

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

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

Rainer Enggruber

Global Head of PEM Water Electrolysis
W. L. Gore & Associates GmbH

Together, improving life



GORE

Agenda

1.0

Addressing the challenges for green hydrogen production

2.0

Making PEM systems more efficient

3.0

Scaling PEM systems demands a reliable supply chain

4.0

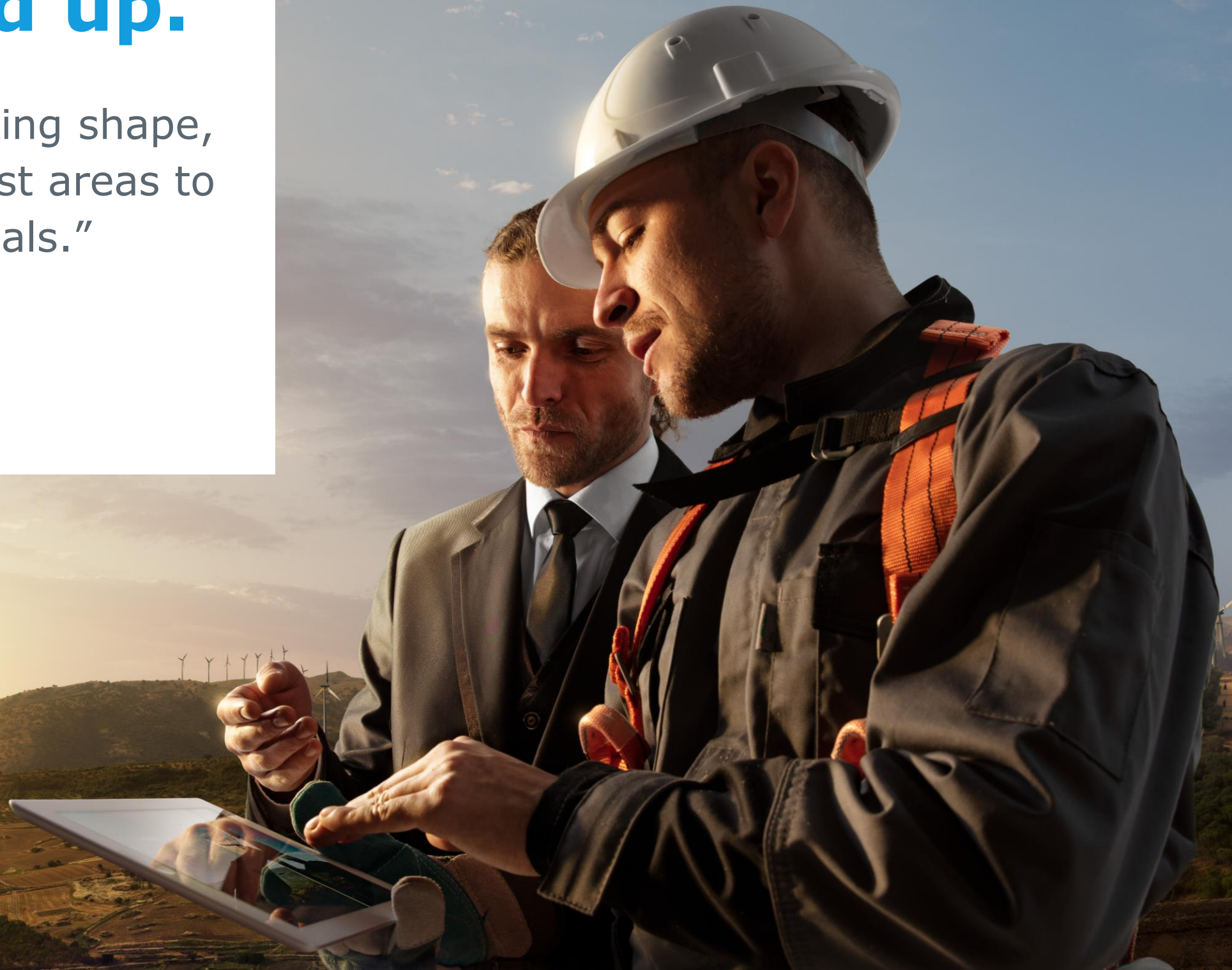
Collaboration is key for complex systems to work



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.”

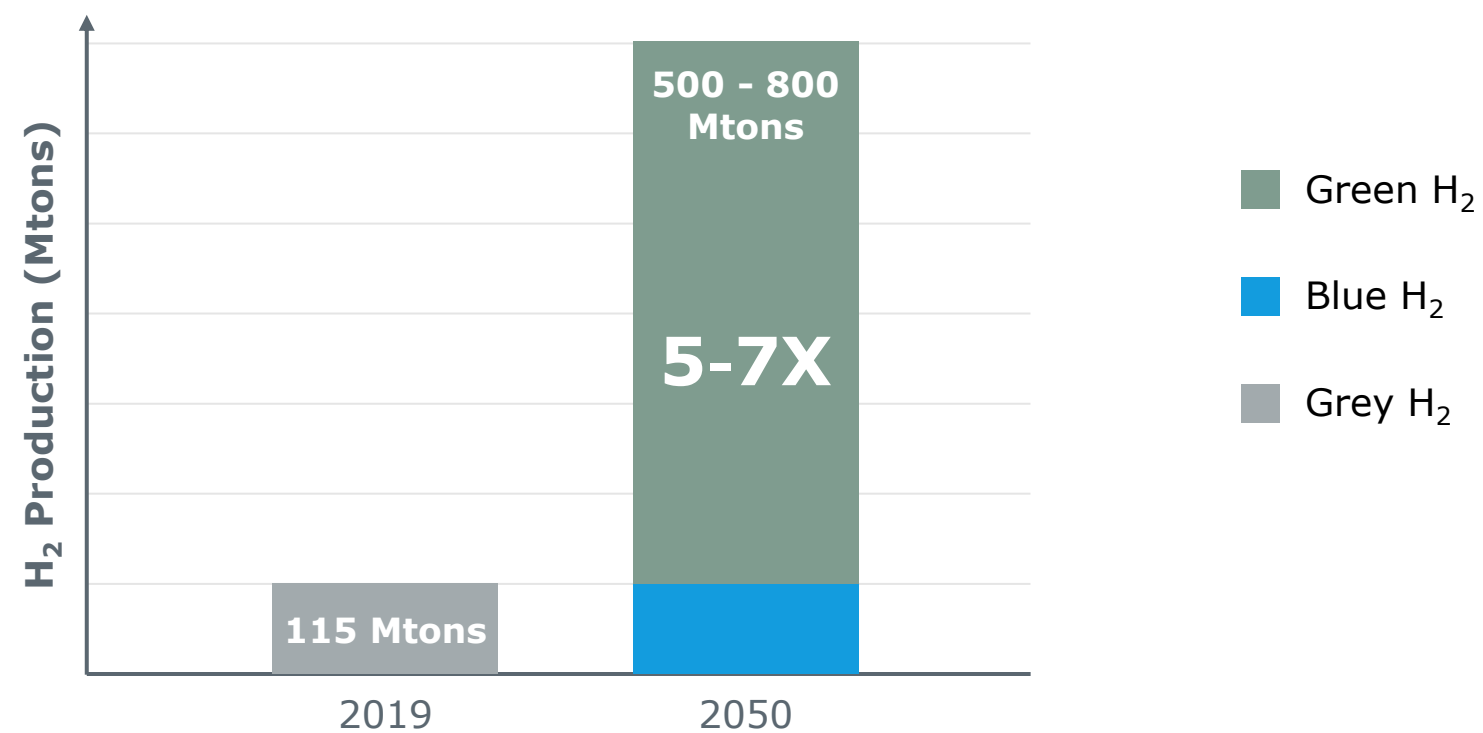
Fatih Birol, Executive Director
International Energy Agency (IEA)



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

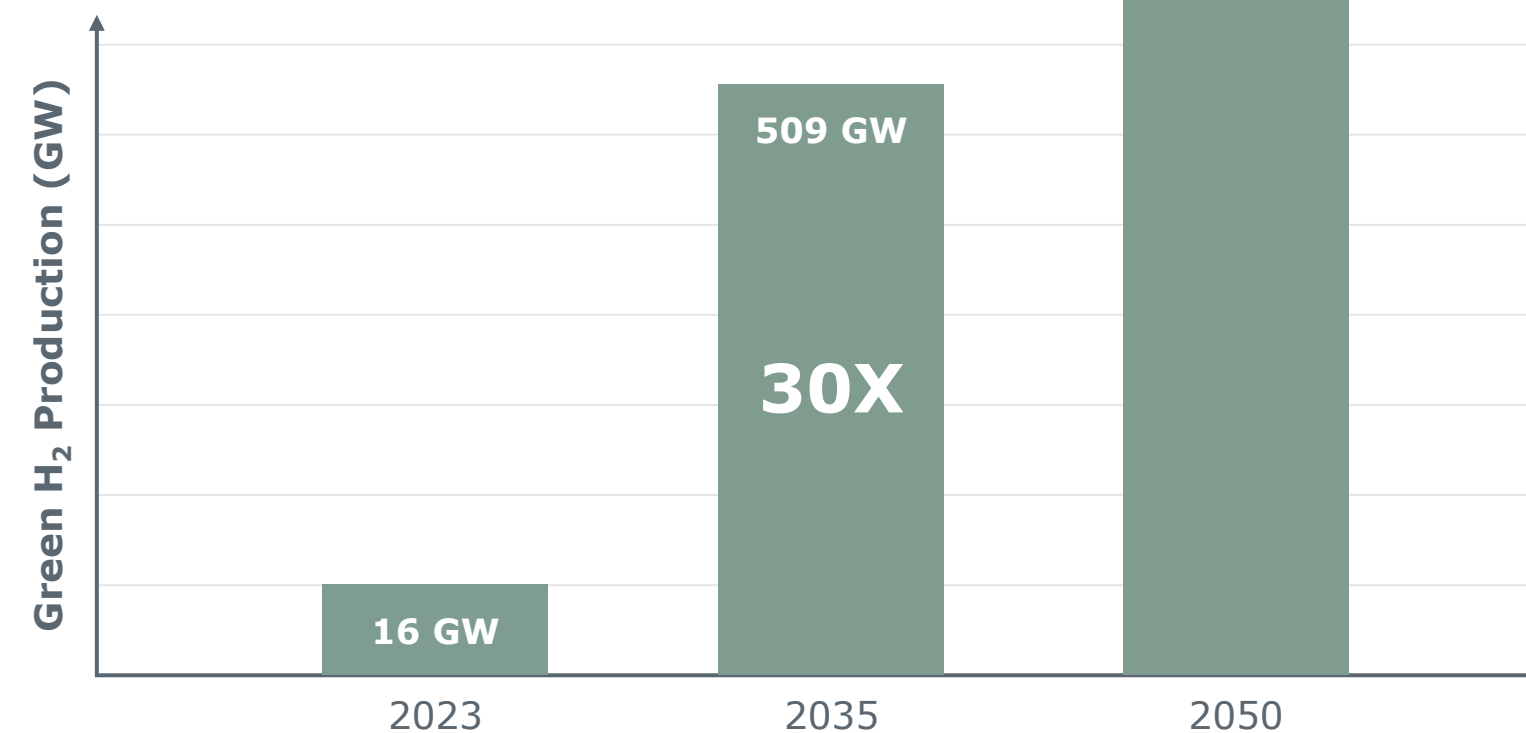
ULTIMATE GOAL

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

Green Hydrogen production scale-up required

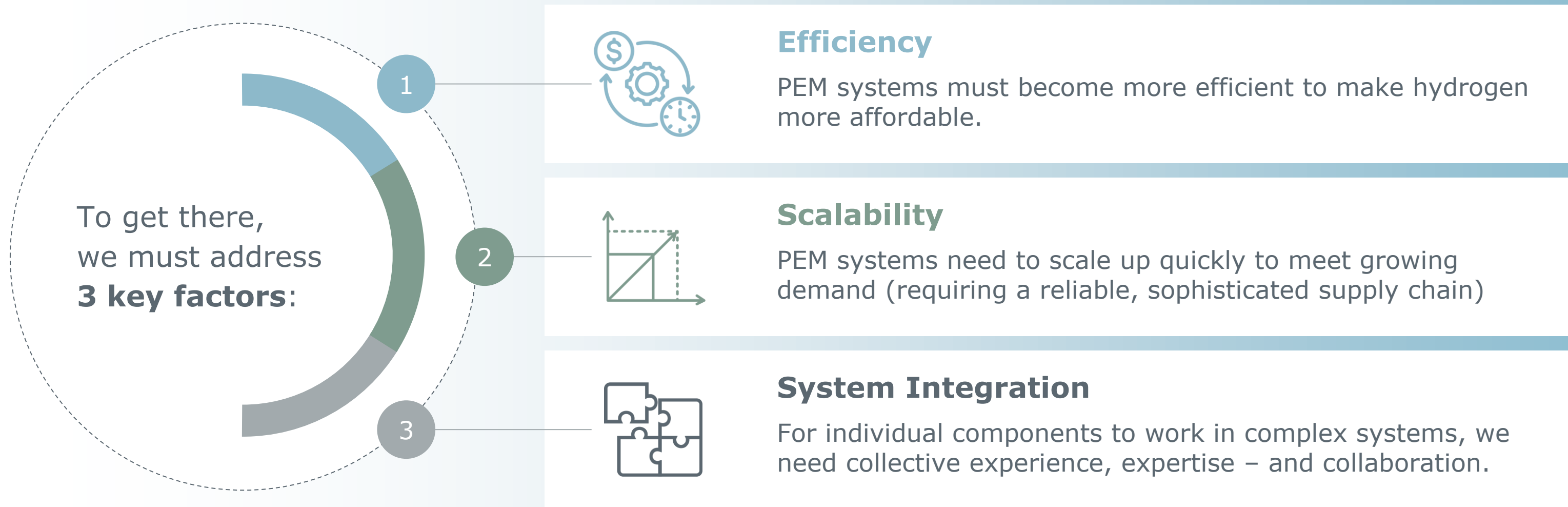


IHS/S&P Global estimates from July 2023

Enabling change in the ecosystem

Finding the pathways to success.

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



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

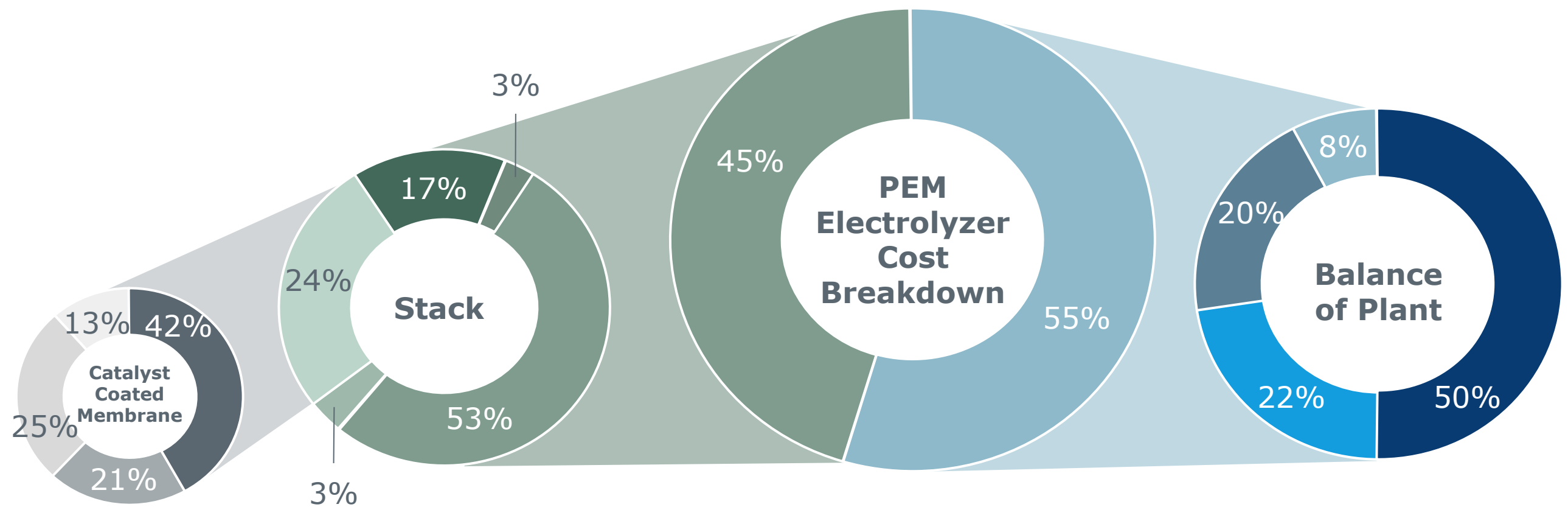
CAPEX is important. OPEX is critical.

TOTAL SYSTEM COST BREAKDOWN

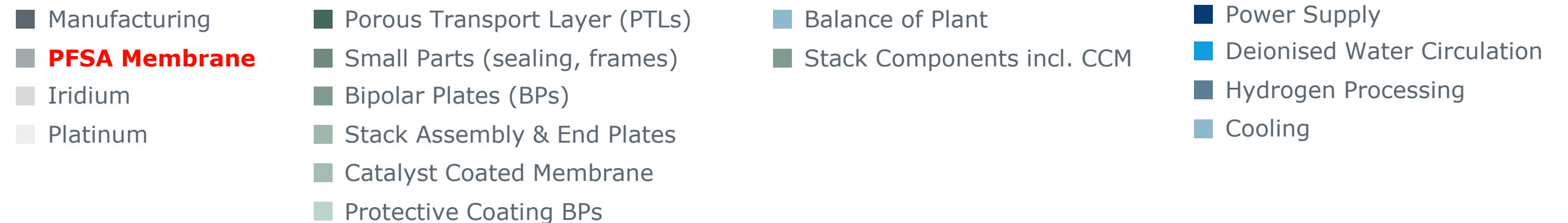
OPEX Costs

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 °C Climate Goal, International Renewable Energy Agency, Abu Dhabi.

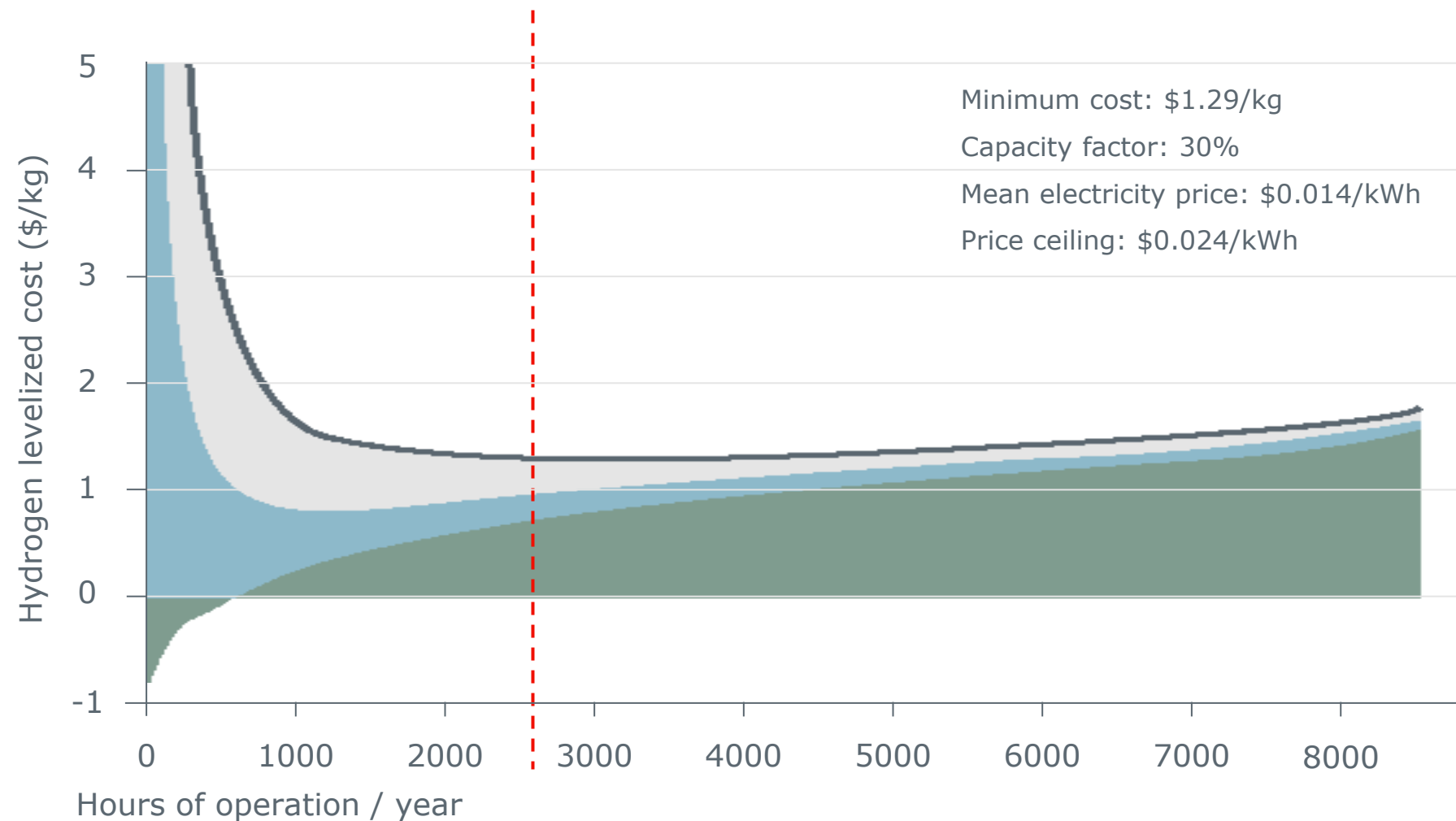


Reducing OPEX is the key to delivering results

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Total System Cost Breakdown

OPEX COSTS



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

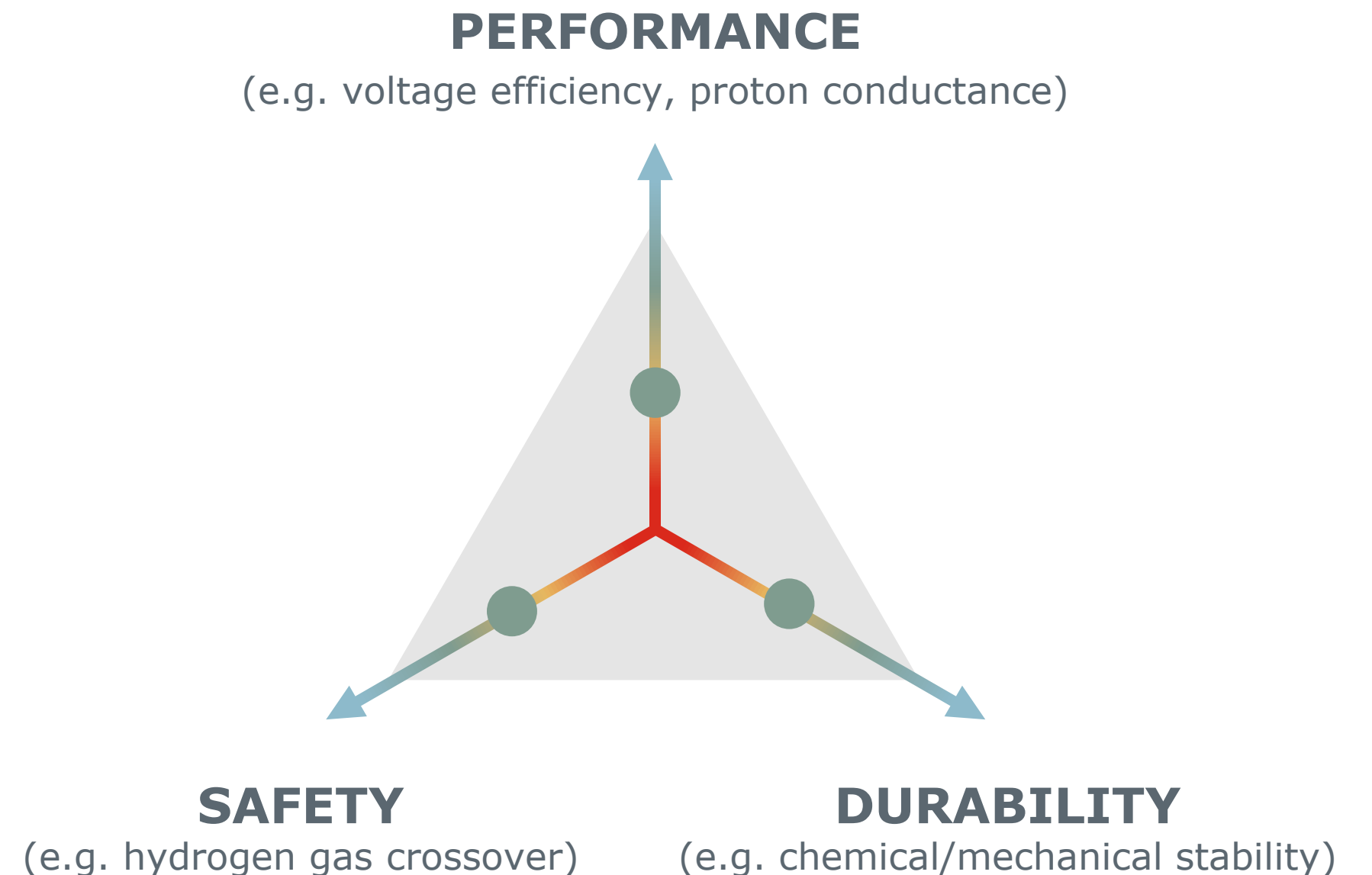
To scale up to meet net-zero demands,
OPEX is the deciding factor in delivering a lower levelized cost of hydrogen.

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

Tackling technology trade-offs to reduce OPEX

Why compromise – when you can optimize?

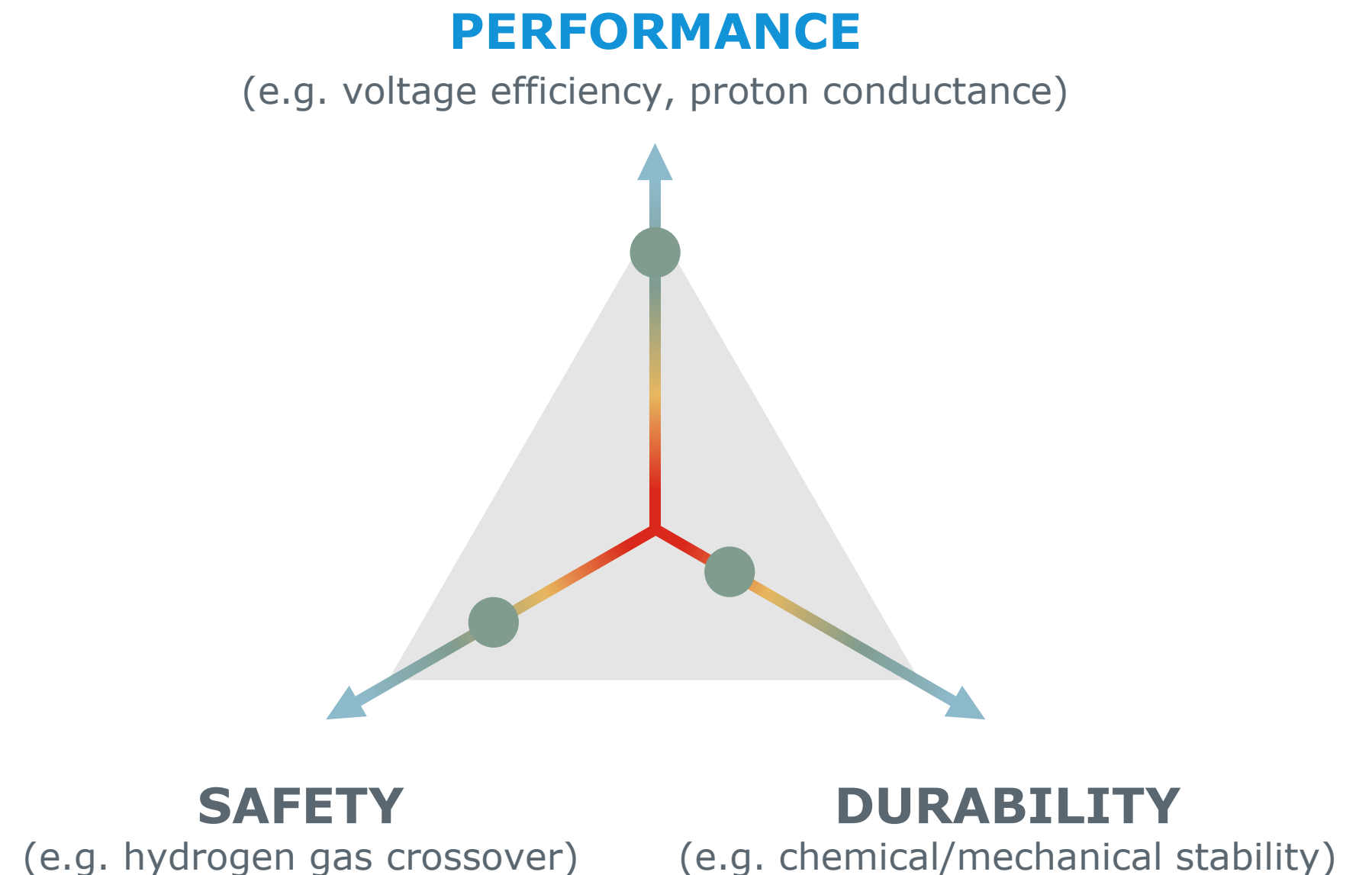
- Engineers typically face the 'system dilemma' of **optimizing performance, safety** and **durability**.
- Optimizing for 1 criteria has meant compromising on the others... until now.
- Gore has developed **an advanced PEM that can optimize them all – at the same time**.



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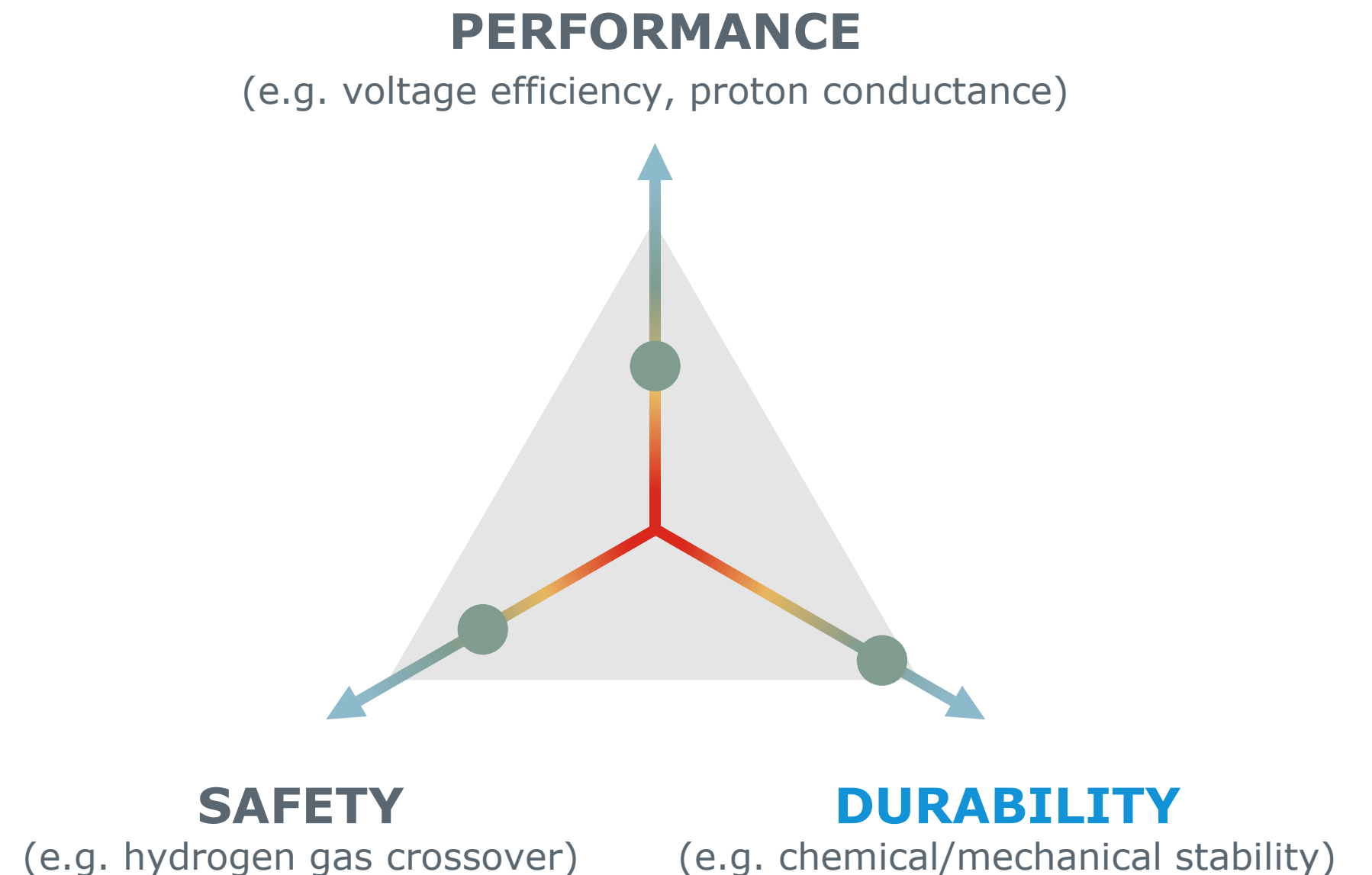
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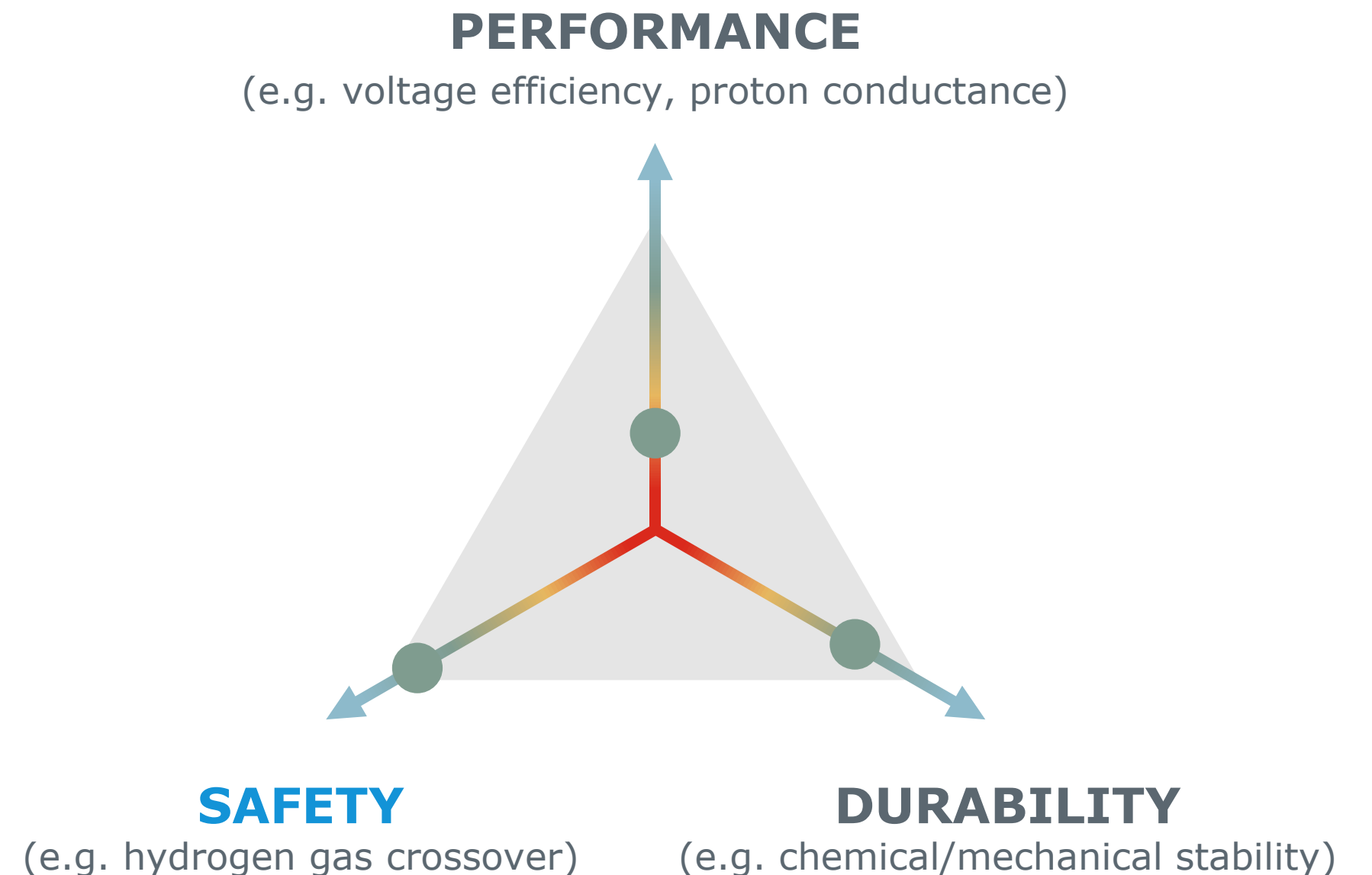
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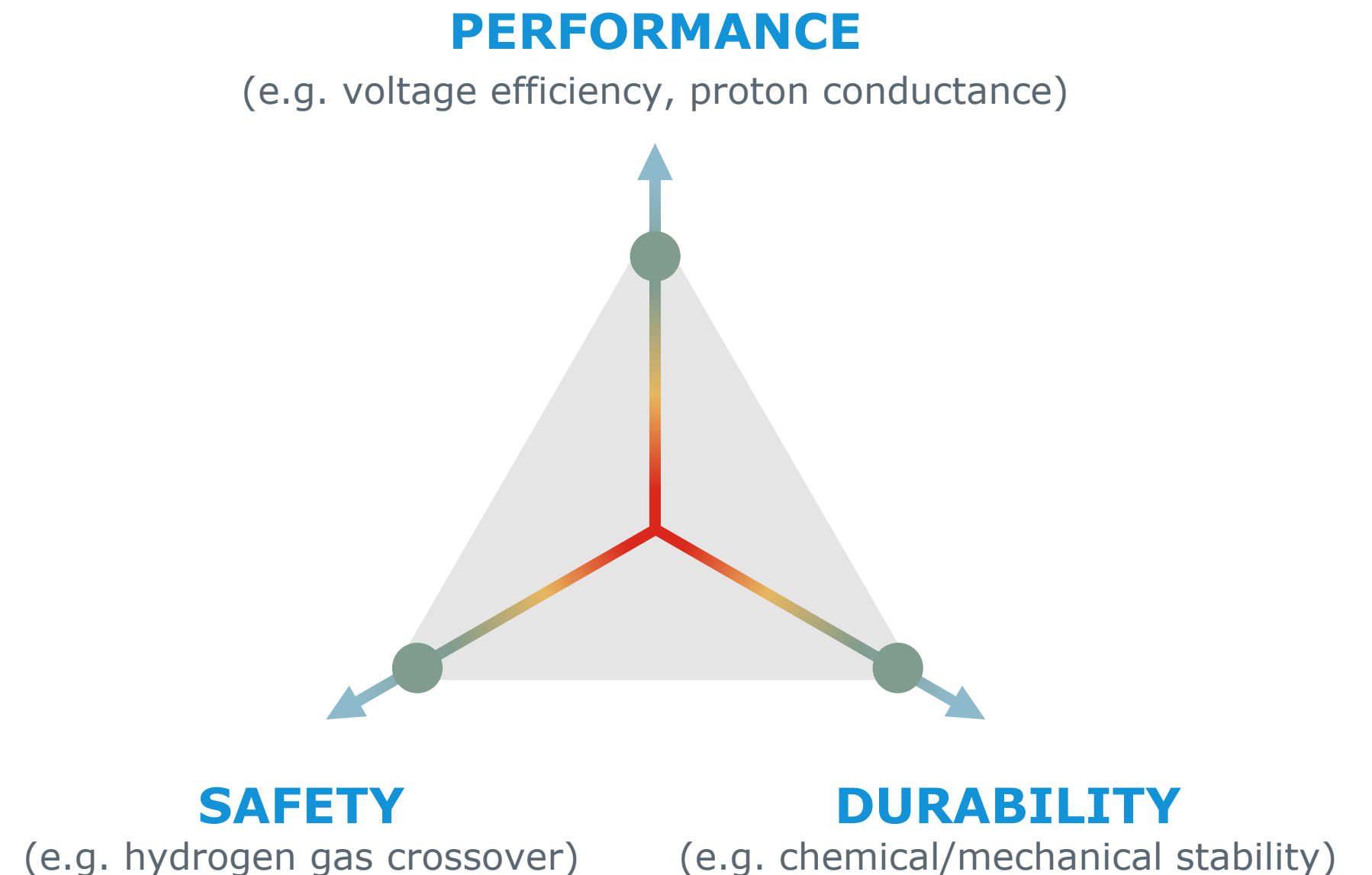
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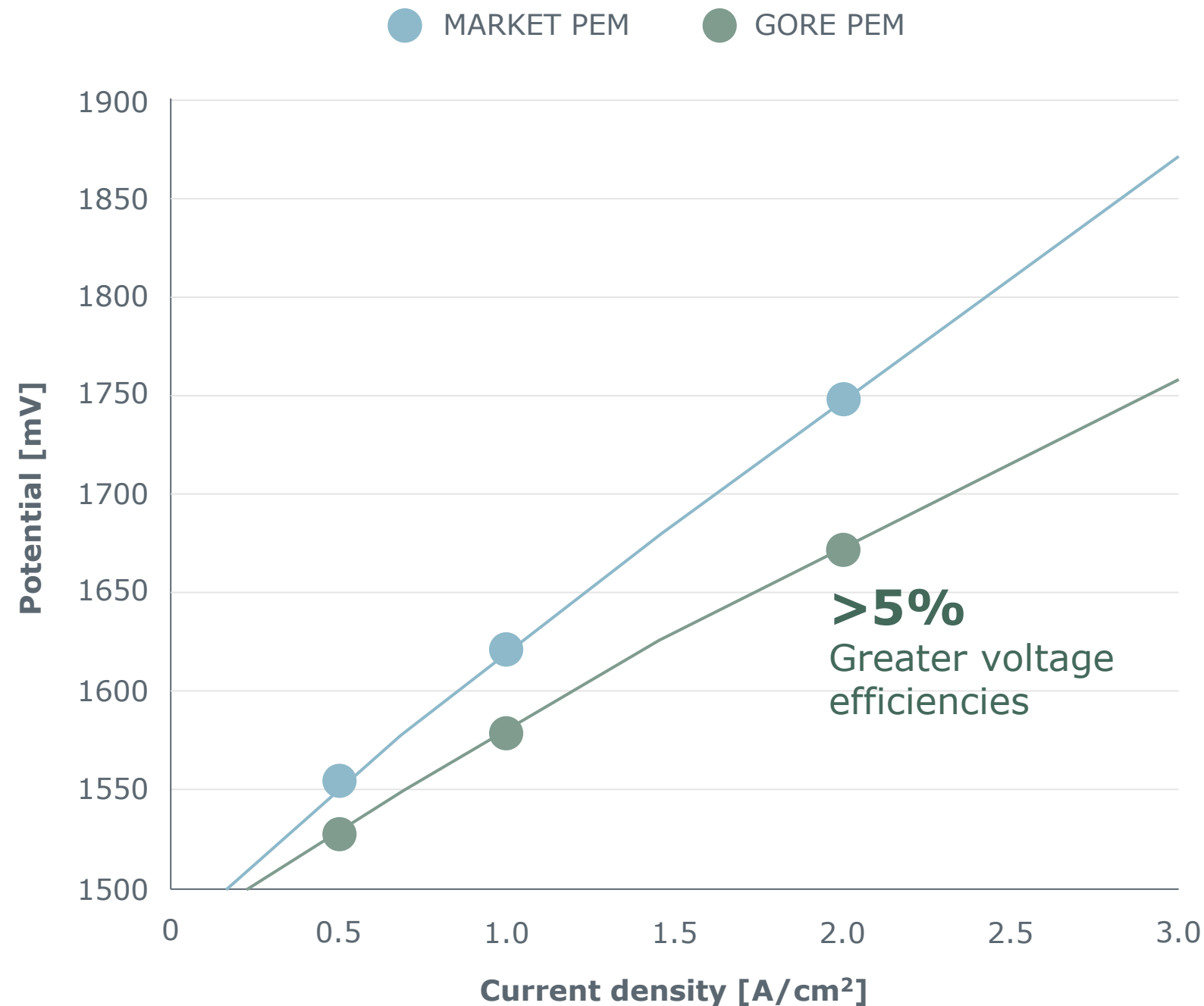
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How does better performance benefit your **output**?

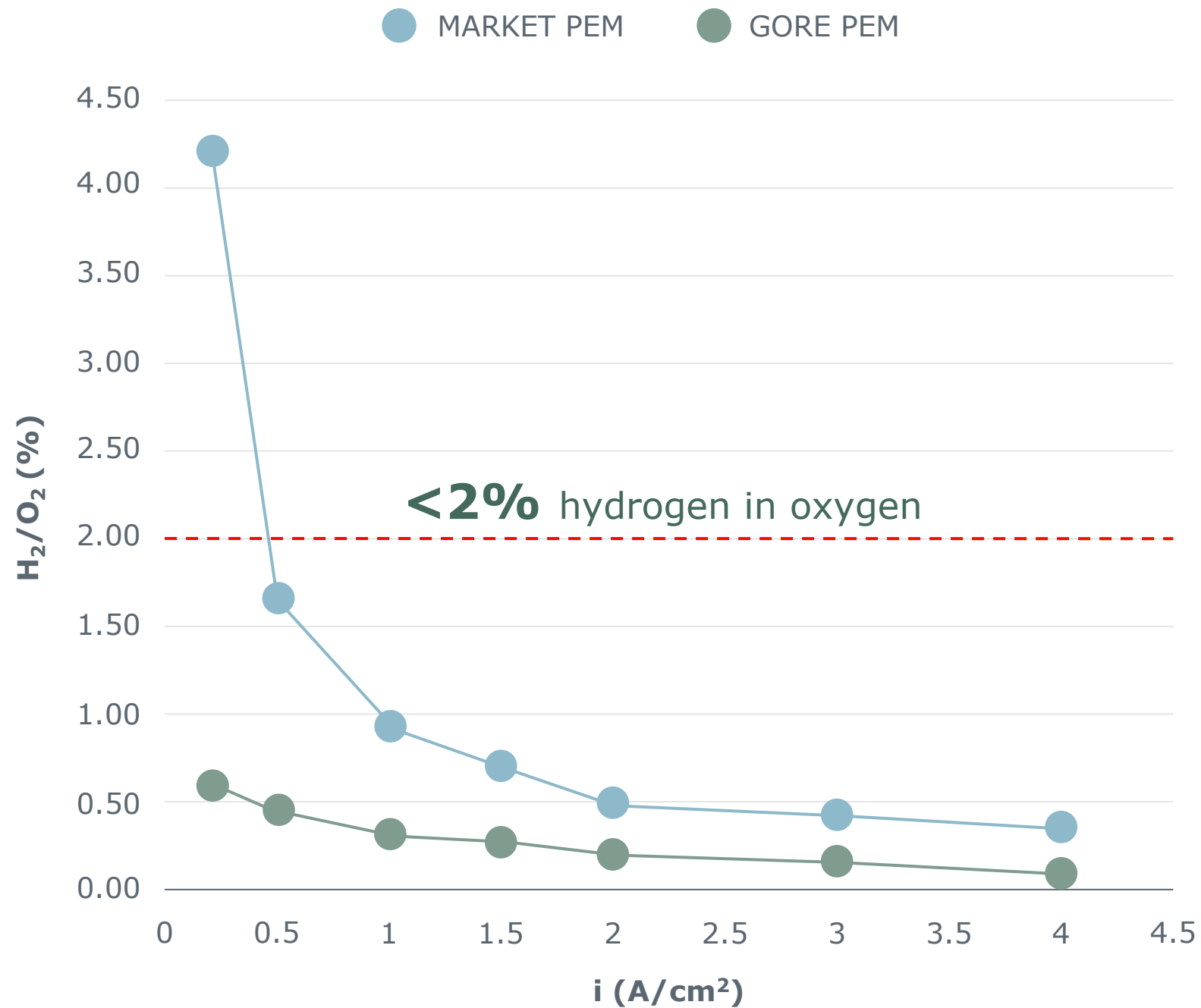


Expected cell performance data at 80 °C and ambient pressure

- Gore's PEM offers **>5% greater cell voltage efficiencies over other PEM** while meeting safety & durability requirements.
- This dramatically **reduces the amount of energy required** to produce 1kg of Hydrogen.

Increasing voltage efficiency enables **higher H2 output for the same energy consumption** (or vice versa; less energy consumption for the same H2 output)

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

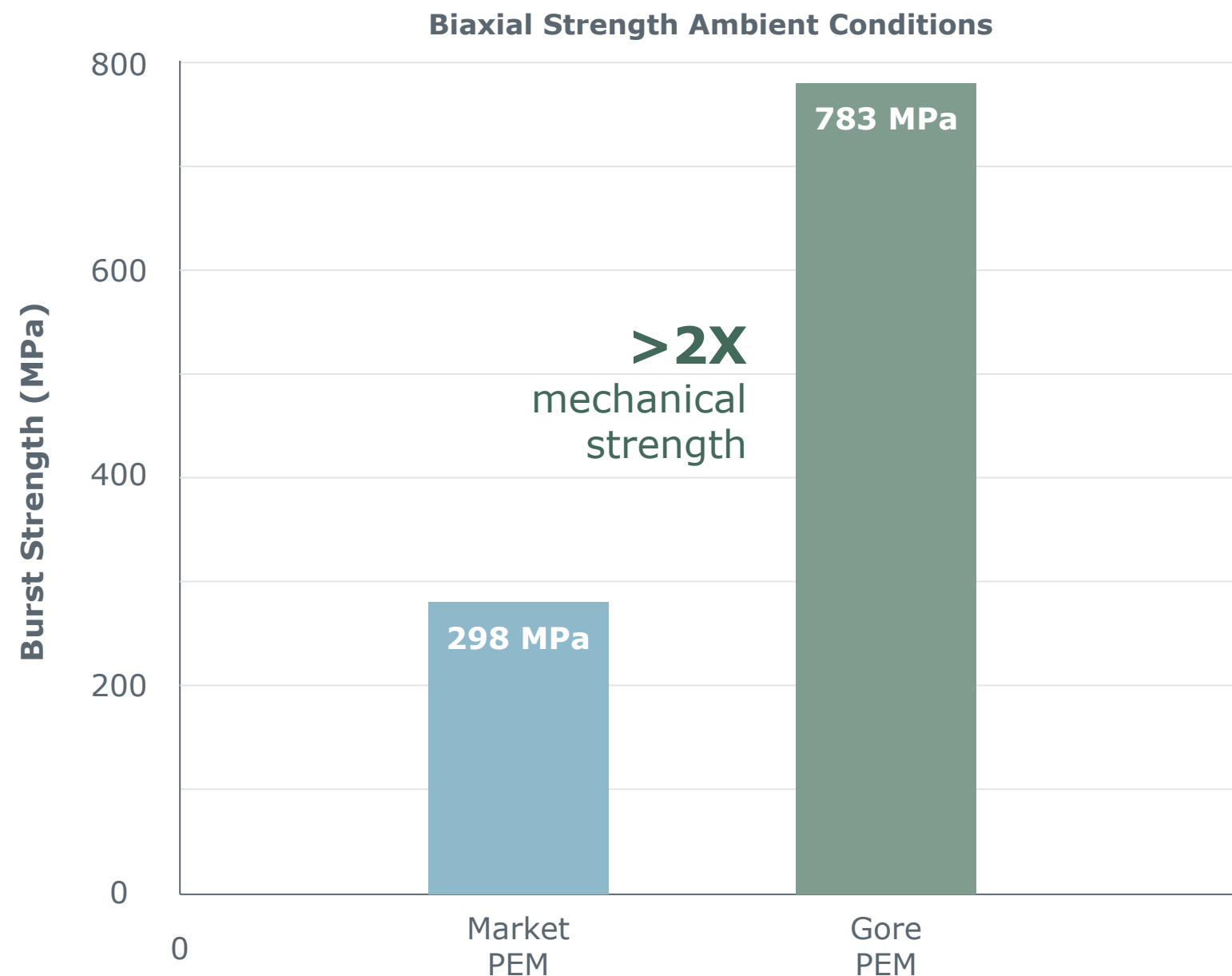


Expected cell performance data at 80 °C and ambient pressure

- 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, 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**

Breaking performance barriers with Gore's high-performance PEM

Reducing system trade-offs with our advanced membrane technology.

Ionomer

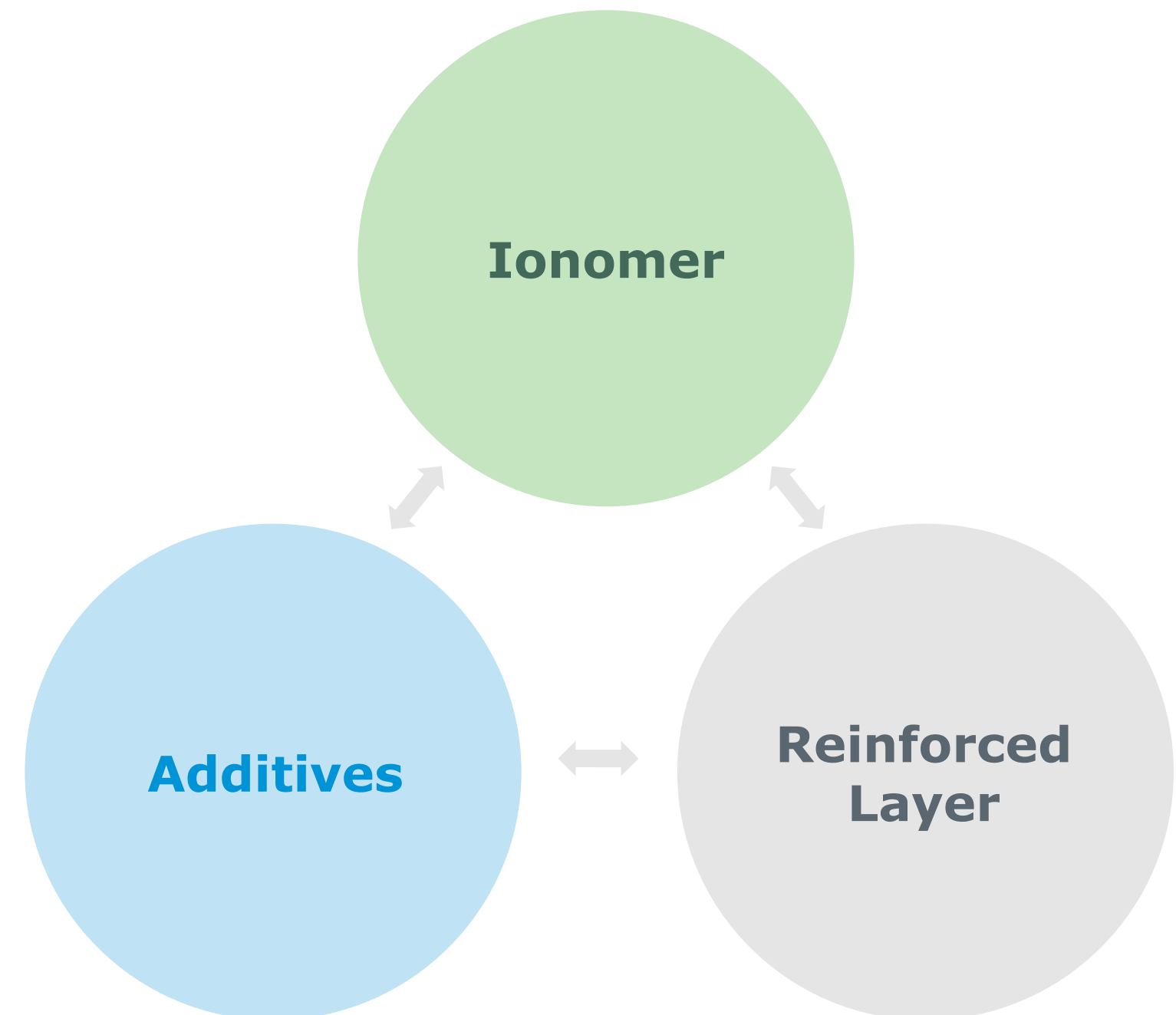
- High proton conductance + high voltage efficiency for **increased performance**

Additives

- Greater chemical durability + reduced H₂ crossover for **increased durability and safety**

Reinforced Layer

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



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.



> 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.**



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.



> 100

Different
models
developed

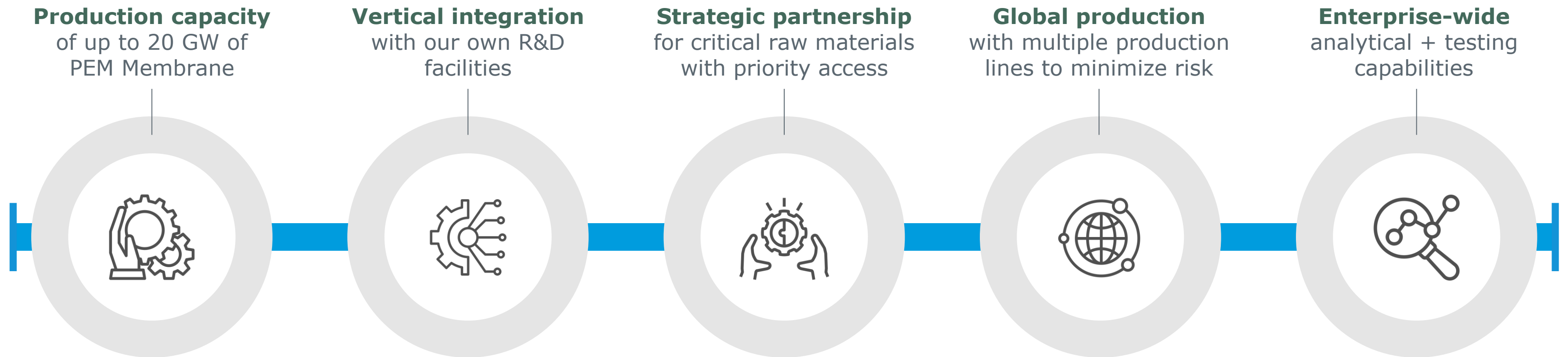


Powering
Hyundai's
NEXO Fuel Cell
EV SUV

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

Applying our fuel cell expertise to water electrolysis

From innovation to infrastructure.



Gore's established supply chain is set up to support **Multi-Gigawatt installations TODAY.**

We're already supplying large-scale electrolysis programs



Dr. Peter Geskes,
VP R&D and Product Management
Hydrogen Electrolyser Systems
Siemens Energy Global GmbH & Co. KG

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“Gore’s experience in the Hydrogen economy will be extremely helpful to advancing our electrolysis effort under consideration of current PEM technology. By leveraging their resilient supply chain and production capacity as well as their process and product expertise, we are confident that Gore’s high-performance PEM will support safe and reliable operation in our electrolysis systems.”

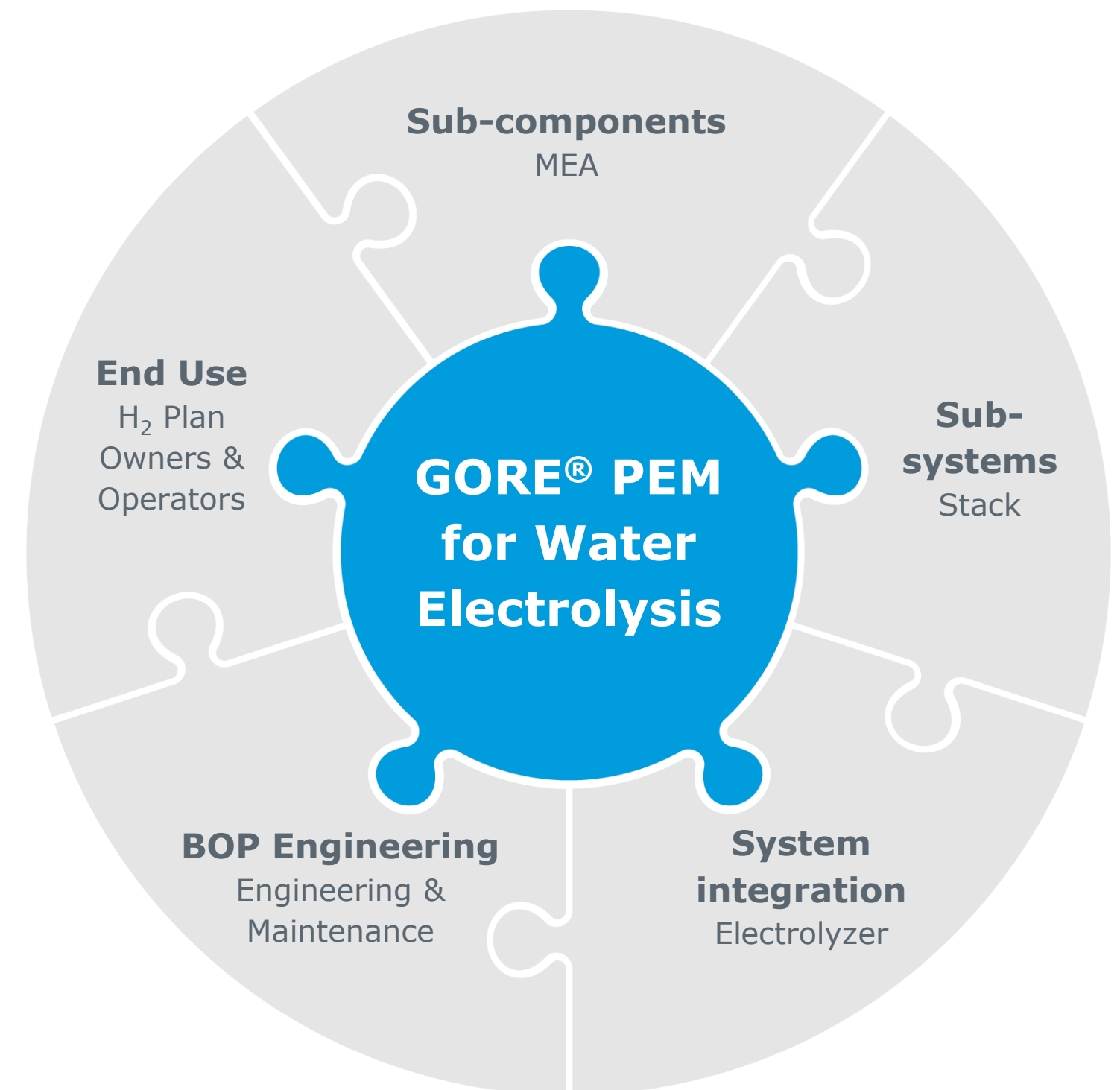
FOR INDIVIDUAL COMPONENTS
TO WORK IN COMPLEX SYSTEMS,
WE NEED COLLECTIVE
EXPERIENCE, EXPERTISE –
AND **COLLABORATION.**



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



“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.”

TO SUMMARIZE...



We can achieve our carbon targets – if we collaborate



EFFICIENCY. SCALABILITY. SYSTEM INTEGRATION.

- PEM systems must become more **efficient** to make hydrogen more affordable.
- PEM systems need to **scale up quickly** to meet growing demand.
- For individual components to work in complex systems, we need collective experience, expertise – and **collaboration**.

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



THANK YOU.

Contact us to learn more about our game-changing new
GORE® PEM for Water Electrolysis.

Together, improving life

