E-TAC AND MORE

**Location dynamics also bring challenges for project planners.**

Global strategies including the USA Inflation Reduction Act, The EU Green Deal, Fit for 55 and REPowerEU, Japan's Green Transformation programme, India's Production Linked Incentive scheme and China who is working to meet and even exceed the goals of its latest Five-Year Plan are all positioning hydrogen at centre stage and the flavour of the month.

This has created a scramble, a green energy 'gold rush' for hydrogen and as a result has created significant demand for larger scale PEM electrolysers. We are witnessing a global rush to large-scale industrial applications. The suitability of both pressurized alkaline and PEM technologies to operate dynamically with intermittent and varying renewable energy inputs enables operation abilities when the renewable inputs are at their optimum and cheapest. This adaptability makes PEM especially very attractive to large green hydrogen projects and we have witnessed some very large orders.

This has had a knock-on effect of delivering longer delivery times from companies with ever burgeoning order books. Dennis Schulz the CEO of ITM Power stated

*'Our PEM technology is state of the art and globally leading. We are deploying our electrolysers for some of the largest and most prominent green hydrogen projects under execution worldwide today.'*

Electrolysis uses rare earth metals in their construction, access and availability to these metals are causing increased delays and costs in the supply chain. One of the major barriers to reducing electrolyser costs is the use of scarce materials.

Current material availability can supply only a fraction of the increasing manufacturing capacity and demand, new solutions are needed to reduce dependence on scarce materials.

The electrolysis process needs catalysts to work – and the best current industrial electrodes use the precious metals iridium, ruthenium, and platinum. None of these metals are common, but iridium is one of the rarest elements on Earth, with less than ten tonnes produced each year. PEM include the expensive iridium and platinum they require, although around 90% of those platinum group metals (PGMs) can be recycled. Researchers around the world are working on better catalysts that don't use these resources. Early results in this field are interesting but it is still early days on a long journey of discovery.

In February 2023 the European Chemicals Agency (ECHA) in Helsinki published a proposal that could lead to the world's largest-ever clampdown on chemicals production. The plan, would heavily restrict the manufacture of more than 12,000 substances, collectively known as forever chemicals.

These chemicals, per- and poly-fluoroalkyl substances (PFASs), are all around us. They coat non-stick cookware, smartphone screens, weatherproof clothing and stain-resistant textiles. They are also used in microchips, jet engines, cars, batteries, medical devices, refrigeration systems and in certain types of electrolysers.

This proposed EU ban could cause 'massive disruption' to European hydrogen sector as fluoropolymers are a vital ingredient in PEM and AEM electrolysis systems, and there is currently no viable alternative. Hydrogen Europe has stated that as far as the hydrogen sector is concerned, there are currently zero alternatives to fluoropolymers, which is why they are advocating for their exemption from the PFAS regulation.

## TECHNOLOGY HEADROOM

**Different projects will ultimately have vastly different considerations and demand.**

That is why the choice of electrolyser is key and all factors including origins, scaling, off take flexibility and much more need to be considered. Norwegian electrolyser manufacturer Nel produce both atmospheric alkaline and PEM electrolysers providing options for the customer. Constantine Levoyannis, head of EU affairs at Nel, said that his company produces because *"not all projects are the same... we need to tailor our offerings to different applications [and] different customer needs".*

Within the GenComm[7] project that developed three hydrogen hubs from different renewable sources wind, solar and bio for different off take uses the choice of electrolyser again was made dependant on opportunity, scale and demand. The work within GenComm highlighted that whilst PEM is the current 'favourite child' there are other electrolyser siblings that have significant innovation headroom and advantage that can be exploited.

The 'sailing ship' effect, a phenomenon by which the introduction of a new technology to a market accelerates the innovation of an incumbent technology has created rapid innovation space in other electrolyser technologies. The demand for PEM has also created a degree of munificence, a thriving market with exceptional demand with room for a range of technologies.

The outcome of this is industry has a diversity of electrolyser technologies to draw upon. In addition to innovation opportunity in electrolysis there also is the opportunity of utilising renewable energy technologies to produce hydrogen without the restrictions of electrolysers. Technologies such as thermochemical technologies, however this is a discussion for another day.



[7] https://vb.nweurope.eu/projects/project-search/gencomm-generating-energy-secure-communities/

## CONCLUSION

**Over the last 5 years we have witnessed significantly increased acceleration in electrolyser deployment and projects, now in the GW scale.**

This momentum is expected to continue as the world looks to clean hydrogen in combating climate change and in delivering national energy autonomy. This scale or demand will drive future innovation especially in electrolysis technologies addressing the urgent need for new solutions to lower costs whilst raising technological efficiency and production capacity. Innovation in the field of electrolysers is a required in order to make the production of hydrogen cost-competitive with other technologies and as green as possible, thus helping to tackle challenges such as decarbonisation and accelerating energy transition.

The European Union, US and Chinese current demands and ambitious targets for green hydrogen are creating significant challenges for Hydrogen production, which is essentially an economy in its infancy. Current production capacities and capabilities for electrolysers are failing to meet demand. Industry is struggling to ramp up to meet planned production scaling of electrolysers. We have too much 'fabricated' demand chasing too few 'proven' technological opportunities.

Decoupling EU energy demand from Russian supplies has created demand for massive electrolysis capacity which suppliers are struggling to meet. This will only become more apparent as planned projects reach commissioning stage and will translate into decisive factors in determining the geographical location of industrial activity and result in economic fragmentism unless it is cohesively managed.

In today's hydrogen driven energy journey, several electrolysis technologies will coexist in the market, each catering to different applications and geographies. They all will face the common challenge of decreasing the cost of hydrogen produced, for which energy efficiency is a major but not the only factor. Ultimately, the decision of which electrolyser technology you choose depends on the specific requirements of your project, the available infrastructure, budget considerations, and the desired environmental impact.

Additional quantifiable factor includes energy requirements, available resources, technological readiness, and supply chain timelines. Each electrolysis technology has its own set of benefits and limitations, so your decision should be based on a comprehensive assessment of your project's needs and goals.

Electrolysers are central to the emerg¬ing green hydrogen world. We are at a critical stage in realising hydrogen potential due to a combination of problems impacting directly on electrolyser availability and supply. Whilst a limited global supply of rare earth metals is impacting on material cost and availability it is also compounded by other challenges including key skills shortages and an acceleration from electrolyser companies to move to ever larger electrolysers.

These are all brought into global focus with the significant increase in worldwide demand for hydrogen as an alternative to fossil fuels in meeting the triple crises of climate change, energy cost and energy security. Industry itself at ***"the confluence of many issues within the electrolysis supply chain and these are all providing cumulative cause for concern".***



**Paul McCormack**
GenComm coordinator