HOW MEMBRANE TECHNOLOGY IS DRIVING THE COMMERCIALIZATION OF FUEL CELLS IN THE AUTOMOTIVE INDUSTRY

Without a doubt, hydrogen is critical to our clean energy future, and as a major downstream application of hydrogen, fuel cell technology is gaining maturity by the day. So much so that at W. L. Gore & Associates (Gore), hydrogen drives our global vision of a low-carbon, sustainable energy system. And nowhere is this more obvious than in the transportation sector, a key player in the adoption of hydrogen as an energy source.

Instrumental to realizing this future potential is the proton exchange membrane (PEM) fuel cell stack, this utilizes a membrane technology that with the right expertise can accelerate the commercialization of FCEVs by dramatically improving the performance and reliability of fuel cell stacks and systems.

Currently, there are two technologies that can reduce the carbon footprint of transportation: Fuel Cell Electric Vehicles (FCEVs) and Battery Electric Vehicles (BEVs).

With a fast refueling time of 3-5 minutes, extended range of over 400 miles, and a quickly expanding available hydrogen infrastructure, fuel cell powered vehicles are gaining incredible amounts of traction in and opening up new possibilities for the future of mobility.

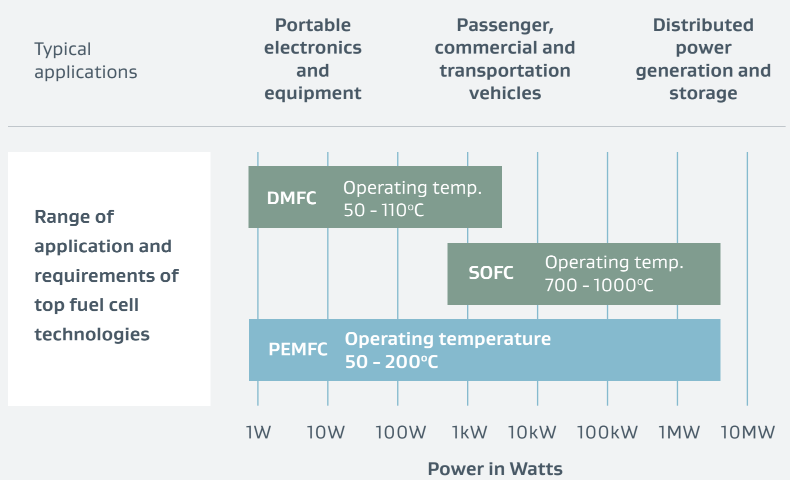
Looking more deeply into the various types of fuel cell technologies, proton exchange membrane (PEM) fuel cells offer many promising possibilities for automotive applications. So let's take a look at some of the many benefits, and reasons why the PEM fuel cell stack system is a great solution for vehicles.

Compared to solid oxide fuel cells (SOFC) and direct methanol fuel cells (DMFC), the hydrogen PEM fuel cell offers high power density, low weight and volume, and an attractive operating temperature window that does not require preheating before operation (Figure 1).

This enables automakers to offer a broader portfolio of fuel cell powered products – from passenger cars to commercial vehicles to long-range logistics trucks. This superior versatility has

Figure 1.

Recent advances in fuel cell applications



A perspective on development of fuel cell materials: Electrodes and electrolyte, Wiley Online Library, 2022, https://onlinelibrary.wiley.com/doi/full/10.1002/er.7635

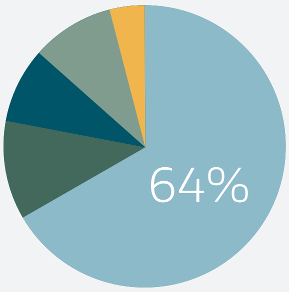
Together, improving life

enabled PEM fuel cell stacks and systems to account for 64% share of the fuel cell market (Figure 2).

Figure 2.

The Fuel Cell Industry Review 2021

Global Fuel Cell Market
share, by product, 2021 (%)



- PEMFC
- PAFC
- MCFC
- SOFC
- Others

Fuel Cell Market Size & Share, Industry Report, 2021-2028, Grand View Research, 2020, https://www.grandviewresearch.com/industry-analysis/fuel-cell-market

The potential benefits of PEM fuel cell technology make it critical for automakers to invest. However, the technology must be commercially viable and competitive to achieve economies of scale. So to gain widespread acceptance, fuel cell stack engineers must partner with membrane technology experts and together optimize the PEM, stack, and system to realize the commercialization needs for FCEVs in three broad categories:

- **Reliable performance**
  Understand PEM's power density and durability characteristics and how to leverage membrane technology for optimal performance in the stack and system.
- **Technical support**
  Ensure fit-for-use solutions, technical expertise, and service support to meet vehicle program objectives.
- **Supply security**
  Maintain a reliable supply chain of hydrogen fuel components and materials to achieve quality, consistency and scalable production.

Reliable performance

The PEM in a fuel cell separates hydrogen from air (oxygen), transports protons from the anode to the cathode, and prevents electrons from short-circuiting in the cell. This makes the PEM an essential component of hydrogen-to-energy conversion in the fuel cell. To operate reliably and provide excellent performance under high temperatures and potentially dry conditions, PEMs in an automotive fuel cell stack must have high proton conductance (enabling power density), be resistant to chemical degradation and mechanical failure, and demonstrate low gas permeance.

Utilizing thinner PEMs, engineers can reduce proton resistance while increasing water transport, and improving performance, especially at low RH (Relative Humidity). However, traditionally thinner PEMs can impact mechanical properties and therefore compromise the fuel cell's life.

In addition, thinner PEMs can result in increases in gas crossover and lower fuel efficiency, as well as increased concentration of harmful radicals that accelerate chemical degradation, leading to decreased product lifetimes.

These tradeoffs can be significantly reduced by micro-reinforcing the PEM with expanded

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polytetrafluoroethylene - or ePTFE. Developed from decades of materials engineering experience, Gore's composite reinforced PEM technology is based on a combination of highly engineered ePTFE, high-performance ionomers, and proprietary membrane additives to combat chemical degradation. The result is a low resistance and durable product design for specific application requirements (Figure 3). Continued R&D efforts in PEM materials and designs, as well as fuel cell stacks and systems, must take a holistic approach to understand their interactions and tradeoffs to optimize the performance and cost of the end application.

and knowledge to support the customized, fit-for-use needs of automakers.

It is important for a component supplier to possess a deep understanding of the potential performance tradeoffs of their component and the potential interactions with other components in the fuel cell stack and system. In the case of the PEM, Gore has developed both modeling, in-situ (in fuel cell) and ex-situ test methods to enable understanding of these interactions and accelerate product design.

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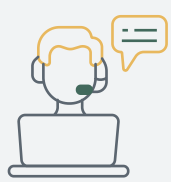
Figure 3.

PEM comparison

	Unit	Conventional PEM	GORE-SELECT® Membrane
Thickness	µm	25	15
Proton resistance	mohm*cm²	150	< 80
Lifetime in chemical durability accelerated stress test	Relative	1x	> 10x
Mechanical durability accelerated stress test	Relative	1x	10x
Gas permeance	mA/cm²/MPa	17	30

Technical support



New and different product requirements arise as we move from PEM research and development to production and commercialization. PEM suppliers must have the technical expertise

low performance and/or power loss over time that could result from changes in material. Ex-situ postmortem analysis tools should be readily available to automotive suppliers to diagnose the failure modes and mechanisms of field-returned MEA/PEM stacks.

To complete the picture for holistic technical support, PEM suppliers should have comprehensive global analysis resources to support surface science investigations, thermal, mechanical and physical characterization, chemical analysis, and microstructural characterization for complex problem solving.

Supply security

As automakers move to mass production of fuel cells, PEM manufacturers must ensure high production yields with consistent high-performance products - while minimizing product costs and quality risks. PEM suppliers with consistent raw materials and precision membrane coating technology can ensure uniformity and quality by minimizing cell-to-cell variability (Figure 4). This allows fuel cell stack manufacturers to precisely control performance distribution both within-cell and cell-to-cell in the stack. Resulting in increased stack production yields and lower costs, as well as improved stack lifetime.

Another important consideration is the supply of raw materials. Few PEM manufacturers have established, proven and reliable raw material supply chains based on extensive R&D collaborations and secure commercial partnerships with sub-suppliers.

It is even more difficult to find suppliers who can produce high-performance PEM in the quantities needed to meet industry demand. Understanding this as crucial to success, Gore leverages its ePTFE reinforcement expertise and global network resources to ensure the security of supply, process stability, and quality consistency at scale.

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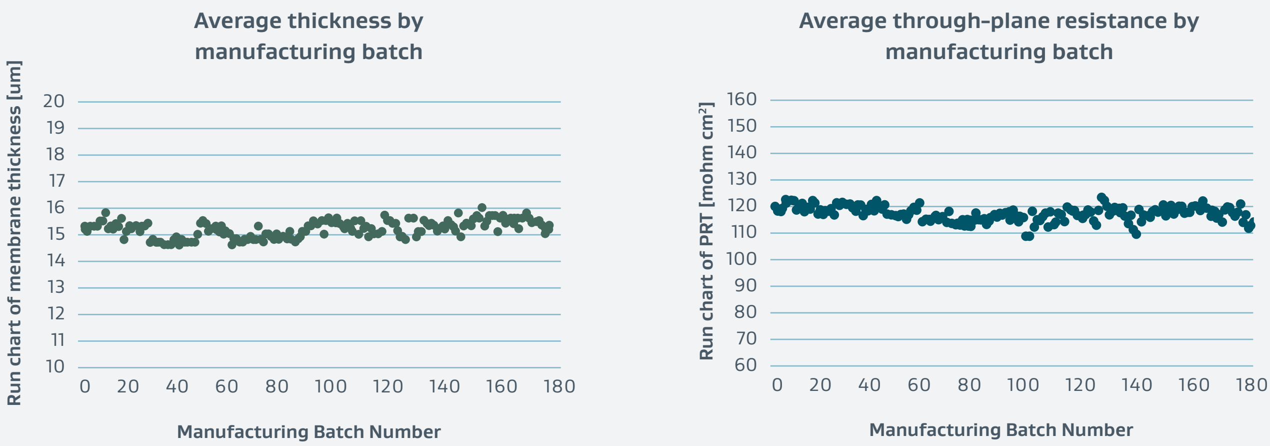
Figure 4.

Gore PEM mass production data over 180 lots



- Test condition: 23°C 50% RH
- Standard deviation: 0.3
- 180 lots

- Test condition: 36°C 50% RH
- Standard deviation: 3.2
- 180 lots

Making fuel cell technology commercially viable for freight transportation and beyond

Today fuel cell technology is being effectively developed, deployed, and tested in FCEVs for passenger vehicles. Great news, because these advancements and learnings are paving the way for the many benefits of PEM technology in other transportation industry sectors. Making fuel cell technology commercially viable for freight transportation industry too.

Fuel cell system developers in commercial application are now looking to similar collaborative models to scale their technology based on advancements in Gore's PEM technology.

And the benefits are clear – trucks that run on clean hydrogen power can use lighter fuel cell stacks, giving them greater payload capacities and improved efficiencies, resulting in reduced total cost of ownership, critical performance indicators in a highly competitive industry.

In summary, we believe that fuel cell stack engineers must partner with membrane technology experts to realize the PEM, stack and system commercialization needs for FCEVs in three broad categories: reliable performance, expert technical support, and having supply security – enabling automakers of all types to be ready for a hydrogen-powered future.

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Simon Cleghorn is W. L. Gore & Associates global product specialist. He is a PhD electrochemist with close to 25 years' experience working in the field of polymer electrolyte membranes for fuel cells and other applications.

If you wish to learn more about Gore and its GORE-SELECT® Membrane technology, please visit https://www.gore.com/alt-energy.

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W. L. Gore & Associates is a global materials science company dedicated to transforming industries and improving lives. Since 1958, Gore has solved complex technical challenges in demanding environments — from outer space to the world's highest peaks to the inner workings of the human body. With more than 13,000 Associates and a strong, team-oriented culture, Gore generates annual revenues of $4.8 billion.

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