# ADVANCED MEMBRANE DESIGN & CRITICAL FACTORS IN SCALING PEM WATER ELECTROLYSIS SYSTEMS

Maximizing the potential
of membrane technology to
meet our net-zero targets.

**Dr. Oliver Teller**
Product Manager PEM Water Electrolysis
W. L. Gore & Associates GmbH

*Together, improving life*

# Agenda

**1.0**

Addressing the challenges for green hydrogen production

**2.0**

Making PEM systems more efficient

**3.0**

Collaboration is key for complex systems to work

**4.0**

Scaling PEM systems demands a reliable supply chain

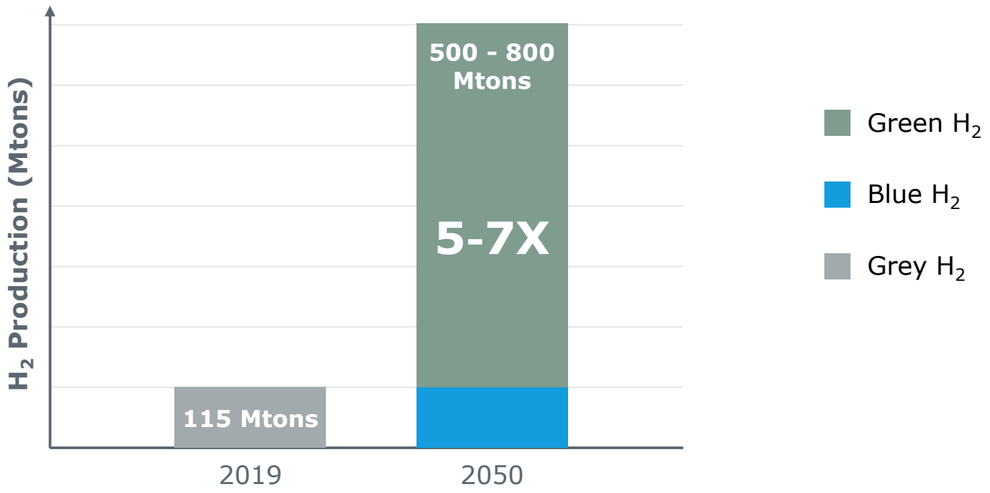
# Our journey has started. Now it’s time to speed up.

“The clean energy economy is rapidly taking shape, but even faster progress is needed in most areas to meet international energy and climate goals.”

**Fatih Birol, Executive Director**
International Energy Agency (IEA)

# The clean hydrogen industry has made great progress - and must go much further.

## Total Hydrogen production scale-up required




Energy Transitions Commission (2021), Making the Hydrogen Economy Possible: Accelerating Clean Hydrogen in an Electrified Economy, Version 1.2

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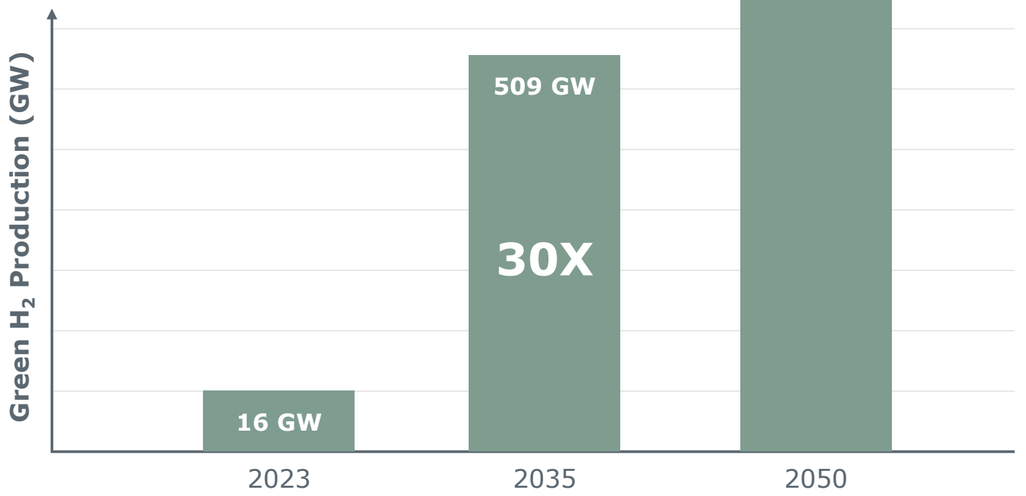



IHS/S&P Global estimates from July 2023

**ULTIMATE GOAL**

# Enabling change in the ecosystem

Finding the pathways to success.

**PEM Electrolysis is a viable production pathway to achieving decarbonisation targets.**


### Efficiency

PEM systems must become more efficient to make hydrogen more affordable.

### Scalability

PEM systems need to scale up quickly to meet growing demand (requiring a reliable, sophisticated supply chain)

### System Integration

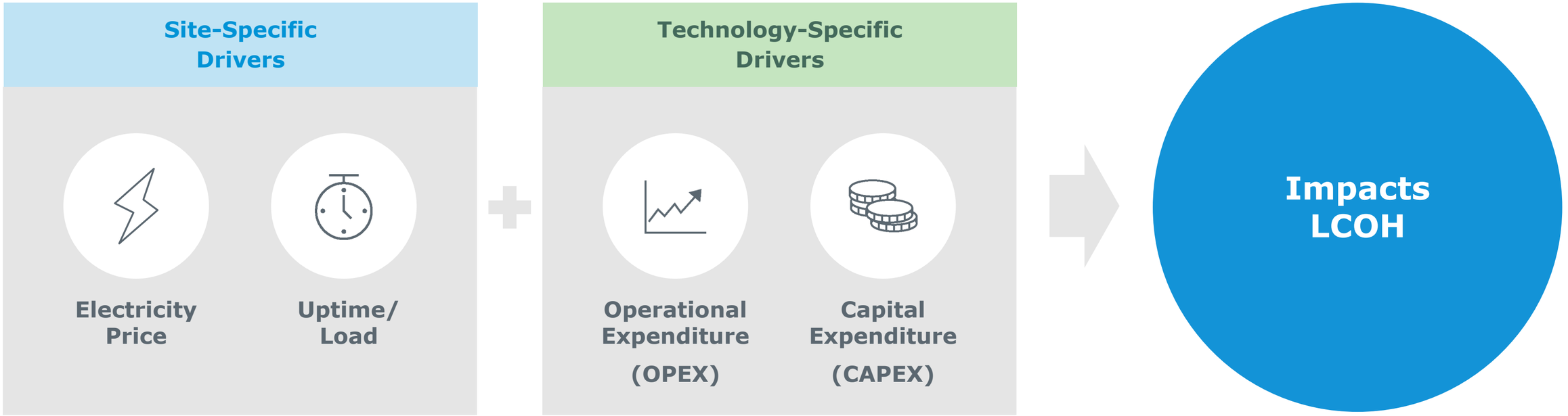
For individual components to work in complex systems, we need collective experience, expertise – and collaboration.

PEM SYSTEMS MUST BECOME MORE **EFFICIENT** TO MAKE HYDROGEN MORE AFFORDABLE.

# “More affordable” requires balancing various factors

Hydrogen production costs depend on site-specific and technology-specific drivers.

Achieving greater efficiency requires **improving both**:



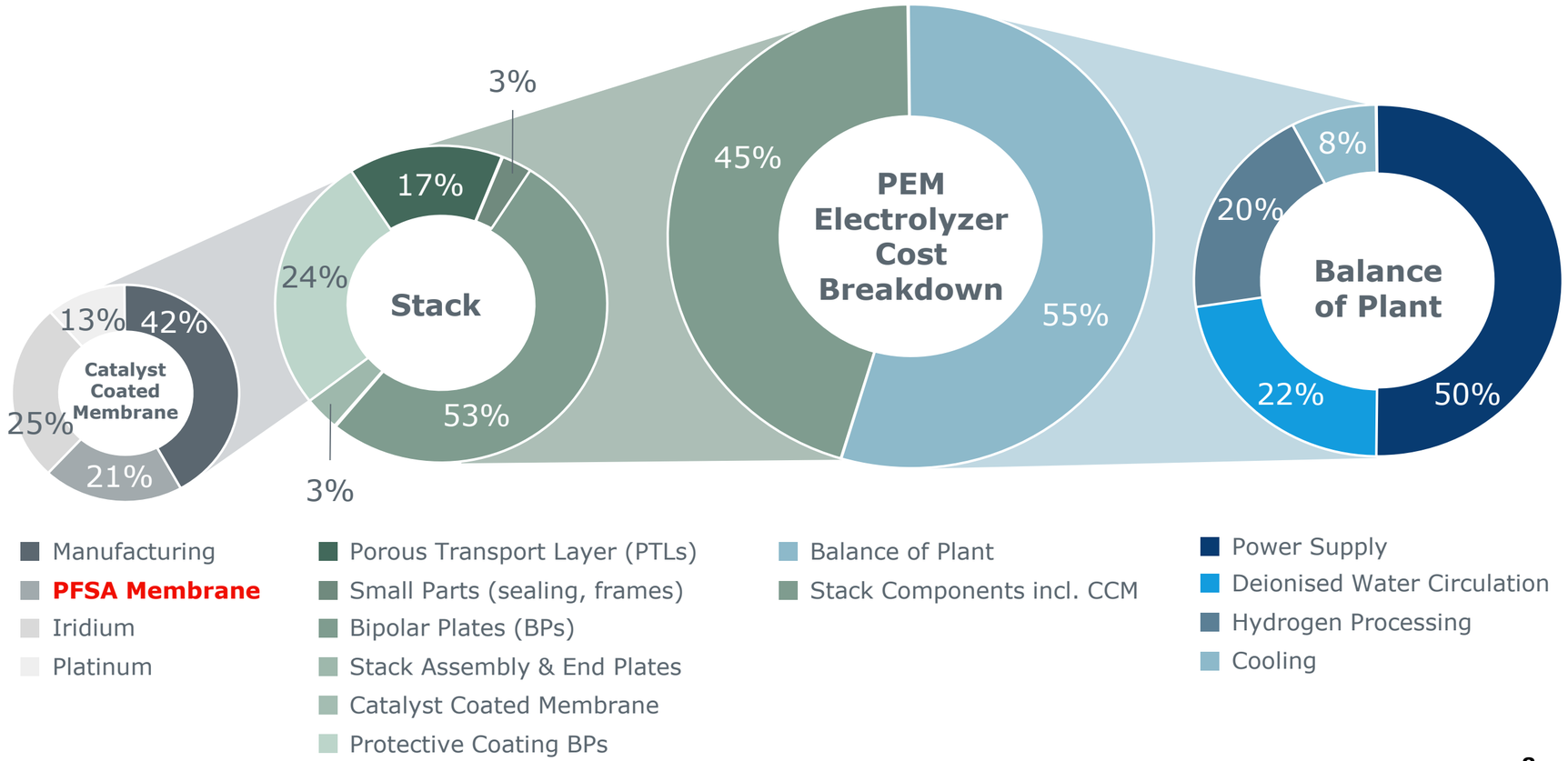
# Reducing OPEX is the key to delivering results

CAPEX is important. OPEX is critical.

**TOTAL SYSTEM COST BREAKDOWN** | OPEX Costs

**Massive industry scale-up will enable lower CAPEX via:**

1. Increased plant size & economies of scale
2. Optimized electrolyzer design & plant integration cost




IRENA (2020), Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5 ºC Climate Goal, International Renewable Energy Agency, Abu Dhabi.

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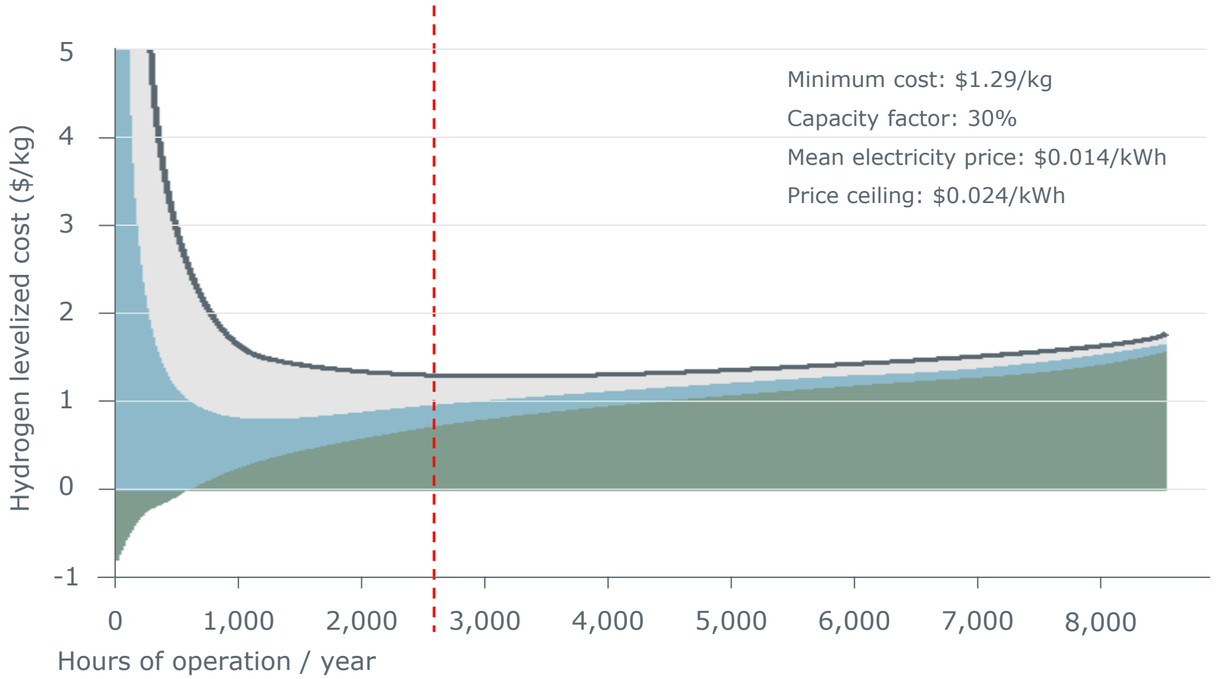
Total System Cost Breakdown

**OPEX COSTS**




NREL (2022), Operating strategies for dispatchable PEM electrolyzers that enable low-cost hydrogen production, Alex Badgett, Bryan Pivovar, Mark Ruth at the International Conference on Electrolysis 2021, Golden, Colorado, US

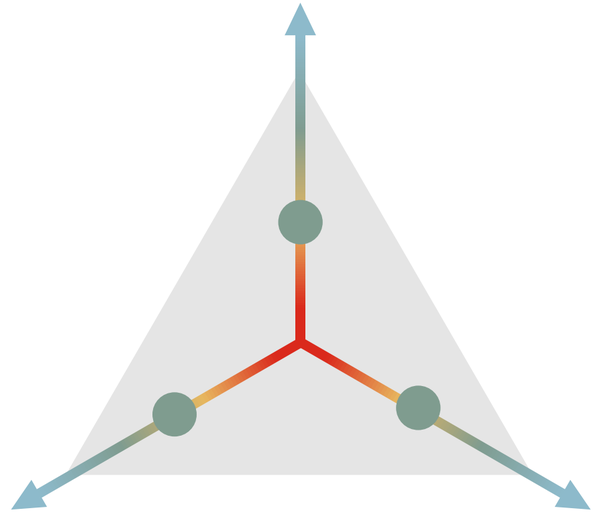
- Hydrogen Levelized Costs
- Minimum costs
- Electricity costs
- Capital costs
- Fixed O&M

**To scale up to meet net-zero demands**, OPEX is the deciding factor in delivering a lower levelized cost of hydrogen.

# Tackling technology trade-offs to reduce OPEX

Why compromise – when you can optimize?

- Engineers typically face the ‘system dilemma’ of **optimizing performance**, **safety** and **durability**.
- Optimizing for 1 criteria has meant compromising on the others... until now.
- Gore has developed **an advanced PEM that can optimize them all – at the same time**.



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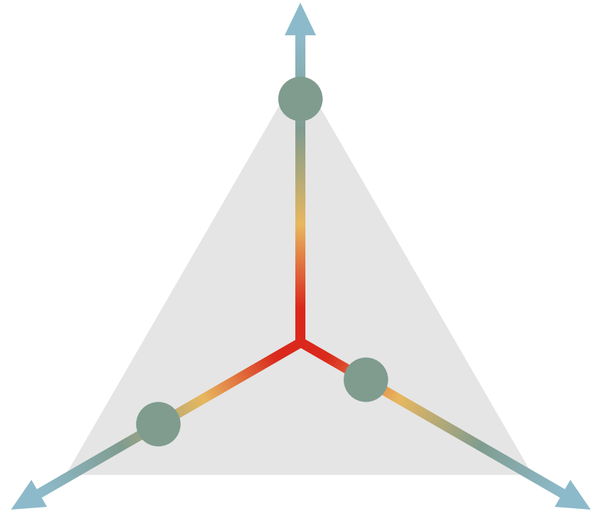

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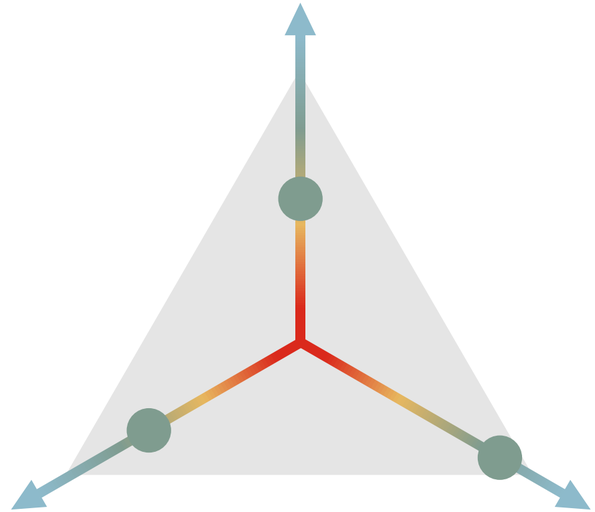

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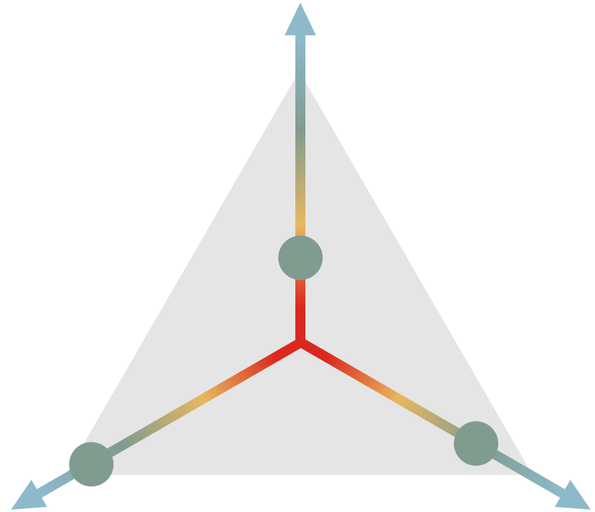

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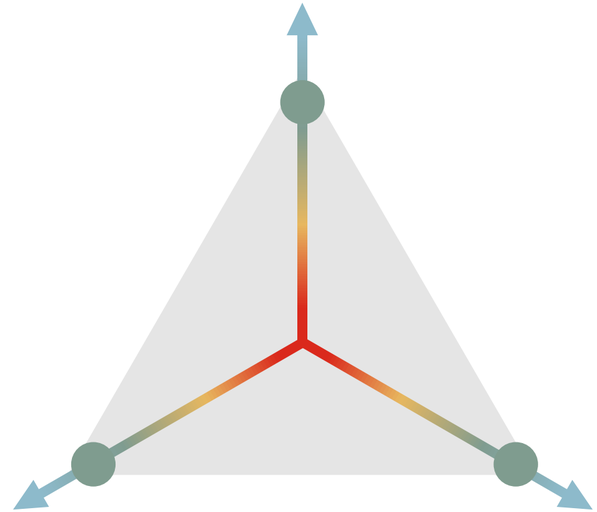
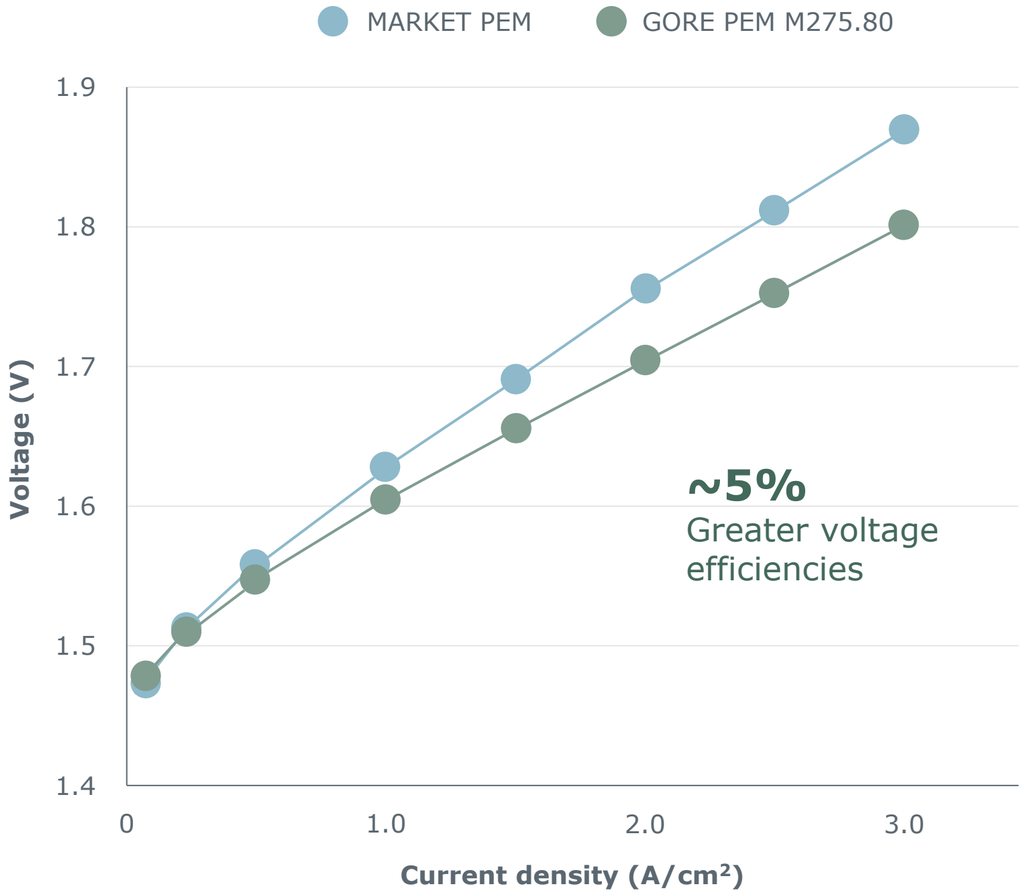


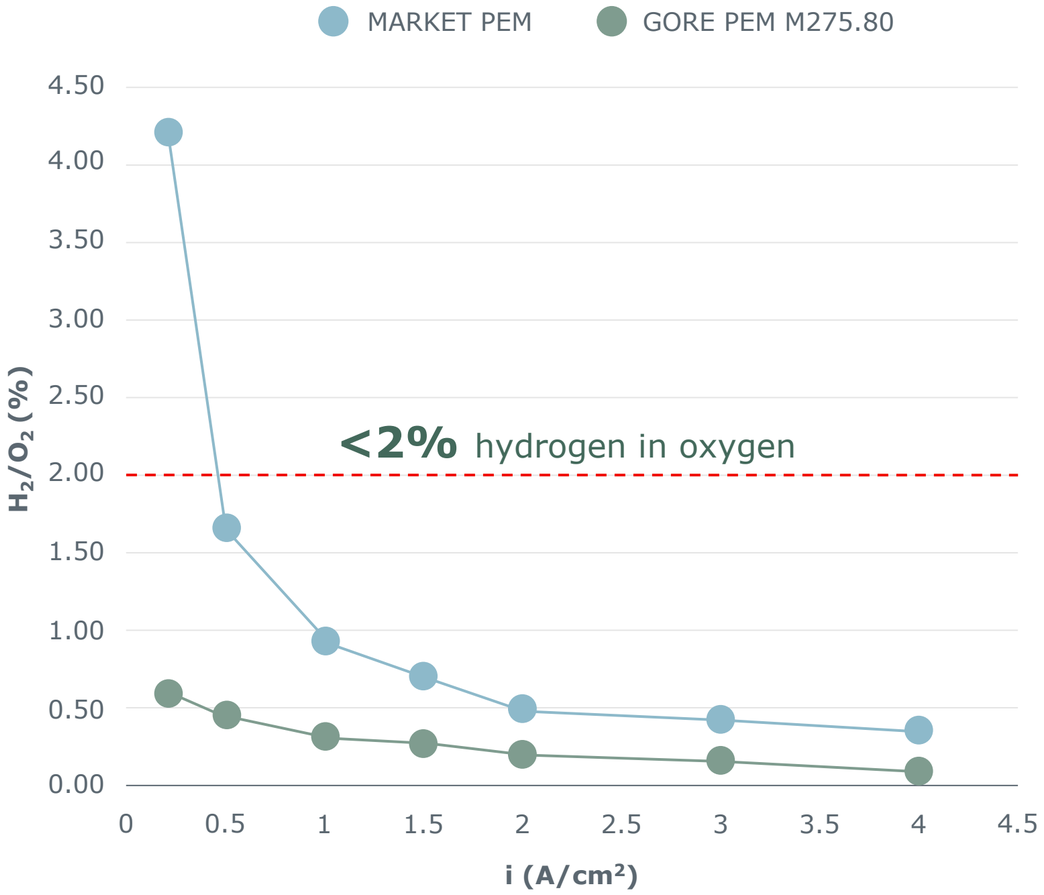
# How does better performance benefit your **output**?




- Gore's PEM M275.80 offers **~5% greater cell voltage efficiencies over other PEM** while meeting safety & durability requirements.
- This **reduces the amount of electricity required** to produce 1 kg of Hydrogen.
- **Approximately $9 Million of annual savings** may be expected for a 500 MW plant generating 80k Tons of $H_2$.

Increasing voltage efficiency enables **higher $H_2$ output for the same energy consumption** (or vice versa; less energy consumption for the same $H_2$ output)

# How does improved safety increase your **uptime**?

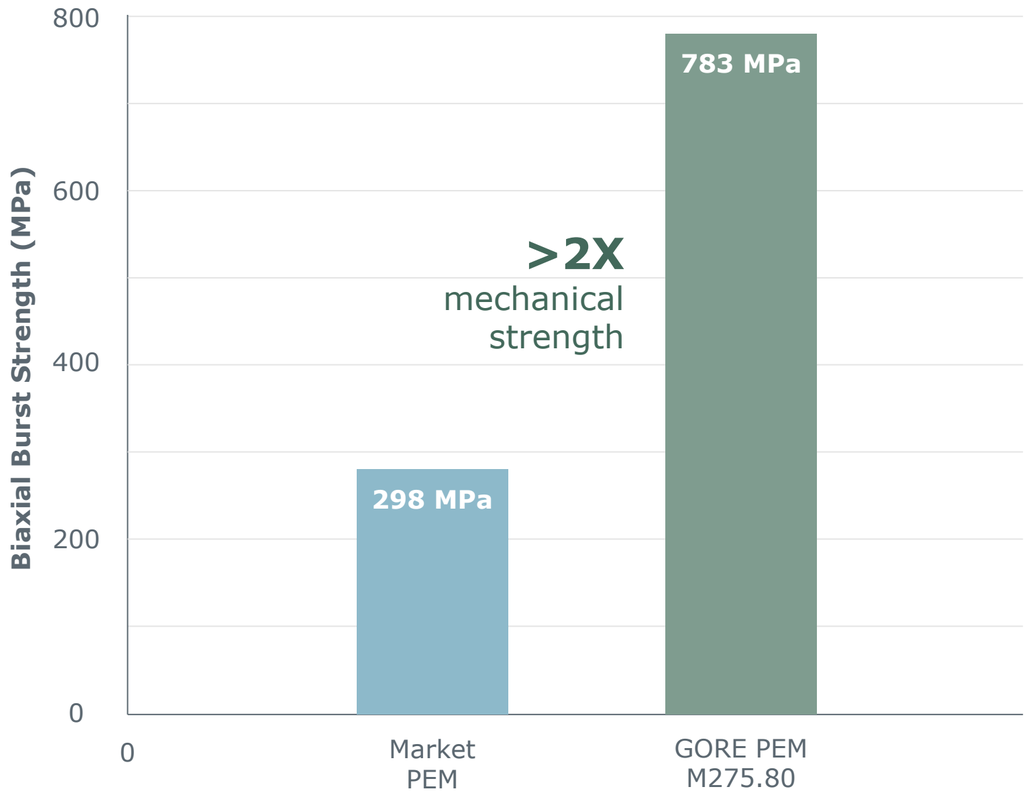



Expected cell performance data at 80 °C and ambient pressure

- Gore's additive technology enables **<2% hydrogen in oxygen concentrations** over a wide operating range - even at low ampere/current densities.
- Other PEM may not meet this threshold — meaning those **electrolyzers must be switched off** for safety reasons.
- With Gore's PEM M275.80, this is not a concern — and electrolyzers can stay running.

Wider Operation Range following load cycles results in **longer uptime while staying below safety limits**

# How does greater durability enable longer **system life** and reduce **maintenance**?

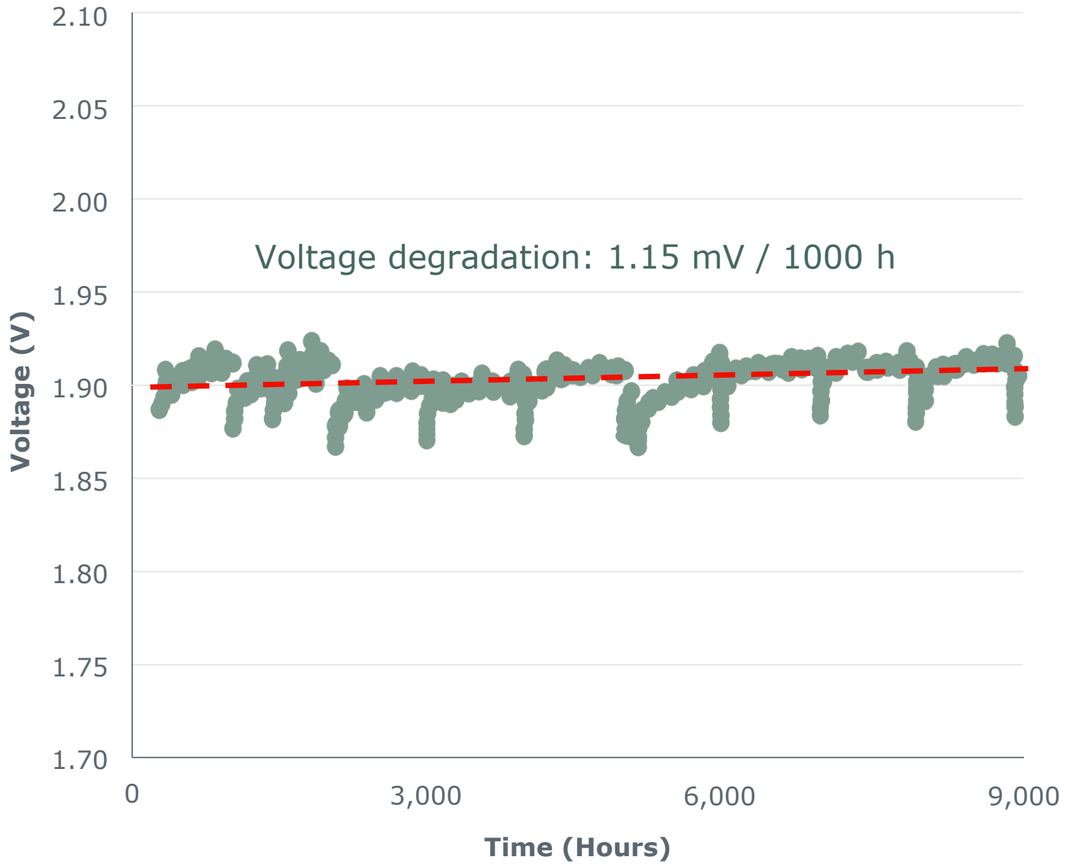



Pressurized Blister specimens tested at 25 °C & 40% RH.

- Gore's reinforced PEM offers **>2x higher mechanical stability** than non-reinforced membranes.
- This **extends WE system durability** and **reduces service intervals** for continuous operation.

Higher mechanical durability **enables long-life WE systems** and reduces maintenance for **longer system uptimes**

# Demonstrating our PEM durability with ITM POWER




Data acquired & shared by ITM Power

- Durability testing of Gore's PEM M275.80.
- Undertaken at ITM's state of the art test facility.
- Test performed under high current conditions (3.3 A/cm²) to maximize hydrogen production.
- Cell operation **>9,000 hours (and ongoing)**.

Test demonstrates **excellent membrane durability and <1% voltage degradation** (over the 9,000 hours test duration)

# Breaking performance barriers with Gore's high-performance PEM

Reducing system trade-offs with our advanced membrane technology.

**Ionomer**

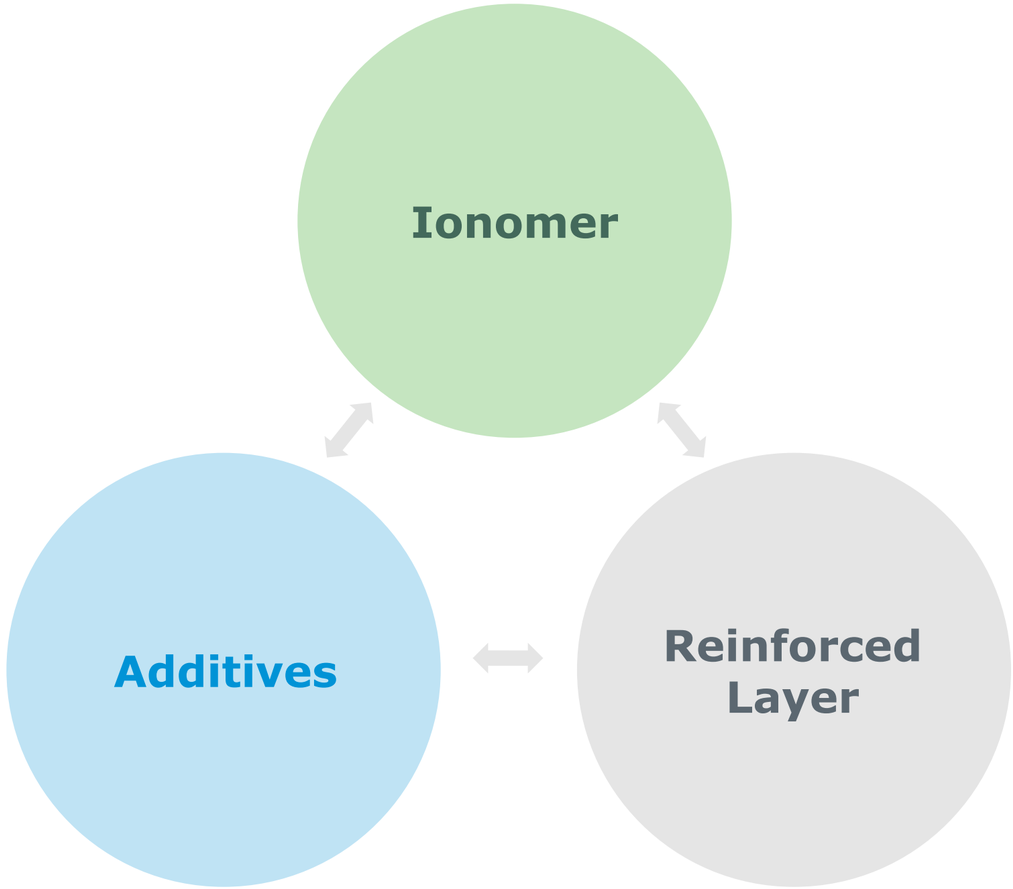
- High proton conductance + high voltage efficiency for **increased performance**

**Additives**

- Greater chemical durability + reduced $H_2$ crossover for **increased durability and safety**

**Reinforced Layer**

- Enabling thin, highly conductive, mechanically + chemically durable membranes for **increased durability and performance**

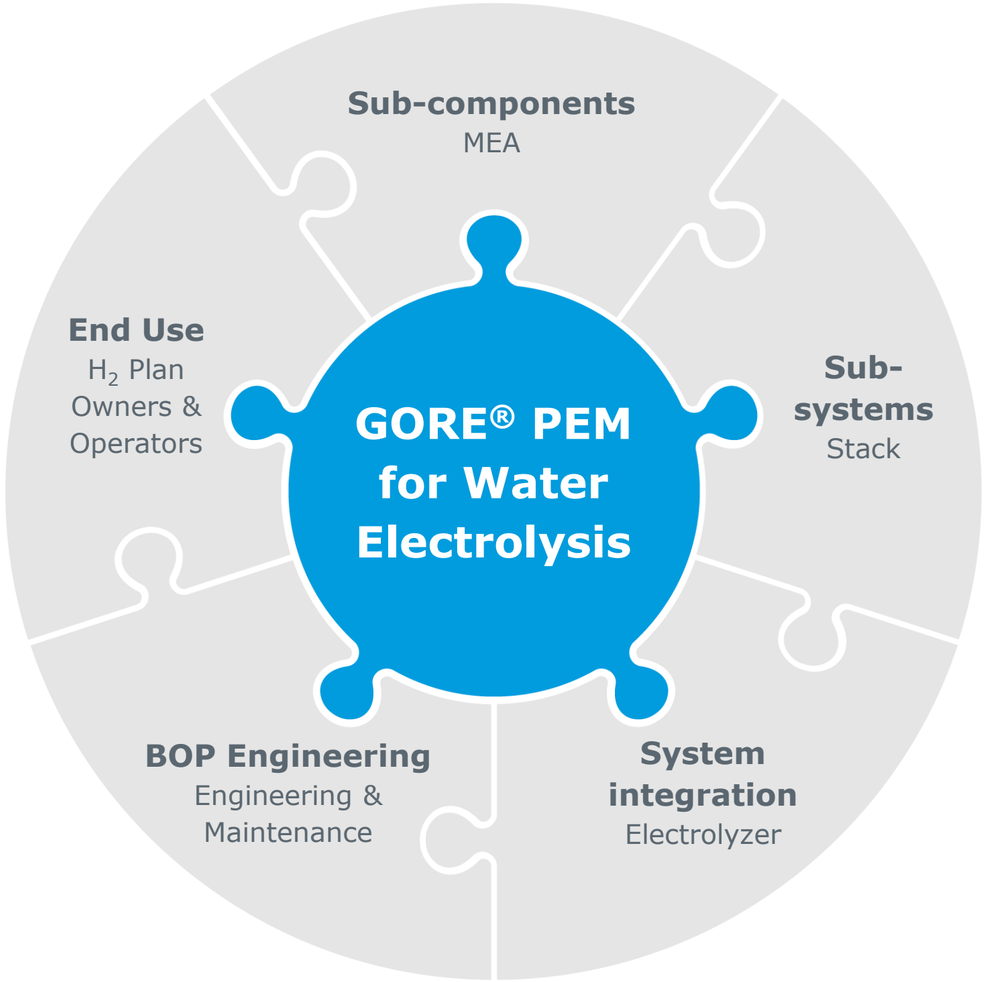


FOR INDIVIDUAL COMPONENTS TO WORK IN COMPLEX SYSTEMS, WE NEED COLLECTIVE EXPERIENCE, EXPERTISE – AND **COLLABORATION**.

# Even an advanced membrane can't do it alone ...

- A new and complex technology presents new and complex challenges.
- Different stakeholders in the supply chain have competing requirements.
- The solution? **Collaboration**.

**Interdependent components require orchestration**. Our collective expertise and experience can solve component integration challenges!



# Creating the clean energy future – together.

- We have developed a "multi-use" membrane for broad application in Water Electrolysis …
- … and with the right partners, we can develop tailored WE membranes for different systems + requirements.


## WE OFFER

1. **25 years' membrane technology & electrochemical expertise**
2. **Global analytical capabilities and prototyping facilities**
3. **Proven, reliable and secure supply**

## WE'RE LOOKING TO

1. **Expand our fundamental understanding on PEM fitness-for-use in Water Electrolysis systems**
2. **Increase our technical insights on system performance and component interactions**
3. **Align on future development vectors and product roadmaps**

# We're taking established partnerships even further

**Dennis Schulz**, CEO ITM Power

ITM POWER

"We are delighted to elevate our collaboration with Gore to the next level. Their understanding of membranes and their product quality and reliability are market-leading, and by forging ahead with this alliance, we are further cementing our technology leadership whilst at the same time ensuring that a key part of our supply chain is future-proof as we scale up."

PEM SYSTEMS NEED TO **SCALE UP** QUICKLY TO MEET GROWING DEMAND, REQUIRING A RELIABLE, SOPHISTICATED SUPPLY CHAIN.

# Leveraging our world-leading fuel cell legacy

Gore has been at the forefront of the fuel cell industry for 25+ years.

**Millions**
Of square metres of PEM & MEA

Our established **process stability & supply security** can produce high volumes of high-quality materials.

**Toyota Project Award Technology Section**
GORE-SELECT® Membrane is incorporated into the 1st & 2nd-generation Toyota MIRAI.

We have established **long-term partnerships** with key global OEMs.


**> 60,000**
Fuel cell vehicles powered

Our quality consistency delivers a uniform product that **reduces risk of failure / quality defects and enables higher process yields**.

**> 100**
Different models developed

**Powering**
Hyundai's NEXO Fuel Cell EV SUV

Our PEM supply is fully **integrated into global commercial FCEV production**.

# Applying our fuel cell expertise to water electrolysis

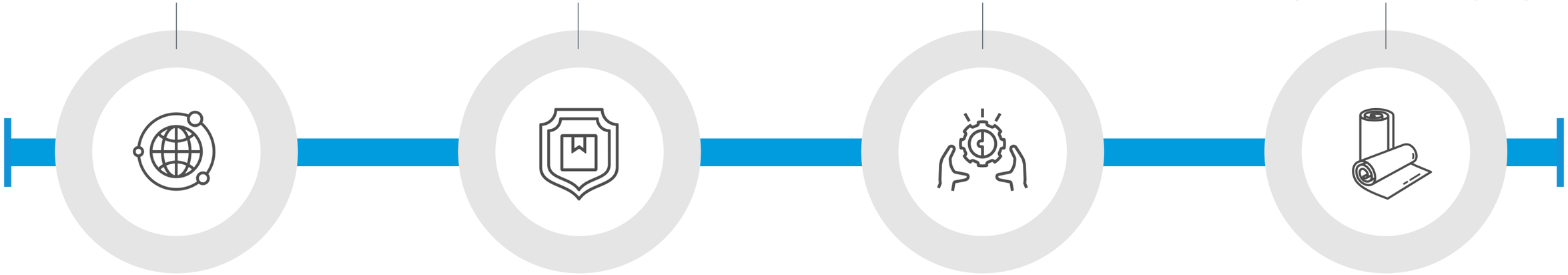
Overcoming challenges and reducing risks in an uncertain environment.

**Global production capacity**
of 20 GW of PEM with multiple production lines

**Proven supply security,**
process stability + consistent quality

**Strategic partnership**
for critical raw materials with priority access

**Market-leading PEM**
that optimizes commercialization while enabling lower cost of hydrogen



Gore’s established enterprise resources are set up to support **Multi-Gigawatt installations TODAY**.

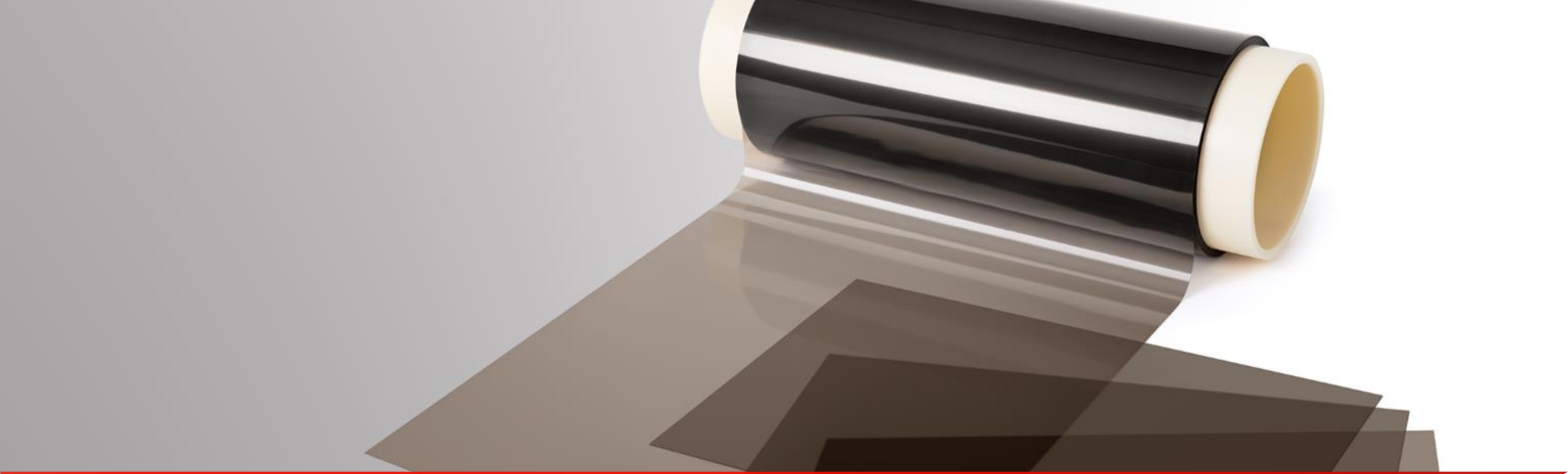
# TO SUMMARIZE…

# We can achieve our carbon targets – if we collaborate


## EFFICIENCY. SCALABILITY. SYSTEM INTEGRATION.

- WE systems must become more **efficient** to make hydrogen more affordable – enabled through Gore‘s **highly conductive and durable PEM.**
- WE PEM systems need to **scale up quickly** to meet growing demand – enabled through Gore‘s already established **high volume capacity and proven supply security.**
- For individual components to work in complex systems, we need **collective experience and expertise** – enabled by **effective collaboration.**

LET'S NOT WAIT TO CREATE A CLEAN ENERGY FUTURE.
PEM TECHNOLOGY IS **AVAILABLE AT SCALE TODAY**.



# THANK YOU.

Contact our Clean Energy team to learn more about the new **GORE® PEM for Water Electrolysis**.

**gore.com/alt-energy**

*Together, improving life*