ADVANCED SEALING TECHNOLOGIES: ENABLING SAFETY, RELIABILITY, AND PERFORMANCE ACROSS THE HYDROGEN VALUE CHAIN

A Technetics Group Company Presentation

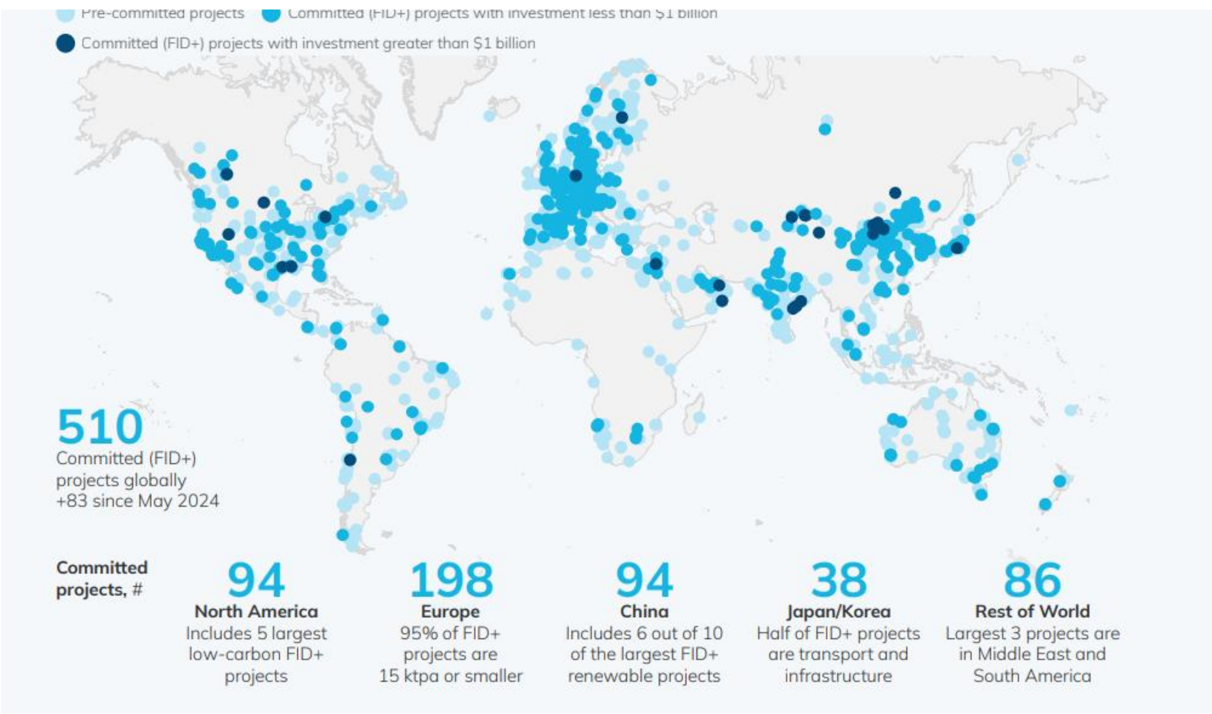
AGENDA

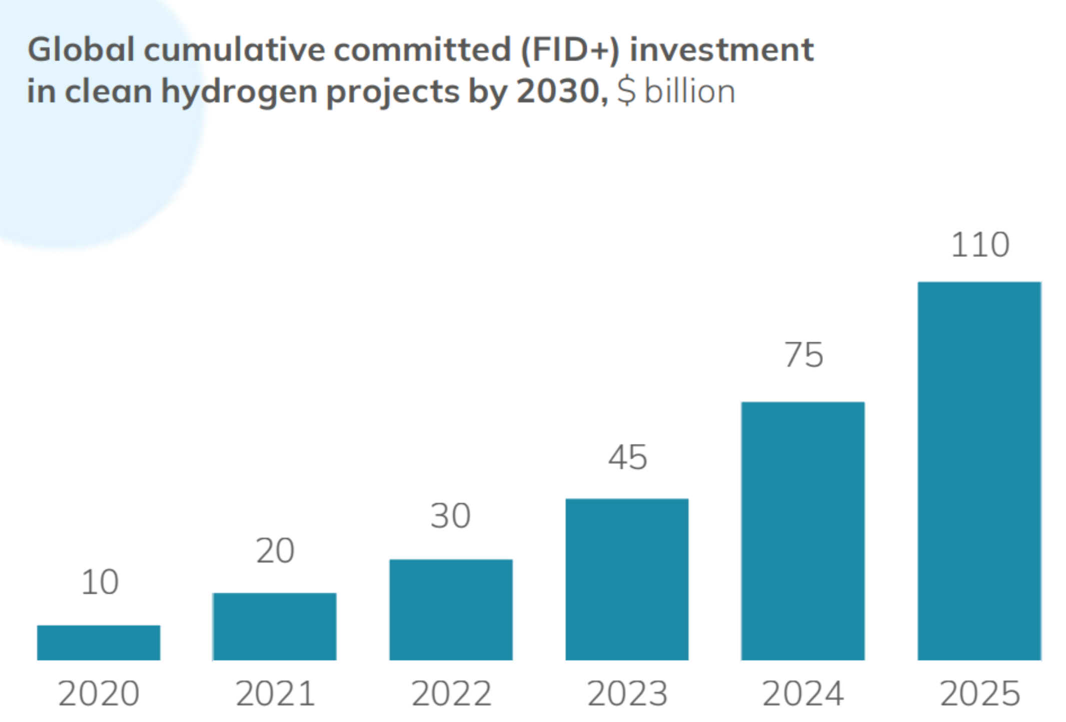
- **Analyzing the Current Hydrogen Landscape**
- **Fundamental Principles of Resilient Sealing**
- **Critical Application Case Studies**

Hydrogen update 2025

Market Maturity: Low-carbon hydrogen is transitioning from a policy-driven niche to an established energy carrier

Scaling Infrastructure: The rapid increase in committed (FID+) clean hydrogen projects, reaching $110 billion by 2025, necessitates robust engineering standards



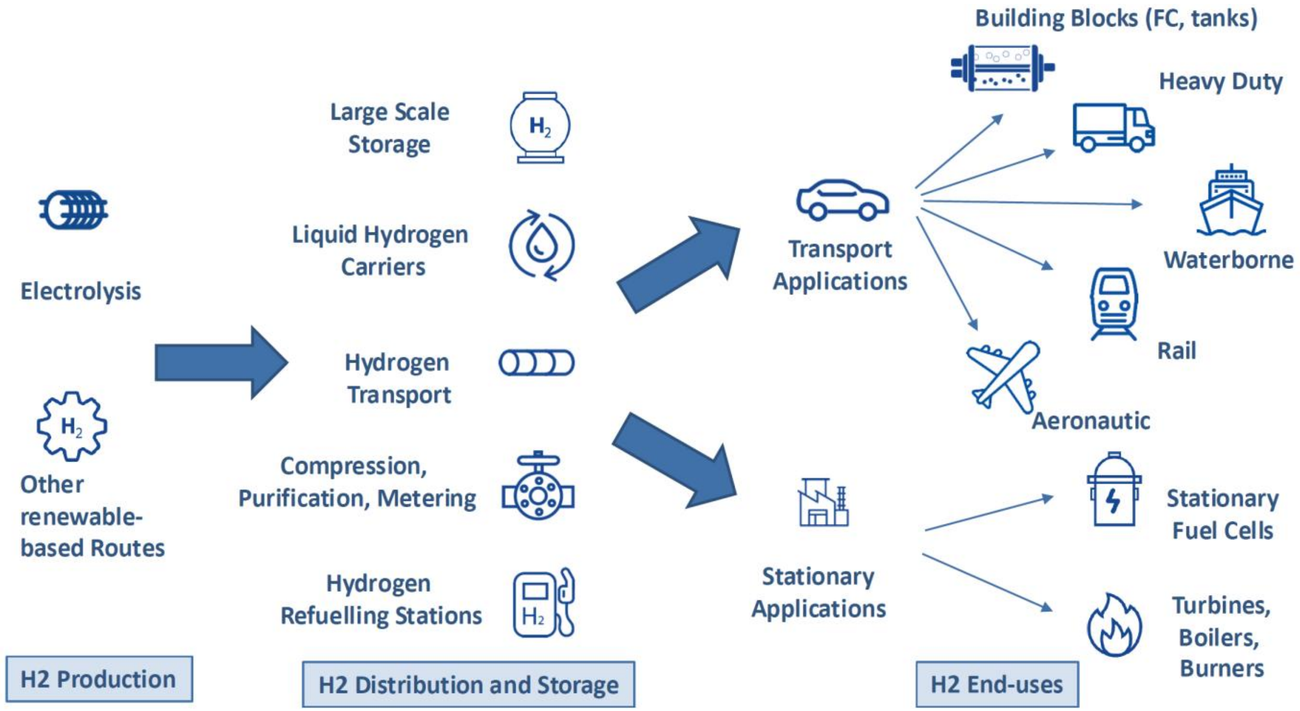


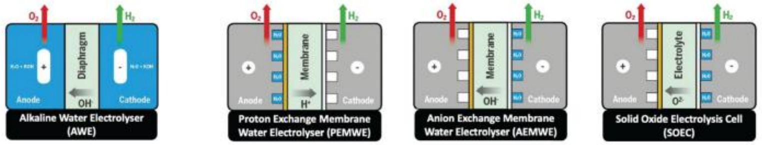
Hydrogen-Council-Global-Hydrogen-Compass-2025.pdf

Hydrogen Value Chain

- Interface Diversity: Each stage of the value chain, from high-temperature electrolysis to cryogenic liquid transport, presents unique thermo-mechanical sealing challenges
- Technical Readiness: Addressing the gap between pilot-stage technologies and commercial-scale deployment through specialized component design and engineering adaptation.

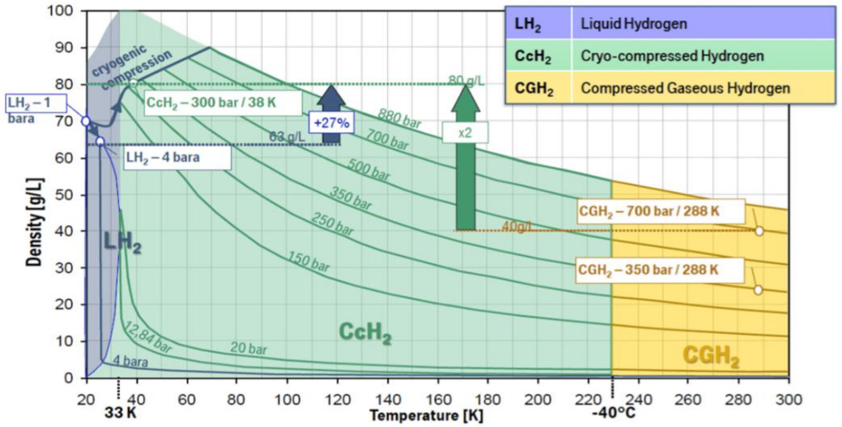
Clean Hydrogen Partnership





Type	Low Temperature				High Temperature
	Atmospheric Alkaline (AWE)	Pressurized Alkaline (PAWE)	Proton-Exchange Membrane (PEM)	Anion Exchange Membrane (AEM)	Solid Oxide Electrolysis Cell (SOEC)
Electrolyte	Liquid ($KOH-OH^-$)		Solid ($NAFION-H^+$)	Solid ($DVB-OH^-$)	Solid ($YSZ/CGO-O^{2-}$)
Temperature	60-80 °C		60-80 °C		600-850 °C
Materials	Ni, carbon steel		Ti, Pt, Ir	Ni, carbon steel	Metal (Y, Zr, Ni, Co) oxides, Stainlesss steel
Stack size	1-5 MW	5 MW	1-2 MW	1-5 kW	10-50 kW

source: Dr. Carlos Bernuy-Lopez, Ramboll

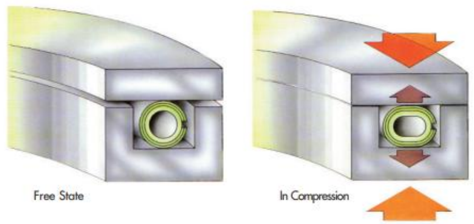


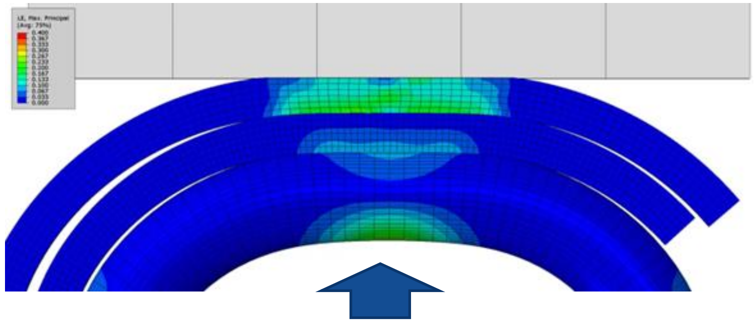
Source: Hyun etc, Energies, 2023

Technetics GROUP

An overview of the resilient metallic seals

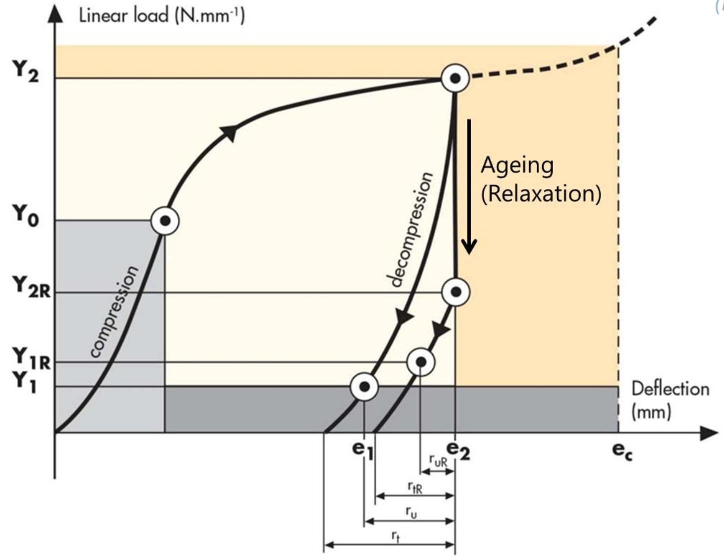
Resilient Metallic Seals: Utilizing plastic deformation of outer materials combined with elastic spring energy to maintain gas tightness under dynamic loads

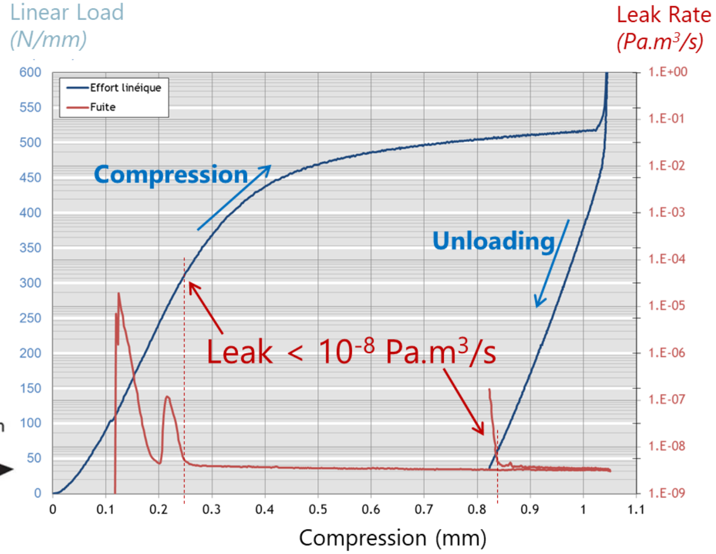




Spring Reaction Force

spring energized metallic seal, a combination of elastic and plastic, defined compression in metal-to-metal concept.





Performance Characterization: Analyzing force-displacement diagrams to define optimal compression in metal-to-metal contact scenarios

STD CC/SEC*	MBAR-L/SEC	TORR LITERS/SEC	TIME FOR ONE CC TO LEAK	TIME FOR ONE BUBBLE** TO LEAK
10^{-1}	1.01×10^{-1}	7.6×10^{-2}	10.0 seconds	0.25 seconds
10^{-2}	1.01×10^{-2}	7.6×10^{-3}	100.0 seconds	2.50 seconds
10^{-3}	1.01×10^{-3}	7.6×10^{-4}	16.7 minutes	25.00 seconds
10^{-4}	1.01×10^{-4}	7.6×10^{-5}	2.8 hours	4.0 minutes
10^{-5}	1.01×10^{-5}	7.6×10^{-6}	28.0 hours	40.00 minutes
10^{-6}	1.01×10^{-6}	7.6×10^{-7}	11.5 days	7.00 hours
10^{-7}	1.01×10^{-7}	7.6×10^{-8}	3.8 months	3.00 days
10^{-8}	1.01×10^{-8}	7.6×10^{-9}	3.2 years	1.00 month
10^{-9}	1.01×10^{-9}	7.6×10^{-10}	32.0 years	9.00 months
10^{-10}	1.01×10^{-10}	7.6×10^{-11}	320.0 years	8.00 years
10^{-11}	1.01×10^{-11}	7.6×10^{-12}	3200.0 years	80.00 years

VISUALIZATION OF STD

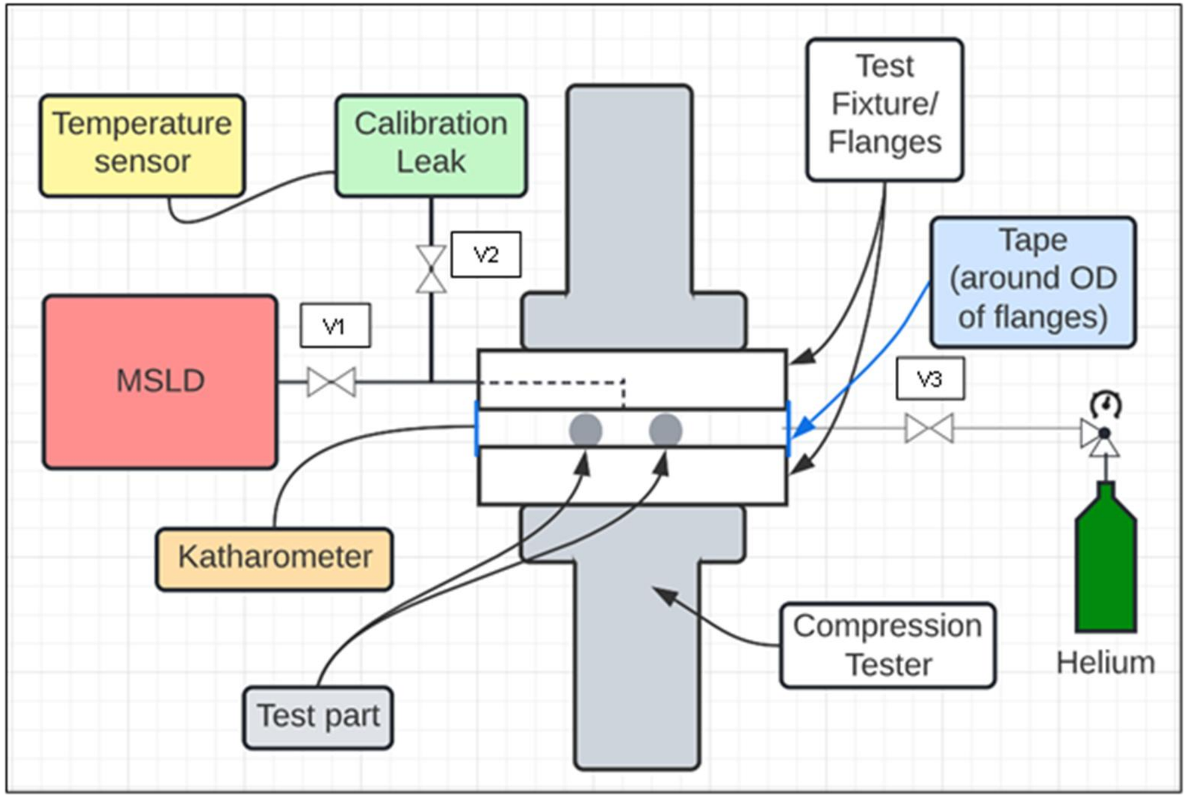
CC TO SCALE

Seal and Mass Spectrometer Leak Detection Fixture

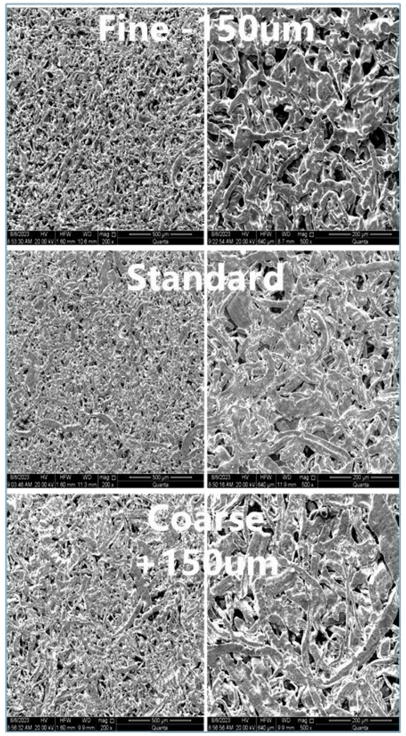
Leak Rate Quantification: Achieving ultra-low leak rates through mass spectrometer leak detection (MSLD)

Component and their Function:

- MSLD –Mass Spectrometer Leak Detector
- Compression Tester – Load control and displacement control
- Katharometer – Helium concentration measurement
- Calibration Leak – Known leak rate value
- Tape – Used to control Helium volume for outside-in testing



Performance Optimization of Sintered Metal Fiber PTLs



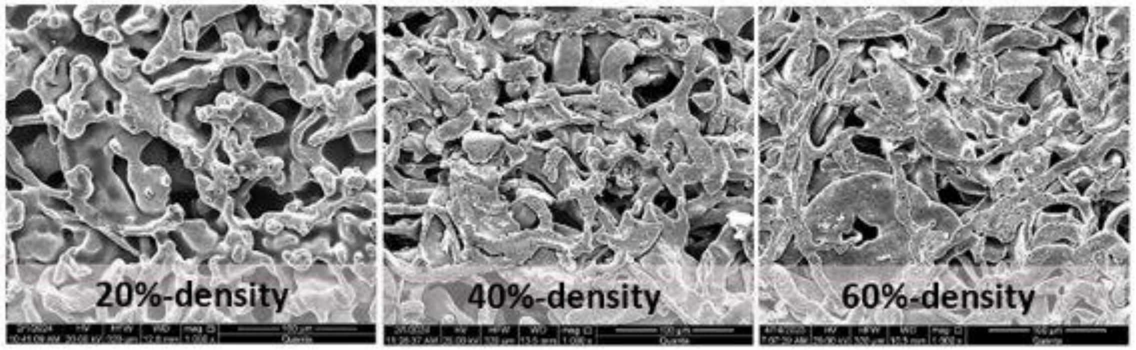
Challenge: Critical Role of PTL in Electrochemical Efficiency

As a core component of the electrolyzer stack, PTL structural integrity directly dictates long-term voltage stability and mass transport efficiency.

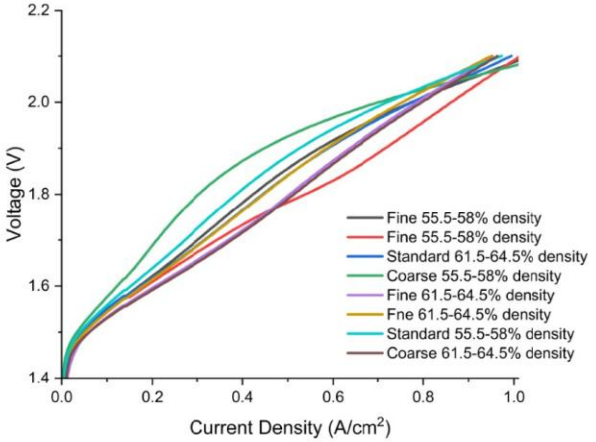
Engineered Porous Networks

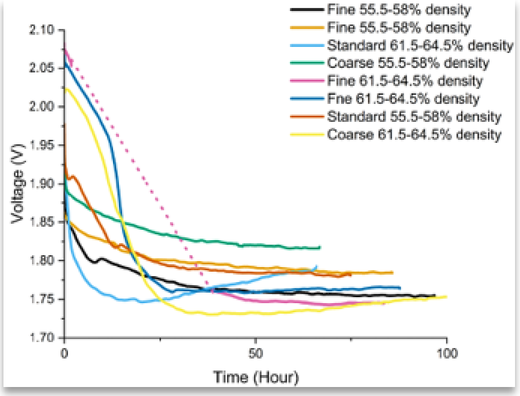
Felt metal sintering facilitates a highly controllable network of open pores.

By modulating fiber morphology, compression, and sintering kinetics, the microstructure can be tailored to minimize interfacial resistance and optimize gaseous diffusion pathways.



SEM images FM PTL surfaces.





Reference: Motyka et al, The Effect of Feltmetal Porous Transport Layer Structure on Performance of Anion Exchange Membrane Water Electrolyzers, ASME, Turbo Expo 2024, Paper No. ***GT2024-129232.***

Metallic Sealing in SOFC/SOEC Systems

The Challenge: Multi-Physics Degradation in High-Temperature Environments

Maintaining a hermetic seal at 700–850°C is a critical bottleneck for project viability due to several engineering hurdles:

Thermo-Mechanical Mismatch

Time-Dependent Creep

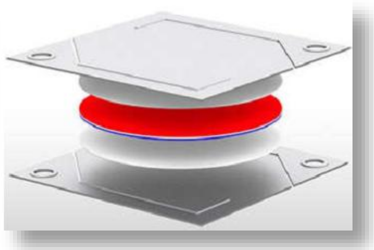
Chemical Degradation

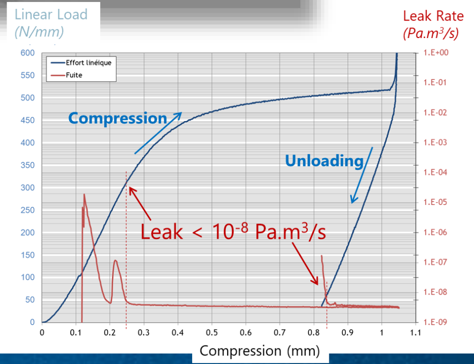
Interstack Sealing:

Compressive Metal-Based Seals: Better CTE matching, Advantages for Stack Maintenance and easy to assemble.

System and Mainfold Sealing:

- Material Selection: Utilization of Nickel-plated SS718 for components to ensure chemical compatibility and high-temperature strength.
- Leakage Control: Maintaining a leak rate of < 10 sccm across 4 ports (2-hydrogen, 2-pure oxygen).
- Operational Longevity: Validated for 40,000 hours of continuous operation at 750°C to ensure commercial viability.





High-Pressure Diaphragm Compressor Reliability

Challenge : Fatigue and Hydrogen-Induced Failure

In the Hydrogen Refueling Station (HRS) environment, diaphragm compressors operate at extreme physical boundaries, directly impacting commercial operational stability:

- Extreme Pressure Dynamics
- Hydrogen Embrittlement
- Thermal Management:

Sealing systems act as proactive engineering countermeasures rather than passive components to resolve these critical challenges:

- Advanced Material Selection
- Optimized Interface Geometry
- Integrated Design Synergies

Application example High pressure Compressors

- Suction pressure up to 900 bar
- Flow up to 800 Nm^3/h

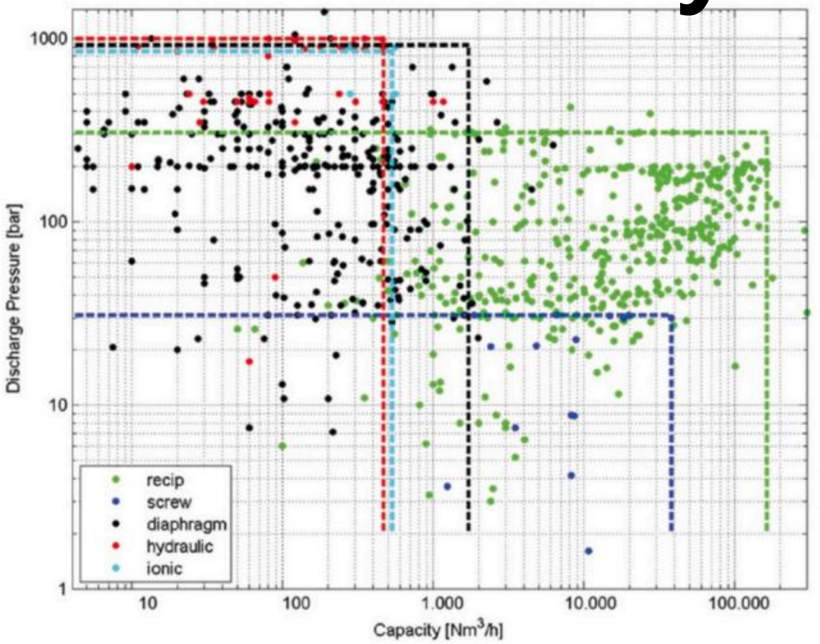
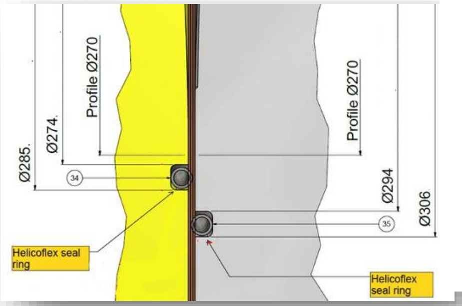
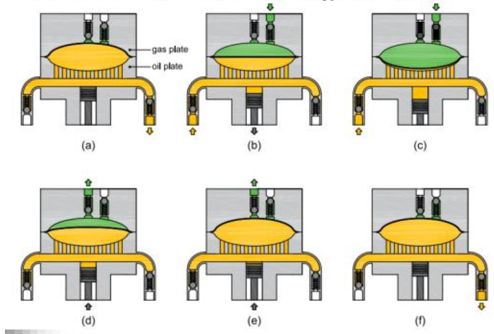


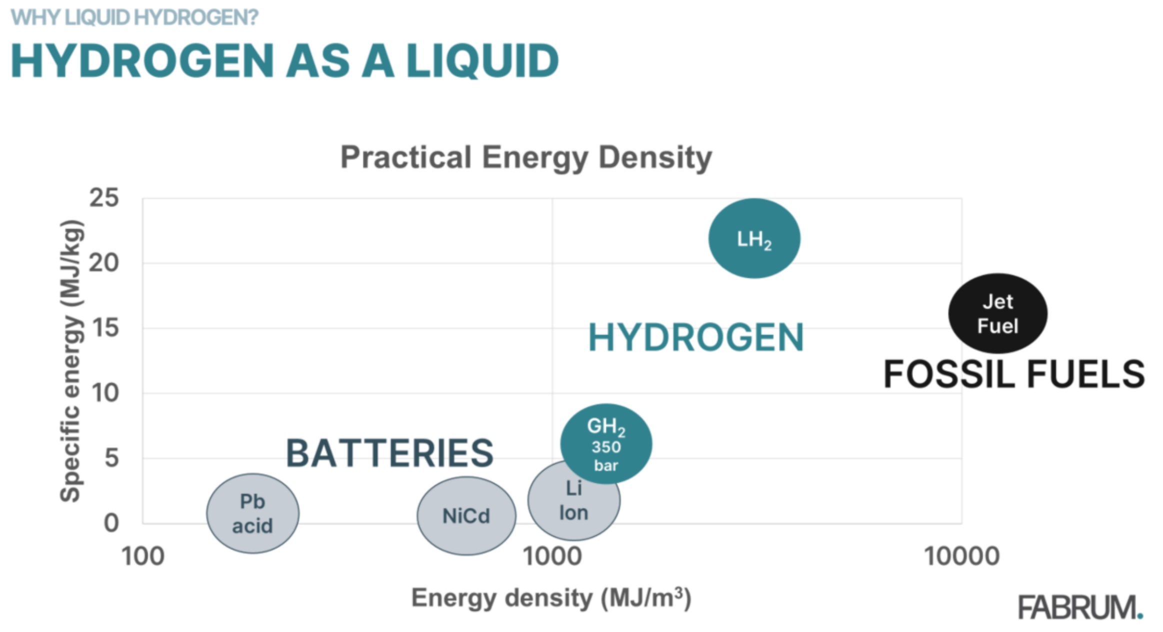
Fig. 1. Mechanical compressor map with industrial references (dots) and performance ranges (dotted lines) for hydrogen applications [6]. The capacity along the horizontal axis can be converted to mass flow rates according to 1000 $Nm^3/h \cong 90$ kg/h.





Reference: *Antonio Giuffrida, Paolo Colbertaldo, Overview of diaphragm compressors for hydrogen service: capacity, discharge pressure and operational challenges, 2025, Journal of Energy Storage.*

Liquid H2 storage tanks



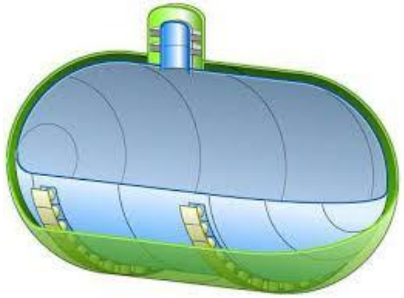
Challenge :

While high temperatures cause creep, cryogenic environments (-253°C) introduce a different set of physical barriers that threaten system viability-

- Material Embrittlement
- Thermal Contraction Gaps
- Phase Equilibrium (BOG Management)

Solutions for Extreme Cryogenic Resilience

- High-Spring-Back Metallic Interfaces
- Tribological Adaptation
- Thermal Cycle Endurance



Maritime

Drones

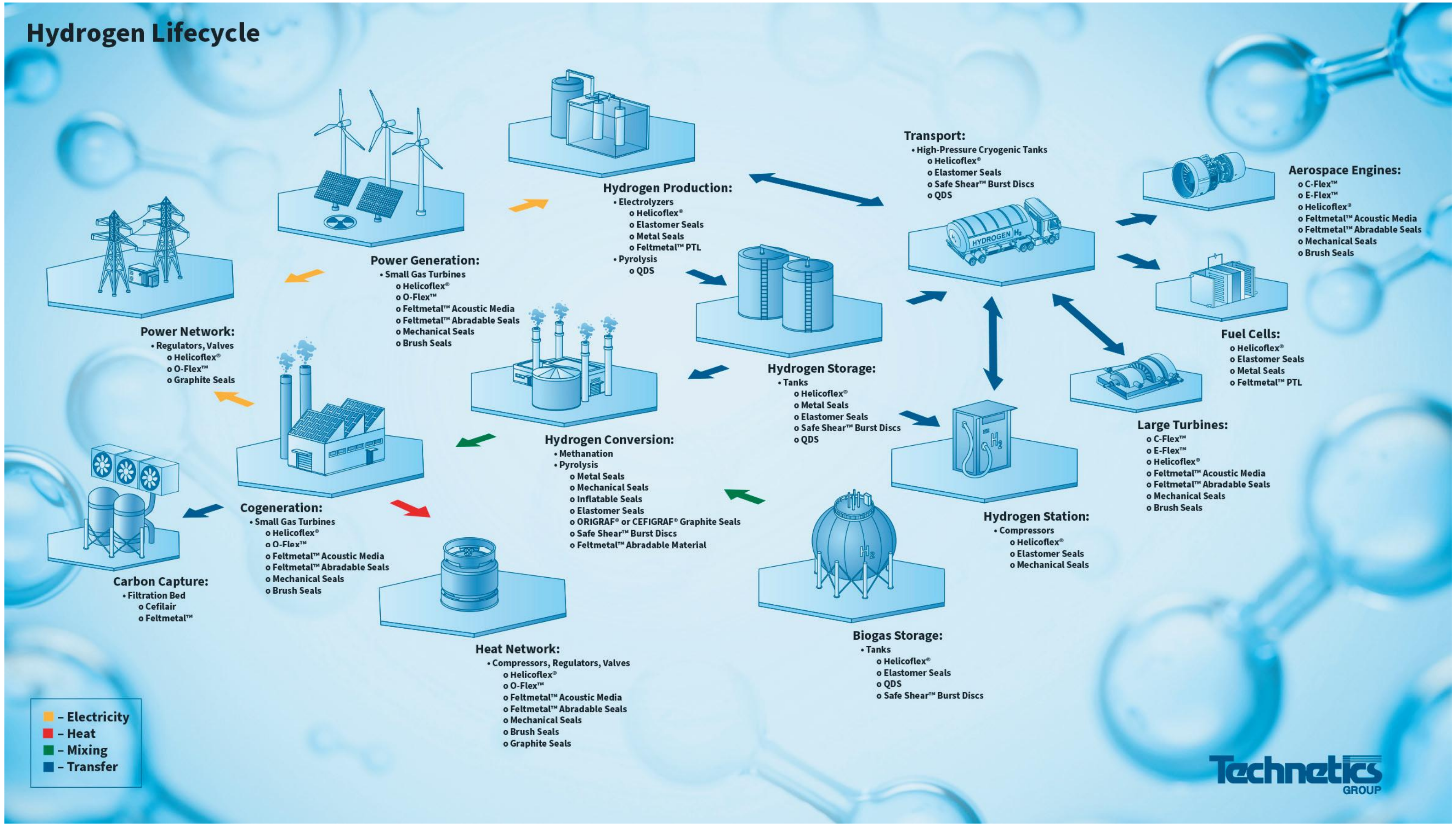
https://hydvance.com/technologies#reservoirs

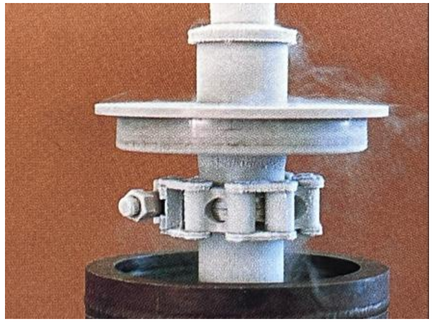
Motor sport

FIA publishes first liquid hydrogen regulations as Le Mans class nears 2028

Aviation

Application of Metallic seals in whole hydrogen value chain



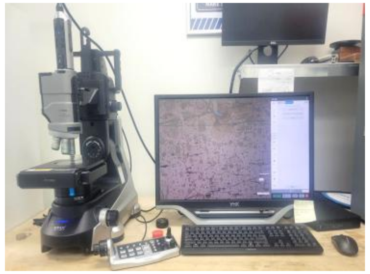


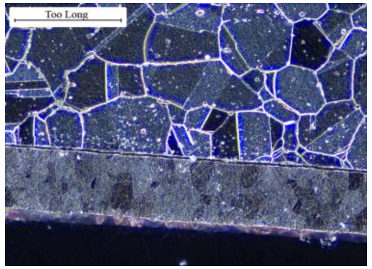
Cryogenic temperature

High temperature

Research and Development

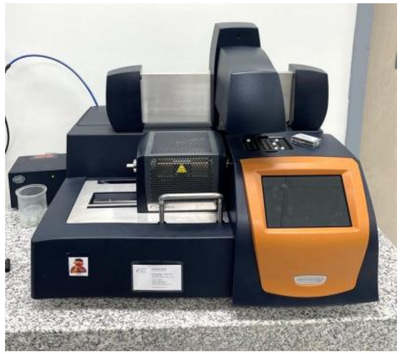
- Physical testing and seal qualification capabilities
- Material science directive, focusing on fundamental control and understanding of performance factors of high temperature metallic materials
    - Hardness, friction, wear, grain structure, tensile and compression behavior, thermal properties at extreme temperatures
- Development of new material selections and expanding product capabilities



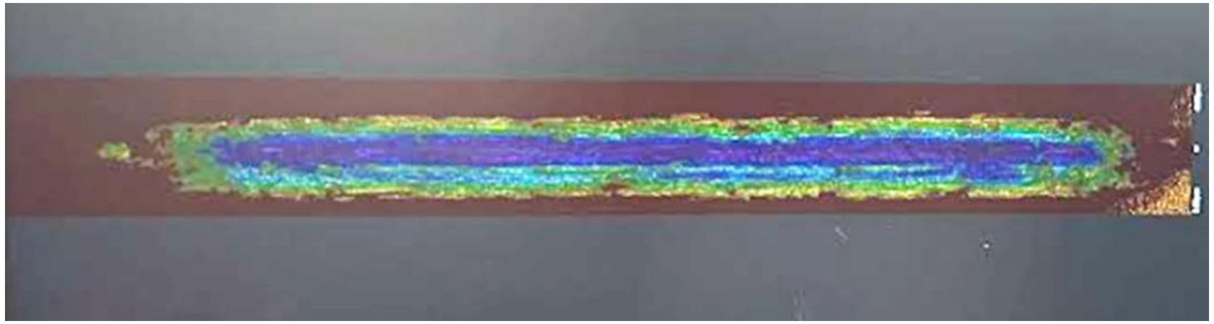


Metallurgical analysis

Tribometer - Friction Testing



Thermal Analysis



Profilometry and wear markings to measuring/characterizing surface finish, wear scar depth/volume.

Research and Development

CEA Marcoule – ISEC Institute

Science and Technology Institute for a Circular Economy of Low Carbon Energies

- Process engineering
- Material science
- Modeling & Simulation
- Eco-design & life cycle analysis

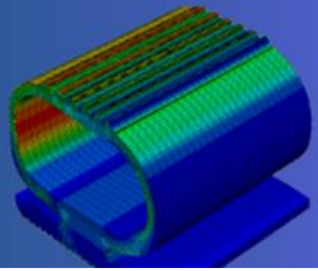
CEA-TECHNETICS joint lab since 1969

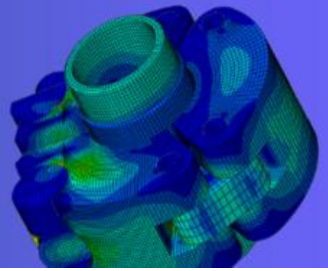
1200 m² dedicated to science of sealing

Missions :

- Sealing Assemblies Qualification
- Products Characterization
- New products Development
- Expertise
- Simulation

MAESTRAL : CEA-TECHNETICS JOINT LAB





MEETING THE MOST **DEMANDING CHALLENGES** WORLDWIDE

With locations around the world, we're ready to solve problems everywhere our clients are.

Technetics GROUP

THANK YOU

Any Questions?

Dr. Chen Cao, Global Hydrogen Market Manager

Chen.cao@technetics.com

Thomas Ritter, Regional Market Manager

Thomas.Ritter@technetics.com

Technetics GROUP