

The role of clean water for a robust and reliable production of Green Hydrogen

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ABSTRACT

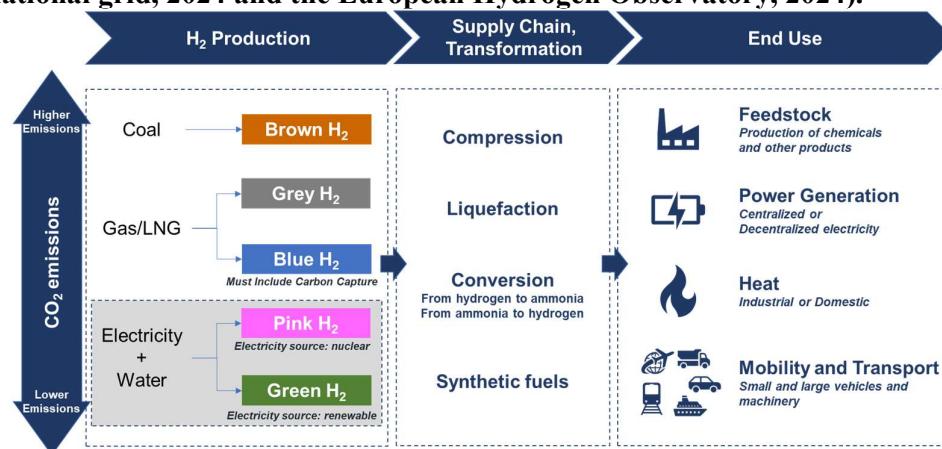
Green Hydrogen, which is produced by water electrolysis, has emerged as a central topic in the pursue of global decarbonization. Water quality can influence the lifetime of electrolyzers' parts, and efficiency of electrolysis. This work will focus on water aspects of electrolysis, in particular for proton-exchange membrane (PEM) electrolyzers, including water quality and specific pollutants, treatment needs, a holistic view of treatment schemes, and with special emphasis on the challenges of PEM recirculation loops, with specific polishing requirements.

CONTEXT: WHY HYDROGEN?

The global pursuit of more sustainable sources of energy and mobility is transforming our economy. Hydrogen has emerged as a promising vector due to its versatility as a fuel or feedstock. Hydrogen can play several major roles in the clean energy transition, contributing to the decarbonization of transportation, heat, and energy sources, both industrial and domestic, and as feedstock, to produce ammonia or methanol, for example.

Hydrogen can be produced by several methods, but the one with more capacity to reduce carbon emissions is termed Green Hydrogen, in which Hydrogen is produced from water by renewable energy powered electrolysis. Although the term Green Hydrogen should be fundamentally used only in the context of renewable energy powered electrolysis, in many forums, the term is being used indistinctly for any installation that produces hydrogen from water electrolysis regardless of whether the electricity is powered from the electricity grid, or directly from a renewable energy source. From the perspective of water quality and water treatment aspects, there is no difference, and the considerations of this work would apply equally to water electrolysis regardless of the electricity source.

Figure 1: An overall view of the hydrogen map, from production up to uses. (Adapted from national grid, 2024 and the European Hydrogen Observatory, 2024).



OVERALL WATER NEEDS FOR HYDROGEN PRODUCTION

Electrolysis is the process of electrically splitting the water molecules into hydrogen and oxygen gas. There are several types of electrolyzers, and they all rely on high purity water as the feedstock to produce hydrogen. At this moment, four main types of water electrolysis technologies can be found in the market with different degree of technology readiness and presence: Alkaline Water Electrolysis (AWE), Proton Exchange Membranes (PEM) electrolyzers, Anion Exchange Membrane (AEM) electrolyzers, and Solid Oxide Electrolysis Cell (SOEC) electrolyzers (El-Shafie, 2023; Kumar and Lim, 2022; Chatenet et al., 2022). Among them, AWE and PEM are the most used ones today, and this situation is expected to last at least until 2030 (International Energy Agency, 2023).

While the industry is split between PEM and AWE being the most generally suitable technology today, there are multiple general and project level aspects to consider, such as: capital costs, technology maturity, availability, electric efficiency, response time, tolerance to fluctuations, footprint, ease-of-maintenance, hydrogen purity, among other aspects. This work

will not debate about which one is more promising, however this work will focus on PEM electrolyzers, as there are still unresolved challenges related to water treatment technology for PEM systems that would help to boost overall system efficiency.

Electrolyzers, including PEM, require a continuous supply of demineralized water. According to the process stoichiometry, the amount of demineralized water required for electrolysis is 9 Liters of water per kg of H₂ produced. This is equal for all electrolyzer technologies. In order to normalize water volume values, an electrolyzer equipment of 1 MW of electric capacity will be considered as reference. A 1 MW system requires a constant supply of approximately 150 L/h (0.66 gpm) of demineralized water.

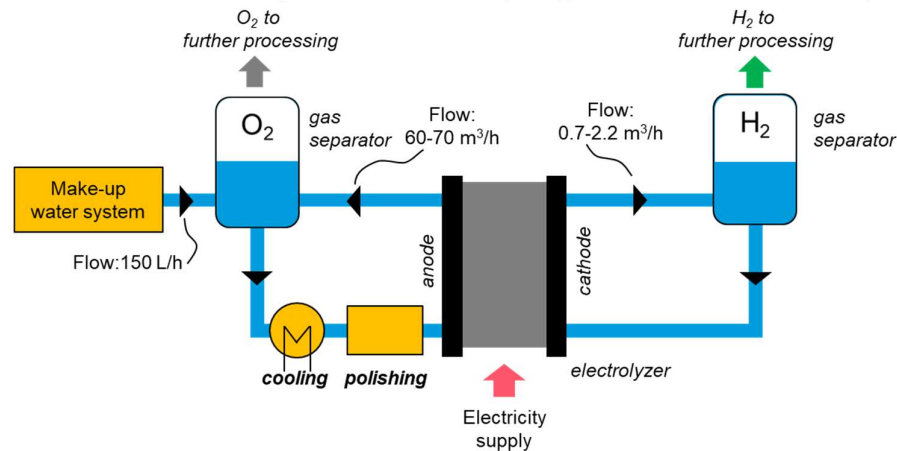
A PEM electrolyzer system, includes liquid-gas separators, at the cathode side, to separate H₂ from water, and the anode side, to separate O₂ from water. Separated water is recirculated back to the inlet of the electrolyzer. Consequently, from the perspective of water streams, a PEM system is a closed loop (so does an AWE system too, with the difference that instead of water, AWE use a 10% potassium hydroxide solution as electrolyte). In a 1 MW system, the anode circulation flow is in the range of 60 to 70 m³/h (264-308 gpm), and the cathode recirculation flow – also known as balancing water, is in the range of 0.7 to 2.2 m³/h (3.1-9.7 gpm). Flow values were provided by the US National Research Energy Laboratory (NREL).

Given the closed loop nature of this circulating water, in order to always maintain water purity within acceptable ranges, a polishing technology within the balance of stack is needed. Otherwise, water impurities entering the system through the make-up water supply, or substances leached by the electrolyzer stack (fluoride, for example) or any equipment part in contact with water (metals from piping, for example) would accumulate and rapidly worsen this circulating water quality.

Additionally, water may be required for other purposes beyond the net requirements of hydrogen production. The electrolysis process transfers significant amounts of energy to water in the form of heat, and therefore electrolyzer plants require cooling. At this moment, the authors find that most of the designs being implemented rely on air-based cooling or hybrid cooling with limited water consumption. However, water-based cooling may come into consideration as soon as projects start to scale up in capacity. In that case, total net water volume needs for an electrolyzer installation could significantly increase. For a 1 MW installation water for cooling can go from 0 L/h in the case of air-based cooling; 7 L/h of cooling water in case of using air-based cooling with spray system; up to 600 L/h of cooling water in the case of using cooling towers (Niekerk, 2022).

Figure 2 depicts a generic PEM electrolyzer system with the various components described in this section and flow rates for a 1 MW electric capacity electrolyzer. This configuration is for a generic system and might not be representative of all existing manufacturers. Additionally, it simplifies a real flow schematic of an electrolyzer. Note that polishing stage position in the circulation loop can also differ among designs. Below in this paper we will provide additional insights about the position and the fraction of water treated by the circulation loop polisher.

Figure 2: Typical system design of a PEM electrolyzer. Flow rates refer to water flow rate for a 1 MW electrolyzer. This configuration is for a generic system and might not be representative of all existing manufacturers (Adapted from IRENA, 2020)



SECTION FINDINGS – There is no green without blue. Water is the key ingredient in water electrolysis, and beyond the net needs of water for producing hydrogen, water treatment technology is needed to polish the large water recirculation streams in a PEM system.

WATER QUALITY TARGETS: A CRITICAL REVIEW

The water quality and dynamic water chemistry have a direct impact on the lifetime of the key components of the electrolyzers: membrane, electrodes, and catalysts. As a result, water quality can influence the overall efficiency and economy of the operations. It is critical that water quality is well understood and managed to ensure efficient operation and maximize the lifetime of the components.

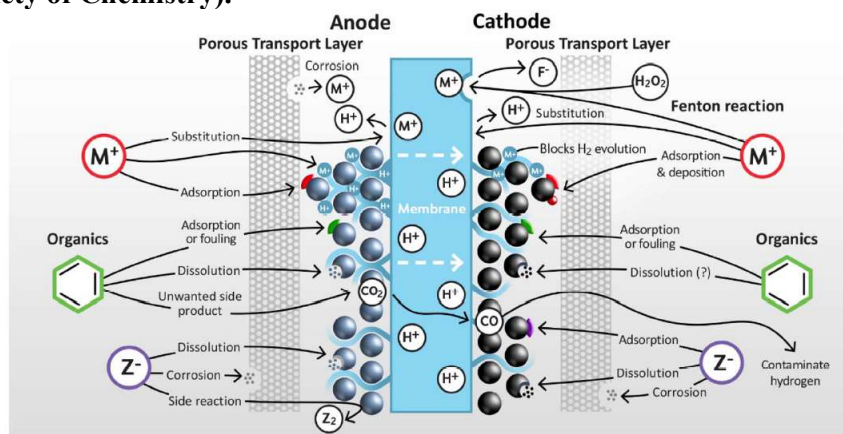
WATER QUALITY IMPACT ON THE COST OF HYDROGEN - There are multiple analysis of the total cost of PEM electrolyzer components, which include stack and all auxiliary equipment (EERE 2022, Reksten et al., 2022, Patonia and Poudineh, 2022). A round number that currently is used in the market as a reference for an electrolyzer equipment cost is 1,000 USD/kW installed (EERE 2022). Consequently, a 1 MW electrolyzer would cost 1 million USD. The industry expects this value to decrease significantly in the next years. Beyond the discrepancies among these studies in the absolute cost numbers, there is consensus on the fact that the electrolyzer stack represents a significant percentage of the total equipment costs. In the usual language of the hydrogen equipment industry, the water treatment system including the make-up treatment system and the circulation loop polishing is included in the “Balance of Plant.” On a wider view of costs, when looking into the total cost of hydrogen electricity costs contributes significantly. Today, average overall energy efficiency of a PEM system is 55 kWh/kg H₂. With typical electricity costs, electricity can represent more than 75% of the total cost of H₂. Damage on the PEM critical stack components may affect equipment electric efficiency, with a significant consequence on the price of hydrogen and the productivity of the installation.

Based on references (Taekker-Madsen, 2024; Dokhani et al., 2023) and our own assessment, the cost of the water treatment contributes a small percentage of the total equipment cost. Taekker Madsen calculates a 1% contribution, and Dokhani et al., estimates the fraction to be

even lower. It is fair to say that the water treatment system has a small contribution in the total capital costs, however, protects a substantial portion of the total equipment costs.

DEFINITION OF WATER QUALITY FOR PEM ELECTROLYZERS - Poor water quality is one of the main reasons for stack failure for PEM electrolyzers (IRENA 2020). What does “poor quality” mean in the context of PEM electrolyzers? The availability of quantitative information of impurities and impact on electrolyzer equipment and parts in the public domain from real electrolyzer operation is low. Becker et al., (2023) published a complete review on the matter, with a qualitative analysis of the impacts of various contaminants on the electrolyzer parts. The study compiles the effects that cations, anions, oxidants, and organics can cause on PEM electrolyzers’ materials (membrane, cathode, anode, and porous transport layers). There are multiple effects and damage mechanisms reported. Figure 3 illustrates the findings; contaminants are grouped in cations, anions, organics, and oxidants (metal cations are represented by M^+ , anions are represented by Z^- , and oxidants by H_2O_2)

Figure 3: Schematic illustration of the impact of distinct types of impurities on PEM electrolyzers (Reproduced from Ref. Becker et al., (2023) with permission from the Royal Society of Chemistry).



Contaminants can have an external origin (introduced through the make-up water supply), can be leached by the auxiliary equipment (pipes, tanks), and can be leached by PEM electrolyzer parts. The authors would like to emphasize the following aspects based on the found relevance:

- Fluoride is leached by the PEM membrane caused by membrane oxidation (Marocco et al., 2021). It becomes a poison for the anode the cathode and cause corrosion on the porous transport layer.
- Silica can accumulate inside the loop. Becker et al. (2023) report the accumulation of silica in the circulation loop after a few hundred hours of operation of a PEM electrolyzer. Silica can block porous transport layer pores, causing malfunction on the electrolyzer.
- CO_2 can reduce the polisher service time; it should not be ignored.
- Beyond the ionic and non-ionic species, the circulation loop is characterized by high water temperature (60-70°C currently, expected to increase in the next years to improve efficiency) and oxidant presence. Oxidants are known to be produced by electrolysis process (Becker et al., 2023; Marocco et al., 2021)

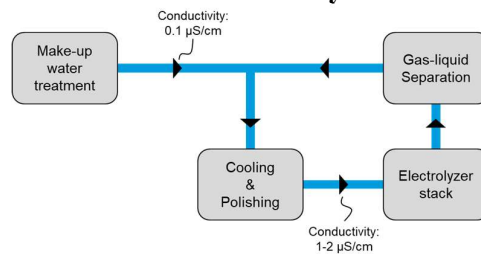
Based on these findings, we summarize below in Table 1 the various pollutants to consider for the design of the make-up water treatment system and the electrolyzer loop polishing.

Table 1: Summary of contaminants to consider in a PEM electrolyzer system and their potential impact.

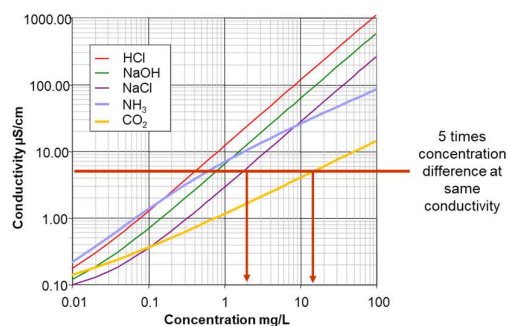
Pollutant	Impact
Salts	Electrolysis inefficiency, scaling, catalyst, and membrane degradation
TOC	PEM membrane fouling and corrosive effects through organic acids form
Silica	Can buildup on catalysts surface
Metals	Electrolyzer membrane aging increasing cell current and causing premature failure
Fluoride	Can corrode surfaces and increase metal release
CO ₂	Can reduce polishing resin life

Surprisingly considering the variety of species that can affect electrolyzer parts, most of the projects define water quality targets or specifications by just water conductivity. Projects typically define water quality specifications or targets for two streams: make-up stream, and electrolyzer stack feed stream, which is the most important value:

- Water conductivity is typically required to be always below 1-2 $\mu\text{S}/\text{cm}$ at the electrolyzer stack feed stream, the value varies depending on the electrolyzer manufacturer.
- In most of the projects, make-up water specification as water quality to be below 0.1 $\mu\text{S}/\text{cm}$.

Figure 4: schematic illustration of a PEM system with the typically required water quality specifications, defined as water conductivity.

CONDUCTIVITY AS A WATER QUALITY INDICATOR – Water electric conductivity has been widely and historically used as an indicator of water quality, especially in the context of water demineralization. However, the response in conductivity for each dissolved species in water is different. In the illustration below (Figure 5), shows conductivity values of various species in water vs its concentration.

Figure 5: Illustration about the estimation of conductivity caused by different substances in water. Emphasis on the comparison between NaCl and CO₂.

Note that the impact of CO₂ on the ionic load is 5 times higher compared to NaCl at the same conductivity values.

Although the limitations of conductivity as a sum indicator of pollutants relevant for PEM electrolysis, the techniques to measure specific contaminants in-line or at real time is limited. A pragmatic approach is to implement wide spectrum treatments, which can limit the concentration of not only charged species, but as well organics, silica, and CO₂.

SECTION CONCLUSIONS – Considering these aspects, these are our recommendations with respect to water treatment:

- Investing in water quality yields significant benefits: the higher the make-up water quality, the better to protect the electrolyzer.
- Do not simplify water quality specifications to just conductivity.
- Apply multi-tech schemes that target a wide spectrum of contaminants.

A HOLISTIC VIEW ON THE DESIGN OF WATER TREATMENT SOLUTIONS: POTENTIAL TREATMENT SCHEMES AND THEIR TECHNOECONOMIC ASPECTS.

With an understanding of the significance of water quality on electrolyzer performance and lifetime, it is clear that this “water for hydrogen” must be considered as a purified water stream with specific targets requiring preparation through an intentionally designed treatment scheme, just as boiler water make-up is not a simple water stream nor water produced for semiconductor fabs taken from a tap. Whether the source water for any given project is from a municipality, surface water, reclaimed wastewater, or seawater, treatment is required to reach specifications for PEM electrolysis, but the technologies exist to do so. Following the terminology in Figure 4, this section describes the main considerations affecting:

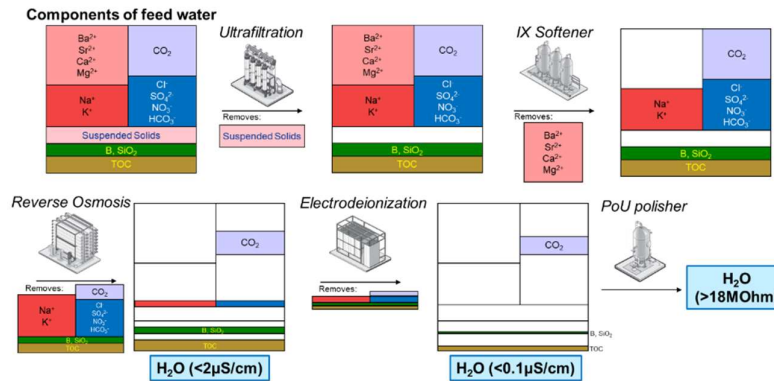
- The design of the make-up water treatment system
- Considerations for the selection of a PEM loop polishing technology
- Holistic design considerations for a robust PEM loop water quality

THE MAKE-UP WATER TREATMENT SYSTEM - A make-up water treatment system typically consists of a combination of technologies in three main categories - pre-treatment to remove solids, colloids, and organic matter; a demineralization stage to remove bulk dissolved solids; and a polishing step to remove the residuals to a minimum level.

A simplified example make-up treatment schematic can be seen in Figure 6 below, in which ultrafiltration is present to remove solids, softening ion exchange resin to remove hardness and limit scale formation in a downstream reverse osmosis (RO) stage where bulk ion removal is performed, followed by electro deionization and finally ion exchange polishing. A team from Evoqua presented a more detailed schematic at IWC Technical Conference in 2023 with multimedia filtration followed by double pass RO to continuous-electro-deionization (CEDI), mixed bed ion exchange, UV for organic destruction, and a final cartridge filter with the intent to achieve ASTM D1193 Type I water, which specifies resistivity (18 MΩ at 25 °C), TOC (50 µg/L max), sodium (1 µg/L max), chloride (1 µg/L max), and silica (3 µg/L max) (Nayar).

Figure 6: Example make-up water treatment schematic to remove solids, bulk ions, and trace ions for high purity effluent.

Multi-tech treatment steps for makeup water purification



It is possible to achieve high purity water from a make-up system that utilizes EDI as its final component; however, the effluent water quality of EDI or CEDI can be a function of feed water quality and flow rate and may be influenced by variability in those conditions. Even the presence of trace levels of weakly ionized species such as CO_2 or silica downstream of EDI can justify mixed bed ion exchange as a form of final polisher (or even required if in fact an ASTM Type I water has been specified). A final polish, point of use mixed bed at the end of a make-up water treatment schematic keeps these trace ions out of the refinement loop where they can impact electrolyzer performance and lifts the burden of ionic removal from the refinement loop polisher where temperature and flow rate are both higher.

PEM REFINEMENT LOOP POLISHING TECHNOLOGY - As discussed in the above section, the closed loop nature of the circulating water within the electrolyzer makes it such that an additional polisher, separate from the make-up water system, is included in the balance of stack in order to remove trace contaminants that reach this loop either from the make-up water or leached from the stack itself or equipment/components within the loop. The refinement loop presents a set of conditions which are challenging for most polishing technologies, including the presence of oxidants and temperatures greater than $60\text{ }^\circ\text{C}$. In addition to ion exchange resins, forms of EDI have also been mentioned as a potential refinement loop polishing technique. While the conditions of service are challenging to ion exchange resins, the ion exchange-based components of EDI in the same service will be exposed to the same stressors as a bed of resin. A bed of ion exchange resin is installed in a fixed vessel. In a well-designed system, the resin can be quickly changed out upon exhaustion after meaningful service life of several months to years (depending on the overall design of the system). A potential benefit of EDI is that it does not reach a point of exhaustion like a mixed bed. However, the lifetime of the capital investment of the EDI is challenged by oxidative conditions in the electrolyzer loop.

The selection of technology for the loop polisher may influence the overall equipment electric efficiency as well. As described above (Figure 4), a cooling stage is required to remove the excess heat generated by the inefficiency of the electrolysis process. Based on conversations with electrolyzer system designers, if the polishing technology requires additional cooling, a second cooling stage is required, which adds capital costs and reduces the overall system efficiency as it consumes electricity. Additionally, in the next years, market expect to achieve a significant reduction of hydrogen production costs. There are multiple actions on materials

and system design expected to deliver efficiency gains. One of the actions is the operation of the electrolyzer at higher temperature. Consequently, the whole loop will operate at higher temperature. A polishing technology that can withstand higher temperature will help to achieve the expected efficiency gains.

In the experience of the authors, the present leading technology for this polisher within the electrolyzer's balance of stack refinement loop is single-use mixed bed ion exchange. Further considerations to support this statement are provided below, in the section dedicated to resin selection and polisher design considerations.

HOLISTIC DESIGN CONSIDERATIONS TO MAINTAIN PEM LOOP WATER QUALITY - The three most critical aspects that influence water quality within the electrolyzer loop include:

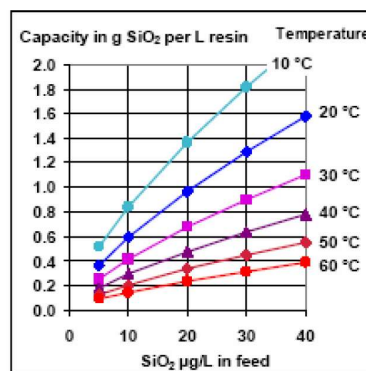
- The feedwater entering the loop: water quality and the role of silica.
- The size of the PEM loop polisher
- The polisher design and type of resin, to ensure stable and high-quality effluent.

Feedwater quality aspects. The run length of the mixed bed polisher is a function of many factors, but most certainly the make-up water quality has an influence on the potential run length of this refinement loop polisher. The approach for introducing high purity feed water has been discussed in detail above, but in short, a low conductivity water of at least less than $0.1 \mu\text{S}/\text{cm}$ which is free of silica and CO_2 should be utilized. Consider the use of a point of use polisher in the make-up system for ensuring the required quality.

Additionally, silica demands particular attention. The capacity for trace silica removal by a mixed bed of ion exchange resin goes down as the concentration decreases and the temperature increases as displayed in the graphic (Figure 7) below (Hoffman, 2006).

Figure 7: Mixed bed silica capacity at varying temperatures and feed water concentrations

Estimated Silica Equilibrium Capacity versus Temperature

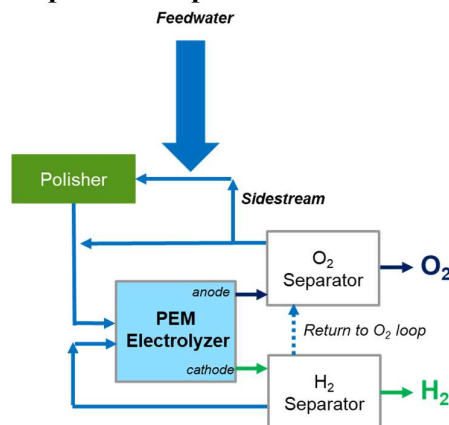


A mixed bed designed at a spatial velocity of 40 Bed Volumes/hour to function as a final polisher for the 150 L/h make-up stream would have a resin volume of 3.75 L. Using values from Figure 7, if this final polisher were faced with $10 \mu\text{g}/\text{L}$ of SiO_2 at $25 \text{ }^\circ\text{C}$ in the make-up water, the estimated capacity would be $\sim 0.5 \text{ g}/\text{L}_{\text{resin}} \times 3.75 \text{ L resin} = 1.875 \text{ g SiO}_2$ or 187,500 L of water ($1.875 \text{ g SiO}_2 / 0.00001 \text{ g}/\text{L}_{\text{water}} = 187,500$

L). To remove the same mass of silica from a stream operating at 60 °C (a typical temperature value of the PEM refinement loop) with the same feed concentration of 10 µg/L, a resin volume of 12.5 L (or 3.33 times greater) would be required. A much smaller resin volume is required to remove the same total mass of silica prior to exhausting when operating at 25°C when compared to 60°C. Removal of trace silica upstream of the higher temperature refinement loop allows for the refinement loop mixed bed to remain available for removal of ions originated in the electrolyzer loop itself.

The size of the PEM loop polisher. In a full-scale PEM system, the loop polisher does not treat the entire electrolyzer feed stream but is placed in a side stream. Figure 8 shows an example of a PEM system, with the recirculation streams and the polisher located in a side stream. The more water treated by the polisher, the higher the quality and more robust the quality in the loop will be. The concept of a mass balance suggests that the more water that is brought to the polisher, the more contaminants that can be removed. When the side stream to the polisher is made larger, a lower conductivity can be achieved, the response to upsets will be faster, and life for fixed entry rate contaminants is not reduced.

Figure 8: Simplified PEM water flows with the polisher in a side stream – Diagrams not for design purposes, only for pictorial representation



The polisher design and type of resin. Ensuring a stable and high-quality effluent from an ion exchange mixed bed polisher relies on multiple factors including proper vessel design, system layout, and the condition/state and selection of the resin installed:

- Vessel design and proper flow distribution impacts resin utilization
- System layout: a mixed bed is recognized to achieve higher water quality compared to single-component cation and anion resin beds.
- Condition of the resin installed refers to the use of non-regenerable vs regenerable mixed beds. A non-regenerable mixed bed offers a chemicals free solution and can achieve higher water quality compared to a regenerable mixed bed-based solution.
- The selection of the resin for this application will impact service time, resin cleanliness (the resin is a potential source of contamination for the loop), and suitability for the application.

The next section goes into detail about the polisher design and resin selection considerations.

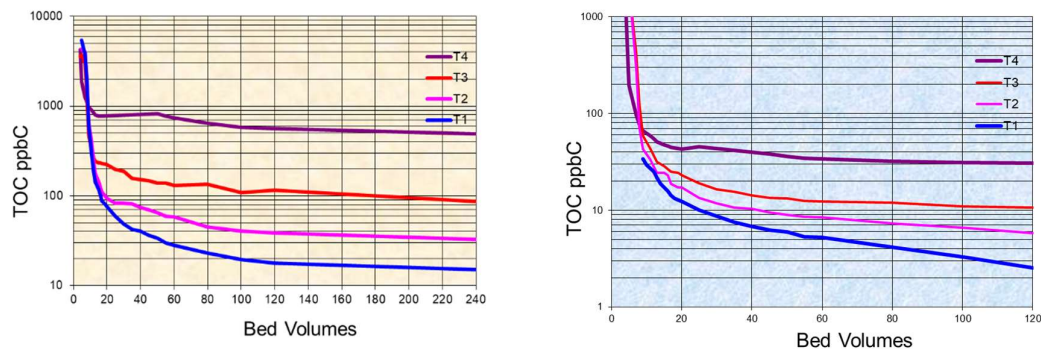
REFINEMENT LOOP POLISHER DESIGN ASPECTS AND RESIN SELECTION CONSIDERATIONS; SERVICE TIME PROJECTION EXAMPLES

VESSEL DESIGN – Ion exchange does not work by fractional removal – so complete removal of the constituent that are expected to be removed by ion exchange is anticipated in a single pass through a bed of resin. However, there is an exchange zone over which that removal takes place and proper distribution, typically considered from a top to the bottom (but in some cases could also be bottom to top) of a vessel for that removal to take place. Also, the beads in the vessel are where the capacity for removal exists – without an evenly spread flow distribution that can reach the beads, the capacity will not be utilized.

SYSTEM LAYOUT – Ions can be removed by single component cation and anion resins. However, for the removal of trace impurities a mixed bed includes both components in a single vessel that can achieve the high resistivity that is desired for the refinement polishing loop.

Another benefit of the use of mixed bed vs separate beds is the protection against TOC leachables. Resin bead can leach organics, consequently the level of TOC leachables from a resin or mixed is an additional quality factor to be considered from an ion exchange system. Each single component resin has its own low levels of ionized TOC leachable – for cation resin the typical consideration is of a polystyrene sulfonate and for the anion resin trimethyl amine. A benefit of mixed bed ion exchange is that the opposite component removes the leachable of the other, allowing for a much lower TOC level when compared to operating separate vessels. The example in Figure 9-left of a single component anion resin TOC rinse down at increasing temperatures (as the ladder of curves goes up) can be compared to the same anion resin being included in a mixed bed at the same set of increasing temperatures in Figure 9-right with results on the order of a factor of 10 lower.

Figure 9: Single component anion resin TOC vs temperature (left); Mixed bed TOC vs temperature (right). In which $T_4 > T_3 > T_2 > T_1$ and $T_1, T_2, T_3,$ and T_4 are the same temperature in each graphic.



THE STATE OF THE RESIN: SINGLE-USE VS REGENERABLE RESINS – It was stated above that ion exchange does not work by fractional removal; however, leakage is still possible when a resin is installed with an incomplete degree of regeneration – as sodium levels are increased on mixed bed cation resin before the start of the service cycle the higher the baseline leakage will be during the service cycle – and the same is true for silica or chloride levels on the anion resin. In reviewing the advantages and disadvantages of considering single-use vs regenerable polishing mixed beds, Brian Hoffman highlighted that

use of a single-use polishing mixed bed includes the benefit of starting every service cycle with unused highly regenerated resins from the manufacturing facility, a simpler operation, and simpler/lower capital-intensive design (Hoffman, 1994). Additionally, a single-use mixed bed allows for a chemical free polisher.

It has also been the experience of the authors that samples returned from a refinement loop polisher application have been oxidized, sticky, and difficult to separate in the ideal conditions of lab columns (Figure 10). In that case, as resins cannot be properly separated, the resins cannot be regenerated with ease to provide the expected water quality. Consequently, the potential technoeconomic advantages of a regenerable resin concepts versus non-regenerable solutions would be at risk. This situation further adds to the benefit of considering single-use mixed beds for the PEM loop polisher application.

Figure 10: Returned end of service competitive refinement loop sample following backwash separation.

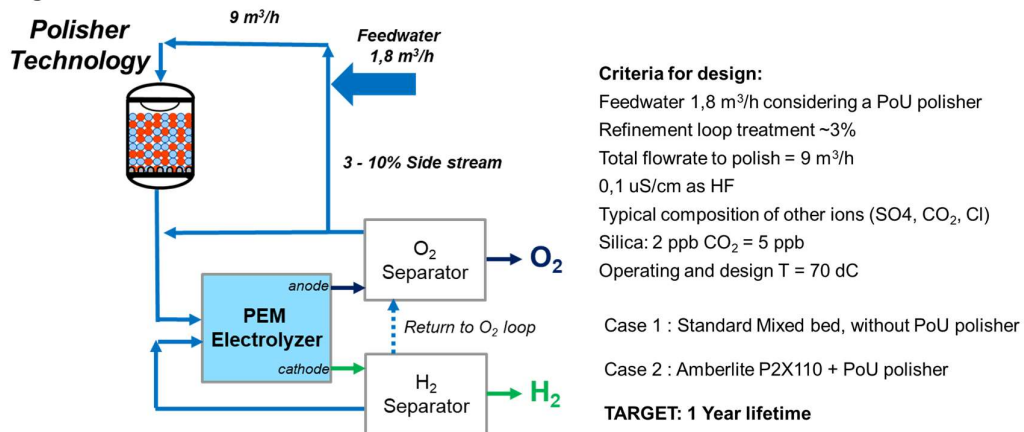


RESIN SELECTION – Considering the application-specific aspects as the potential contaminants to remove defined above, the thermal and oxidative environment, and layout and form considerations, a mixed bed resin for this application should tolerate temperature, should not become a significant source of contamination for the electrolyzer (resin cleanliness) and offer effective removal capacity, i.e., removal capacity optimized to the water chemistry of the loop. The reason for effective capacity to be a critical factor is that an increase of capacity provides a measurable increase in service time. Operators benefit from expanded service time with a decrease of resin replacement frequency. Additionally, longer service time strengthens the feasibility for single-use application of a mixed versus concepts based on resin regeneration.

The authors note at this point that DuPont has recently launched a mixed bed resin designed specifically for this application named DuPont™ AmberLite™ P2X110 ion exchange resin (from here onwards “The Product”). The Product has been designed following DuPont’s best understanding of PEM loop water chemistry to maximize removal capacity. In the next section, service time projection examples are calculated, using The Product as one of the options.

POLISHER SIZING AND SERVICE TIME PROJECTIONS – The refinement loop mixed bed lifetime can be estimated for comparison of scenarios which consider a standard mixed bed, The Product, which was designed for the application, and also when a point of use polisher is utilized or excluded according to the conditions summarized in Figure 12.

Figure 12: Illustration of PEM loop for service cycle length illustration & Criteria for Design.



When a refinement loop polisher is installed without a point-of-use polisher in place on the make-up water system, silica capacity (again, this goes down as stream temperature increases) becomes a limiting factor. As seen in Table 1, a refinement loop polisher utilizing a standard mixed bed that could achieve a full year service length (Lifetime incl TOC/CO₂ estimation) with no consideration of silica is reduced to just over a quarter of a year when including silica introduced from a make-up water stream which contained no point of use polisher – this wide discrepancy of throughput highlights the value of the point of use polisher.

Table 2: Projection of service life for a standard mixed bed with and without a point of use polisher included in the make-up water system.

Result refinement loop polisher – Standard Mixed Bed	
Vessel diamer	0,55M1
surface area	0,24M2
resin volume**	321Liter
bedheight	1351,8Mm
linear velocity	38m/h
specific velocity	28Bvh
Lifetime* incl TOC/CO2 estimation	8890 H 1,01 Years
Lifetime* Excl TOC/CO2 estimation	16820 H 1,92 years
Lifetime incl SILICA Estimation	2377,78 h 0,27 years

Including a point of use polisher with a 50 BV/h spatial velocity on a 1.8 m³/h make-up stream adds a bed of resin 36 liters in volume. The combination of adding this point of use polisher and utilizing The Product specifically designed for the PEM electrolyzer refinement loop, a much smaller refinement loop bed can be utilized when compared to the standard mixed bed scenario for a much greater run length – 260 liters vs 321 liters and 1.44 years run length vs 0.27 years run length.

Table 3: Point of Use Polisher Design

Result PoU polisher	
Vessel diamer	0,22m1
surface area	0,04m2
resin volume**	36 liter
bedheight	947,5mm
linear velocity	47m/h
specific velocity	50bv/h
Lifetime estimate	57500h
	6,56years*
Lifetime silica	8533h
	0,97years
*excl Silica	
**incl safety	

Table 4: Refinement Loop Projection using The Product & a Point of Use Polisher in the Make-up Water system.

Result refinement loop polisher – The Product	
Vessel diamer	0,5m1
surface area	0,20m2
resin volume**	260 liter
bedheight	1324,8mm
linear velocity	46m/h
specific velocity	35bv/h
Lifetime* incl TOC/CO2 estimation	12619h 1,44years
Lifetime* Excl TOC/CO2 estimation	29196h 3,33years

A summary of the total resin installed (Table 4) for each case shows that a lower overall resin volume is installed when utilizing a point of use polisher and The Product designed for the PEM electrolyzer application. A smaller vessel with less resin usage over time with minimal waste is also utilized in the scenario in which The Product designed for the PEM electrolyzer application is installed.

Table 5: Case Comparison

	Case 1: Standard Mixed bed and No PoU polisher	Case 2: The Product With PoU polisher	
Vessel diameter PoU	--	220	mm
Vessel diameter Polisher	550	500	mm
Installed resin volume PoU		36	liter
Installed resin volume Polisher	321	260	liter
Annual resin usage	317 - 1000*	216	liter/year
*Depending on silica			

SUMMARY

In summary, water quality is a particularly crucial factor in electrolyzer operation. An intentionally designed make-up water system with a point of use polisher is essential to maintaining water quality in the PEM loop to protect the electrolyzer stack, which is the largest cost contributor of a PEM system. A polisher in the PEM loop is critical to removing trace contaminants introduced by components in the loop or make-up water upsets. Considering the current PEM designs -given the combination of water impurities, elevated temperature, and presence of oxidants- this unique application requires intentionally designed mixed beds, in non-regenerable service, which offer a simple vessel design and chemical-free operation. As the industry continues to evolve, increasing project size or operating temperature, the authors will continue to evaluate the needs and suitable solutions to produce the water that is required to help to make Green Hydrogen a true decarbonization enabler.

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