WELCOME! The webinar will begin shortly.

A recording of the webinar and the slides will be available afterwards.

FIND OUT HOW TO REPLACE “DIFFICULT” PFAS USES WITH SAFER ALTERNATIVES

chemsec
INTERNATIONAL CHEMICAL SECRETARIAT

ChemSec, 19 June 2023

FIND OUT HOW TO REPLACE “DIFFICULT” PFAS USES WITH SAFER ALTERNATIVES

chemsec
INTERNATIONAL CHEMICAL SECRETARIAT

ChemSec, 19 June 2023

TODAY

- **Introduction** to ChemSec
- **Smorgasbord** of **PFAS alternatives**
  - **Technical textiles**
  - Alternatives to **F-gases**
  - **Semiconductor manufacturing**
  - **Green energy solutions**
- **Questions** - use the Q&A function!

❑ Slides and recording will be available afterwards

I-N-MR INNOVATIONS

ATMO sphere

TRANSENE COMPANY, INC.

sympatex®

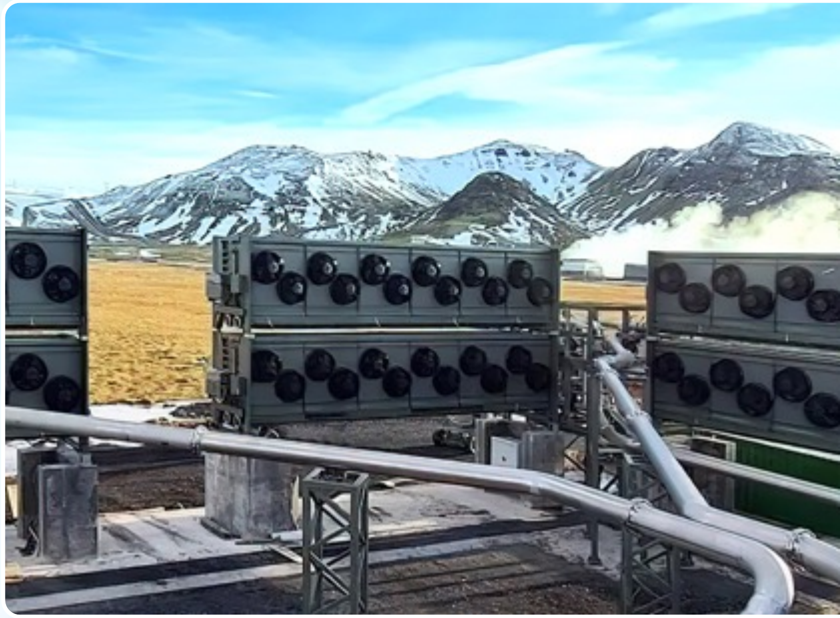
WHAT WE DO AT CHEMSEC

- Drive the political discussion on hazardous chemicals
- Challenge companies to improve their chemicals management
- Develop online tools to help companies switch to safer chemicals
- Inform investors about risks and opportunities in the chemical industry

IONOMR INNOVATIONS

19 June 2023 | ionomr.com

Breakthrough Hydrocarbon Materials for the Energy Transformation



Founded 2018

50 Employees

$30M+ USD Funding

Two Breakthrough Materials Families

Company Overview

Ionomr – the leader in next-gen ion-exchange materials

Diverse Marketplace

Hydrogen Production, Fuel Cells & CCUS

Industry Experts

Supported by more than 10 years / 100K hours of R&D

Innovative

50-year breakthroughs in both AEM and PEM solutions

Protected IP

Broad patent portfolio: material, process, composite, device

IONOMR INNOVATIONS

Selected Recognition

NOURYON'S IMAGINE CHEMISTRY

"Collaborative innovation challenge" winner and recipient of JDA for eco-friendly membrane technology

F-CELL "PRODUCTS & MARKETS"

Pemion® as a breakthrough product for FCEV's @ largest European FC Expo (Stuttgart)

SHELL GAMECHANGER ACCELERATOR

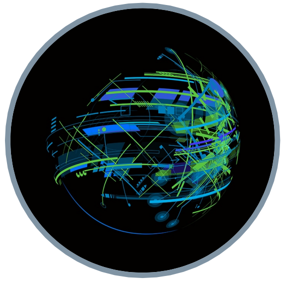
Powered by Shell & NREL, validating Aemion+® for electrolysis & CCU

WEF TOP 100 TECHNOLOGY PIONEERS

World-leading innovative companies solving critical global challenges

GLOBAL CLEANTECH 100

Top companies globally driving the future sustainable economy



DELOITTE TECHNOLOGY FAST 50

"Ones to watch" technology companies in Canada

GLOBAL CLEANTECH 100

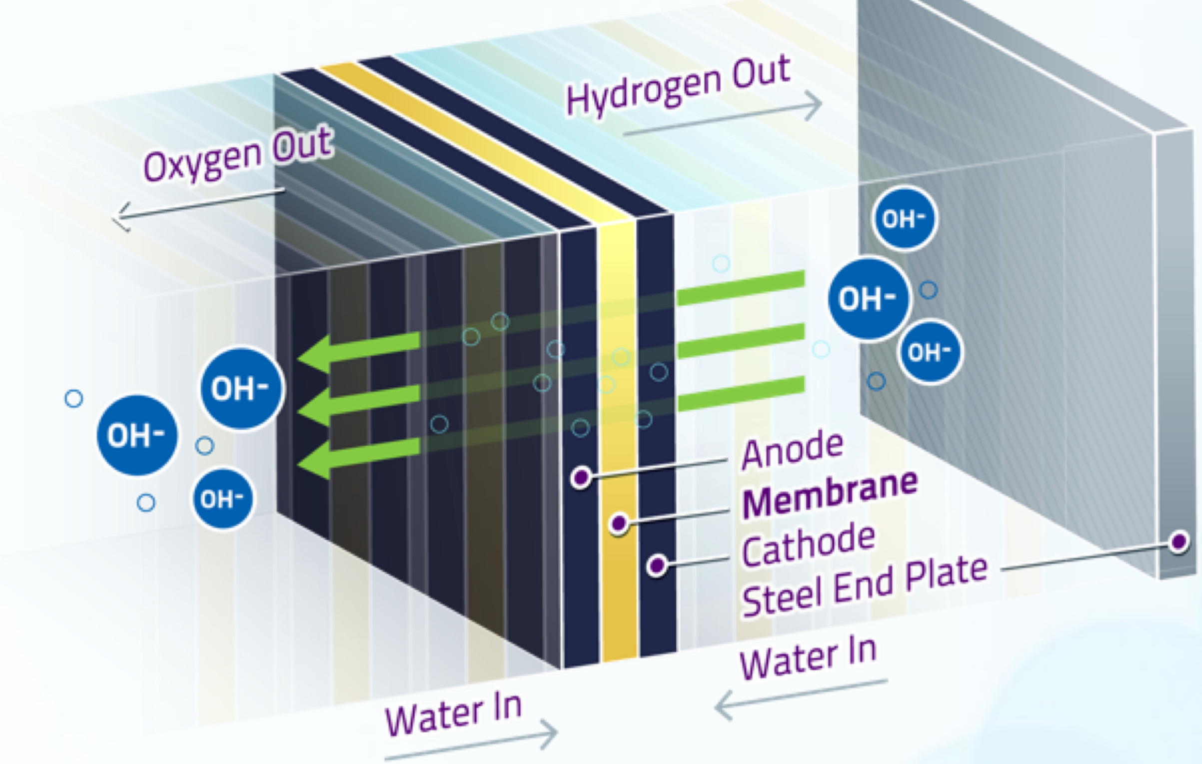
The leading companies and innovators in cleantech today

2020 — 2021 — 2022 — 2023

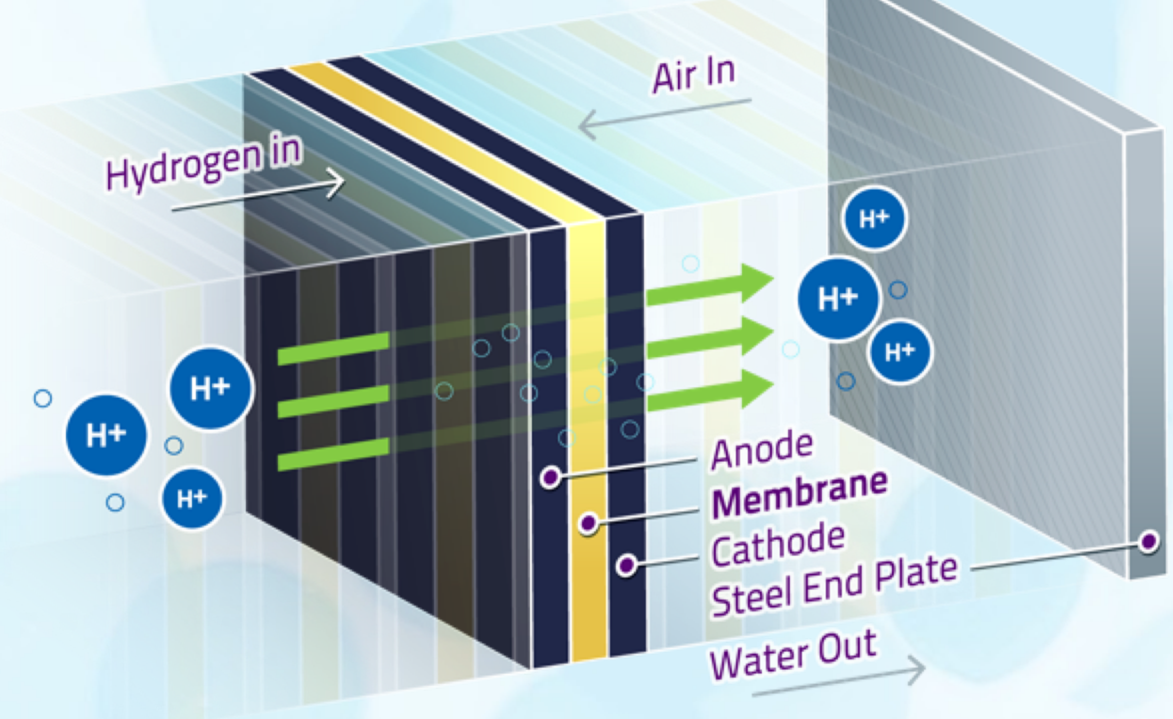
IONOMR INNOVATIONS

Electrochemistry Needs Advanced Membranes

ELECTROLYZERS



FUEL CELLS



The ion-exchange membrane defines and determines a system's **durability**, **performance** and **efficiency**.

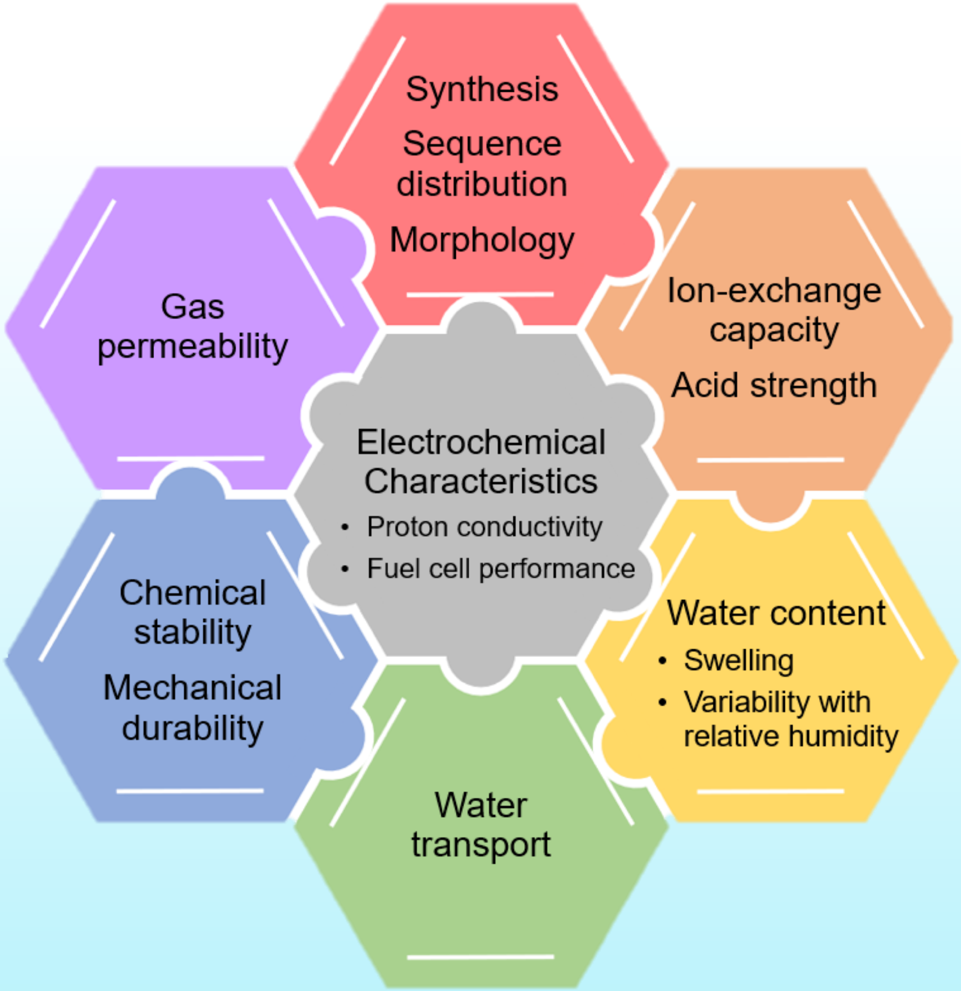
I⁘N⁘MR INNOVATIONS

Material Design Considerations

Ion-exchange materials have numerous interconnected properties

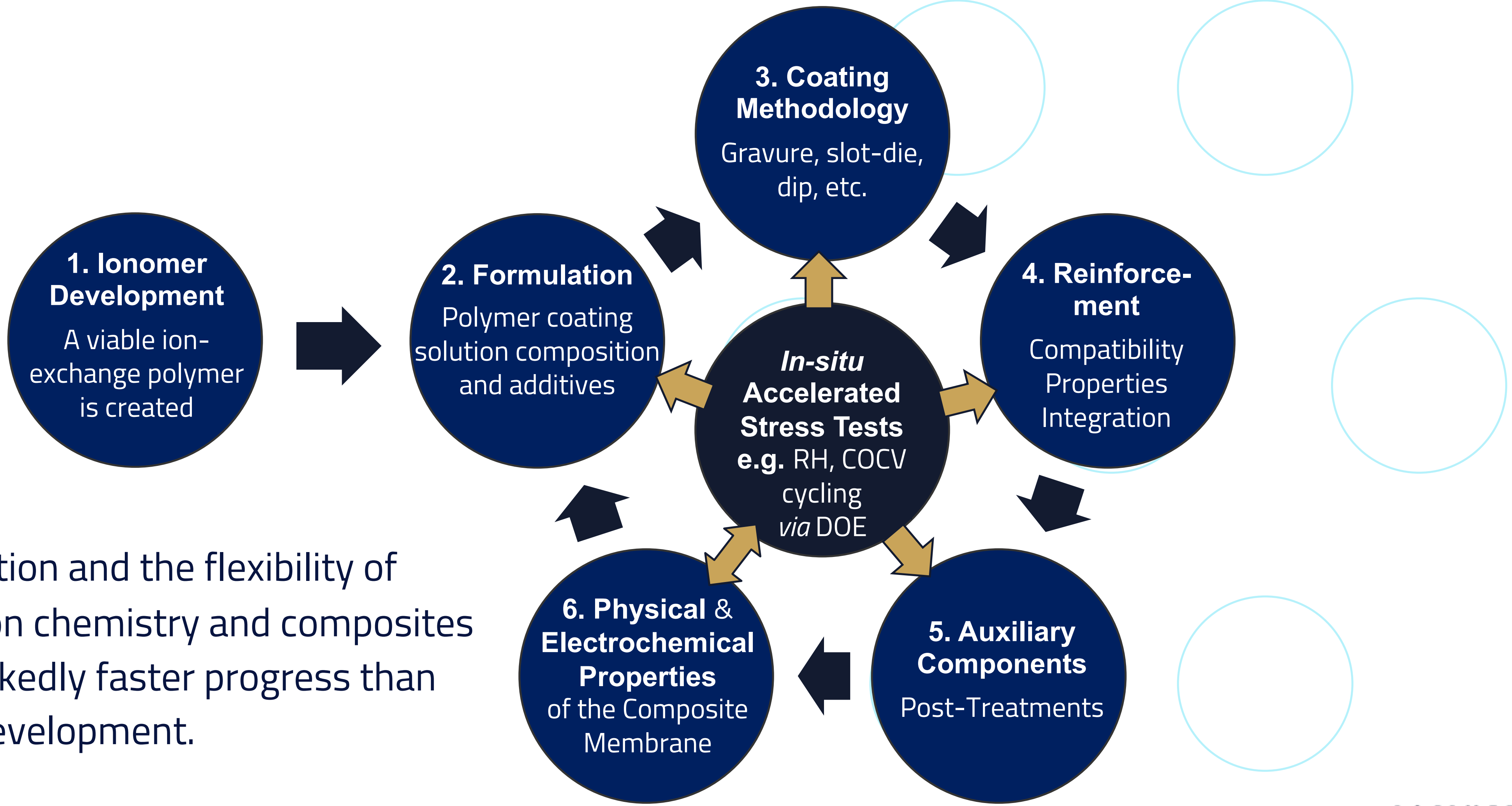
Ionomr's design experience enables creation of next-generation membranes and ionomers

- Strong emphasis on fundamental R&D and materials knowledge
- Rigorous design, development, & new product integration / characterization processes
- Each material is specifically application-designed with properties comprehensively screened prior to scale-up and pre-production release



IONOMR INNOVATIONS

Developing Next-Generation Materials

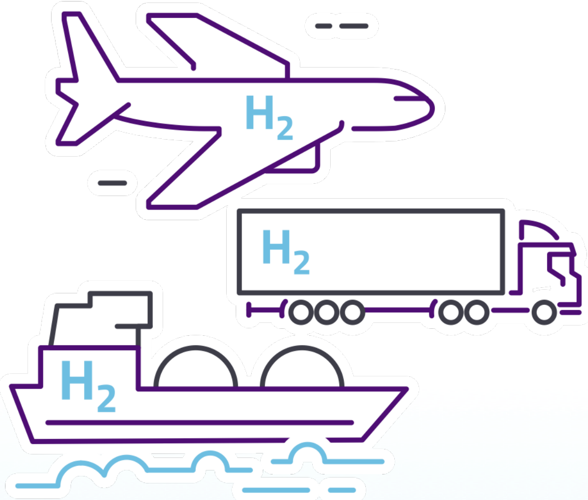


Rapid iteration and the flexibility of hydrocarbon chemistry and composites allows markedly faster progress than previous development.

IONOMR INNOVATIONS

Ionomr's Focus Verticals

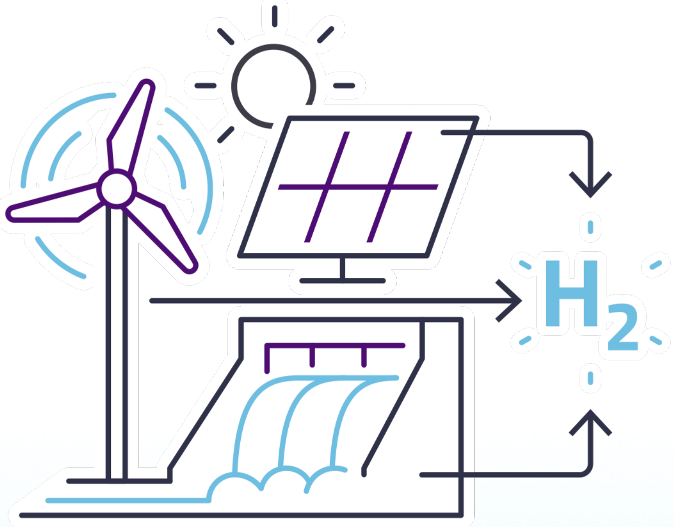
Heavy Duty Fuel Cells



Cost & Efficiency Breakthrough

Materials exceeding world-leading performance, full-scale cells being tested & full-scale system pilots in bring-up

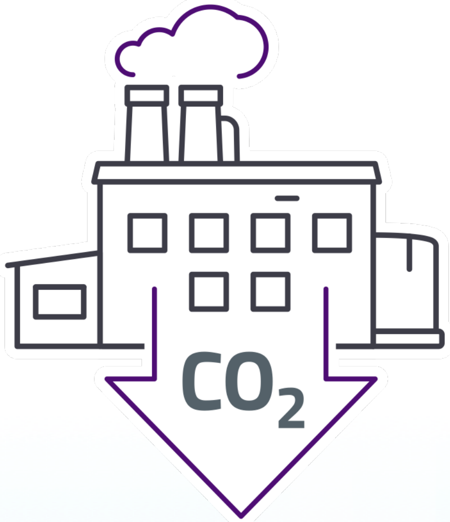
Green Hydrogen



Enabling CAPEX-effective H_2

9000+ hour durability demo, >700x durability in industry-relevant conditions, whole system exceeding EU 2024 goals

CO_2 Capture (CCUS)



Unlocking Carbon-to-Value

Numerous systems including a 3x for CO_2-to-CO + the first/only long-lived direct conversion to high-value 'C2+'

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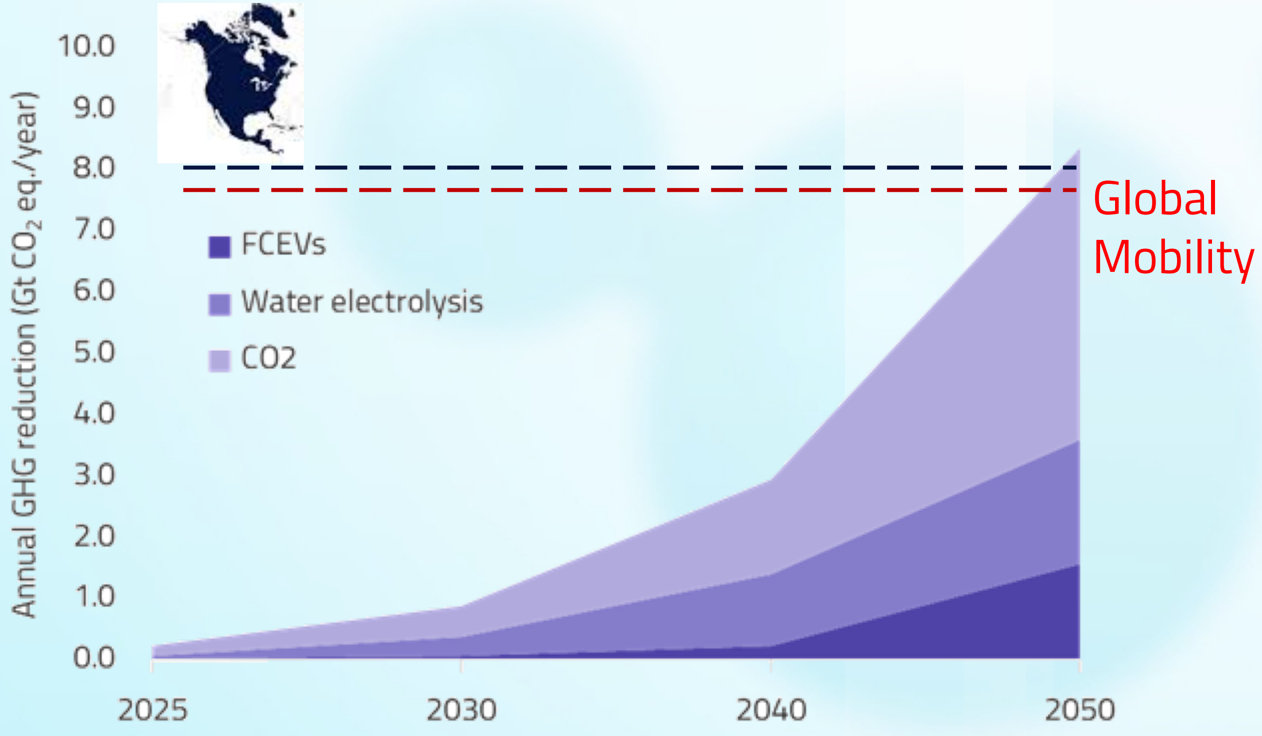
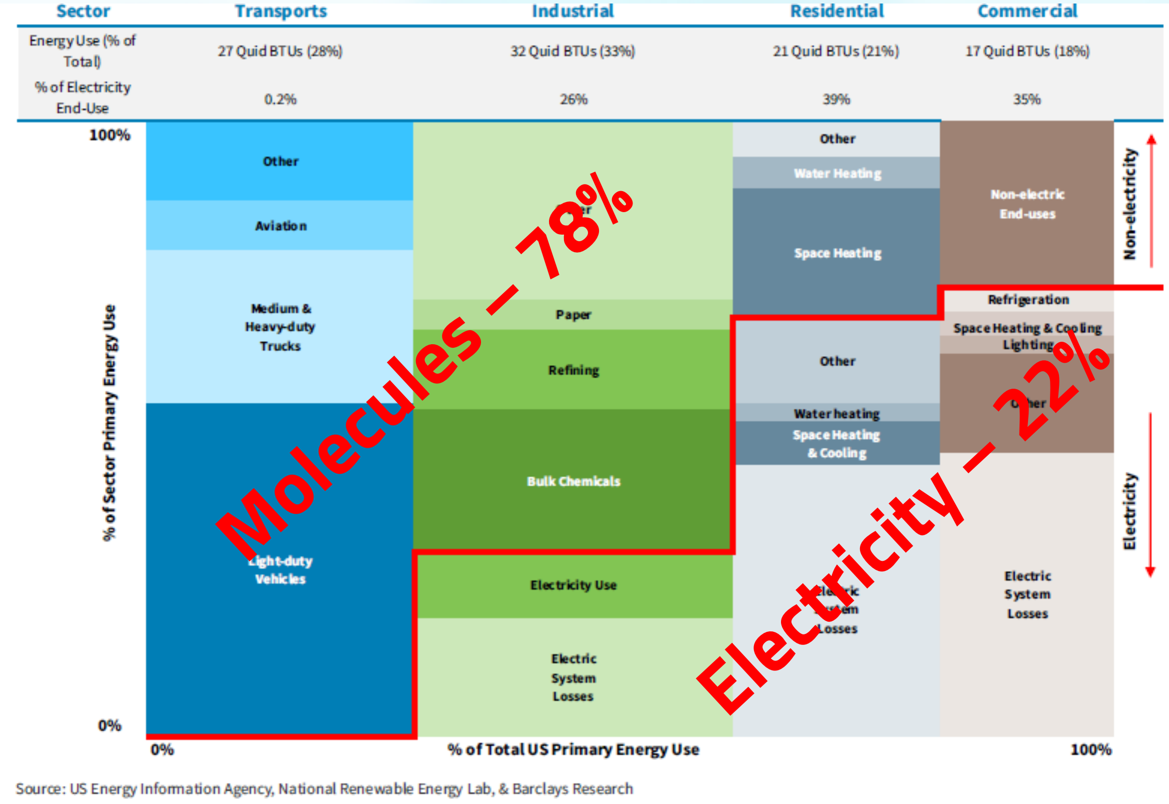
The Urgency

- **We must decarbonize before 2050 and limit warming to <1.5 °C**
- What stands in the way? Rate-limiting factors must be removed, primarily supply & grid-related issues
  - Speed, certainty, low environmental impact, & circularity are all highly valuable

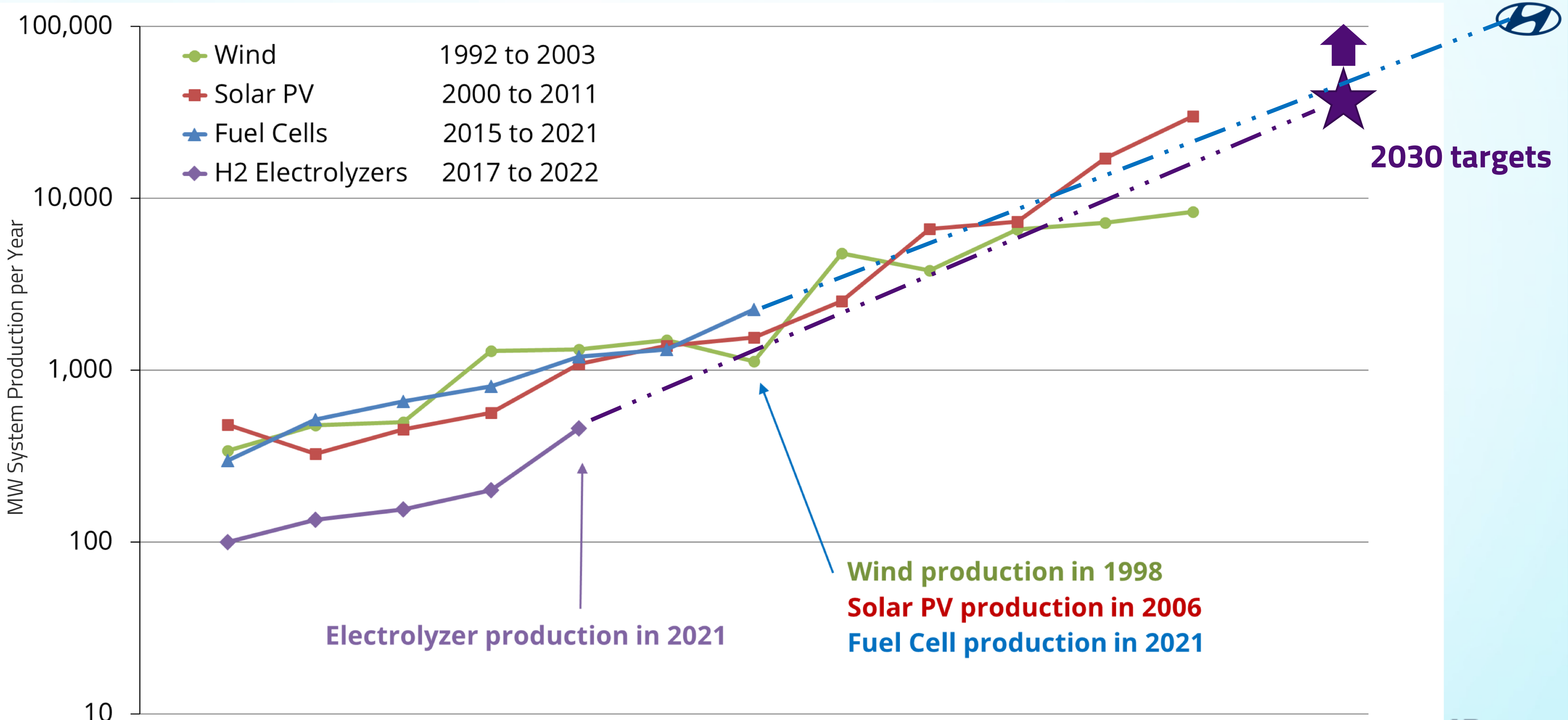




"Limiting warming to 1.5 °C would reduce economic damages relative to 2 °C... the accumulated global benefits will exceed US $20 trillion" – Burke et al (Nature, 2019)

I:::N:::MR INNOVATIONS

Hydrogen on the same exponential growth as wind & solar

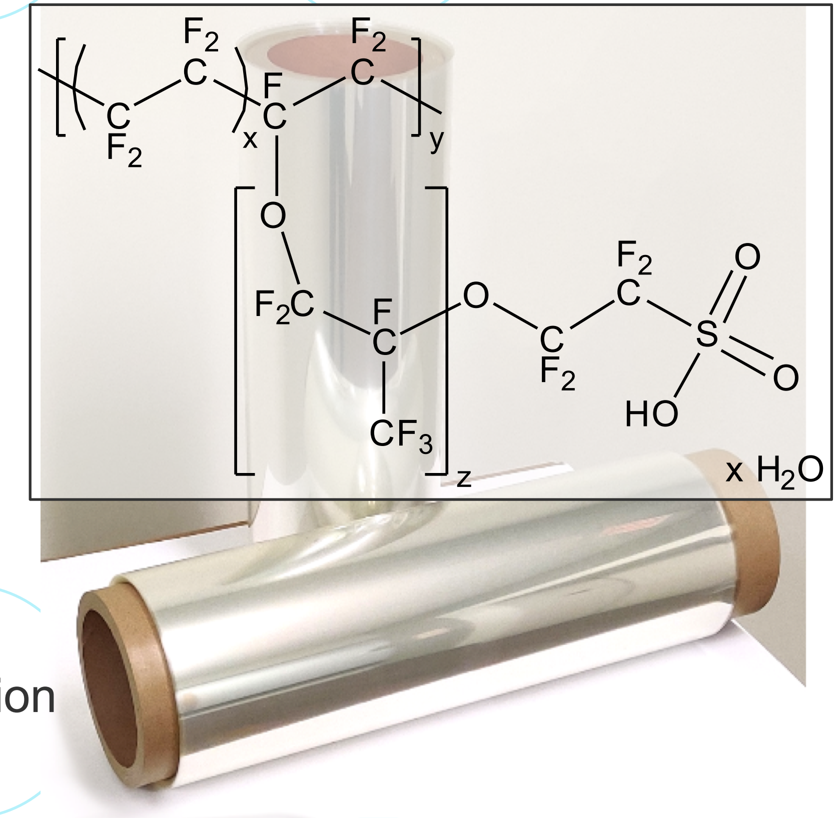


Adapted from chart: M Klippenstein (@ElectronComm). Data: . **World on the Edge**, **Global Outlook on Photovoltaics Report 2014-2018**, E4Tech, Bernstein Research, BNEF.
Hyundai FCEV Vision 2030 https://www.hyundai.news/eu/articles/press-releases/hyundai-motor-group-reveals-fcev-vision-2030.html

Current Ion-Exchange Materials: PFSAs

Perfluorosulfonic acid-based materials

- Archetypal Nafion® membranes and ionomers & short side chain (SSC) variants
- Fundamental chemistry unchanged for over 50 years



Perfluorination gives rise to advantageous properties

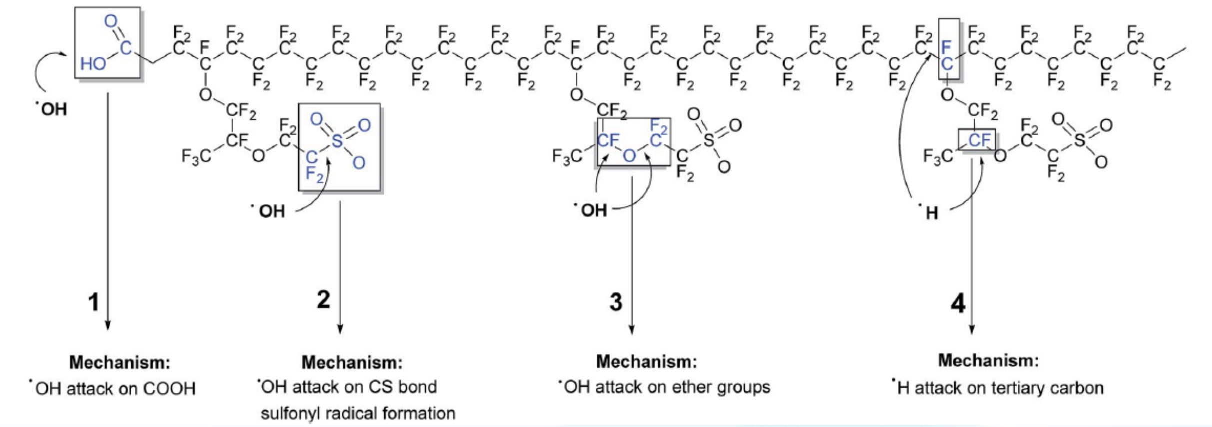
- Hydrophobic backbone
- Chemical stability
- Water management
- Ionic conductivity

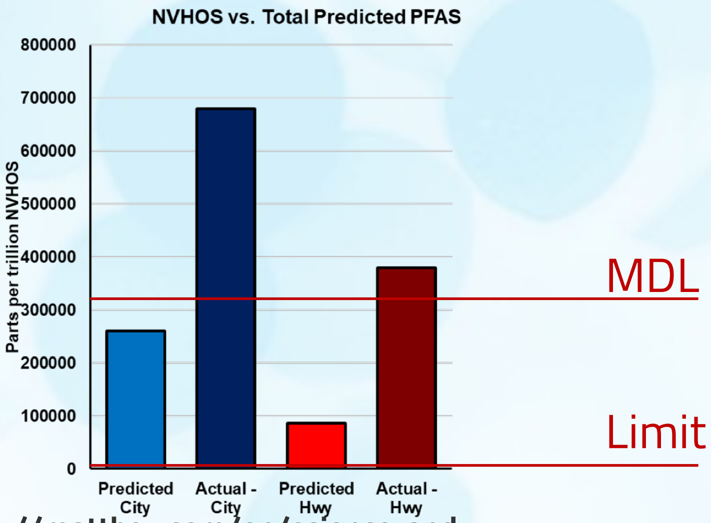
However..

- High material costs & scalability challenges
- High gas crossover – undesirable permeability of the hydrophobic region
- **Growing environmental concerns & impending regulation**

Use & End-of-Life

- *In situ* degradation mechanisms established theoretically & experimentally (e.g. F-release rate)
- Mitigations can be established immediately but not to ultimately acceptable levels (<1 part per trillion)
- End-of-Life – thermolysis of PFSAs generate PFAS of the highest concern in meaningful abundance[1]
  - Higher temperatures no panacea, also an issue in battery recycling, (e.g. LiPF6-carbonate forms at 230 ℃ but not at 195 ℃)[2]
  - Environmental mobility of sulfonic acids >100,000 km & persistence >1 m.a. >100x of other still-to-be-regulated PFAS (ECHA Annex B p108ff)
  - Iridium recycling necessary for PEMWE scaling or will only achieve 10-15% of market share by 2050 (e.g. JM Whitepaper)[3]





[1] M. Feng *et al*. *Sci. Rep.* 2015. DOI: 10.1038/srep09859
[2] Z Liao *et al. J. Energy Chem.* 2020 DOI: 10.1016/j.jechem.2020.01.030
[3] JM Whitepaper "Recycling and thrifting: the answer to the iridium question in electrolyzer growth" https://matthey.com/en/science-and-innovation/expert-insights/2022/recycling-and-thrifting-the-answer-to-the-iridium-question-in-electrolyser-growth
[4] M Zaton, J Roziere, & DJ Jones, *RSC Sustain. Energy Fuels* 1(3) 2017.

IONMR INNOVATIONS

Pemion® for Fuel Cells

Pemion®: The Future of Hydrogen Fuel Cells

Unlike Nafion, Hydrocarbons Achieve:	Pemion®
High efficiency & high performance Increased conductivity, water transport	✓
Selectivity for improved H_2 efficiency Impermeable to reactant gases (H_2, O_2)	✓
Extreme Durability Long lifetimes to meet HD requirements	✓
Cost-effective and scalable chemistry Capable of meeting growing PEM demands	✓
Environmentally friendly materials Green chemistry for the green revolution	✓
High temperature stability Operation up to 120 °C for major system cost reduction, meeting long-term goals	✓

IONOMR INNOVATIONS

Pemion® – Corrects Past Shortfalls of Hydrocarbons

Historical Challenges

- Functionalization control
- Water uptake and swelling
- Solubility in hot water at high IECs
- Ketones, sulfones, & protected ethers unstable
- Sensitivity to oxidative degradation
- Incompatibility with antioxidants – irreversible rxn

Responses

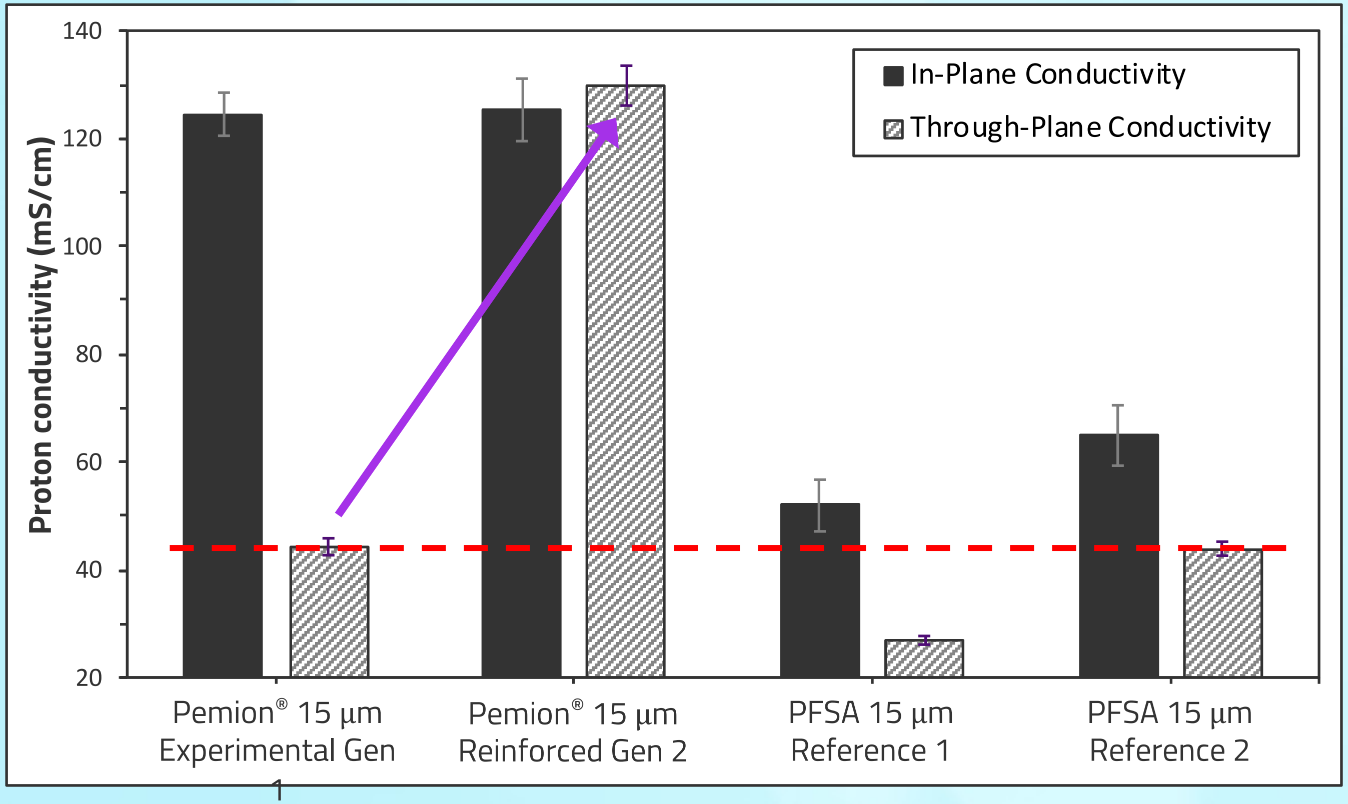
- Controlled functionalization
- Chemical strategy & down-selection/optimization limits
- Insoluble to IECs of ~4 / EWs ~250 (!)
- Zero ketones, sulfones, or ethers – all sp^2 C & $-SO_3H$
- Above strategy orders-of-magnitude improvement
- Enables antioxidant compatibility – reversible 1st rxn

IONOMR INNOVATIONS

Pemion® Reinforced Membranes Today

- Current generation composite membrane design yields greatly improved through-plane conductivity, eliminating anisotropy
- Higher conductivity corroborated by large *in-situ* resistance decreases

→ Greater fuel cell efficiency & performance in all conditions



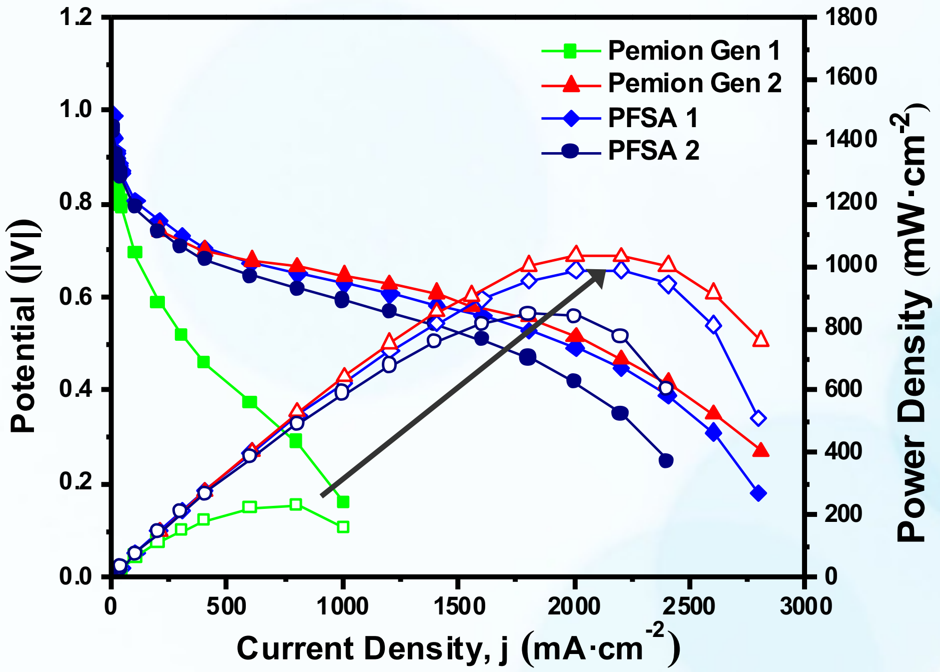
In-plane and through-plane conductivity of membranes measured at rt after soaking in liquid water (24 h)

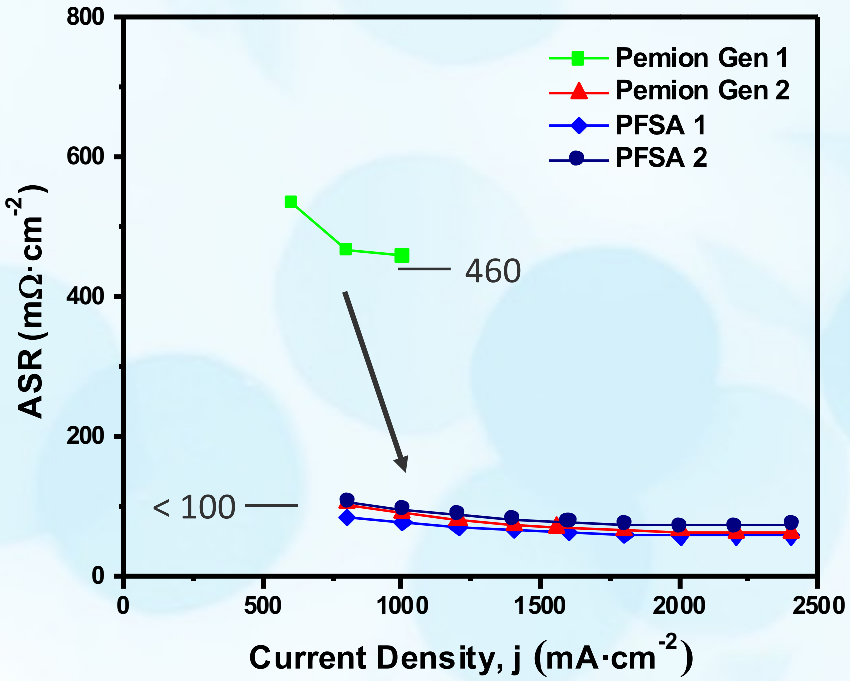
IONOMR INNOVATIONS

Pemion® – Low-Humidity Performance

Dramatic improvements to water management and 400% higher performance over previous-generation R2R membranes under hot/dry

- Decreases in area resistance >75%, in-line with performance improvements
- Unprecedented (!) performance for a hydrocarbon-based polymer electrolyte membrane



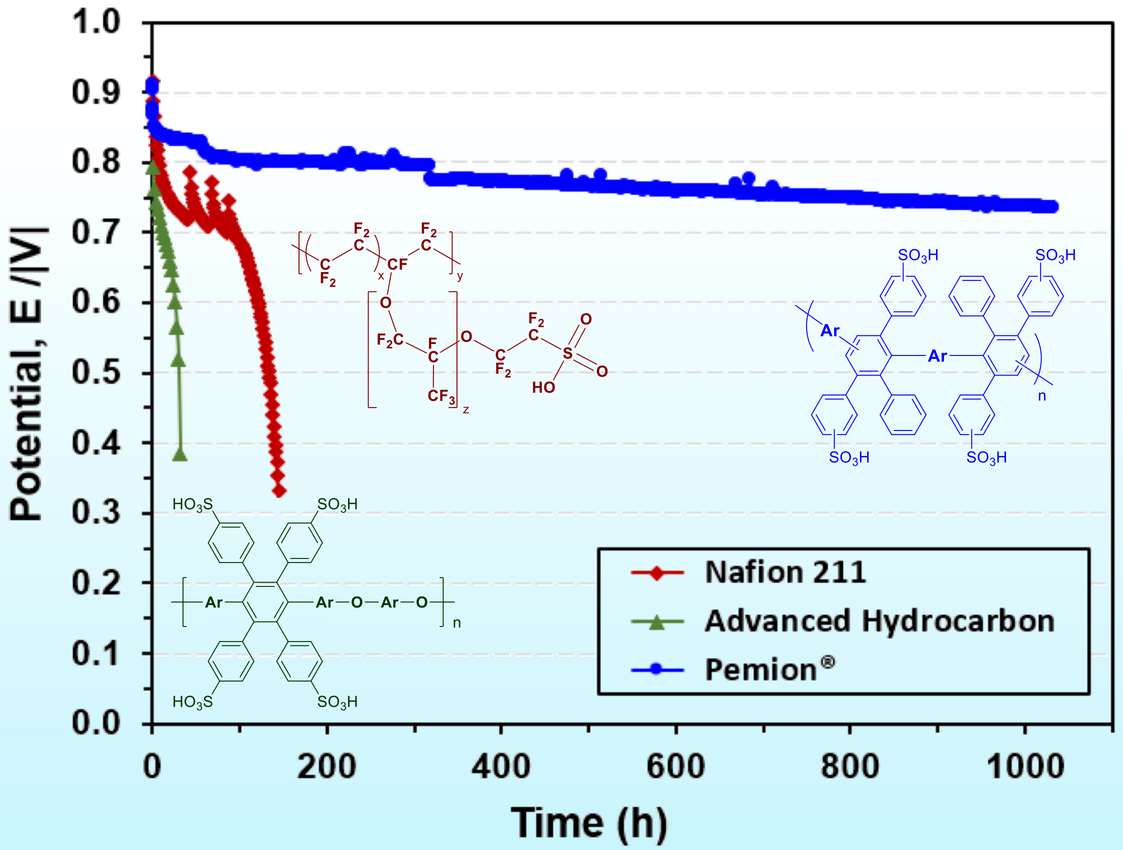


Graph 4: Polarization (left) and resistance (right) curves of membranes measured under 30/30 %RH, H_2/Air 150 kPa$_g$ symmetrical, 80 °C (3 min/pt)

Pemion® – Extreme Chemical Stability

The Pemion® polymer is **inherently chemically resilient** against radical-induced degradation

- 1000 h without failure (2x DOE membrane target) **without radical scavengers**
- DOE-specified chemical stability accelerated stress test – extended hold at open circuit voltage under 30% RH, 90 °C
- Successful PEMFC operation after accelerated stress test @ ~70% of initial performance

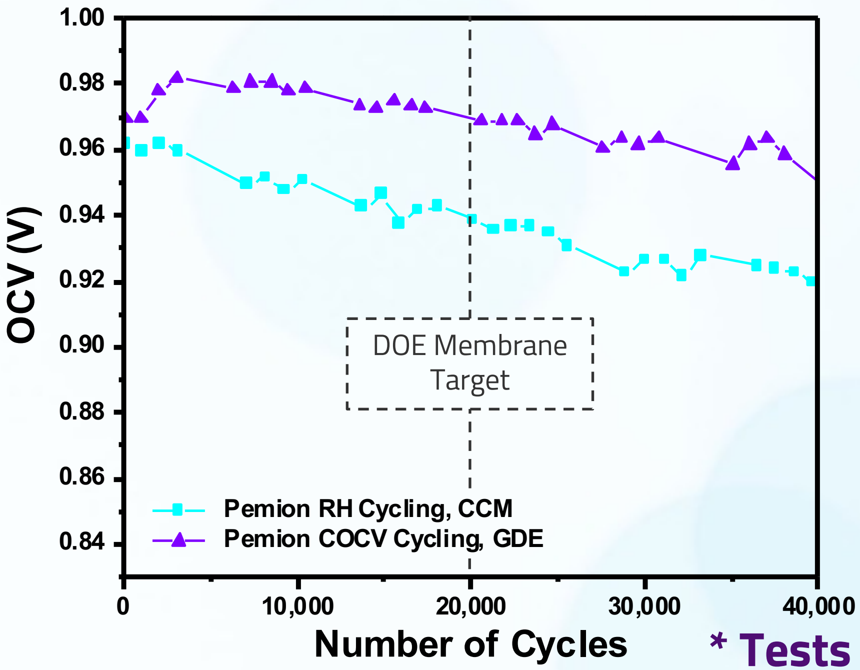


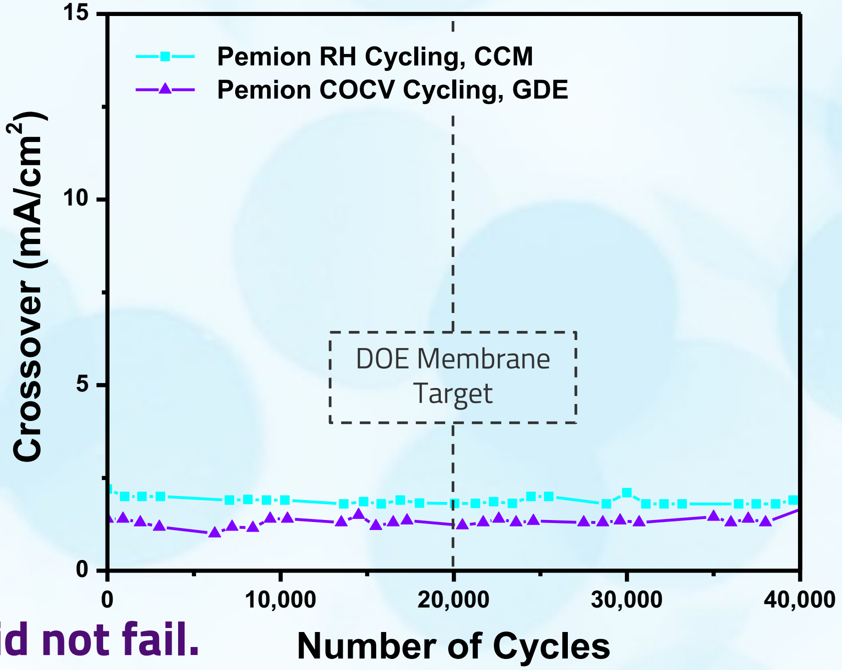
Graph 5: Conditions at 30/30 % RH, 90 °C, OCV

State-of-the-Art Membrane Durability

First and only hydrocarbon-based material to ever achieve industry durability targets

- Multiple tests showcase limited degradation across entire target timeline
- **20k cycle target achieved, and doubled**, under combined chemical/mechanical (COCV cycling) via DOE protocol
- Membrane gas crossover < ⅓ PFSA membranes for life of test





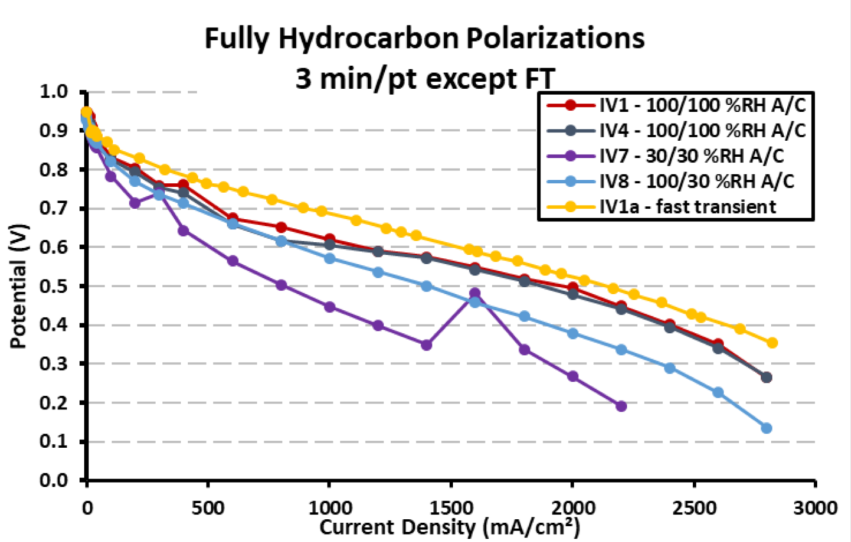
*** Tests stopped – did not fail.**

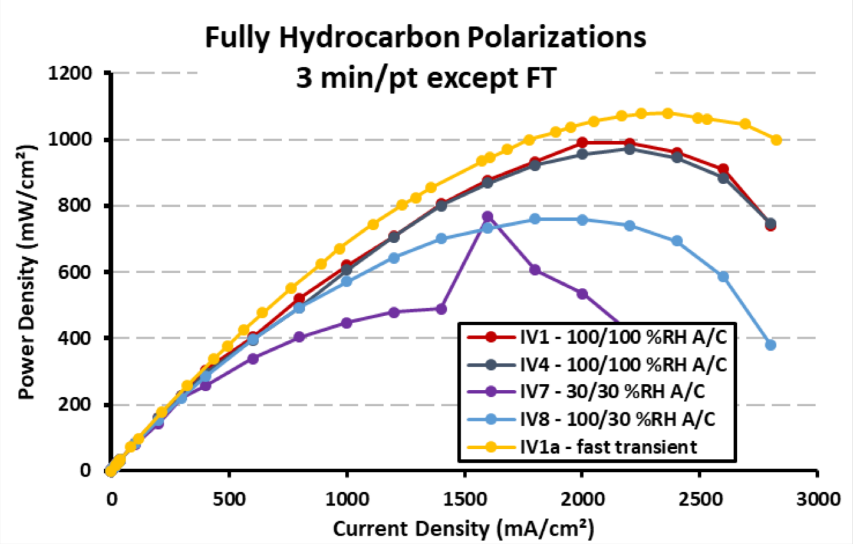
OCV (left) and gas crossover current @ 100 kPa$_g$ cathode, 50 kPa$_g$ anode (50 kPa differential) – (right) curves of membranes measured under COCV (OCV and cycling RH ambient to 100%) at 90 ℃ as well as RH cycling (OCV step added for comparison). Both methods per DOE ASTM protocols, method validated by area resistance differentials.

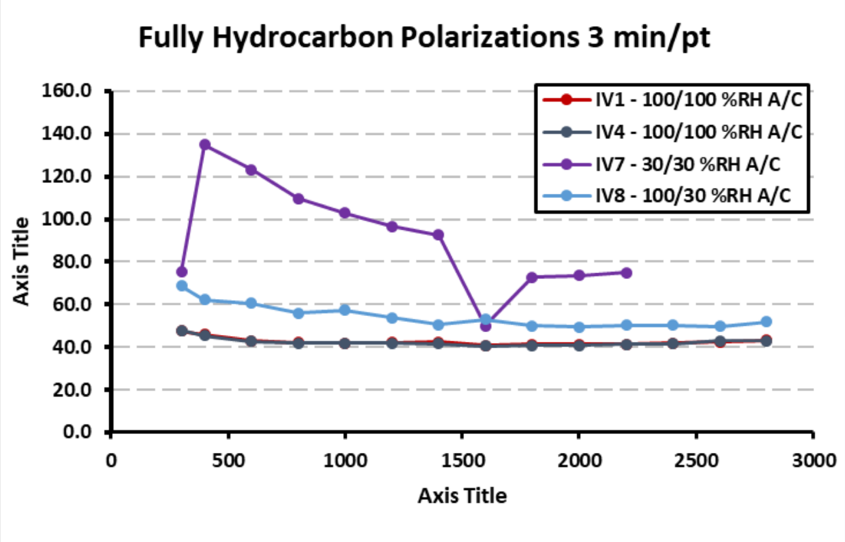
Pemion® – Hydrocarbon Membrane + Ionomer Performance

Highly preliminary data in non-optimized conditions, but performances near-parity

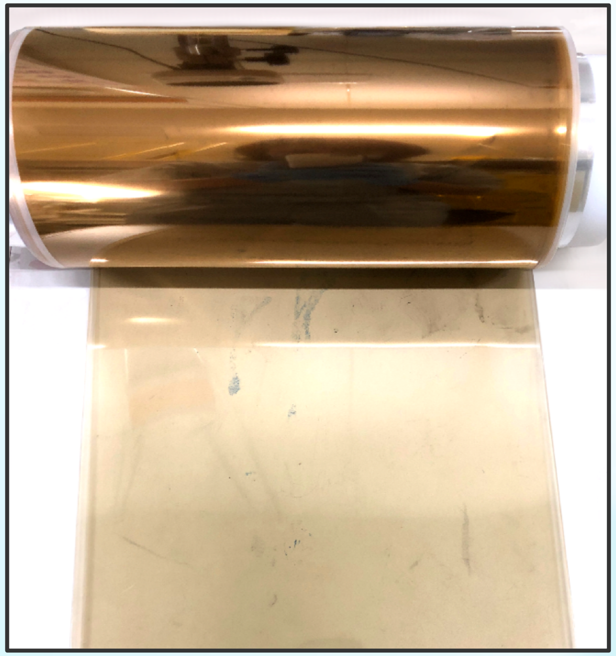
- 5 cm² active area, high stoichiometry, 80 °C, 150 kPa_g H_2/air backpressure, **consistent performance ~1 W/cm²**
- 0.3 mg Pt/cm² cathode / 0.1 mg Pt/cm² anode (**25% lower cathode loading vs. slides 4-6**), ultrasonic spray-coated
- **Comparable area resistance in all conditions** (~3-5 mΩ·cm² increase fully humidified, <10 mΩ·cm² dry, consistent w/ high stoichiometry & slightly thinner electrodes), **comparable kinetics both high and low RH**
- Fast transient quite comparable with PFSA-based results, suggests unit cell design & optimization fully effective to approximate performance parity







Pemion® Materials



Composite Membranes

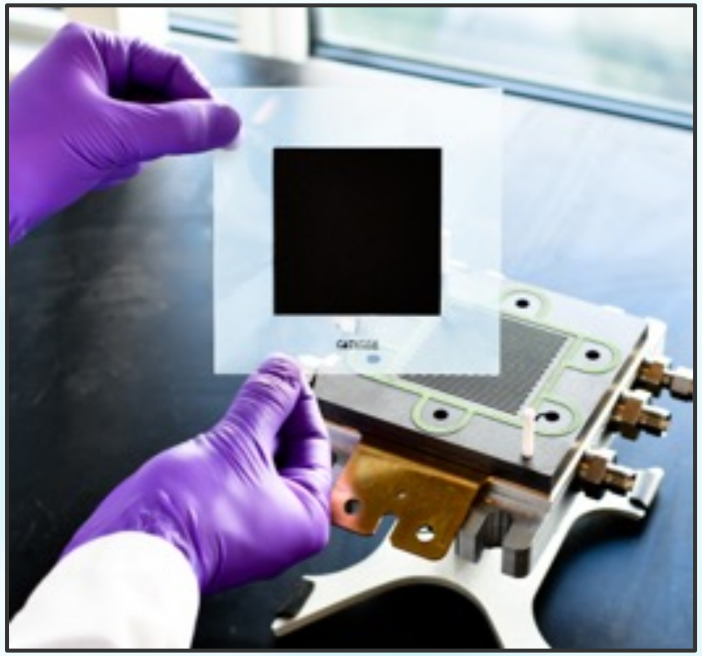
PF1-HLF8-15-X

Our standard reinforced membrane ("Gen 2")

Ionomer Powders

PP1-HNN8-00

Readily soluble in common low boiling point solvents



PEMFC Reference Platforms

Catalyst coated membranes

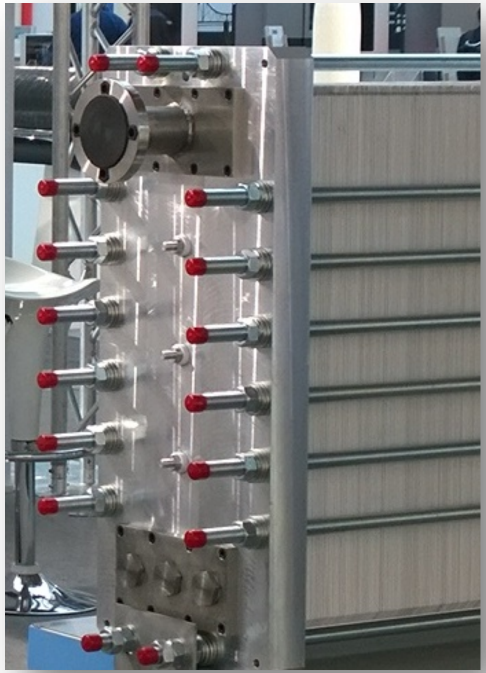
&

Membrane electrode assemblies

Aemion® Electrolyzers for Capital-Efficient Green Hydrogen

IONOMR INNOVATIONS

Aemion+® Unlocks Disruptive Hydrogen Economics



AEMWE for the Most Cost-Effective Green H_2

Enables Cost-Effective Hydrogen

- ✓ High-performance, high-efficiency, compact systems
- ✓ Step-change in CAPEX & OPEX to meet 'hydrogen shot' $1/kg

High electron efficiency / low hydrogen crossover

- ✓ Efficient renewable pairing
- ✓ Highest safety factor

Solved key durability challenges

- ✓ Long-lived, efficient catalysts enabled by hot caustic
- ✓ Only indefinitely stable material to meet industrial req's
- ✓ Exceeds 2024 EU targets, meeting 2030 targets

Compact, Scalable Systems

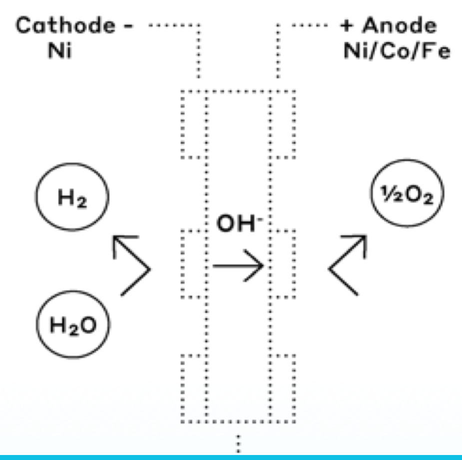
- ✓ Abundant, low-cost catalysts eliminating iridium use
- ✓ Enables scalable, low-cost alloys for system reductions
- ✓ Enables full circularity

The Evolution of Water Electrolysis

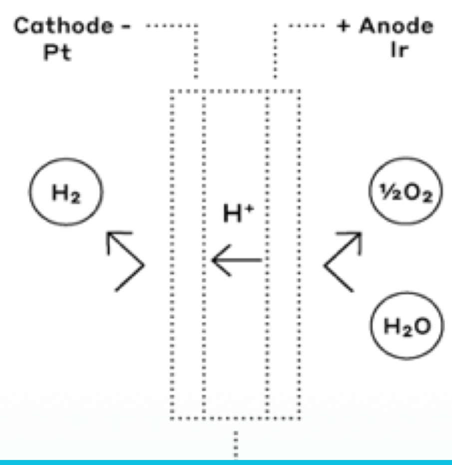
An ideal system exhibits:	AWE	PEM	Aemion®
High performance = <150 mΩ·cm² area resistance Enables compact, cost-effective systems	✗ → !	✓	✓
Low gas permeability with variable load Safety + turn-down required for renewable pairing	! → ✗	✓	✓✓
Durability Long lifetimes to meet system requirements	✓	✓	✓
Cost-effective, scalable membrane, electrode, and stack components To enable and meet rapid market growth	✓	✗	✓✓
Be made from environmentally friendly materials Meets the requirements of the circular economy	✓	✗	✓
High temperature & pressure stability Operation to 90 °C, ≥5 bar for large system design	!	!	✓

Aemion+® Unlocks Disruptive Hydrogen Economics

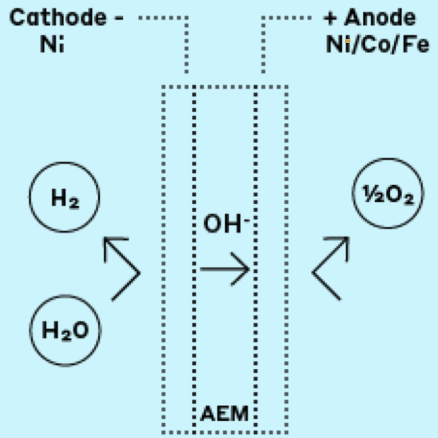
Alkaline electrolysis



PEM electrolysis



AEM electrolysis



AEMWE is a hybrid of the two systems – AEL components and PEMWE design, de-risking scalability

	AEL $500/kW	PEM $650/kW	AEM <$350/kW	EU Clean H_2 JU 2030 #s
BENEFITS	Scalable	Highly Compact	Compact + Scalable	✓
	High Stability	Pairs with Renewables	Pairs with Renewables	✓
ISSUES	Very Large Systems	Scale Issues: Ir & PFAS	Moderate Performance	✗
	Poor Renewables Pairing	Very High Cost	Poor Durability	✗
	Low Safety at Pressure	Toxic Material Use	Poor Consistency	

Ionomr's Breakthroughs Solve These

AEMWE Flexibility Only Way to Meets H_2 Shot $1/kg by 2030

Electricity $/MWh

75% CF	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70
0	$0.21	$0.48	$0.75	$1.01	$1.28	$1.55	$1.81	$2.08	$2.35	$2.61	$2.88	$3.15	$3.41	$3.68	$3.95
50	$0.25	$0.52	$0.79	$1.05	$1.32	$1.59	$1.85	$2.12	$2.39	$2.65	$2.92	$3.19	$3.45	$3.72	$3.99
100	$0.29	$0.56	$0.83	$1.09	$1.36	$1.63	$1.89	$2.16	$2.43	$2.69	$2.96	$3.23	$3.49	$3.76	$4.03
150	$0.34	$0.60	$0.87	$1.14	$1.40	$1.67	$1.94	$2.20	$2.47	$2.73	$3.00	$3.27	$3.53	$3.80	$4.07
200	$0.38	$0.64	$0.91	$1.18	$1.44	$1.71	$1.98	$2.24	$2.51	$2.78	$3.04	$3.31	$3.58	$3.84	$4.11
250	$0.42	$0.68	$0.95	$1.22	$1.48	$1.75	$2.02	$2.28	$2.55	$2.82	$3.08	$3.35	$3.62	$3.88	$4.15
300	$0.46	$0.72	$0.99	$1.26	$1.52	$1.79	$2.06	$2.32	$2.59	$2.86	$3.12	$3.39	$3.66	$3.92	$4.19
350	$0.50	$0.76	$1.03	$1.30	$1.56	$1.83	$2.10	$2.36	$2.63	$2.90	$3.16	$3.43	$3.70	$3.96	$4.23
400	$0.54	$0.80	$1.07	$1.34	$1.60	$1.87	$2.14	$2.40	$2.67	$2.94	$3.20	$3.47	$3.74	$4.00	$4.27
450	$0.58	$0.85	$1.11	$1.38	$1.65	$1.91	$2.18	$2.45	$2.71	$2.98	$3.24	$3.51	$3.78	$4.04	$4.31
500	$0.62	$0.89	$1.15	$1.42	$1.69	$1.95	$2.22	$2.49	$2.75	$3.02	$3.29	$3.55	$3.82	$4.09	$4.35
550	$0.66	$0.93	$1.19	$1.46	$1.73	$1.99	$2.26	$2.53	$2.79	$3.06	$3.33	$3.59	$3.86	$4.13	$4.39
600	$0.70	$0.97	$1.23	$1.50	$1.77	$2.03	$2.30	$2.57	$2.83	$3.10	$3.37	$3.63	$3.90	$4.17	$4.43
650	$0.74	$1.01	$1.27	$1.54	$1.81	$2.07	$2.34	$2.61	$2.87	$3.14	$3.41	$3.67	$3.94	$4.21	$4.47
700	$0.78	$1.05	$1.31	$1.58	$1.85	$2.11	$2.38	$2.65	$2.91	$3.18	$3.45	$3.71	$3.98	$4.25	$4.51
750	$0.82	$1.09	$1.36	$1.62	$1.89	$2.16	$2.42	$2.69	$2.95	$3.22	$3.49	$3.75	$4.02	$4.29	$4.55
800	$0.86	$1.13	$1.40	$1.66	$1.93	$2.20	$2.46	$2.73	$3.00	$3.26	$3.53	$3.80	$4.06	$4.33	$4.60
850	$0.90	$1.17	$1.44	$1.70	$1.97	$2.24	$2.50	$2.77	$3.04	$3.30	$3.57	$3.84	$4.10	$4.37	$4.64
900	$0.94	$1.21	$1.48	$1.74	$2.01	$2.28	$2.54	$2.81	$3.08	$3.34	$3.61	$3.88	$4.14	$4.41	$4.68
950	$0.98	$1.25	$1.52	$1.78	$2.05	$2.32	$2.58	$2.85	$3.12	$3.38	$3.65	$3.92	$4.18	$4.45	$4.72
1,000.00	$1.02	$1.29	$1.56	$1.82	$2.09	$2.36	$2.62	$2.89	$3.16	$3.42	$3.69	$3.96	$4.22	$4.49	$4.76

Capex ($/kW)

AEM

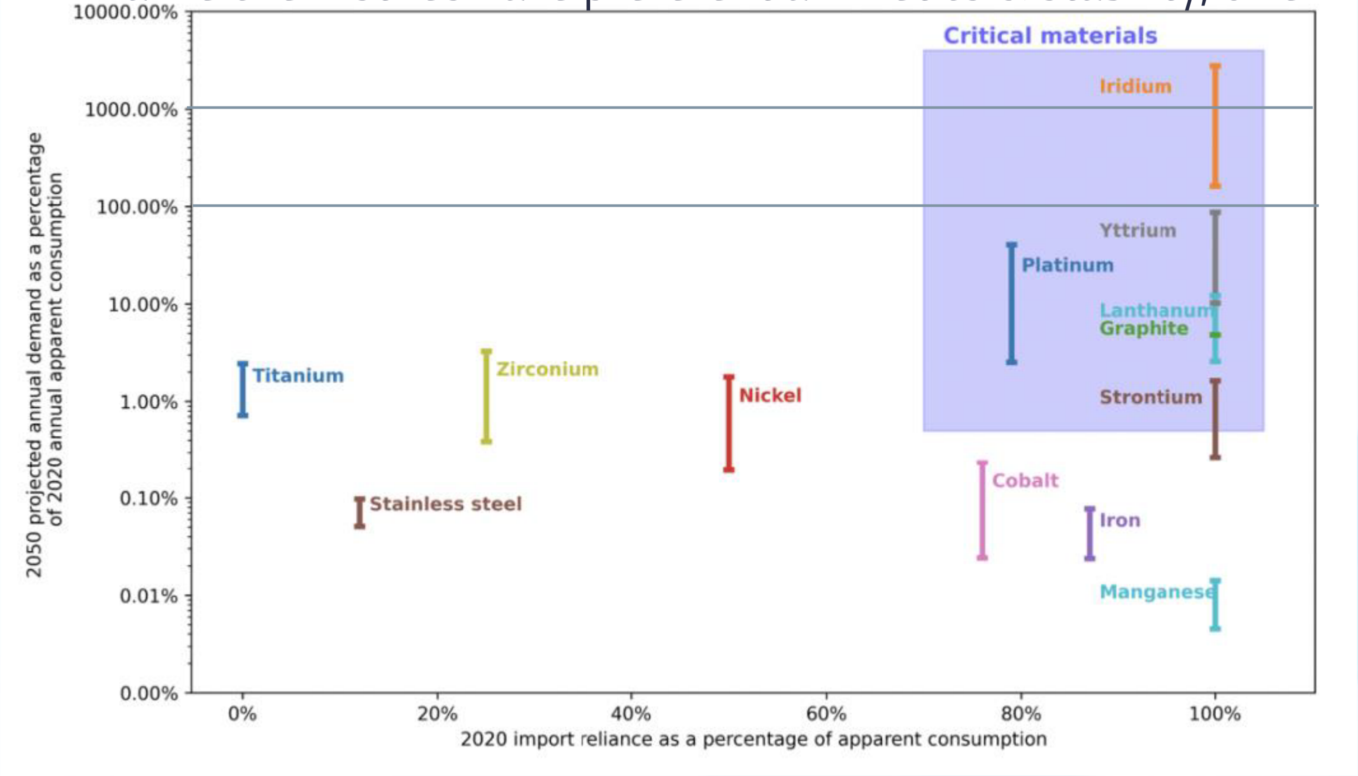
PEM

AEL

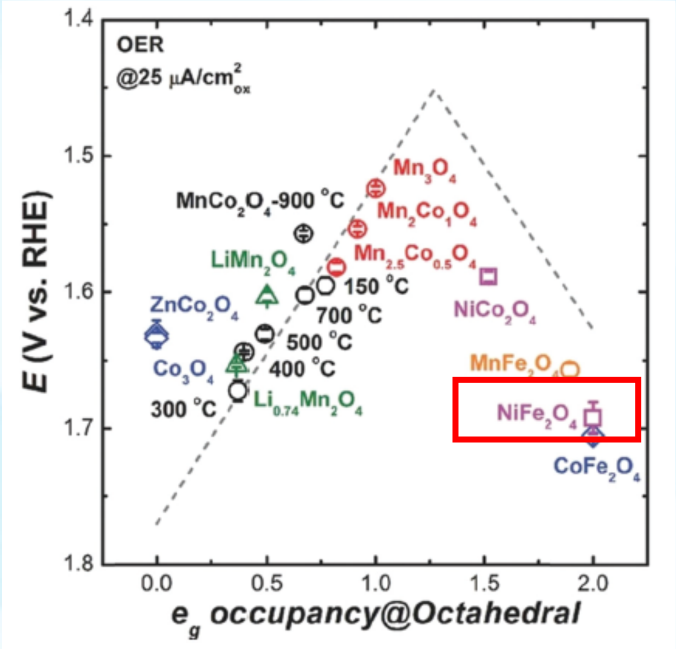
- Traditional alkaline is slated for 60-92% market share, nominally 80%, but entirely fails to serve grid needs (!)
- PEM off the bottom of the graph in reality – CAPEX cost >$1/kg and PGM use is intractable
- Hard to properly cost higher power densities when low-cost electricity on the grid, 3x rated possible

Critical Catalysis Advantages in Alkaline

- Acidic electrolyzers have irreconcilable supply challenges due to iridium (& other PGM) + PFSA requirements
- **PFSA scaling arguably more problematic than iridium *independent of PFAS issues*** – difficult & dangerous chemistry
- Alkaline chemistries have preferential kinetics & stability, offering a wealth of potential improvements



Source: US DOE 2022 "Water Electrolyzers and Fuel Cells Supply Chain Deep Dive Assessment"



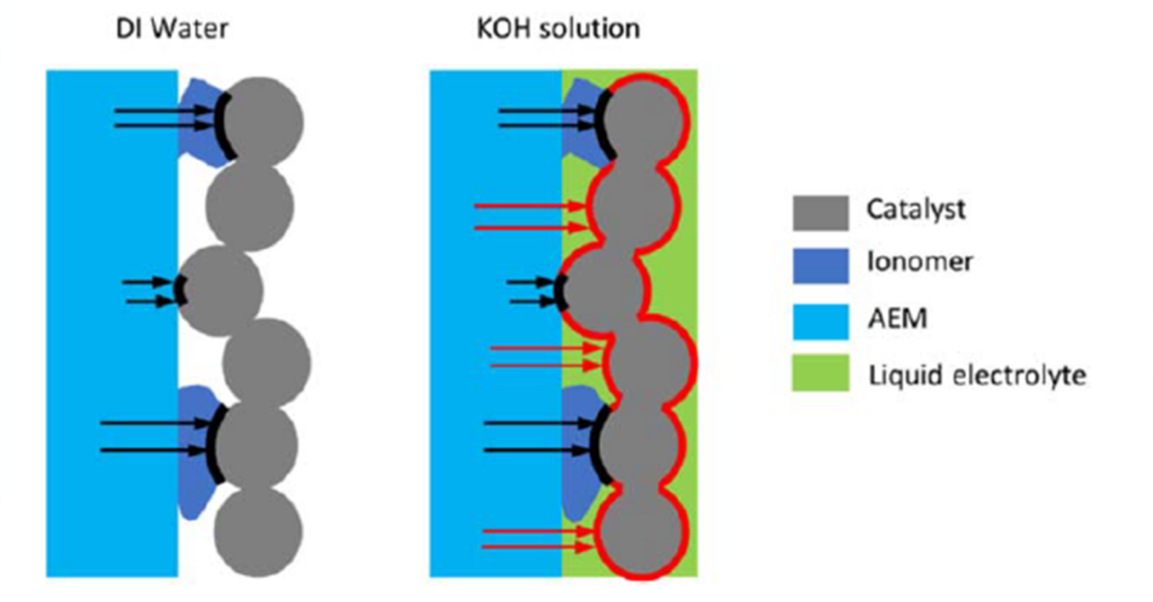
Onset potential of various spinels

M. Chatenet *et al* – 2022 Chem Soc Rev 10.1039/d0cs01079k

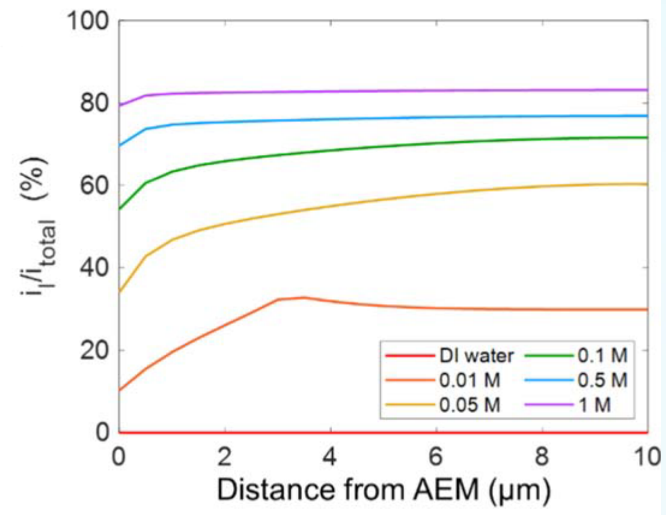
IONOMR INNOVATIONS

Alkaline Electrolyte, the Superpower of AEMWE

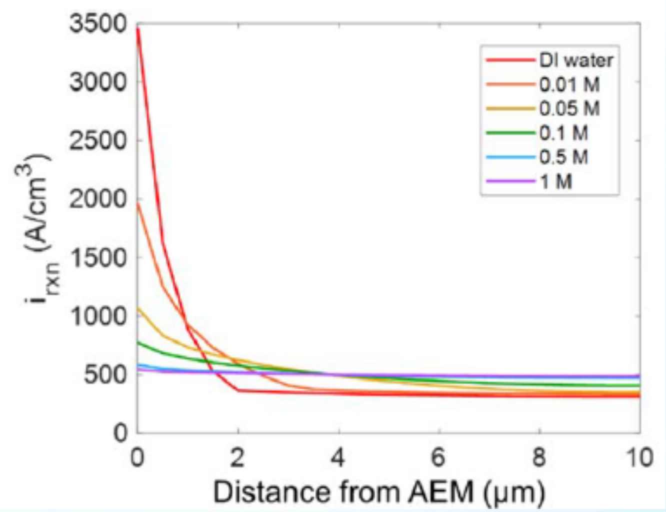
- DI water limits 'reaction band' to ~2 μm
- ≥0.1 M KOH electronic connectivity enables a reaction band potentially mm-scale (e.g. VRFBs) + non-conducting oxides
- Markedly higher performances achievable
- Lower turnover frequency assists long-lived non-PGM
- **'Iridium equal' performances achieved in AEMWE**



Weber & coworkers, 2021 - https://doi.org/10.1149/1945-7111/ac0019/meta
Also see Danilovic & coworkers 2022 – https://doi.org/10.1149/1945-7111/ac4fed



% of current through liquid pathways at 0.5 A/cm^2



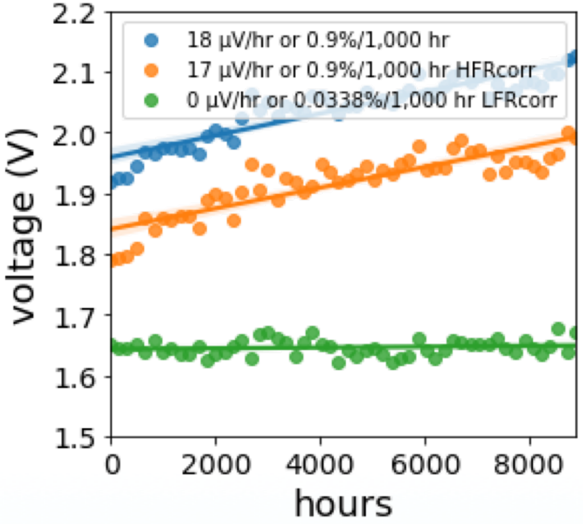
Total volumetric reaction current

Exceeding Stability Targets

AEM Water Electrolysis with 2nd Gen Aemion+®

1) 9000+ hour AEM electrolyzer demonstration in large 50 cm² lab-scale cell

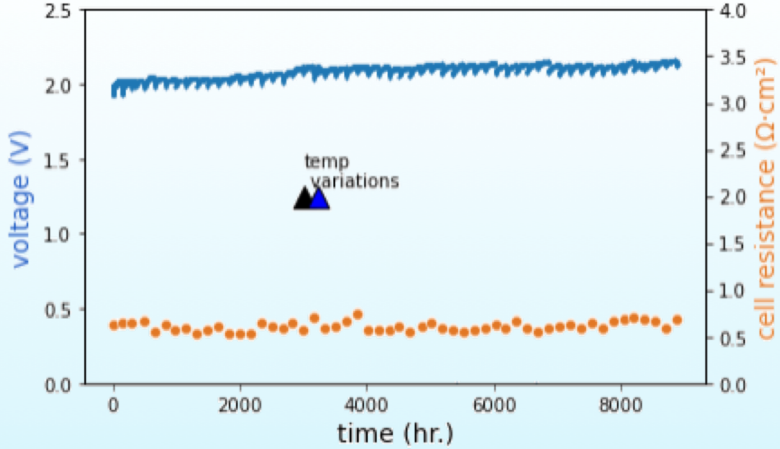
- First long-lived stability demonstration in industry-relevant conditions
- Degradation rate within 2024 EU target
  - Membrane: 0.034%/1000 hr
  - System: 0.52%/1000 hr
- System lifetime: >25000 hr, 3 years constant operation to 2.2 V cutoff

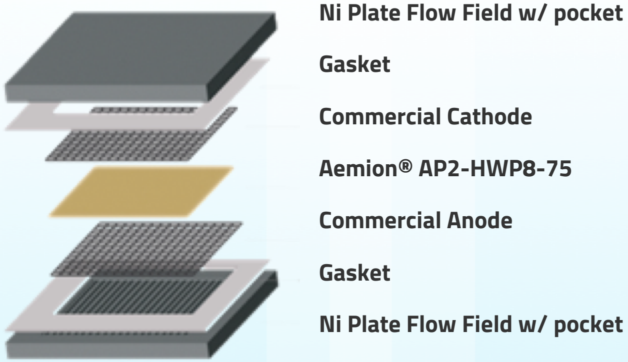


- Measured cell voltage
- 'Low frequency' resistances (metal component oxidation)
- **No membrane-associated losses**

2) 5000 hours at 3x current density with no measurable degradation (whole system)

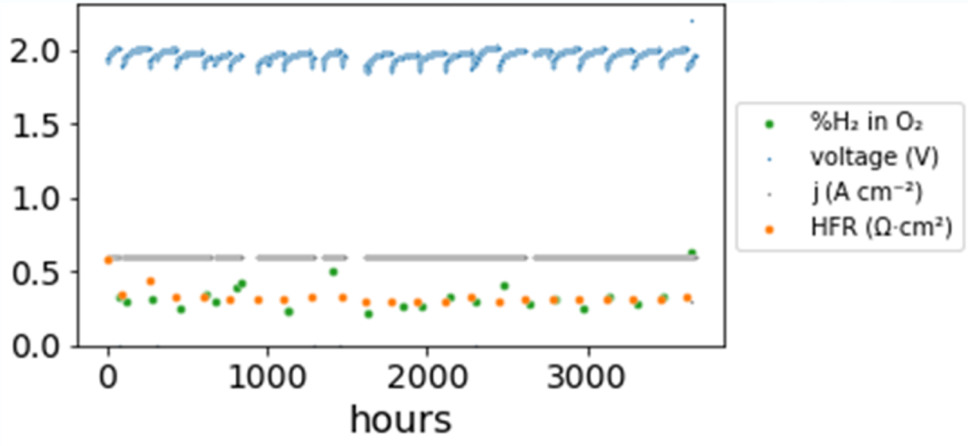
- Exceeding all 2024 EU Clean Hydrogen Joint Undertaking targets together at once
- Degradation rate
  - Membrane: 0.04%/1000 hr
  - System: 0.62%/1000 hr
- System lifetime: 55000 hr – 4.4 years to 2.2 V cutoff

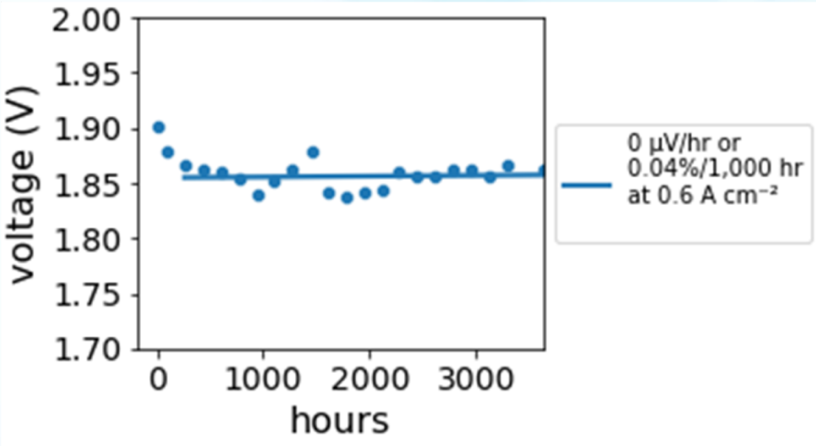


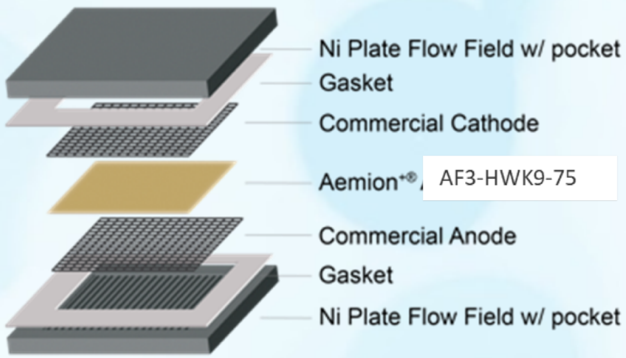


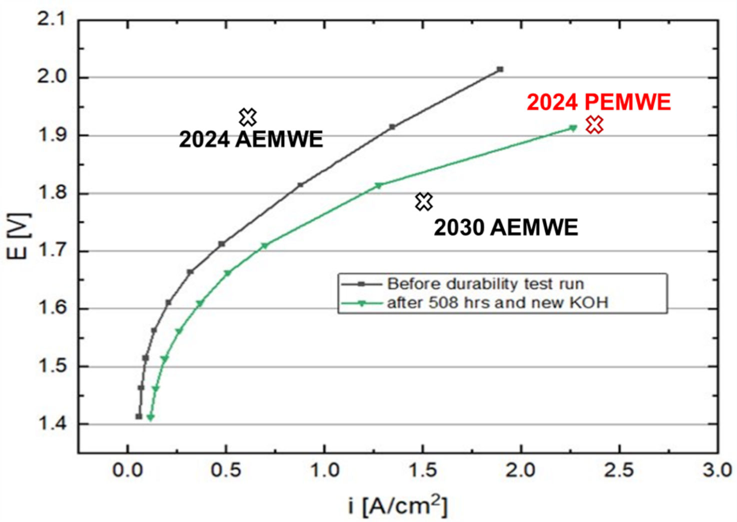
Moreno-Gonzalez *et al.* "One Year Operation of an Anion-Exchange membrane Water Electrolyzer…" *J. Power Sources Adv.*, **2023**; 19, 100109. https://doi.org/10.1016/j.powera.2023.100109

Breakthrough Durability & Performance





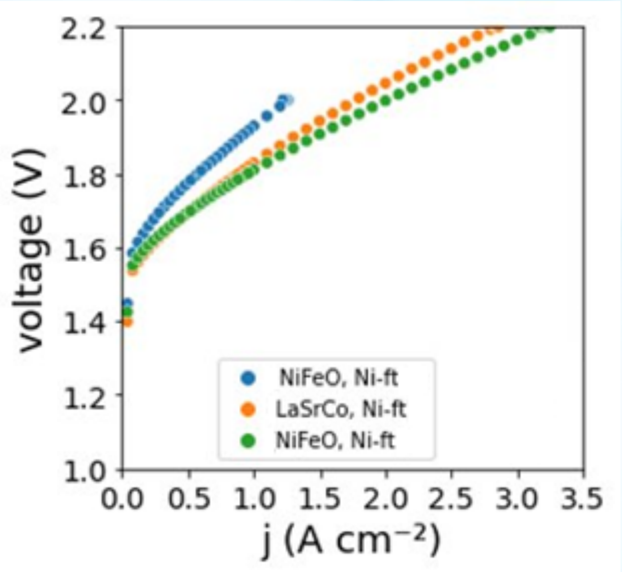




AEM Water Electrolysis with 3rd Gen Aemion+®
Exceeding every 2024 EU target, now achieving all 2030 targets

Numerous demonstrations of breakthrough durability, >1000x achieved in AEMWE:

- No measurable *membrane* degradation in tests up to 9000 h (2nd gen)
- No *whole-system* degradation >3500 h (3rd gen) (<1 µV/h, >3x 2030 target)



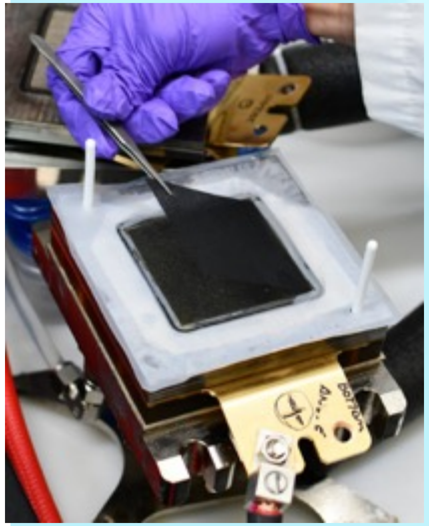
← S. Alia & coworkers @ NREL, through Shell Gamechanger program

IONOMR INNOVATIONS

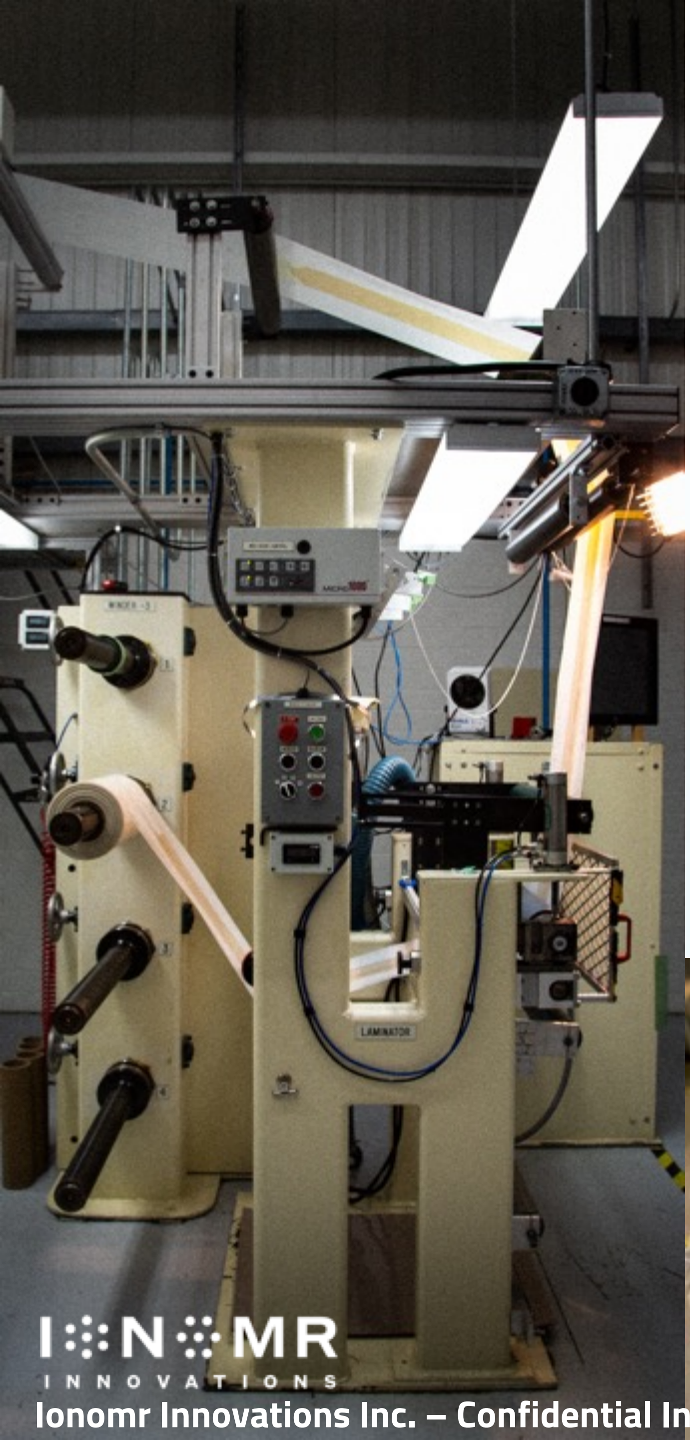
Ionomr Providing AEMWE Reference Designs

Cost-effective, short lead-time design for efficient & scalable testing

- Specify all cell components for mesh electrode or CCM
- Ensures first-pass success for rapid adoption
- Small performance cell 5-10 cm^2
- Large durability cell 50 cm^2
- Cost-effective, especially for pressure
- <16 week lead time vs. 52+ weeks



Ionomr Innovations Inc. – Confidential Information



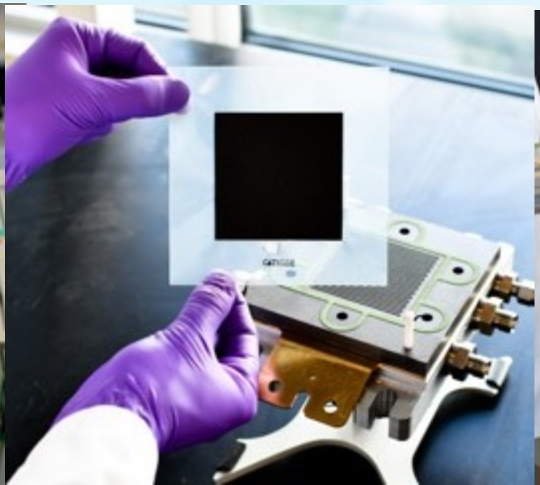
Scaling Our Advanced Solutions

Development → Production qualification → **Pemion®** → Mass Production

Development → Production qualification → **Aemion⁺®** → Mass Production

ISO 9001/14001 & IATF 16949

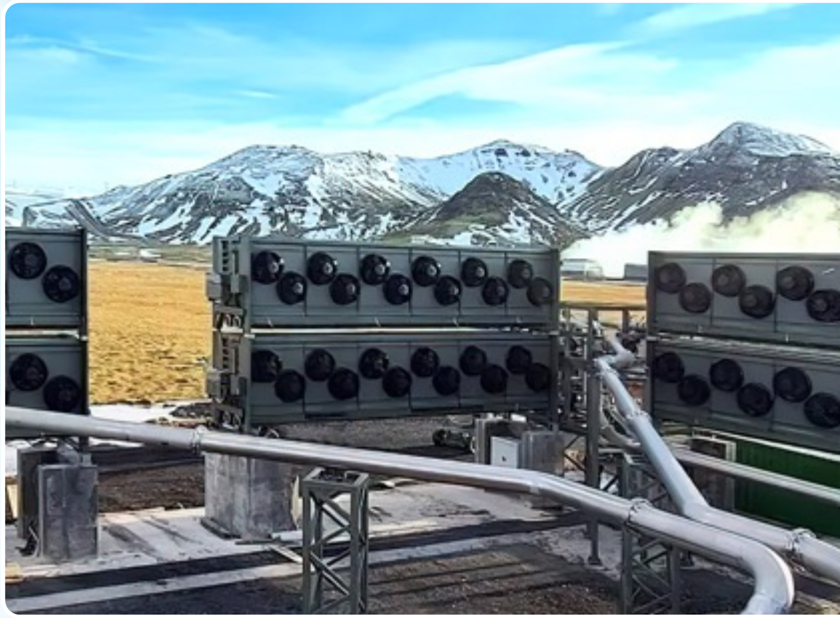
Quality & environment systems being implemented



IONOMR INNOVATIONS

ionomr.com

Thank You



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Rochester, New York 14623
USA

ATMO sphere

Accelerating Clean Cooling & Heating

www.atmosphere.cool

Alternatives to PFAS working fluids – natural refrigerants

ATMOsphere
Thomas Trevisan

Deputy Manger for Public Affairs –
Ozone, Climate, Energy and Chemicals

www.atmosphere.cool

#GoNatRefs

About ATMOsphere

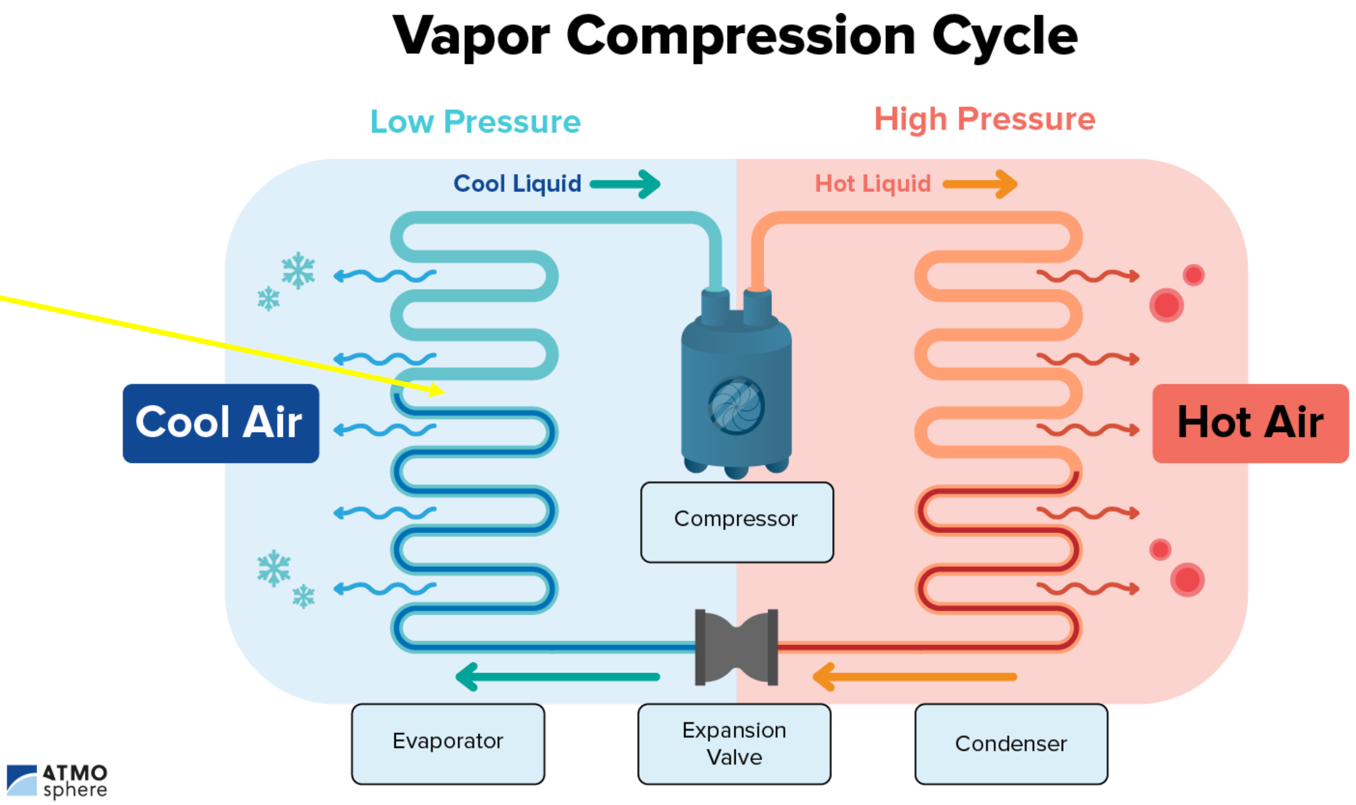
ATMOsphere is a global, independent market accelerator with a mission to clean up heating and cooling.

Whether you are an investor, an end-user, or a manufacturer, we have developed a comprehensive offering to assist you in transitioning to more sustainable technologies – globally and at scale.

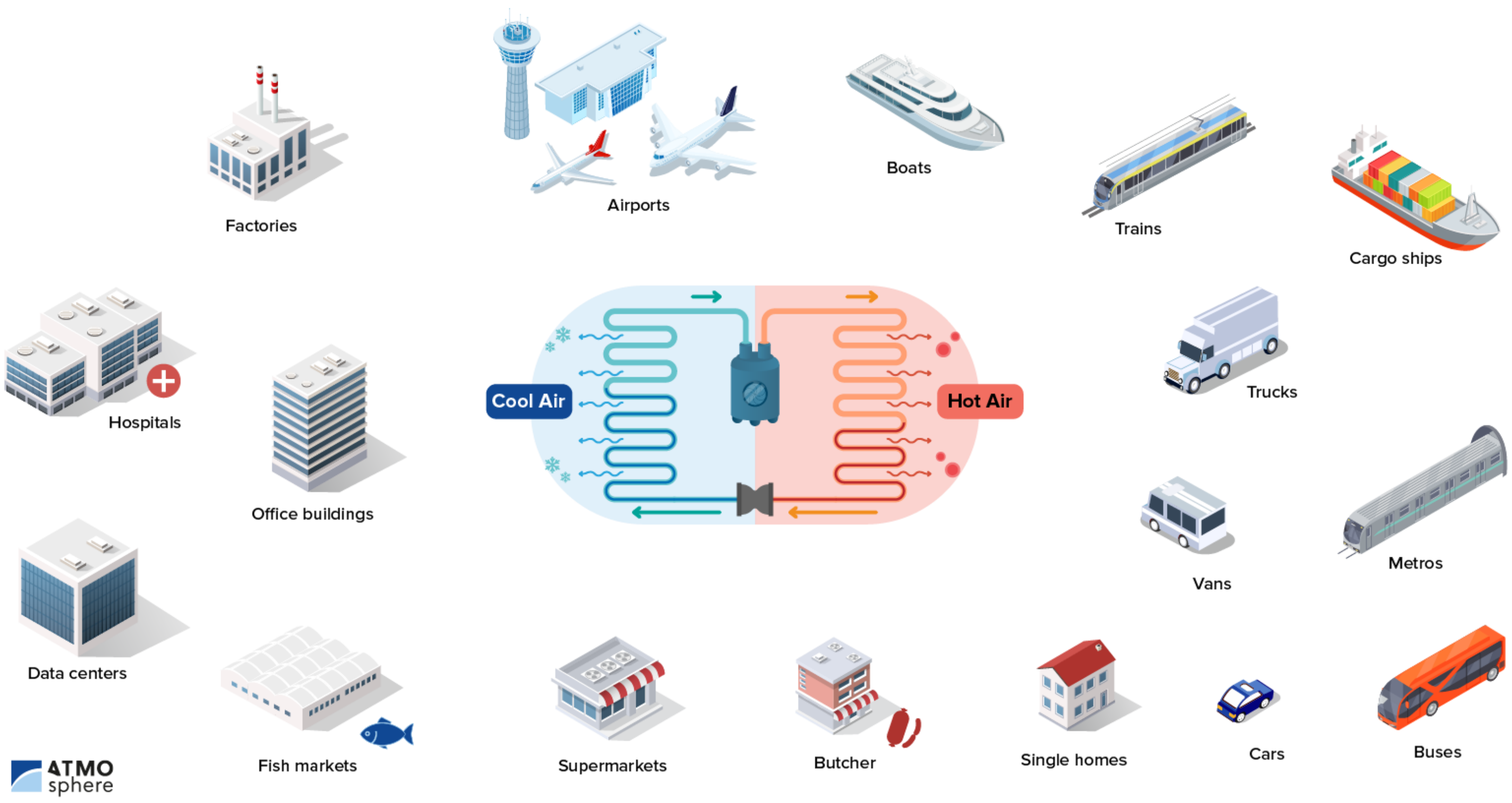
Ever asked yourself how does your fridge work?

Why are refrigerants important? The vapour compression cycle

The blood of the system: refrigerant, heat carrier, heat medium, working fluid -> f-gases and often PFAS, or alterntives



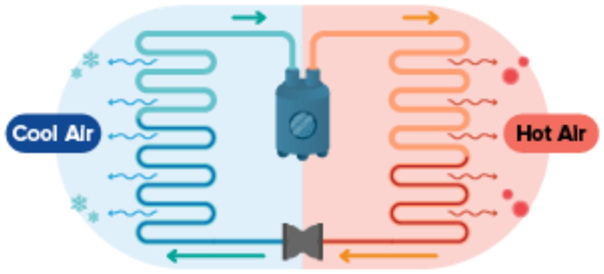
Where do we control mechanically temperatures? In more familiar places than we can think of…



Refrigerants can factually be everywhere!

Where can f-gases that are PFAS leak from?

Manufacturing



Operation

Landfill

The chemical treadmill of refrigerants

Mechanical control of temperatures –
refrigeration, cooling and heating

Halogenated substances

CFCs, HCFCs, HFCs, HFOs..

Ozone hole
Global warming
Persistent chemicals

- Substances not produced by nature -> hence, synthetic
- Useful in the past when environmental problems were less of a concern

Natural heat carriers

Carbon dioxide, hydrocarbons, ammonia, air, water

NO Ozone hole
NEGLIGIBLE global warming
NO persistent chemicals

- Substances that nature produce -> hence, natural
- Inherent concerns such as flammability and toxicity are well manged by industry

- RACHP: Refrigeration, air-conditioning and heat pumps
- HVAC&R: Heating, ventilation, air-conditioning and refrigeration

Availability across applications, regions, and temperatures

- F-gases that are PFAS used as working fluids are not essential
- Natural refrigerants are not a regrettable substitution
- Also development of systems without refrigerants – not-in-kind technologies

	CO_2 / R744	NH_3 / R717	HC	H_2O / R718	Air / R729
Domestic applications	✓		✓	✓	
Commercial refrigeration	✓	✓	✓	✓	
Industrial refrigeration and heat pump systems	✓	✓	✓	✓	✓
Water and space heating heat pumps	✓	✓	✓		
Chillers	✓	✓	✓	✓	
Vehicle air conditioning	✓		✓		✓

Sources: European Commission, German Environmental Agency - UBA, Norwegian Environmental Agency, UNEP, ATMOsphere

But concretely, which natural refrigerants can be used in which application TODAY?

ATMO sphere

Some examples for stationary and mobile refrigeration equipment – e.g., supermarkets, butchers, delivery trucks, industrial facilities…

Refrigerants	Composition	Global warming potential (IPCC Sixth AR – 20 and 100 years)	PFAS (OECD)	TFA creation (UBA)
HFC-134a	Single component	4140 - 1530	Yes CF3-CH2F	Yes 7 – 20%
HFC-404a	Blend	7208 - 4728	Yes, HFC-125: CF3-CHF2 HFC-134a: CF3-CH2F HFC-143a: CF3-CH3	Yes No HFC-125 HFC-134a: 7 – 20% HFC-143a: < 10%
HFO-513a	Blend	1823 - 673	Yes, HFC-134a: CF3-CH2F HFO-1234yf: CH2=CF-CF3	Yes HFC-134a: 7 – 20% HFO-1234yf: 100%
R-744	Single component – carbon dioxide	**1**	**No**	**No**
Hydrocarbons	Single components – isobutane, propane, propene…	**Less than 1**	**No**	**No**
R-717	Single component - ammonia	**No**	**No**	**No**

Sources: European Commission, German Environmental Agency - UBA, Norwegian Environmental Agency, UNEP, ATMOsphere

But concretely, which natural refrigerants can be used in which application TODAY?

Some examples for stationary cooling and heating equipment – e.g., heat pumps, ACs, chillers…

Refrigerants	Composition	Global warming potential (IPCC Sixth AR – 20 and 100 years)	PFAS (OECD)	TFA creation (UBA)
HFC-410A	Blend	4715 - 2255	Yes HFC-125: CF3-CHF2	No
HFC-32	Single component	2690 - 771	No	No
HFC-407C	Blend	4456 - 1907	Yes, HFC-125: CF3-CHF2 HFC-134a: CF3-CH2F	Yes HFC-134a: 7 – 20%
R-744	Single component – carbon dioxide	**1**	**No**	**No**
Hydrocarbons	Single components – isobutane, propane, propene…	**Less than 1**	**No**	**No**
R-717	Single component - ammonia	**No**	**No**	**No**
R-718	Single component - water	**No**	**No**	**No**

Sources: European Commission, German Environmental Agency - UBA, Norwegian Environmental Agency, UNEP, ATMOsphere

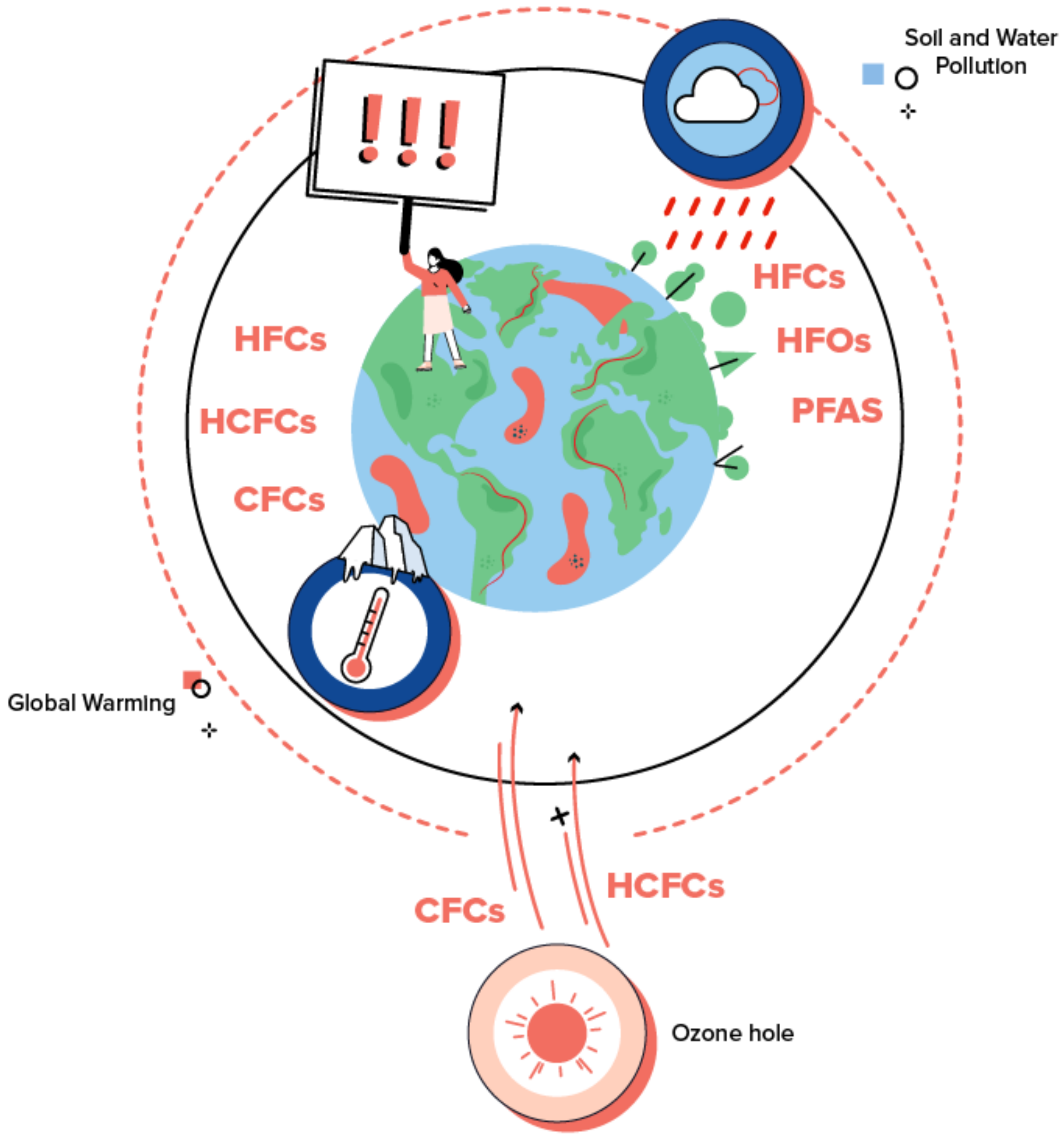
But concretely, which natural refrigerants can be used in which application TODAY?

Some examples for mobile air conditioning – e.g., cars, buses, metros, trains, ships…

Refrigerants	Composition	Global warming potential (IPCC Sixth AR – 20 and 100 years)	PFAS (OECD)	TFA creation (UBA)
HFO-1234yf	Single component	1.81 - 0.501	Yes, HFO-1234yf: CH2=CF-CF3 -	Yes HFO-1234yf: 100%
HFC-32	Single component	2690 - 771	No	No
HFC-134a	Single component	4140 - 1530	Yes CF3-CH2F	Yes 7 – 20%
R-744	Single component – carbon dioxide	**1**	**No**	**No**
Hydrocarbons	Single components – isobutane, propane, propene…	**Less than 1**	**No**	**No**
R-729	Single component - air	**No**	**No**	**No**

Sources: European Commission, German Environmental Agency - UBA, Norwegian Environmental Agency, UNEP, ATMOsphere

Enough!


Soil and Water Pollution
HFCs
HFOs
PFAS
HFCs
HCFCs
CFCs
Global Warming
CFCs
HCFCs
Ozone hole

Thank you for listening.

Find out more on

www.atmosphere.cool

JOURNEY AWAY FROM PFAS

TRANSENE COMPANY, INC.

10 Electronics Ave. Danvers Mass. - www.transene.com

TRANSENE COMPANY, INC.

ACKNOWLEDGMENTS

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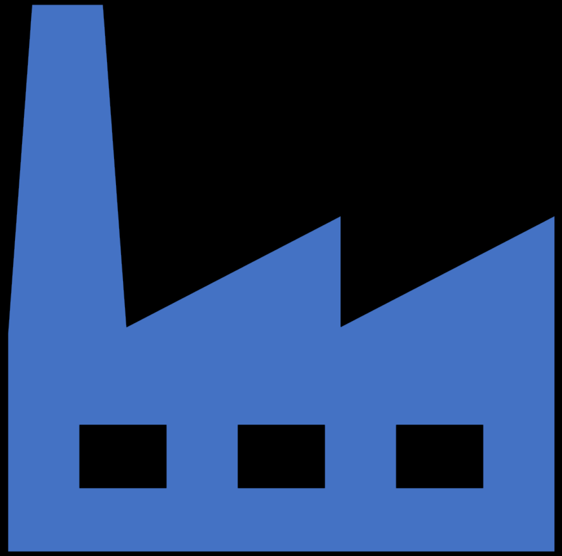
- Investigator: Prof. Ramaswamy Nagarajan, Plastics Engineering
- Research Manager: Dr. Gregory Morose, Toxics Use Reduction Institute
- TURI for funding academic research grant



COMPANY HISTORY

- Founded in 1965
- Manufacturer of electronic chemicals, diagnostic stains and reagents, analytical chemicals
- Factories in Danvers MA and Oakland CA, USA
- 33 Employees

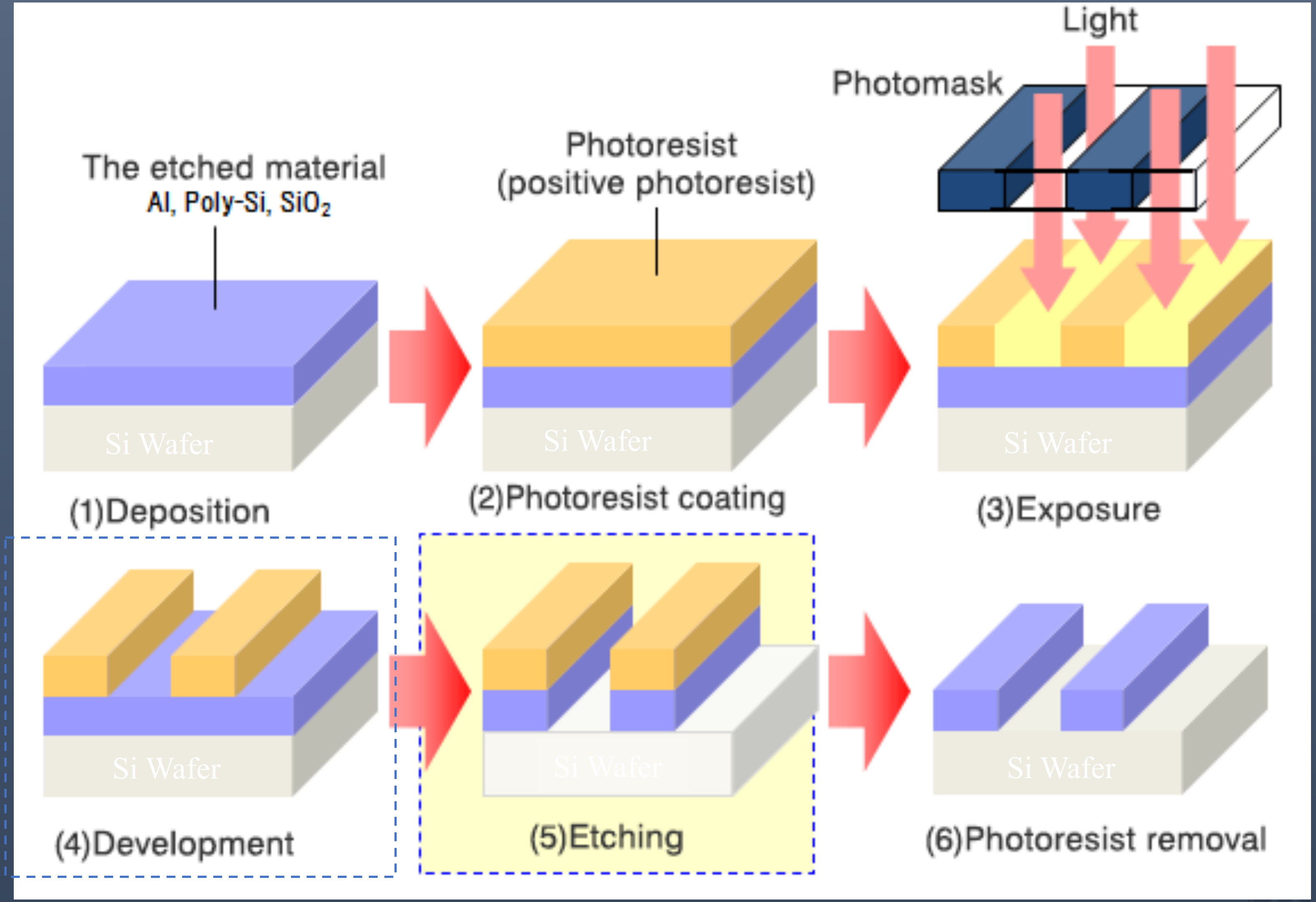
WHO ARE ELECTRONICS CUSTOMERS?

- Semiconductor fabs
- Chip manufacturers
- MEMS
- Photronics
- Optics

ROLE OF SURFACTANTS IN SEMICONDUCTOR INDUSTRY (ETCHING PROCESS)

Desired Surfactant Properties:

- Increase the wettability of the etching solution
- Allow for release of gases
- No residue/contamination
- Effective at low concentration
- Low or no foaming



PFAS surfactants may be found in steps 4 - 6

PFAS REPLACEMENT REQUIREMENTS

Compatibility: Strongly acidic/oxidizing solutions - nitric acid, phosphoric acid etc.

Sufficient surface tension reduction: 75 to 25-30 mN/m with < 0.1wt% surfactant concentration

Contaminants: low sodium ions

Stability: > 1 year shelf life in solution

Low foaming

Cost

PFAS HISTORY AT TRANSENE

PFOS

TYPE 1

TYPE 2

TYPE 3

CUST SPEC

PFAS---PFAS---PFAS---PFAS---PFAS---PFAS---PFAS

WHAT NEXT?

IDENTIFYING OPTIONS

Transene focused on sources we knew

UML group had other options

Group technology	Related materials

CUSTOMER ACCEPTANCE

Customers use the chemicals in different ways (spray, circulate, etc.)

Easy targets—one-off purchases

Initial phase engendered some comments about foaming—slight level reduction

No complaints? Let some customers know the change has been made

Still no complaints? Start qualifications with the big customers

Not a 100% success rate

CONCLUSIONS

- Strength of industry-academic collaboration

- PFAS replacement is viable

- Cost impact; sales impact

- Reduced liability

NICOLE HUEHN, 19 JUNE 2023

Performance and development of PFAS-free textile alternatives

sympatex®

SYMPATEX JOURNEY

OVERVIEW

01

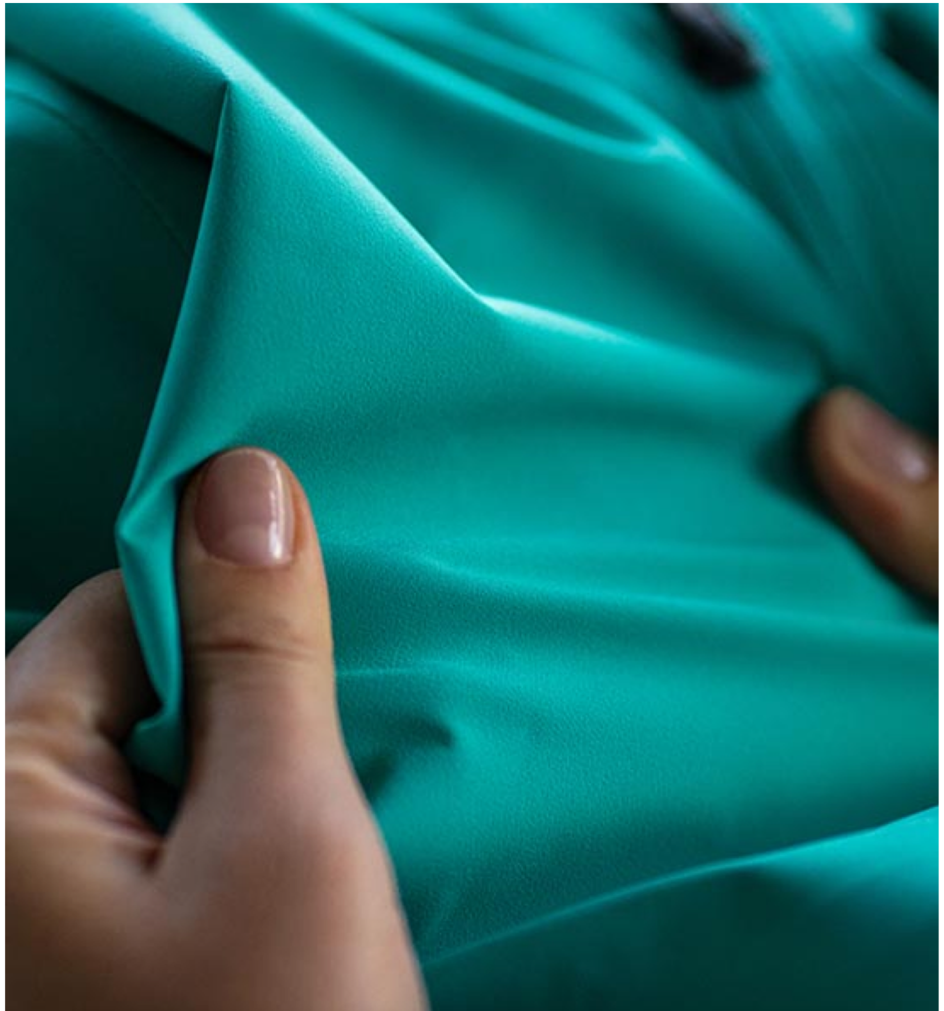
FUNCTIONAL FABRICS

02

PERFORMANCE OF PFAS-FREE FABRICS

03

DEVELOPMENT OF PFAS-FREE FABRICS

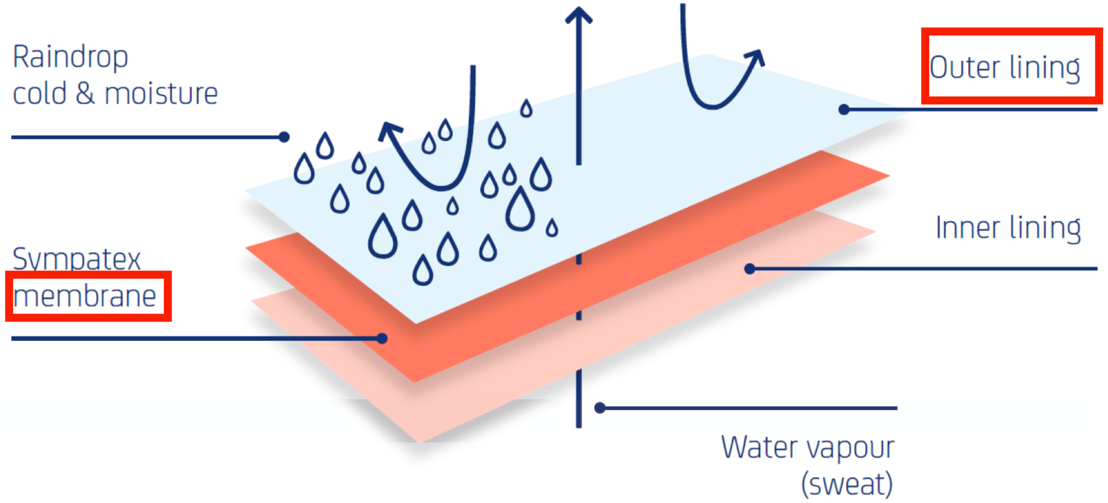


sympatex®

Functional fabrics for garment & shoes

- Outer lining
  → treatment
  → water repellence

- Barrier layer
  → membrane or coating
  → waterproofness



sympatex®

PERFORMANCE – PFAS VS. PFAS-FREE

WATER REPELLENCE

- Spray Test (ISO 4920)
- Bundesmann Test (ISO 9865)
- Rain Tower Test (EN 14360)

→ Slightly more frequent reimpregnation of fluorine-free DWR after washing could be necessary

WATERPROOFNESS

- Determination of resistance to water penetration (EN 1734)

→ No difference, compact systems even better

PERFORMANCE - WATER REPELLENCE

Correct adjustment of all parameters:

1. textile surface
2. DWR
3. Finishing paramter
4. Intended use

→ same performance of PFAS-free and PFAS DWR:

10 min Bundesmann grade 5, even after 5x 40°C washing

DEVELOPMENT OF PFAS-FREE ALTERNATIVES

PFAS-FREE WATER REPELLENCE

- 2008 – 1st fluorine free DWR
- 2012 – increased demand from customers
- 2013 – today: testing of market available DWRs

Currently **2 working groups** at Sympatex

- Performance comparison C0 – C6
- Customer oriented issues:
  - Customer communication
  - Benchmark
  - different DWR on Sympatex laminate

LET’S DIVE INTO THE QUESTIONS!

CHEMSEC CHANNELS

- **Website:** chemsec.org
- **PFAS Guide**: pfas.chemsec.org
- **SIN List:** sinlist.chemsec.org
- **Marketplace:** marketplace.chemsec.org

- **LinkedIn:** @chemsec
- **Twitter:** @chemsec
- **Instagram:** @no_to_pfas
- **Facebook:** @chemsecsweden