WhitePaper

Not just a layer

Microporous layers are shaping PEM

Bekaert

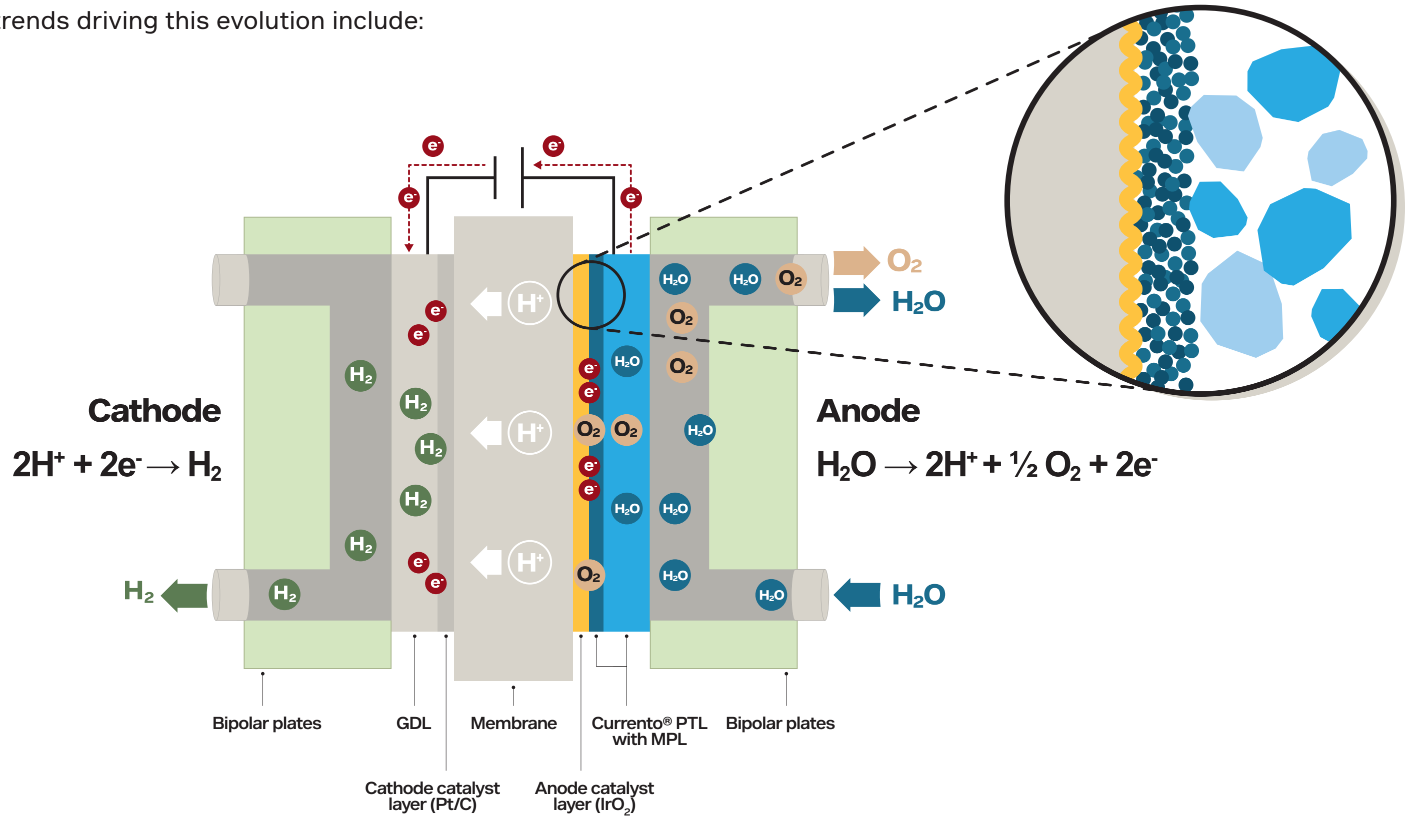
Contents

Understanding the role of MPL in PEM

The Microporous Layer (MPL) is a carefully engineered interfacial component increasingly used in Proton Exchange Membrane (PEM) electrolyzers to enhance mass transport, catalyst utilization, and overall system stability. Positioned between the catalyst layer (CL) and the porous transport layer (PTL), the MPL consists of a controlled network of micro-scale pores designed to regulate water and gas movement within the electrochemical cell.

Recent advances in PEM electrolyzer technology, driven by the need to reduce both CAPEX and OPEX for competitive green hydrogen, have delivered: higher efficiency, lower precious-metal loadings, and improved membrane durability. As PEM electrolyzer technology continues to evolve, the role of an MPL has grown. Key trends driving this evolution include:

- **Thinner membranes (≈80 µm or below)**
  Reduce electrical resistance and capital costs (CAPEX), but become more sensitive to local dry-out, gas crossover, and catalyst deactivation caused by growing gas bubbles.
- **Lower precious-metal catalyst loadings**
  Reduce material costs but require more efficient electric connectivity to maintain high catalyst utilization.
- **Higher current density operation**
  Increases the importance of even current distribution, precise water management, and uniform gas removal.



Schematic of a PEM electrolyzer showing water oxidation at the anode to produce oxygen, protons, and electrons, proton transport through the polymer electrolyte membrane, and hydrogen evolution at the cathode via electron flow through the external circuit.

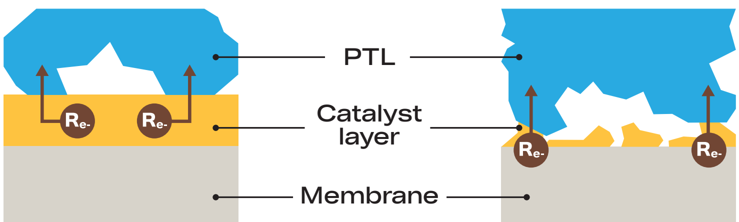


Fig 1: Schematic view on the low Ir-loaded catalytic layer (CL), indicating the need for the MPL to connect to all active sites of the CL.

MPL Core Functions

The MPL performs fundamental functions that directly influence the electrochemical, mechanical, and mass-transport behavior of PEM electrolyzers. Forming a finely engineered interface, the MPL's properties determine how efficiently water, gas, heat, and current move through the cell.

At its core, the roles of an MPL can be grouped into two main functional categories.

1. Interfacial engineering between the PTL and CL
The MPL acts as a transitional layer, optimizing how the PTL and CL interact. Its contributions include:

- **Improved mechanical conformity**
  The MPL smooths the macroscopic roughness of the PTL, creating a more uniform contact surface for the catalyst layer. This becomes especially important when using thinner membranes, which are more sensitive to uneven compression or mechanical stresses.

- **Reduced interfacial resistance**
  By increasing the true contact area and minimizing voids at the PTL-CL interface, the MPL lowers local electronic and ionic resistances. This contributes to higher cell efficiency at any operating current density, as well as lower iridium (Ir) catalyst loading.

- **Enhanced structural support for thin membranes**
  As PEM technology moves toward membranes ≤80 µm, mechanical stability becomes a challenge. The MPL helps distribute compressive loads more uniformly, reducing the likelihood of membrane deformation, pinhole formation, or local dry-out.

2. Mass-transport regulation of water management and gas bubble dynamics
Efficient water supply and oxygen evacuation are essential for stable Oxygen Evolution Reaction (OER) performance. The MPL supports mass transport through two key mechanisms:

- **Uniform water distribution to the catalyst layer**
  The MPL acts as a micro-channel network, spreading water evenly across the catalyst surface. This prevents localized dehydration, ensures all catalyst sites remain active, and maintains thermal stability by avoiding hot spots that could damage the membrane.

- **Facilitation of gas bubble detachment**
  Oxygen generated at the anode must detach quickly from the catalyst layer to avoid blocking active sites. The MPL's microstructure provides preferential pathways for bubble growth and release, reducing gas blockage and ensuring continuous oxygen removal to the PTL

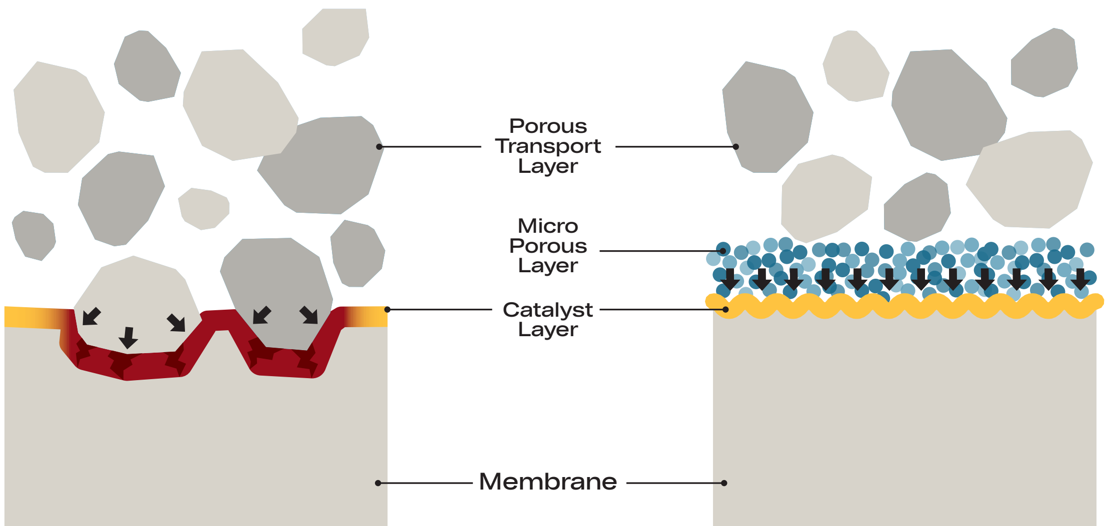


Fig 2: Differences in mechanical stresses of PTL and MPL onto CL and membrane.

Current solutions and materials

MPL offerings for PEM electrolyzers range from commercially available products to emerging research concepts. While they are less mature than the carbon-based MPLs used in PEM fuel cells, several fabrication methods are now under investigation or moving toward industrial-scale production. With the two variables of membrane thickness and Ir-loadings, four blocks generate the following segmentation:

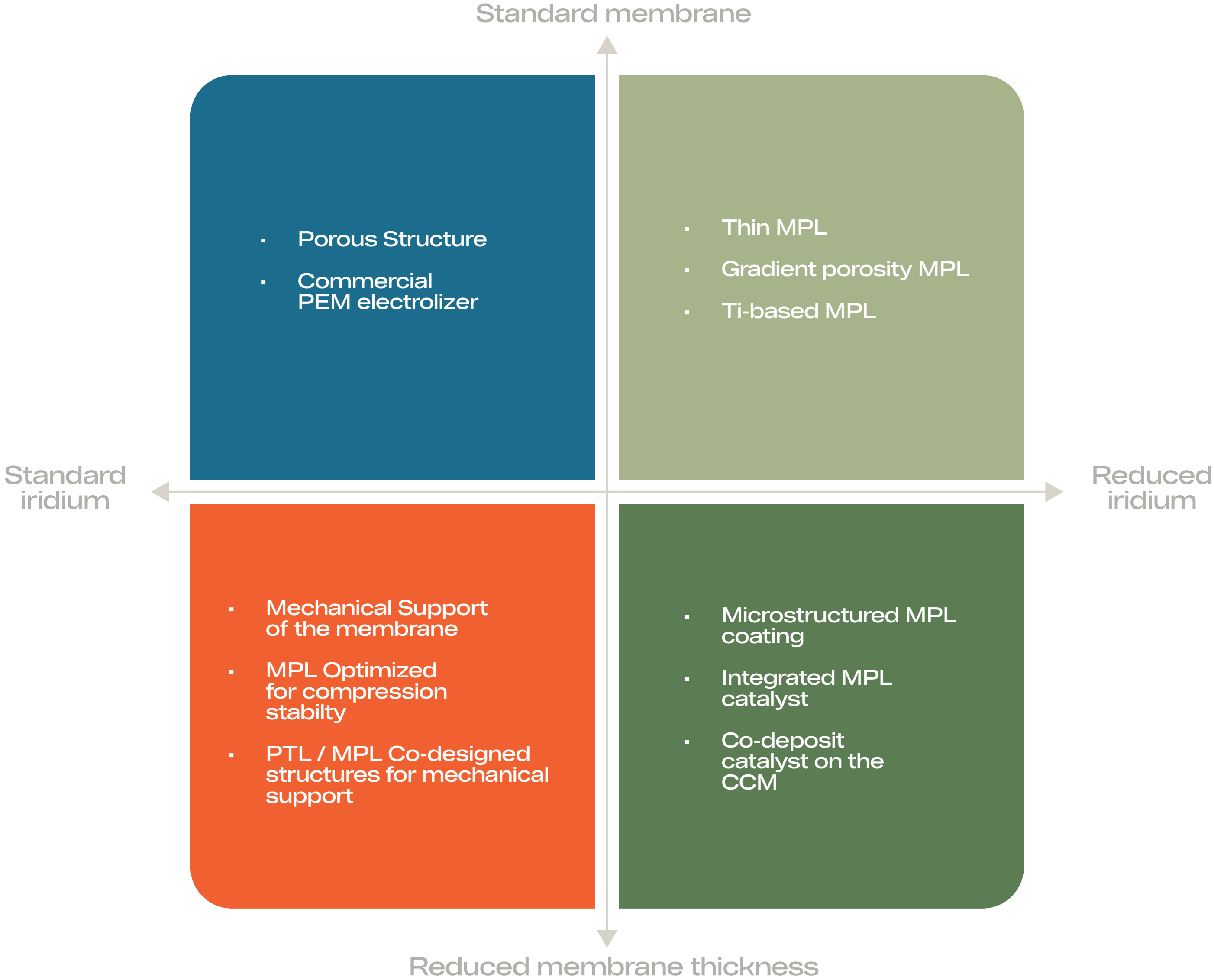


Fig 3: Overview of reported and emerging microporous layer (MPL) concepts for PEM electrolyzers, mapping different structural, material, and integration approaches studied in the literature against membrane thickness and iridium loading.

Differences in MPL development

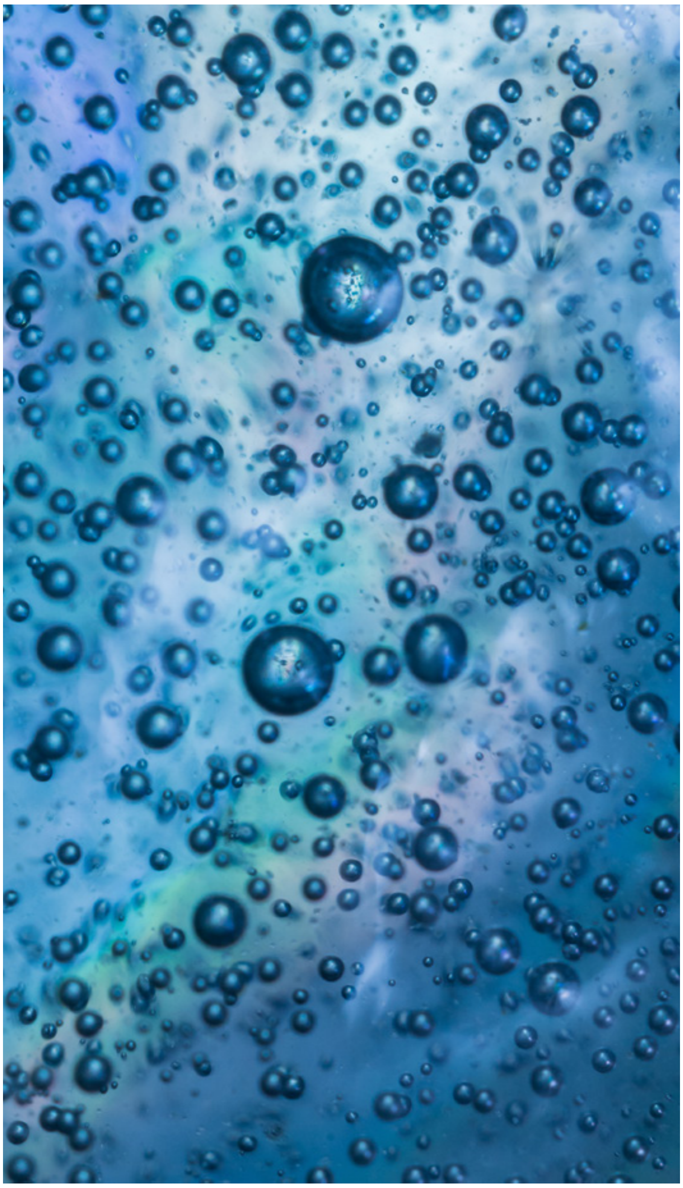
The evolution of the Microporous Layer (MPL) has traditionally been driven by fuel-cell research, where it became a mature component several years before being adopted in PEM electrolyzers.

While these principles are shared, electrolyzers operate under conditions that demand a fundamentally different approach. The strongly oxidative environment at the anode requires carbon-free, corrosion-resistant materials capable of maintaining structural integrity under high potentials and pressure gradients.

Functional priorities also diverge: electrolyzers must ensure reliable water supply for the oxygen evolution reaction (OER) while enabling efficient oxygen bubble detachment at current densities exceeding 3–4 A/cm². These requirements make engineered porosity and robust interfacial contact critical for durability and efficiency.

As the industry moves toward ultra-thin membranes (<50–70 μm) and very low Ir loadings (<0.3 mg/cm²), MPLs must deliver uniform performance while minimizing resistance and **providing required flow characteristics to achieve consistent thermal management and removal of oxygen.**

Unlike fully mature components in other systems, MPLs for electrolyzers remain in an early stage of development. Major innovation is expected over the next decade, particularly in scalability, coating uniformity, and integration with advanced MEA architectures. High-current operation and robust MPL design are essential for lowering the levelized cost of hydrogen (LCOH), making MPL optimization a strategic priority for achieving cost-effective green hydrogen production.



Lessons learned

The long history of MPL development in PEM fuel cells provides a strong foundation for advancing MPL technology in PEM electrolyzers. Although the operating environments differ, many principles governing microstructure design, interfacial engineering, and mass-transport optimization remain applicable. By studying fuel cell MPL evolution, electrolyzer developers can adopt strategies that improve performance, durability, and scalability.

Technical and operational takeaways

Electrolyzer performance depends heavily on precise control of MPL microstructure. Porosity and pore-size distribution must be engineered to balance water delivery to the CL with efficient oxygen removal, minimizing dry-out events. Combining micro- and mesoporous networks creates pathways that optimize mass transport under high current densities.

Uniformity in MPL thickness and composition is equally critical. Inconsistent microstructures can lead to localized hot spots and uneven current distribution, especially in systems using thin membranes. Consistency in fabrication ensures stable operation and prevents performance losses. Additionally, optimized interfacial contact between the MPL and PTL reduces resistance and enhances electron transport, improving overall system efficiency.

Durability and mechanical robustness

Electrolyzers operate under harsh oxidative conditions and significant pressure gradients, making MPL durability a priority. Mechanical fragility can lead to cracking during assembly or long-term operation, so process-controlled compression and robust material selection are essential. Corrosion resistance is another critical factor: electrolyzers demand titanium or other corrosion-resistant materials to withstand aggressive environments.

Components integration

MPL performance cannot be optimized in isolation. It must be co-designed with the CL and PTL to ensure seamless integration across the membrane electrode assembly (MEA). Overly complex MPL architectures may increase cost without proportional performance gains, so designs should balance functionality with manufacturability. Standardized durability testing protocols, similar to those established for fuel cells, are urgently needed to accelerate innovation and ensure comparability across the industry.

Innovation pathways

Future development will likely focus on gradient-engineered MPLs that enable thinner membranes and lower catalyst loadings, improving efficiency without sacrificing durability. Early collaboration between industry and academia remains vital for breakthroughs in corrosion-resistant materials and scalable coating processes.

Problems left to solve

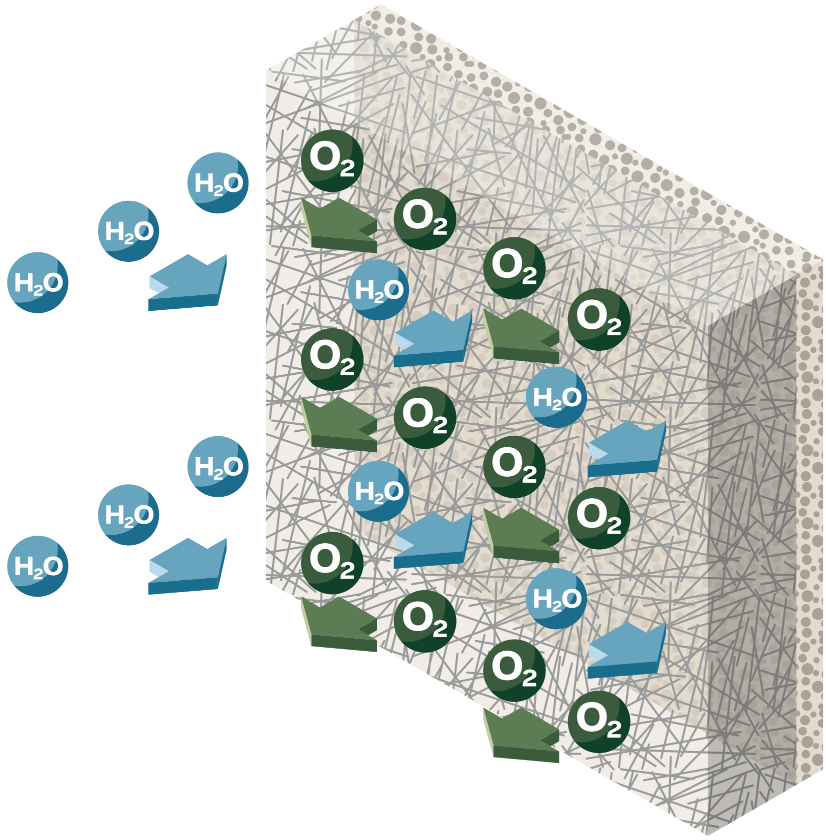


Fig 4: Schematic illustration of multiphase transport within a PEM electrolyzer microporous layer (MPL), showing water ingress, oxygen generation, and gas–liquid transport pathways through a porous structure.

Despite significant progress, current MPL technologies for PEM electrolyzers still face critical challenges that limit high-efficiency, high-current-density operation at competitive cost. These issues arise from the extreme anodic environment, complex multiphase transport requirements, and the need for scalable, low-cost manufacturing. There are still many key problems current MPL solutions have yet to solve.

Material and mechanical stability

Electrolyzers operate under severe oxidative conditions and pressure gradients, making MPL durability a major concern. Cycling between wet and dry states can cause cracking, delamination, and deformation. Corrosion resistance is essential, yet current materials often degrade under prolonged exposure, especially when paired with ultra-thin membranes and low Ir loadings.

Mass transport and interface limitations

Random pore networks cannot consistently balance water supply and oxygen evacuation, and poor adhesion to titanium PTLs introduces non-uniform contact resistance. These issues compromise electrochemical performance and accelerate degradation under dynamic, renewables-driven operation.

Manufacturing scalability and standardization

High-performance MPLs create several challenges in scaling production processes. Variability in layer thicknesses and defects leads to inconsistent performance across suppliers. The absence of standardized fabrication protocols and durability testing slows innovation and market adoption. Sustainability also remains a gap, with limited recyclable materials and scarce long-term durability data (>30,000–50,000 hours).

Ongoing MPL research in the PTL/MPL landscape

As the industry moves toward higher current densities, lower catalyst loadings, and more durable, cost-efficient system architectures, research into MPLs for PEM electrolyzers will continue to accelerate. The next-generation of MPL materials aims to address the limitations of existing Ti-structures, while introducing new functionalities tailored to extreme anodic environment of water electrolysis.

From our observation of activities, current research directions cluster around material innovation, structural engineering, and manufacturability.

Engineered porosity and gradient structures

Advanced MPL architectures aim to control mass transport at multiple scales:

- **Gradient-porosity MPLs with increasing pore size from CL to PTL.**
- **Advanced porous structures for fast oxygen bubble removal.**

These designs target high-current operation (>3–4 A/cm²) by facilitating bubble detachment .

Low-cost and scalable manufacturing materials

Research is progressing towards:

- **Deposition methods compatible with high-throughput roll-to-roll systems.**
- **Mass production processes well established in other dominions of industry.**

Catalytically active MPLs

Next-generation MPLs may incorporate catalytic functionality:

- **Supporting Ir dispersion or anchoring to reduce loadings.**
- **Enhancing catalyst utilization by improving homogeneous current distribution and water access.**

Conclusions, Summaries and Afterwords

Future outlook

In the short term, MPL development is expected to move from lab innovation to commercialization. Ti-based MPLs will see broader market adoption, supported by adhesion, coating, uniformity, and durability improvements. The industry is moving toward greater alignment on standardized MPL characterization methods, improving comparability across suppliers, and reducing the number of qualification cycles for electrolyzer manufacturers.

On the medium term, MPL architecture will become increasingly sophisticated. Gradient-porosity and hierarchical designs are expected to gain widespread adoption as electrolyzers push toward higher current densities and lower precious metal loadings. MPLs will begin seeing co-engineered development alongside ultra-thin membranes and next-gen anodes with minimal Ir content. Thereby enabling system-level efficiency gains and reduced material dependency.

And, in the long term, innovation will be driven by digitalization and sustainability. Digital twin models will inform MPL design, using simulations of bubble dynamics, local water saturation, and degradation mechanisms to optimize performance before production. Material selection will shift toward sustainable and recyclable solutions, aligning components with circular-economy principles and long-term regulatory expectations.

Contributors

Dieter Hellert

Dieter Hellert graduated from Julius-Maximilians-University in Würzburg in 1995 with a PhD in natural sciences with a thesis in metalorganic chemistry. Four years later, he joined Bekaert developing customized products to transfer application requirements into real life solutions. With over 25 years of experience in various functions, Dieter has held the role of market manager, business development manager, and product manager within hydrogen at Bekaert. He brings deep expertise in advanced metal fiber compositions for filtration, wicking, and conductive plastics, successfully translating electrolyzer stack requirements into PTL solutions validated by leading PEM electrolyzer OEMs.
In his role as product manager, Dieter has driven the development of advanced MPL structures for more than 5 years. He initiated and supported the track from supply of semi-finished goods to PTLs, ready for stack assembly comprising cut to final dimensions and protective coating features.

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