GORE Clean Energy



ULTRA-LOW DEGRADATION IN PEM ELECTROLYSIS: ENABLING SCALABLE AND EFFICIENT GREEN HYDROGEN PRODUCTION

In collaboration with ITM Power

In the industry, we all have our part to play to pave the way for cost-competitive, low-carbon hydrogen. Although as a proton exchange membrane (PEM) supplier, we cannot influence significant cost drivers like renewable electricity price and availability, our best lever is to strongly and positively impact the levelized cost of hydrogen (LCOH) through increased membrane efficiency, reduced stack downtime, and reduced replacement costs via improved membrane durability.



This white paper summarizes long-term performance data of 85 µm and 50 µm thin reinforced proton exchange membrane prototypes generated in a partnership between W. L. Gore and ITM Power. While both prototypes exceed state-of-the-art benchmarks for voltage and chemical durability, the 50 µm thin membrane further exhibits remarkable levels of gas purity.

Proton Exchange Membrane Water Electrolysis (PEMWE) is a core technology for green hydrogen production. There is a growing demand for large-scale electrolyzer systems, where robustness under high differential pressure and high current densities become the benchmark for this market. However, the industry is constrained by a lack of comprehensive long-term durability data, where multiple key performance indicators (KPIs) are measured under application-relevant conditions. This data gap is especially critical given the move toward thinner membranes, which, though favored for higher energy efficiencies, are intrinsically more susceptible to gas crossover and related degradation phenomena.

To address this issue and respond more rapidly to the growing demand for large-scale PEMWE systems, ITM Power and W. L. Gore partnered to co-design innovative membranes and electrolyzer cell technologies.

Driven by the distinct scientific and technological strengths of both companies, two prototypes were developed and rigorously evaluated—accumulating 28,000 hours of testing for Concept 1 and 11,000 hours for Concept 2—under industry-relevant conditions using state-of-the-art instrumentation. Monitoring multiple KPIs—including cell voltage as a proxy for energy efficiency, anodic hydrogen as an indicator of gas crossover, and fluoride release rate correlating with membrane thinning—together with end-of-test diagnostics, enabled mechanistic insight into membrane durability beyond any single parameter.

This work, revealed publicly for the first time, demonstrates how collaborative research and development can accelerate innovation and support the rapid scale-up and broad adoption of PEMWE for green hydrogen production.

Innovative PEM and electrolyzer cell technologies made possible by the Gore–ITM collaboration provide a foundation for the highest efficiency and durability in green hydrogen production.

Prototype Concept 1:

Sustained, efficient operation with a low rate of degradation at ambient pressure

Prototype Concept 1

- 85 µm thickness
- Expanded polytetrafluoroethylene (ePTFE)-reinforced perfluorosulfonic acid (PFSA) polymer membrane
- Platinum (Pt)-based recombination catalyst interface to reduce anodic hydrogen content

Summary of Concept 1 Performance at Ambient Pressure

- Test parameters: 55 °C, 3.3 A/cm^2 for 28,000 hours in an 8 cm^2 active area cell
- Voltage decay: 1.9 µV/h or < 1%/year[1]
- Efficiency: 51.4 kWh/kg*
- Sustained membrane structural integrity confirmed by SEM and permeation measurements

*Efficiencies include faradaic losses derived from our precise electrochemical permeation method.

Concept 1 membrane integrity was confirmed after 28,000 hours of operation.



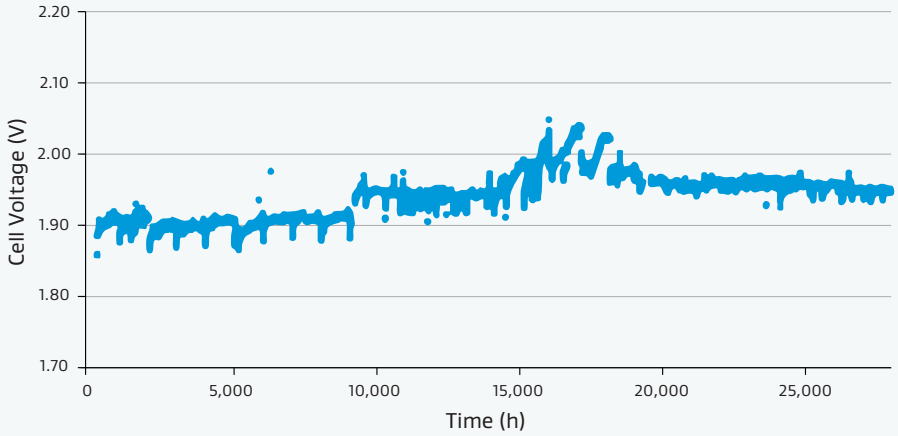
Proton Exchange Membrane electrolyzer test cell, courtesy of ITM Power.

The irreversible voltage decay rate of Concept 1 was 1.9 µV/h, equivalent to < 1%/year performance degradation (Figure 1), which meets or exceeds 2030 international targets.[2,3] Between 15,000 h and 19,000 h, an increase in voltage was observed, which was largely reversible in nature. In this time period, the ion exchange resin employed to maintain high quality water became exhausted, allowing low levels of contaminants to reach the membrane.

Cations can displace the protons in the membrane, leading to higher resistance and increased voltage. The electric field drives the cations to the cathode where, if allowed to accumulate, the high concentration of cations could lead to a depletion of protons at high current density, impacting the hydrogen evolution reaction. In this case, replacing the resin to switch back to an ultra-high purity water feed allowed the contaminant ions to be flushed out of the membrane, recovering the voltage performance. These findings emphasize the level of attention required with respect to system cleanliness.

1. Tsotridis, G., & Pilenga, A. (2021). EU harmonised protocols for testing of low temperature water electrolyzers, EUR 30752 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-39266-8, doi: 10.2760/58880, JRC122565.
2. U.S. Department of Energy. (2025). Technical Targets for Proton Exchange Membrane Electrolysis. https://www.energy.gov/eere/fuelcells/technical-targets-proton-exchange-membrane-electrolysis.
3. European Commission / Clean Hydrogen Partnership. (2026). Technology KPIs: State-of-the-art and future targets. https://www.clean-hydrogen.europa.eu/knowledge-management/strategy-map-and-key-performance-indicators/clean-hydrogen-ju-sria-key-performance-indicators-kpis_en.

Figure 1.



Test parameters

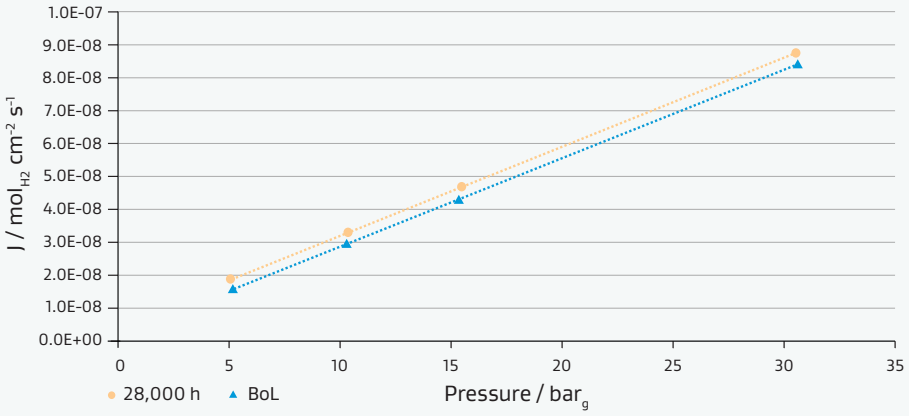
55 °C, 3.3 A/cm² for 28,000 hours in an 8 cm² active area cell

Voltage decay:
1.9 µV/h or < 1%/year[1]

Concept 1 voltage profile[1] when current density was held at 3.3 A/cm².

Concept 1 demonstrated membrane integrity after 28,000 hours of operation, with only a small increase in hydrogen permeation (Figure 2) and no evidence of structural degradation of any layer and interlayer features of the membrane (Figure 3). Both end-of-test diagnotics are useful for ruling out degradation effects such as severe thinning or pinholes.

Figure 2.



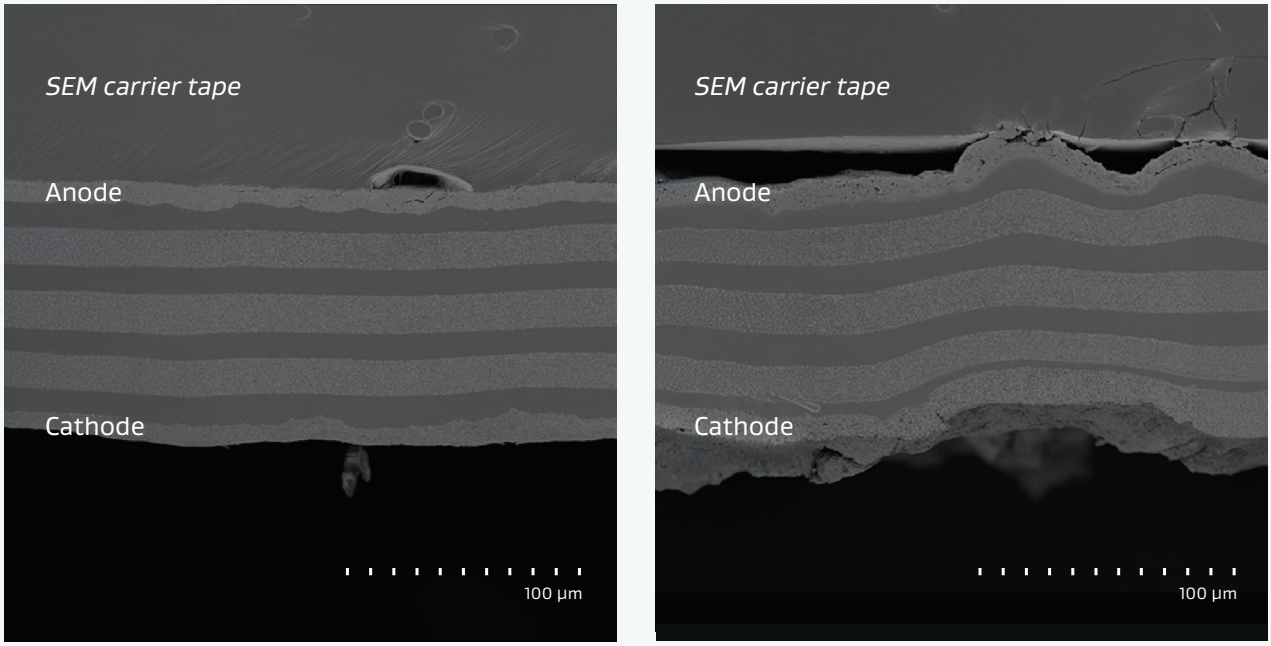
Test parameters

55 °C, 3.3 A/cm² for 28,000 hours in an 8 cm² active area cell

Small increase in hydrogen permeation

Concept 1 membrane hydrogen permeation at beginning of life (24 hours, blue line) and after 28,000 hours of operation (orange line), maintained through increasing pressures.

Figure 3.



Scanning electron microscopy (SEM) image of Concept 1 catalyst-coated membrane in the sealing edge (left) and active area (right) after 28,000 hours of operation. The light grey areas within the membrane depict the ePTFE-reinforced layers.

While Concept 1 demonstrated sustained durability and integrity of the membrane under ambient conditions, industry-relevant applications of PEMWE technology are usually done under elevated differential pressure conditions.

Summary of Concept 1 Performance at Differential Pressure

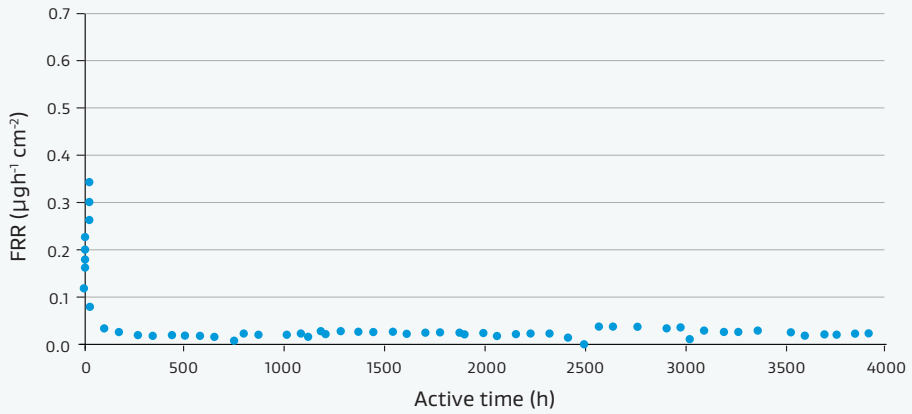
- Test parameters: 55 °C, 3.3 A/cm^2 for 4,000 hours at 20 bar differential pressure in a 130 cm^2 active area short stack
- Confirmed membrane chemical stability
- Hydrogen crossover: < 2%

Chemical stability testing of the membrane, measured by high-pressure ion chromatography (HPIC), revealed an initial peak of fluoride release which then decreased and remained near the limit of quantitation for the remainder of the test. The steady state fluoride release was calculated to be 0.02 µg/cm^2/hr (Figure 4). The fluoride emission trend agreed with the published literature, with most operation modes exhibiting the highest emission rate at the beginning of the test followed by a decline to a more steady state behavior[4,5]; however, the fluoride release achieved here was lower than that reported in literature.

Anodic hydrogen content measured by state-of-the-art H_2-in-O_2 mass spectrometry detection instruments stabilized after some initial degradation and gas purities remained well within the safety limit of <2% H_2 in O_2 (50% LEL) over the test duration (Figure 5).

The H_2 in O_2 crossover and its stability are known to be affected by various mechanisms rooted in different components.[6,7] These include changes in H_2 supersaturation due to increased mass transport resistance in the electrode or gas diffusion layer (GDL), and changes in membrane diffusivity due to factors such as membrane thinning. An additional degradation mechanism—barely described in the literature for PEMWE and specific to systems deploying a recombination catalyst—is a change in recombination catalyst efficiency. We conducted an extensive post-mortem and root cause analysis to understand the mechanisms at play and positively identified recombination catalyst degradation as the mechanism underlying the initial slow rise in H_2 in O_2 (Figure 5). The two observed effects were catalyst deactivation and the coarsening of recombination catalyst particles. These findings were incorporated into the Concept 2 PEM design.

Figure 4.



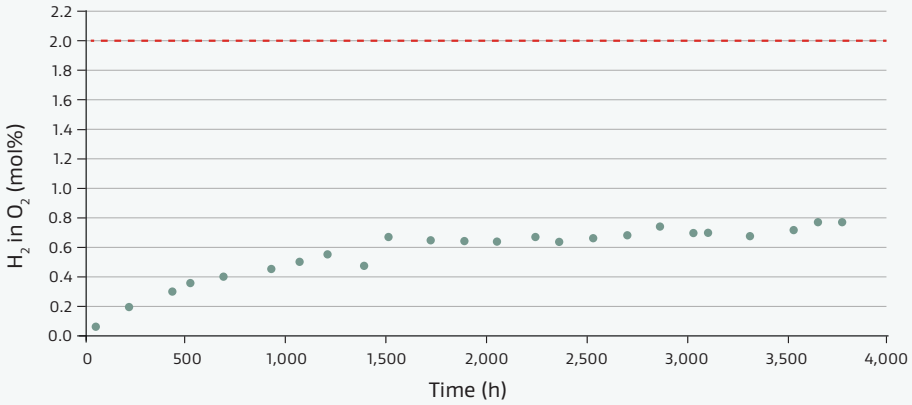
Test parameters

55 °C, 3.3 A/cm² for 4,000 hours at 20 bar differential pressure in a 130 cm² active area short stack

Fluoride release rate: 0.02 µg/cm²/hr

Concept 1 fluoride release rate (FRR): Over 4,000 hours of operation, the fluoride release rate declined to a steady, single-digit ppb range.

Figure 5.



Test parameters

55 °C, 3.3 A/cm² for 4,000 hours at 20 bar differential pressure in a 130 cm² active area short stack

Hydrogen crossover: < 2%

Concept 1 membrane hydrogen crossover: The hydrogen-in-oxygen percentage rose during the first few hundred hours of operation and then leveled off (green dots), consistently staying below the limit (red line).

4. Frensch, S.H., Fouda-Onana, F., Serre, G., Thoby, D., Araya, S.S., & Kær, S.K. (2019) Influence of the operation mode on PEM water electrolysis degradation, International Journal of Hydrogen Energy, 44(57), 29889-29898.
5. Chandesris, M., Medeau, V., Guillet, N., Chelghoum, S., Thoby, D., & Fouda-Onana, F. (2015) , Membrane degradation in PEM water electrolyzer: Numerical modeling and experimental evidence of the influence of temperature and current density, International Journal of Hydrogen Energy, 40(3), 1353-1366.
6. Omrani, R., & Shabani, B. (2021), Hydrogen crossover in proton exchange membrane electrolyzers: The effect of current density, pressure, temperature, and compression, Electrochimica Acta, 377, 138085.
7. Trinke, P., Bensmann, B., & Hanke-Rauschenbach, R. (2017), Current density effect on hydrogen permeation in PEM water electrolyzers, International Journal of Hydrogen Energy, 42(21), 14355-14366.

Prototype Concept 2:

Thinner membrane with improved crossover durability

Prototype Concept 2

- 50 µm thickness
- ePTFE-reinforced perfluorosulfonic acid (PFSA) polymer membrane
- Enhanced with an optimized recombination catalyst design*
- Area-specific resistance: 43.9 mOhm/cm^2 (~40% reduction compared to Concept 1)

Summary of Concept 2 Performance

- Test parameters: 55 °C, 3.3 A/cm^2 for 11,000 hours at 20 bar differential pressure in a 130 cm^2 active area short stack
- Voltage decay: 1.2 µV/h or < 0.6% per year
- Efficiency gain: 48.3 - 49.5 kWh/kg (~4% improvement over Concept 1)
- Hydrogen crossover: < 0.4%
- Membrane chemical and structural stability achieved with a 50 µm membrane

*Measured at 80 °C, ambient pressure, single cell.

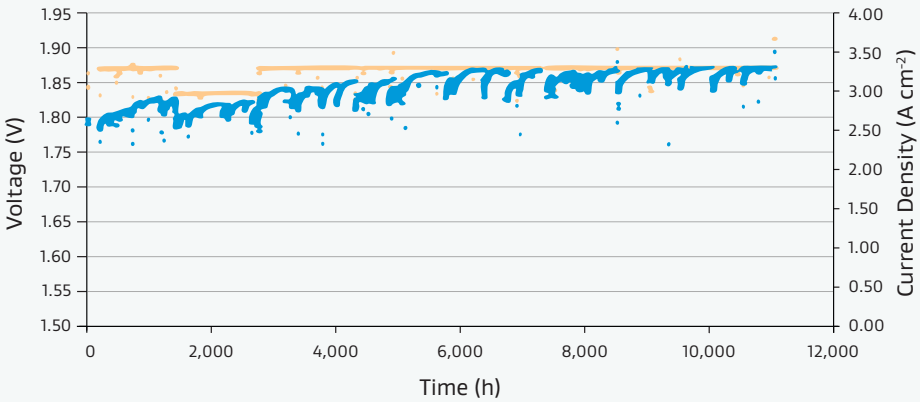
To further improve efficiency and lower anodic hydrogen content, a second PEMWE prototype with a thinner membrane (50 µm) and different recombination catalyst design was operated for 11,000 hours under differential pressure conditions.

End-of-test ex situ analysis confirmed that the new design extends the durability of the recombination catalyst and stabilizes the measured H_2-in-O_2 crossover at a level well below the 2% limit (Figure 7). While the steady state fluoride emissions were as low as in Concept 1, the initial peak was extended, due to a known cause, leading to a low level of iron contamination at the beginning of the test. These results provide further evidence of the crucial importance of cleanliness for cell performance.

Concept 2 demonstrated

- Stable and durable operation for 11,000 hours at differential pressure.
- A voltage decay rate of 1.2 µV/h, 40% lower than 2030 international degradation targets (Figure 6),[2,3] with performance degradation of less than 0.6% per year.
- Efficiency that ranged from 48.3 to 49.5 kWh/kg H_2, in line or better than international targets.[2,3]
- Percentage hydrogen in oxygen that remained below 0.4%, consistent with negligible degradation of the recombination catalyst (Figure 7).
- Membrane durability with a long-term average fluoride release rate of below 0.02 µg/cm^2/hr, confirming chemical stability (Figure 8).
- Considering multiple cell KPIs, a predicted longevity of approximately 80,000 hours based on conservative considerations of anodic H_2 content and voltage decay.

Figure 6.



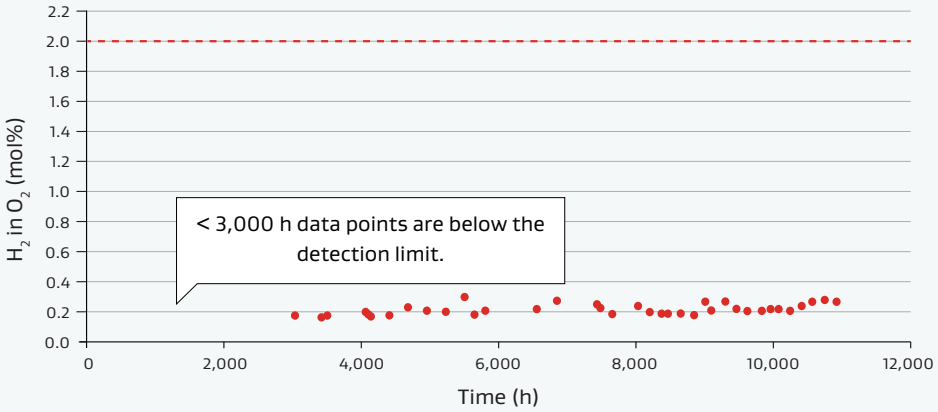
Test parameters

55 °C, 3.3 A/cm^2 for 11,000 hours at 20 bar differential pressure in a 130 cm^2 active area short stack

Voltage decay:
1.2 µV/h or < 0.6% per year

Concept 2 voltage decay rate: Yellow dots indicate current density; blue dots indicate cell voltage.

Figure 7.



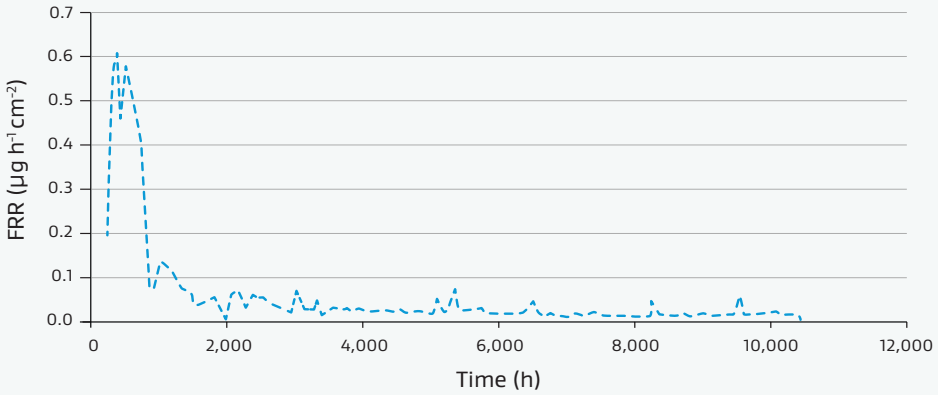
Test parameters

55 °C, 3.3 A/cm² for 11,000 hours at 20 bar differential pressure in a 130 cm² active area short stack

Hydrogen crossover: < 0.4%

Concept 2 membrane hydrogen crossover: Red dots indicate the hydrogen-in-oxygen percentage over time; red dashed line indicates the safety limit.

Figure 8.



Test parameters

55 °C, 3.3 A/cm² for 11,000 hours at 20 bar differential pressure in a 130 cm² active area short stack

Stabilized fluoride release rate: 0.02 µg/cm²/hr

Concept 2 fluoride release rate (FRR) over 11,000 hours of operation.

Advancing PEMWE technology: Concept 2 voltage decay rates exceed the 2030 international targets for PEM electrolyzer stacks.

Addressing the thin-membrane challenge: Improved voltage efficiency with a 50 µm membrane, without compromising stability or safe operation.

Conclusion and Outlook

Utilizing advanced analytical techniques and rigorous in situ and ex situ testing, the Gore-ITM Power collaboration enabled and accelerated the development of next-generation membrane technology for PEMWE, delivering improved efficiency and durability through shared capabilities and expertise. While thin membranes raise concerns about longevity and safety, when comparing 85 µm and 50 µm, the 50 µm membrane of Concept 2 not only demonstrated extended durability over 11,000 hours but also showed significant improvements in cell efficiency at full load and at modest temperatures, exceeding the 2030 and ultimate performance targets set by the EU and DOE. Higher current density at a lower power consumption—using ultra-thin Gore PEM with longer lifetimes—has the potential to offer significant cost savings by lowering LCOH[8] and reducing maintenance.

Building on these innovations, commercial sector CAPEX and OPEX will be gradually improved at scale, with higher current density at lower power consumption enabled by novel, ultra-thin PEM and appropriate stack design.



> "Demonstrating the extended durability of these PEM prototype concepts builds the foundation for our next-generation membranes. We have a proven solution to ensure industry needs are met with high-performance technology. For users, this translates into predictable energy consumption, as ultra-low performance decay enables consistently lower stack electricity consumption per kg of hydrogen."
>
> **- Jason Manthey,**
> Business Technical Leader, Clean Energy

8. Kobaisy, A., Teller, O., Thienel, D., (2024). Minimizing LCOH with advanced proton exchange membranes, https://www.gore.com/products/pem-water-electrolysis-membranes-hydrogen-production.

Methods Appendix

Rigorous, industry-relevant testing protocols and key performance indicators (KPIs) were used in continuous improvement pipelines to evaluate prototype performance. All in situ testing was conducted using state-of-the-art instrumentation within a closed loop to ensure online monitoring with minimal interference.

Voltage decay was determined using the method recommended by Tsotridis and Pilenga,[9] with voltage sampling every 15 minutes.

Polarisation curves were measured at intervals of 1000 h. Electrochemical impedance spectra were measured in galvanostatic mode to provide complementary data. A Biologic VMP3 potentiostat with 10 A and 100 A boosters was used for electrochemical measurements.

Water quality was monitored throughout all tests. Total organic carbon and total inorganic carbon were analyzed using an OI Analytical Aurora 1030W total organic carbon and total inorganic carbon analyzer with a 1088 rotary autosampler.

Membrane permeability was measured at end of life using inductively coupled plasma mass spectrometry (ICP-MS), an electrochemical technique that determines hydrogen permeation via diffusion in the absence of additional driving forces such as supersaturation. The PerkinElmer Nexion 2000B ICP-MS instrument contains a triple cone interface and quadrupole ion deflector and utilises a Teledyne Cetac ASX 560 autosampler system.

Membrane structural integrity at end of life was examined after cell disassembly via scanning electron microscopy (SEM; Hitachi SU8230 Field Emission Scanning Electron Microscope using Oxford Instruments ULTIM Extreme detector for EDS) of cross-sections of the catalyst-coated membrane. Samples were cut with a Gatan® Illion 2 Broad Beam Ion Mill, which uses high energy argon ion bombardment under vacuum and a cryogenic unit to reduce and dissipate heat. SEM allows an extremely forensic and precise approach to probe cross-sections of the membrane materials and the electrochemical cell, as well as regions where the membrane interacts with cell hardware and other components.

Membrane chemical stability was evaluated by monitoring fluoride in the water using high-pressure ion chromatography (HPIC) with the Thermo Scientific Dionex Integrion HPIC system fitted with an AG28-Fast-4-µm separation column. The system utilizes a Gilson GX-271 autosampler system. HPIC has a high accuracy of 5% and a limit of quantitation of 4 ppb, which provides an exceptional level of sensitivity that is rarely applied to the testing of commercial electrolyzers.

Hydrogen crossover, measured as percentage hydrogen-in-oxygen, was monitored at 100- to 200- hour intervals using highly accurate, state-of-the-art mass spectrometry methods.

The integrity of the recombination catalyst was evaluated by examining changes in recombination catalyst particles on < 100-nm thin cross-sectional slices of membrane via transmission electron microscopy (TEM). Degradation in recombination catalyst efficiency is rarely described in the PEMWE literature or for other systems that deploy a recombination catalyst. TEM imaging was guided by a W. L. Gore associate on equipment provided by University of Delaware and Penn State University.

9. Tsotridis, G., & Pilenga, A. (2021). EU harmonised protocols for testing of low temperature water electrolysers, EUR 30752 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-39266-8, doi: 10.2760/58880, JRC122565.

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