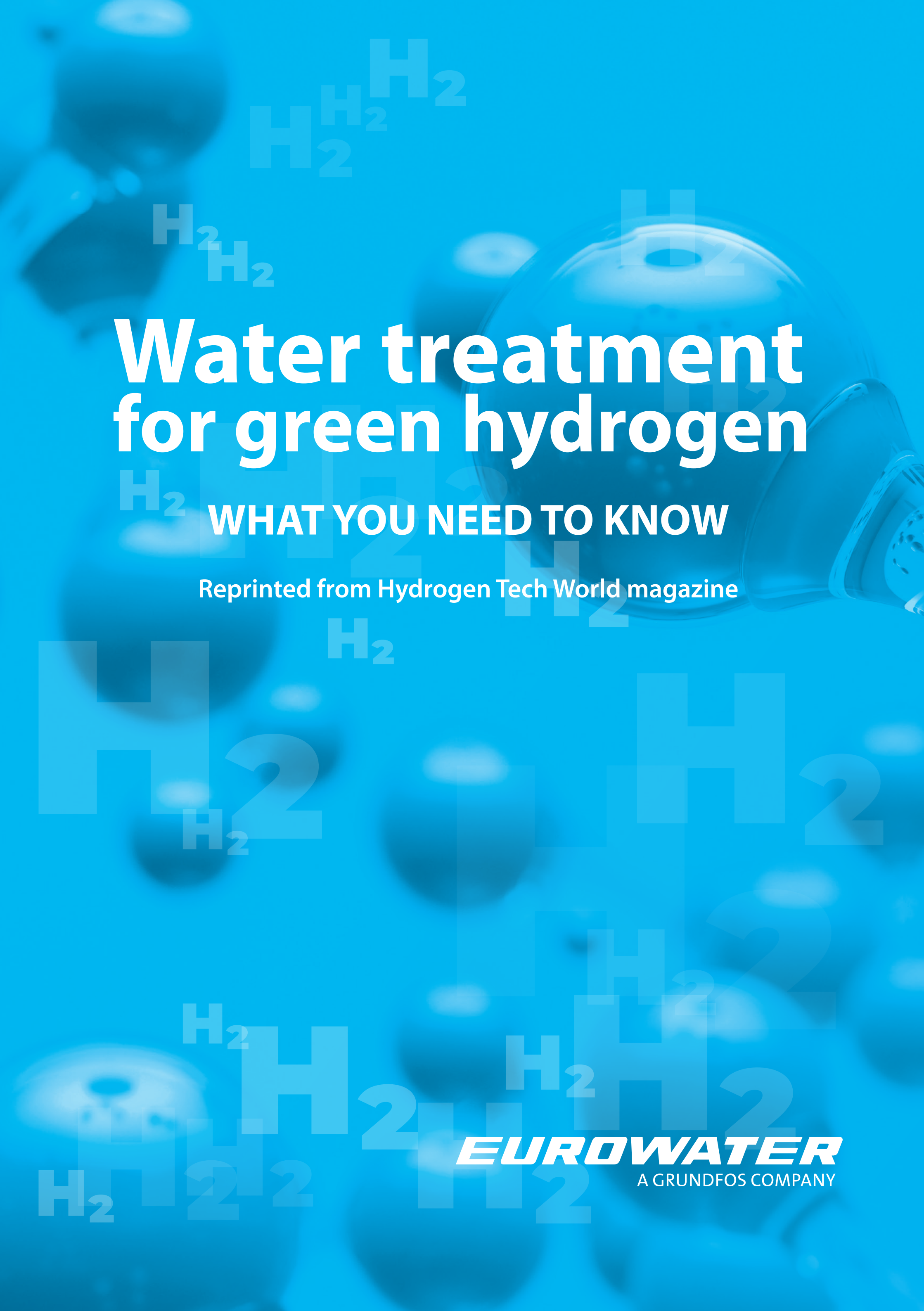

Water treatment for green hydrogen

WHAT YOU NEED TO KNOW

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EUROWATER
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Water treatment for green hydrogen

Water is essential for the production of green hydrogen and as the market matures, crucial questions about the use of water are starting to arise: How much water is needed? Which quality is sufficient? And where should the water come from? Let's shed some light on these essential questions.

To have a qualified discussion about use of water for green hydrogen, we first need to define what we mean when we say "water".

In the production of green hydrogen, it is necessary to distinguish between three types of water:

- Ultrapure water (used as feedstock for the electrolyser)
- Cooling water
- Raw water

The quantity of ultrapure water used for electrolysis will be different from that of raw water extracted from the environment and the quality of ultrapure water and cooling water is also different. Therefore, we need to deal with each one separately. Let's first look at ultrapure water.

What is ultrapure water?

Water suitable for electrolysis is commonly called ultrapure, but what is to be understood by this label?

Several parameters influence what quality water must have to be suitable for electrolysis. These include the type of electrolyser, electrode material, system design and even brand of electrolyser.

Add to this, that each of the ions and molecules in water will affect the electrolyser differently. Some can increase OPEX because of corrosion or increased need for cleaning, while others can lower the electrolyser efficiency and/or irreversibly damage and degrade the electrolysers.

With so many variables and effects, it is no surprise that water treatment is often tailored to the specific project, making it very difficult to come up with a unified standard for water quality for all electrolysers.

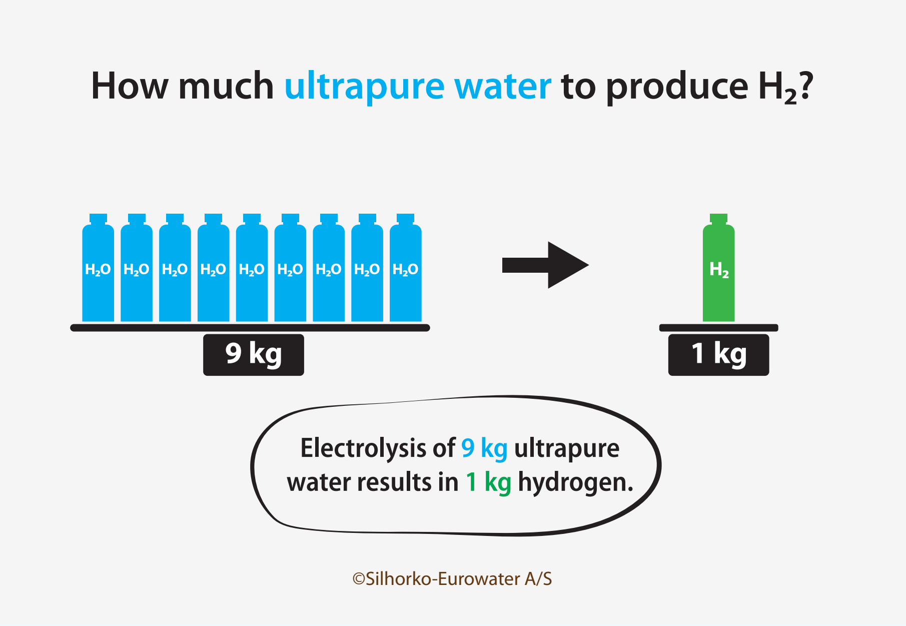

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Figure 1 *The 1:9 rule for consumption of ultrapure water in green hydrogen production.*

One strategy that electrolyser manufacturers can follow to simplify the issue is to set the requirements for conductivity sufficiently low to ensure that the concentration levels of problematic ions and molecules will in all certainty be below the electrolyser requirements. A good starting point can be <1 µS/cm for standard alkaline electrolysers[1], and < 0.1 µS/cm for PEM electrolysers and alkaline electrolysers[1] relying on advanced electrodes. However, it is worthwhile to remember two things: 1) water treatment constitutes a relatively minor part of the total CAPEX of a hydrogen plant and 2) no electrolyser was ever damaged by using water that was too clean. Ensuring high quality and reliability in the water treatment may thus be the best investment to be made for an electrolyser system.

Consumption of ultrapure water

We can accurately calculate the amount of ultrapure water required for production of green hydrogen, using the atomic composition of

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[1] *Many will say that 5 µS/cm should be the limit for standard alkaline electrolysis, but what we see from the market today is a trend towards higher requirements for water quality – also for alkaline electrolysis.*

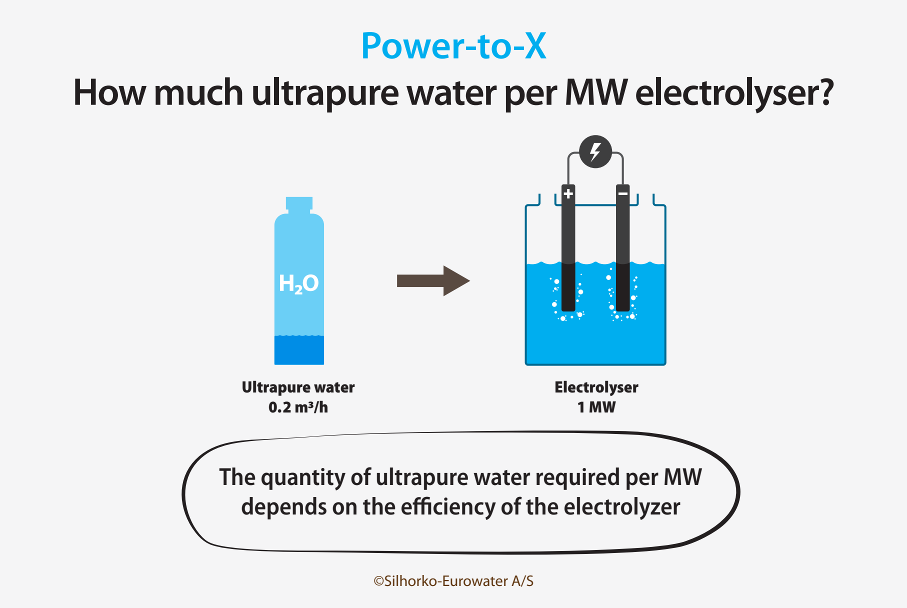

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Figure 2 *Rule of thumb for consumption of ultrapure water per MW electrolyser capacity.*

water, H_2O. Since oxygen is 16 times heavier than hydrogen, it is responsible for 89% of the mass of water, which means that 9 L of water is needed to produce 1 kg of hydrogen (Figure 1). This ratio can be quite useful to determine the water requirements for a specific production capacity of hydrogen. For instance, production of 100,000 tons of green hydrogen per year will consume 900,000 m^3 (tons) of ultrapure water.

This approach tells us how much water is needed on average, but it will not tell us about the rate of water consumption (m^3/h), and this is required for dimensioning the water treatment system. Here we need to look at the electrolyser power rating (MW). The power rating will determine the rate at which hydrogen is produced and thus the rate of water consumption. The amount of ultrapure water needed per MW depends on how much energy the electrolyser needs to convert the 9L (kg) of ultrapure water to 1 kg of hydrogen. Most electrolysers consume 45-55 kWh per kg hydrogen, which means that 0.16-0.2 L of ultrapure water are required per kWh or 163-200 L/h of ultrapure water required per MW electrolyser capacity.

A flow of 200 L/h has proven to be an excellent rule of thumb as a first estimate of the requirements for ultrapure water (Figure 2). Thus a 10 MW plant needs 2 m^3/h and a 1 GW plant needs 200 m^3/h of ultrapure water.

Consumption of cooling water

While the consumption of ultrapure water as feedstock will always be part of a green hydrogen facility, it is more difficult to give a precise evaluation of the consumption of cooling water. Many of the smaller projects that are realized today are based on dry cooling, while the very large electrolyser systems currently in planning may seek to integrate the waste heat into other water-based infrastructure systems such as wastewater treatment plants and district heating systems. Also, offshore based systems may rely on the use of seawater for cooling.

For the projects where a water-based cooling system is chosen, the specific design of the cooling solution will determine the water usage. For an evaporative cooling tower relevant parameters include the starting water quality, the ratio between conductive and evaporative cooling, drift ratio, and concentration factor. All these factors make it complicated to come with an accurate number, but to get a first estimate a good rule of thumb is that 400 L/h of cooling water is needed per MW electrolyser, or roughly twice the amount required for electrolysis.

It is important to have in mind that cooling water and water for electrolysis will have very different quality requirements.

Consumption of raw water

To determine the impact of a green hydrogen system on the local water systems, it is necessary to not only focus on the consumption of ultrapure water, but also on how much water must be taken from the raw water source to produce the ultrapure water.

Water can come from many sources. For most of the smaller projects seen today, water from the drinking water network is used. However, as hydrogen plants increase in size, this approach becomes unsustainable, and water must be sourced from elsewhere.

The three most common raw water sources for large scale hydrogen projects are: Groundwater, treated wastewater and seawater. From the perspective of a water treatment system, surface water from rivers and lakes will in many ways be similar to treated wastewater and these can therefore be considered as one.

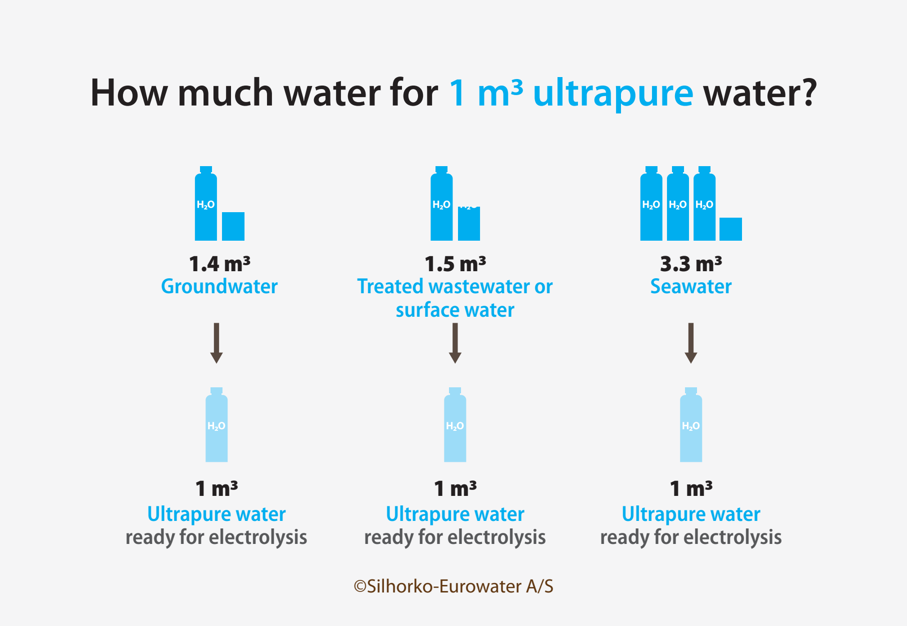

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Figure 3 *Raw water quantities required for production of ultrapure water for electrolysis*

Each type of raw water will require different water treatment systems, and this affects how much raw water must be extracted. Of these you need to extract the least raw water using groundwater and most when using seawater, see Figure 3. Extraction of treated wastewater will be similar to groundwater.

The differences stem from the recoveries that can be obtained in the initial pretreatment of each raw water source before it is polished to ultrapure quality. For groundwater standard filtration can reach very high recovery values, >98%. Treated wastewater filtered with ultrafiltration will typically have a slightly lower recovery of 90-95%. For seawater desalination, recovery is normally limited to 40-50% due to increasing osmotic pressure. The treatment to ultrapure quality comes with its own recovery, typically 75%.

With these rules of thumb numbers, it is possible to quickly estimate the water requirements for a given hydrogen project. The same electrolyser designed to produce 100,000 tons of hydrogen will require 900,000 m^3 of ultrapure water and will need to extract 1,200,000 m^3 of groundwater, 1,300,000 m^3 of treated wastewater or 3,000,000 m^3 of seawater.

Often concerns about the energy consumption of the water treatment process is brought up for discussion, especially when talking about seawater desalination. However, it is important to remember that while water treatment must overcome the attractive forces between water molecules and ions, electrolysis must overcome the strong covalent bonds between the atoms in the water molecules. As seen in Figure 4, turning seawater into ultrapure water may require 3-4 times as much energy as groundwater and treated wastewater, but it is still only around a thousandth of the energy required for electrolysis.

Production of ultrapure water

The process from raw water to ultrapure water can be divided into two overall steps:

1. Pretreatment of raw water
2. Polishing to ultrapure water

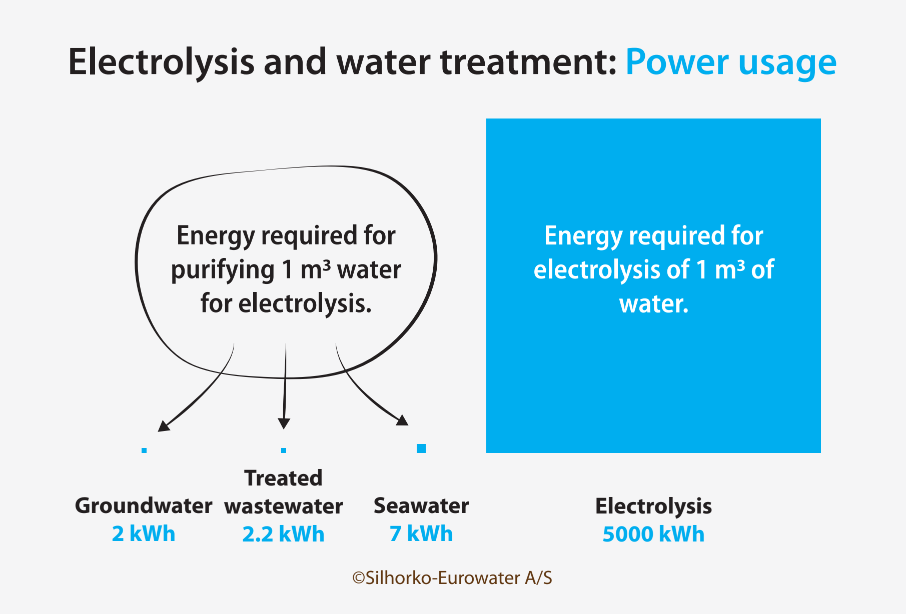

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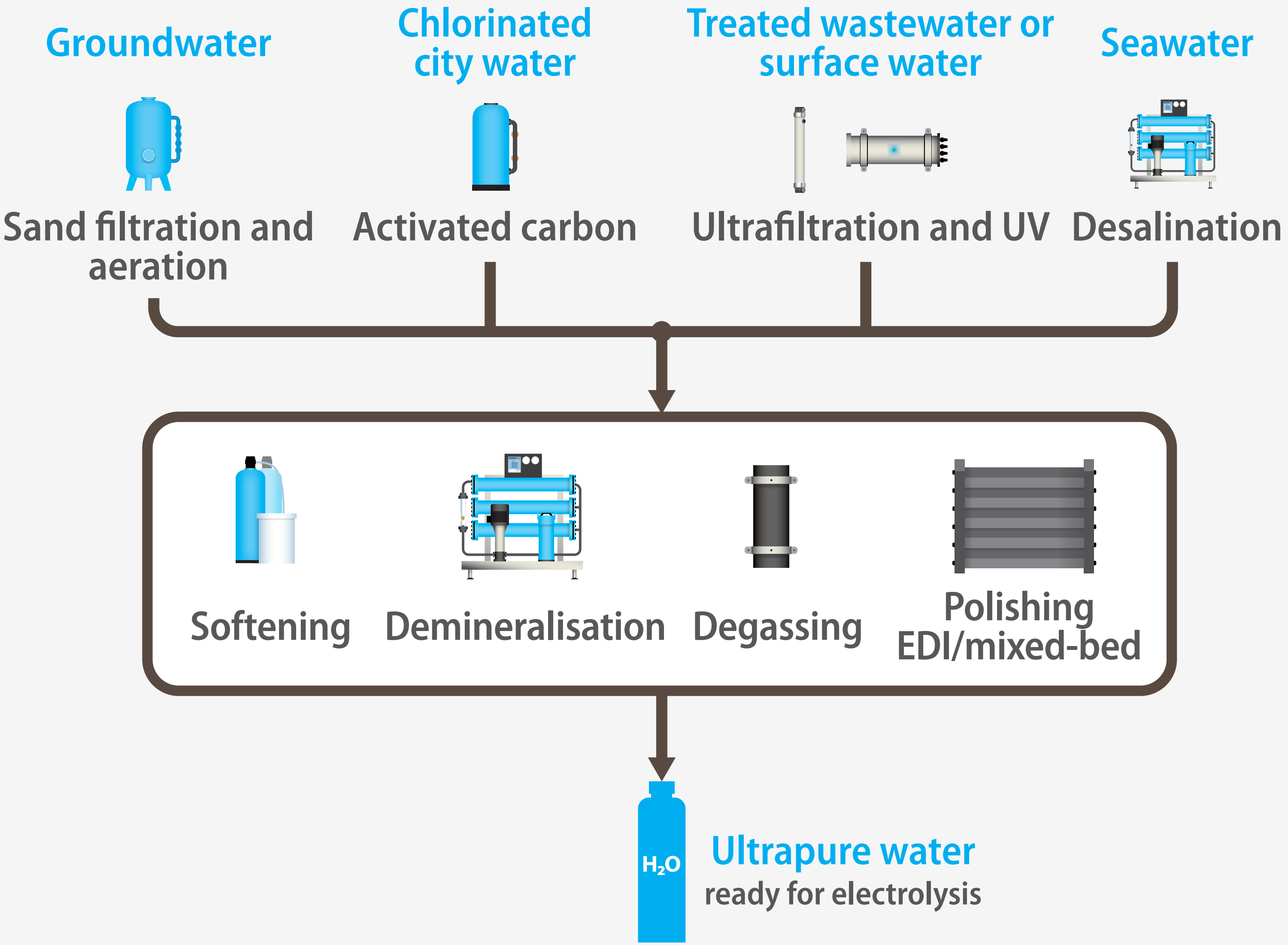
Figure 4 *The energy required to produce ultrapure water from different raw water sources.*

How is water treated for green H_2?



Groundwater

Sand filtration and aeration

Chlorinated city water

Activated carbon

Treated wastewater or surface water

Ultrafiltration and UV

Seawater

Desalination

Softening

Demineralisation

Degassing

Polishing EDI/mixed-bed

Ultrapure water

ready for electrolysis

Figure 5 *Overview of the water treatment train from raw water to ultrapure water suitable for electrolysis.*

The role of the pretreatment system is to make the raw water suitable as a feed source for the polishing system. This means bringing the water to a state where it resembles city water quality. The type of pretreatment system depends on the source of water as each will come with their own challenges. Groundwater contains dissolved redox active species such as iron and manganese that can precipitate in and clog the polishing system. These can be effectively removed using aeration and sand filtration. For treated wastewater the primary concern is particles, organics, and microorganisms. Here ultrafiltration in combination with UV can be used to bring the water to a suitable quality. Seawater primarily requires removal of salts, but also particles and dormant microorganisms. Using standardized reverse osmosis (RO) desalination is sufficient.

Once the raw water has been pretreated, we need to address the following issues to turn it into ultrapure quality:

- Content of ions – conductivity
- Hardness
- TOC
- Silica
- Gasses

To remove the bulk of the ionic load RO is used. The membrane blocks ions, molecules and particles and will therefore also remove organics (TOC) and silica. To reach sufficiently low concentrations it is often necessary to employ a double pass RO system, where the permeate from the first RO process is filtered again in a secondary RO system. For the RO system to operate properly, the water must first be conditioned to avoid scaling and damage to the membranes. If there is free chlorine in the water, this must be removed using active carbon, to avoid oxidation of the selective layer of the membrane. Hardness due to ions such as Ca and Mg can cause scaling and limit the recovery rate. This can be handled by either using a softener that will exchange multivalent ions with Na or by dosing in an antiscalant that will stop the scaling process. RO membranes do not stop dissolved gasses such as CO_2. These must therefore be removed with a dedicated process. For a chemical free option, a membrane degasser can be installed after the RO membrane. Alternatively, lye can be does in front of the membranes to convert CO_2 to bicarbonate ions that can be removed with the RO system. To reach the very low conductivities required by many electrolysers, it is necessary with a final deionization. Here either a mixed bed filter or an electrodeionization (EDI) unit can be used. These processes will take any remaining ions and exchange them for H+ and OH- ions. The mixed bed must be regenerated or exchanged once spent while the EDI can operate continuously due to a self-regenerating design. Often the two deionization technologies will be employed together with the mixed bed placed as a "police filter" after the EDI.

Figure 5 illustrates this general process configuration, while Figure 6 shows an example of such a system.

Case – Everfuel

As a specific example of water treatment for green hydrogen we can look to the HySynergy project by Everfuel. This project contains 3 phases: 20 MW (2022), 300 MW (2025) and 1 GW (2030) and seeks to provide green hydrogen for both mobility and industrial end users. For the first phase, an alkaline electrolyser was chosen requiring a flow of ultrapure water of 4.5 m³/h with a conductivity <5 µS/cm. The water was sourced from the drinking water network with a hardness of 11 °dH and no free chlorine. In this case the quality criteria could be met using a double pass RO system combined with CO_2 removal and with an ion exchange softener in front of the RO membranes to ensure very low concentration of multivalent ions.

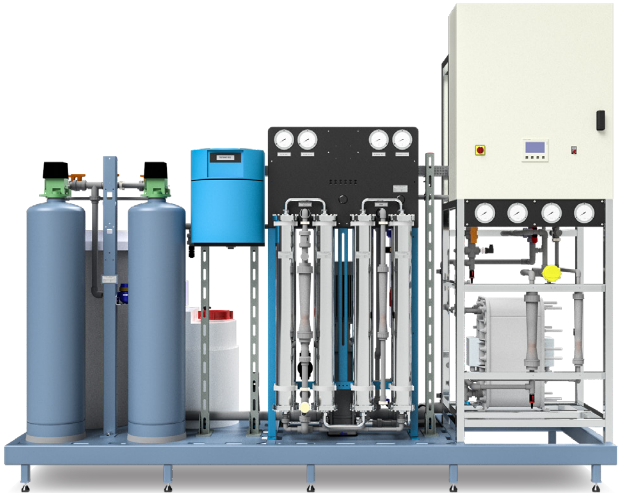


Figure 6 *Frame mounted water treatment system for production of water suitable for electrolysis (<0.1 µS/cm). This system has a capacity of 1-2 m³/h equal to an electrolyser capacity of 5-10 MW.*

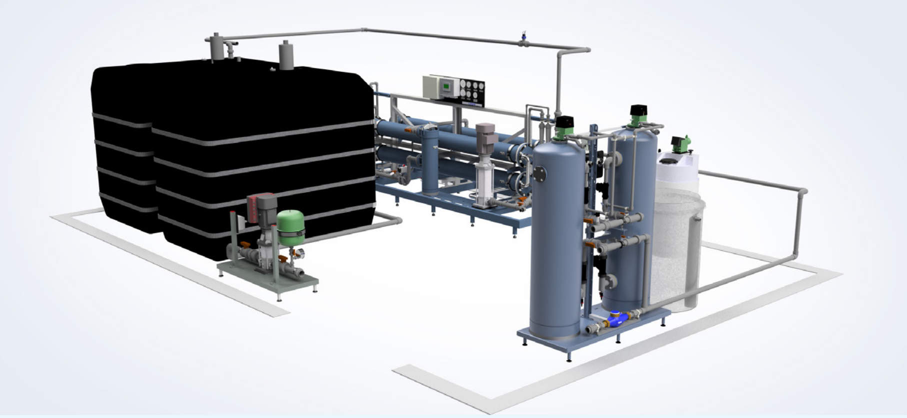


Figure 7 *Water treatment system for the 20 MW HySynergy project.*

Internal polishing of water

For electrolyser systems like PEM and AEM operating directly on ultrapure water, water treatment does not stop with the make-up water. After entering the electrolyser system, the water is continuously contaminated with metal ions from the piping and process equipment as well as ions and organics from the electrolyser stack. These contaminants must be removed to maintain the lifetime of electrolyser.

The way to solve this problem is to introduce a side stream polisher internally in the electrolyser on the anode circulation system.

Two processes are available for handling the side stream polishing: mixed bed ion exchange and EDI. In this application EDI is limited due to operational temperatures and the fact that it produces a concentrate waste stream. Mixed beds are the preferred option because they allow for zero waste of water and a higher flexibility in meeting the process requirements of the electrolyser system.

The side stream loop should be dimensioned to remove contaminants at a rate equal to or higher than the release rate to avoid accumulation in the electrolyser. The release rate is complicated to estimate as it depends both on material choices in the process equipment and the electrolyser as well as operating conditions. Typically, the flow of the polisher loop will be in the range of 2-10 % of the anode circulation flow rate. The higher the percentage, the higher quality of the water sent to the electrolyser will be.

But what about the pumps?

Finally, we must also address the need for pumping and the effect it has on water quality. Pumps are used in several places in electrolyser systems, but the most central role is for circulation over the electrolyser stack. Large amounts of heat are released during electrolysis, and to maintain an acceptable temperature differential across the stack, very high flow rates are required. To keep the temperature increase between 2-4 °C a flow rate of 50-100 m^3/h per MW is required. That means that the flow rate is 250-500 times larger than the flow of make-up water into the electrolyser system. Because of this, pumps take up a significant part of the CAPEX for a green hydrogen system, 10-20% of the combined CAPEX for stack components and balance of plant, and this presents operators with a difficult challenge. The cost of pumps pushes for cost effective solutions, but the strict quality requirements as well as the harsh operating conditions pushes for high quality and specialized products. Part of the solution to this challenge is to adopt a holistic approach and think water treatment

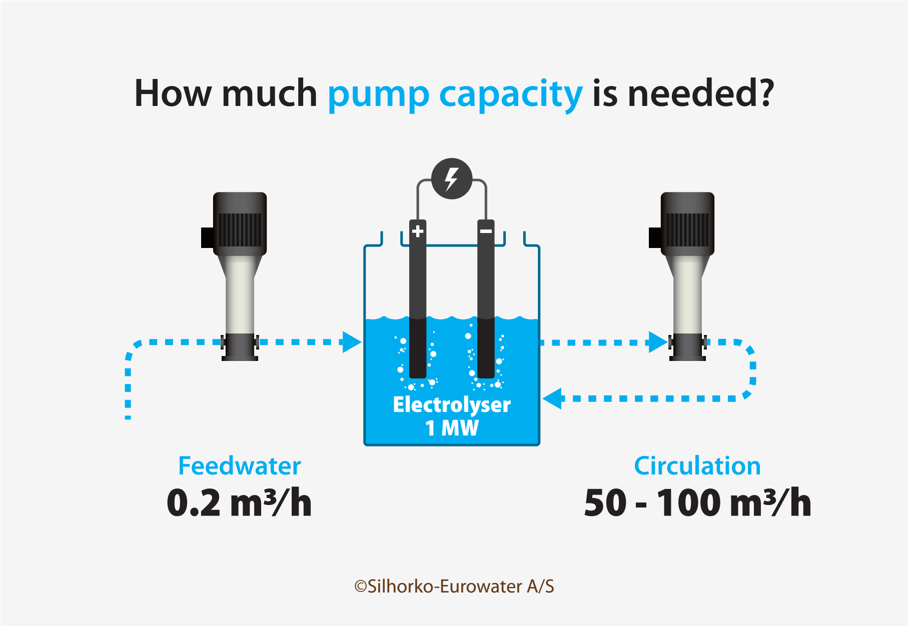


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Figure 8 *Pumping requirement for circulation of ultrapure water over the electrolyser stack .*

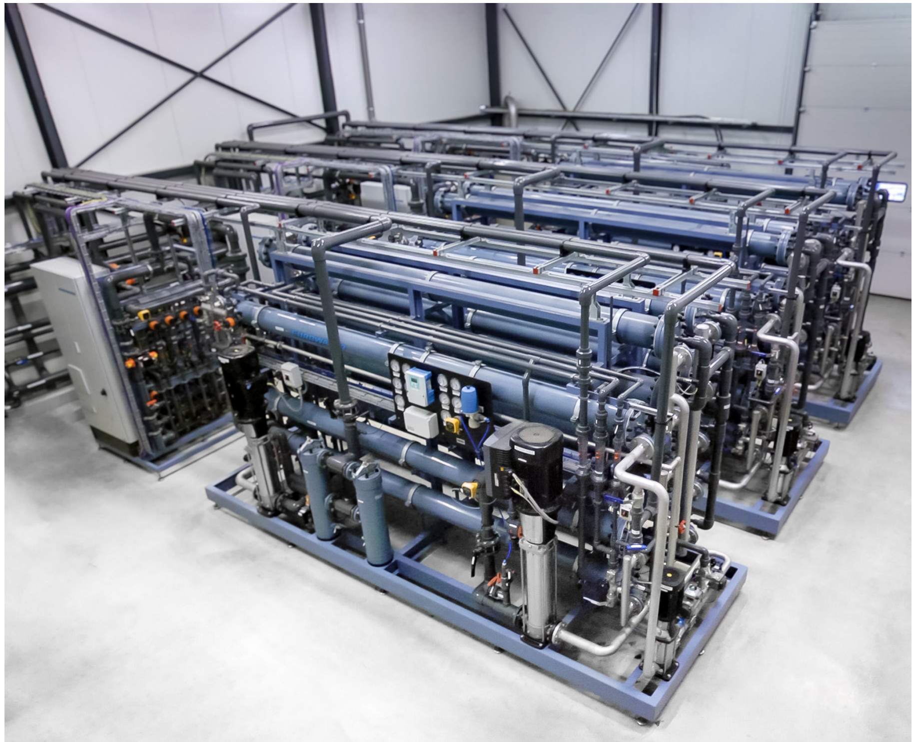

Figure 9 *Modular water treatment solution for a 300 MW electrolyser.*

in combination with pumping. By improving the polishing system, it can overcome the release of metals and thus lower the requirements for the pumps used for recirculation.

Looking ahead, it is clear that water treatment will play an essential role for the green hydrogen industry, and like the other components in a green hydrogen plant, water treatment systems will also face important questions about scalability, modularity, redundancy etc. as the industry matures. Figure 9 shows an example of how such large scale installations could look.

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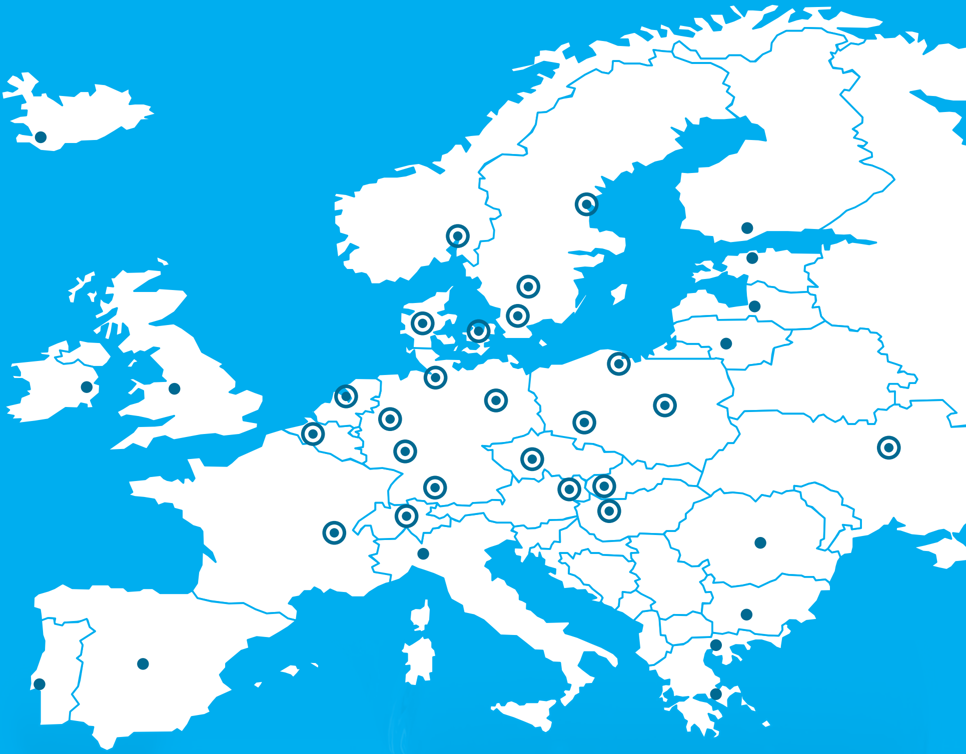

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