De-risking green hydrogen and ammonia projects

Protecting electrolyser investments with ultrapure water

By **Stephen B. Harrison, sbh4 consulting**

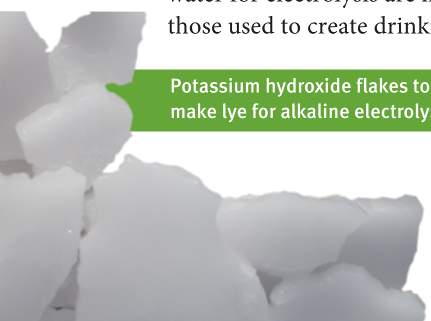
The dominant path to green hydrogen is splitting ultrapure water using renewable electrical power on an electrolyser. For each kg of green hydrogen produced, 9-to-10 litres of water are consumed by electrolysis.

This equates to around 200 litres of water per MW of electrolyser capacity. To generate that amount of ultrapure water, about 1.5 times as much fresh water is required. And to generate desalinated fresh water, approximately twice as much seawater is required. So, for each litre of ultrapure water, 3 litres of seawater must be processed.

There are many steps between seawater and ultrapure water. If any of those fails, the electrolyser stack could be damaged beyond repair. If the water processing plant fails, the electrolyser must shut down, resulting in failure to supply off takers, or causing problems with downstream ammonia synthesis. Reliability and consistent ultrapure water quality are key.

Proven technologies for desalination and purification

Technologies to generate ultrapure water for electrolysis are like those used to create drinking water, deionised water for laboratories and boiler water for thermal power generation. For each MWh of power produced by coal, gas, oil, or nuclear plants between 2 and 2.5 tonnes of water is required. In comparison, 1 MWh of electrolysis consumes only 0.2 tonnes of water. Technologies for boiler water processing can be leveraged at an appropriate scale to protect electrolyser investments and ensure green hydrogen projects are de-risked.



Potassium hydroxide flakes to make lye for alkaline electrolysers

International competitiveness is essential for GW-scale projects that are being developed to produce green hydrogen and convert that to green ammonia as a clean energy vector for international trade. The market is global, and the customers are free to choose the lowest cost supplier. Coastal regions of Australia, Egypt, Chile, Namibia, Oman, and Saudi Arabia stand out as excellent green ammonia export hubs. However, freshwater resources in these locations are not abundant and desalination of seawater will be required to yield ultrapure water for electrolysis.

De-risking billion dollar investments

Helios, the largest green hydrogen project under construction, is rated at 2GW of electrolyser capacity and will cost more than $8 billion to execute. It will use renewable wind and solar power in northwest Saudi Arabia to generate green hydrogen which will be converted to green ammonia for export.

Impure water can be extremely damaging to valuable electrolysers. Calcium or magnesium cations in the water will rapidly damage a proton exchange membrane (PEM) electrolyser membrane due to interaction with the water-splitting catalyst that coats the membrane. Alkaline and solid oxide electrolysers (SOEC) are also sensitive to poisons in the water.

The SOEC technology is well aligned to green ammonia projects due to the potential for process integration and energy efficiency.

> "For each kg of green hydrogen produced, 9-to-10 litres of water are consumed by electrolysis"

Ultrafilter cartridge

Waste heat from the Haber-Bosch ammonia synthesis can be used to reduce the electrical power input to the SOEC electrolyser, which operates at high temperatures.

When fed with steam, an SOEC requires around 20% less power than a PEM or alkaline electrolyser to generate the same amount of hydrogen.

The catalysts used in SOEC technology are sensitive to sulphate ions as well as silicates, siloxanes, and aluminium oxides. These impurities must be reduced to less than 5 or 10 parts per billion to avoid degradation of the SOEC stack performance.

It is essential to meet the ultrapure feed water specification that the electrolyser manufacturer requires and design a suitable ultrapure water treatment facility.

Electrolyser feed water specifications

There are two internationally recognised standards that refer to ultrapure water quality. The ASTM D1193-06(2018) Standard Specification for Reagent Water and the ISO 3696:1987.

The ISO standard is titled 'Specifications for Water for Analytical Laboratory Use' and includes three grades of purity. The typical feed

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for an electrolyser would be Grade 2 with a maximum conductivity of less than 2µS/cm (0.2 mS/m) as the target. They may also offer the required water purification equipment as part of a complete package to ensure ultrapure water is generated according to their requirements.

Purification technologies

In the initial stage of water treatment, a grate can be used to trap debris. After this, additives such as aluminium sulphate may be used to flocculate dissolved metals. Pre-chlorination can support the removal of heavy metals. A sand bed filter can be used to trap the precipitated particles.

An activated carbon filter can then be used to remove the chlorine which would corrode membranes that are used in subsequent water purification processes such as reverse osmosis. Chlorine would also damage the membrane used in PEM electrolyser stacks.

The activated carbon filter will also remove much of the dissolved organic material from the water. Organic molecules would be converted to carbon monoxide in the electrolyser and the hydrogen product could therefore be contaminated.

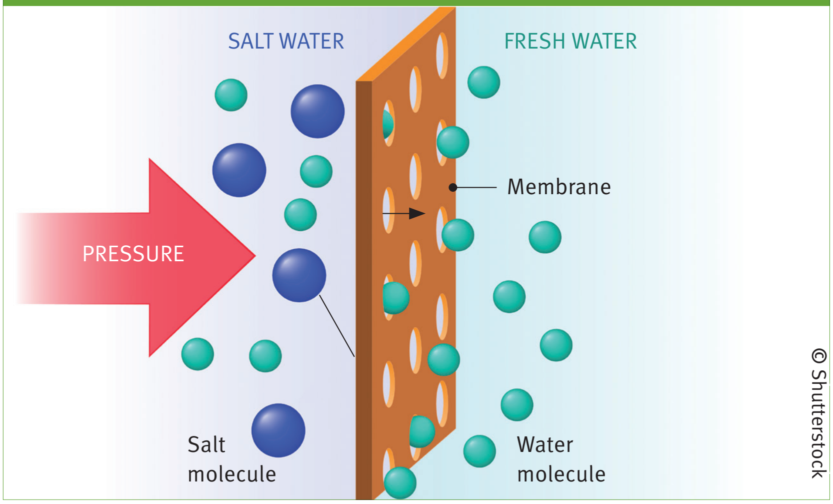
Water softening is often used to remove calcium and magnesium ions in hard water areas. These are especially damaging to electrode assembly catalysts that are used in PEM electrolysers.

Reverse osmosis (RO) is a core technology for the final stages of freshwater purification and seawater desalination. To purify fresh water, low pressure reverse osmosis (LPRO) can be used. It operates at around 15 bar. The power consumption of an LPRO plant is in the order of 10 kWh per m3 of water purified and between 70 and 85% of the water is recovered.

For seawater reverse osmosis (SWRO) an operating pressure up to 80 bar is used. SWRO is common in coastal areas to provide fresh water to communities. A plant that serves a population of 1 million people would produce around 400,000 cbm of fresh water per day. The plot for this facility would be about 350m x 200m. This scale of SWRO plant would be sufficient to supply an 80 GW electrolyser scheme that generates 40,000 tonnes per day of hydrogen or 220,000 tonnes per day of green ammonia.

After the RO purification, the water may flow through an electro deionisation (EDI) plant. Here the power requirement may be similar to LPRO at 10 kWh/m3 of water. After

Reverse Osmosis



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EDI, microbial contamination must be removed. Post-chlorination is not suitable, due to the incompatibility of chlorine with the sensitive electrolyser components. Therefore, a UV steriliser lamp is preferred.

Following the UV lamp, an ultrafilter would be used to trap the dead bacteria. The power requirement for the ultrafilter may be around 3 kWh/m3 of water. The ultrapure water is now ready to be introduced to the electrolyser water or lye recirculation circuit.

Recirculation water and lye purification

Pure water recirculates through a PEM electrolyser at approximately 250-to-500 times the feed water flow rate. The ratio of lye recirculation flow to feed water input in an alkaline electrolyser is similar. These flows equate to 50-to -100 m3/hr of water or lye recirculation per MW of electrolyser capacity.

During operation of each electrolyser, a tiny amount of corrosion of metal from the pipework takes place. Critical stack components such as bipolar plates, electrodes, and the porous transport layer (PTL) may also experience corrosion during operation.

These mechanisms introduce tiny amounts of ions into the recirculation water. These dissolved metal cations and could damage the membrane in a PEM electrolyser and must therefore be removed. As with the feed water preparation, EDI polishing can be used to remove ions from the recirculation water in PEM electrolysers.

Alkaline electrolysers tend to be more tolerant to dissolved ions, and the lye that recirculates within them is typically a 30% potassium hydroxide solution. De-ionisation within the recirculating lye circuit is not required.

In alkaline electrolysers carbon dioxide (CO_2) can be introduced with the feed water or can build up due to the oxidation of organic compounds. These compounds may have been present in the feedwater or may gradually dissolve into the lye from sealing gaskets or plastic pipework in the electrolyser equipment.

The CO_2 reacts with the potassium hydroxide in the lye to form insoluble potassium carbonate which must be removed through filtration. This is also a reason that the lye must occasionally be replenished. Dissolved CO_2 gas can be removed within the recirculation circuit using degassing equipment.

The business case for investing in ultrapure water

The capital costs of ultrapure water production are generally between 4

Activated carbon for removal of chlorine and organic molecules

and 8% the project total cost of a green hydrogen project electrolyser scheme. Where desalination is also required, the capital cost of the water processing equipment may represent 10 to 15% of the total equipment capex. But the consequences of failure can be very high: reliability is therefore key.

An interruption to the water supply would mean the electrolyser must shut down. For a PEM system that is unlikely to result in equipment damage. However, for alkaline or solid oxide electrolysers, an unplanned shutdown may result in degradation of the electrolyser's performance and a reduction in its efficiency. The interruption in hydrogen supply would also have adverse effects on the downstream ammonia synthesis or may have contractual consequences with off takers.

Electrolysers are expensive capital assets and represent the largest portion of the investment for green hydrogen or green ammonia projects. Protecting the core of the investment with high quality, reliable ultrapure water equipment will undoubtedly be a sound business decision. gw

Ultrapure water conductivity measurement