Electrolyser innovations
PEM, alkaline, SOEC, and AEM

Stephen B. Harrison, Managing Director, sbh4 consulting

Hydrogen Tech World Conference, Essen

26th June 2024

Agenda

1. Innovations in alkaline electrolysis
2. Innovations in PEM electrolysis
3. Innovations in PEM and alkaline electrolyser safety
4. Innovations in solid oxide electrolysis
5. Innovations in AEM electrolysis
6. Innovation or chaos?
7. Innovation in electrolyser manufacturing
8. Innovation in electrolyser supply chains

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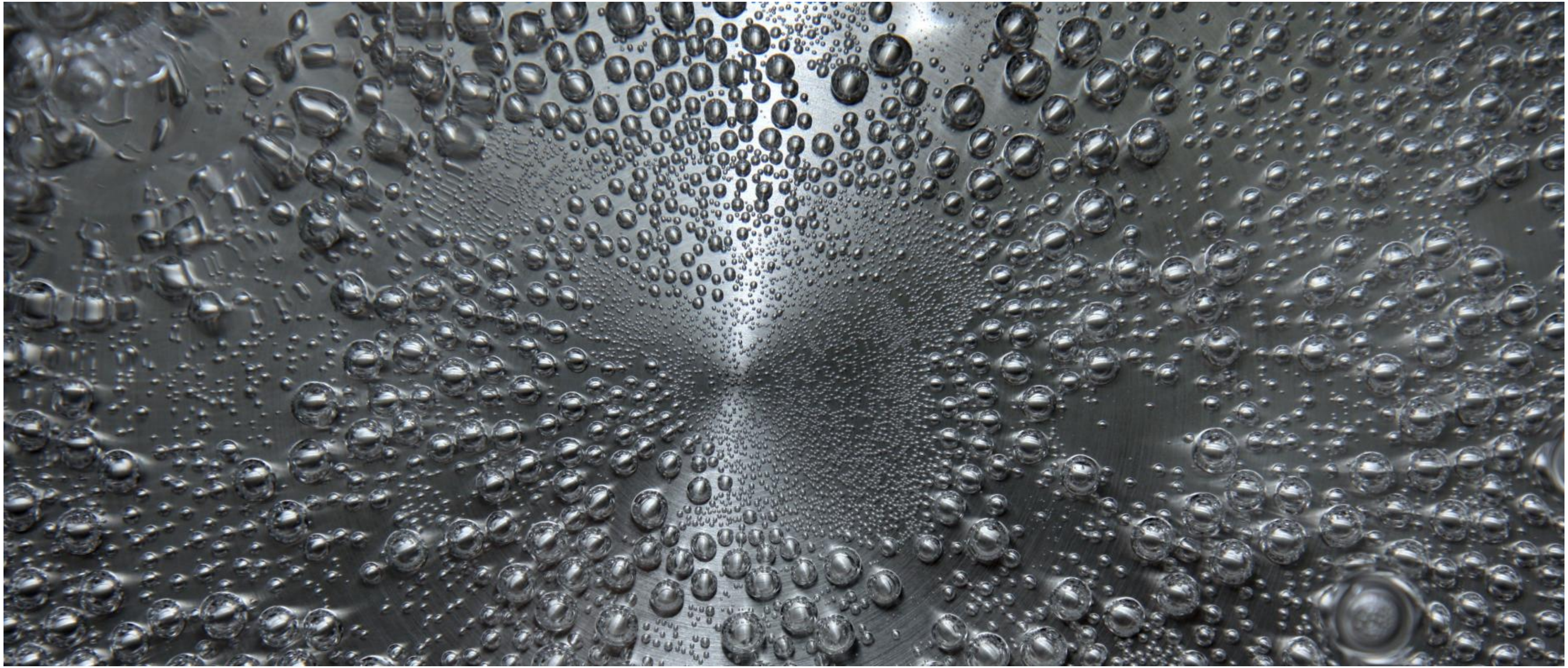
Innovations in alkaline electrolysis

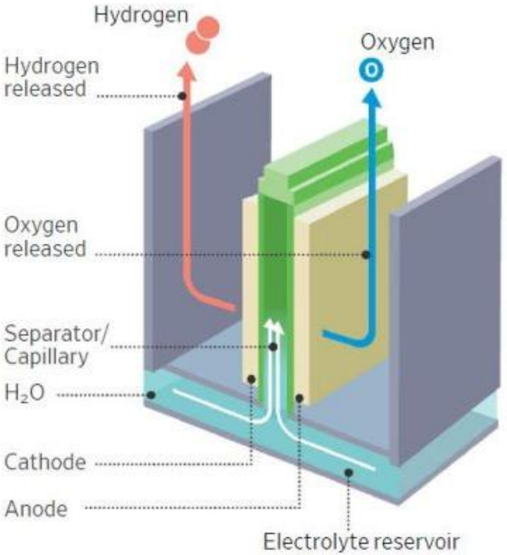
A typical 400 kW PEM / AEM / Alkaline stack generates 120 kW of heat. Should an electrolyser produce heat, or hydrogen? Reducing resistance is a key path to improving efficiency and reducing the BOP costs of heat exchangers and cooling towers.

Hydrogen and oxygen gas bubbles on the electrolyser electrodes or membrane increase resistance and reduces efficiency. Hysata’s bubble-free electrolysis addresses this issue.

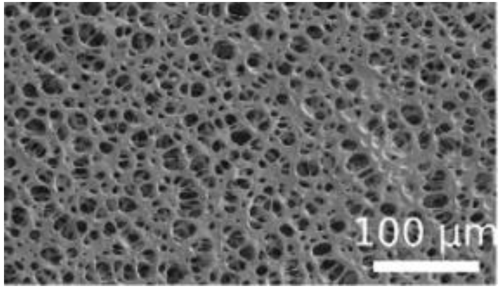


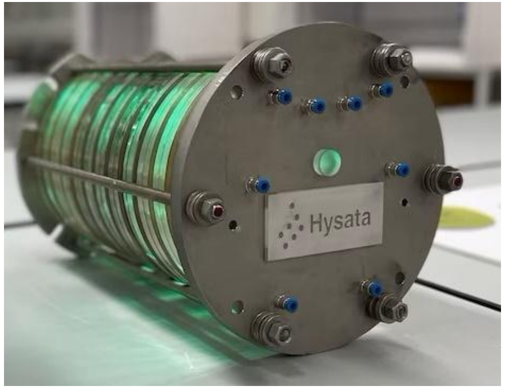
Hysata proposed cell integration into low-cost stack. High efficiency reduces waste heat generation and reduces BOP cooling cost.

Rather than surrounding the electrodes, water is drawn up to the electrodes using capillary action. That means bubbles don't form on the anode and cathode and less energy is wasted, Hysata says.



- NiFeOOH Oxygen electrocatalyst
- Pt/C Hydrogen electrocatalyst
- 27 wt% KOH lye eletrolyte
- 80 – 85 °C operating temperature
- 95% efficiency (HHV) at 0.8 A/cm^2 current density
- 100% efficiency (HHV) at 0.3 A/cm^2 current density
- 39.4 to 41.5 kWh / kg H_2
- Porous, hydrophilic polyether sulphone (PES) capillary separator





https://www.wsj.com/articles/startups-bring-down-cost-green-hydrogen-11668117024?reflink=share_mobilewebshare
https://www.linkedin.com/posts/areisf_hydrogen-greenhydrogen-netzero-activity-6960655606722502656-SE7h?utm_source=linkedin_share&utm_medium=member_desktop_web
https://www.nature.com/articles/s41467-022-28953-x

Pressurised alkaline electrolysis process

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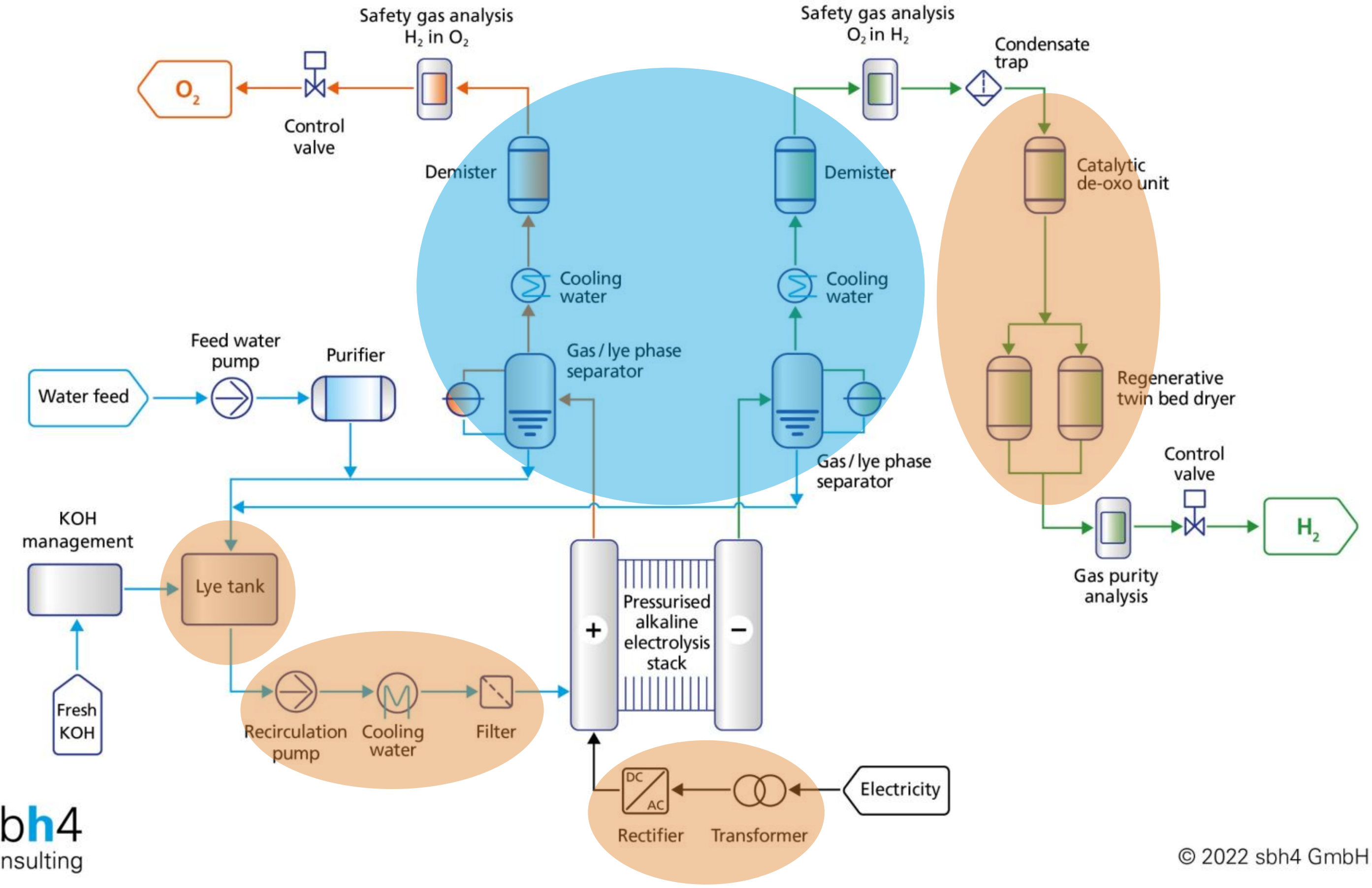

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Hysata high-efficiency, capillary-fed, zero bubble pressurised alkaline electrolysis results in BOP cost reductions compared to other pressurised alkaline electrolysis systems due to reduced size of power management, less cooling requirement and elimination of gas / liquid separation

🟠 Reduced size / reduced cost BOP items

🔵 Eliminated BOP items

High pressure hydrogen for ammonia production or hydrogen mobility. Newes, NL. Tested 1.5 kW alkaline electrolyser with 140 bar hydrogen delivery at 99.3% purity in 2022, target to achieve 350 bar in 2023.

https://www.newes.nl/hydrogen/

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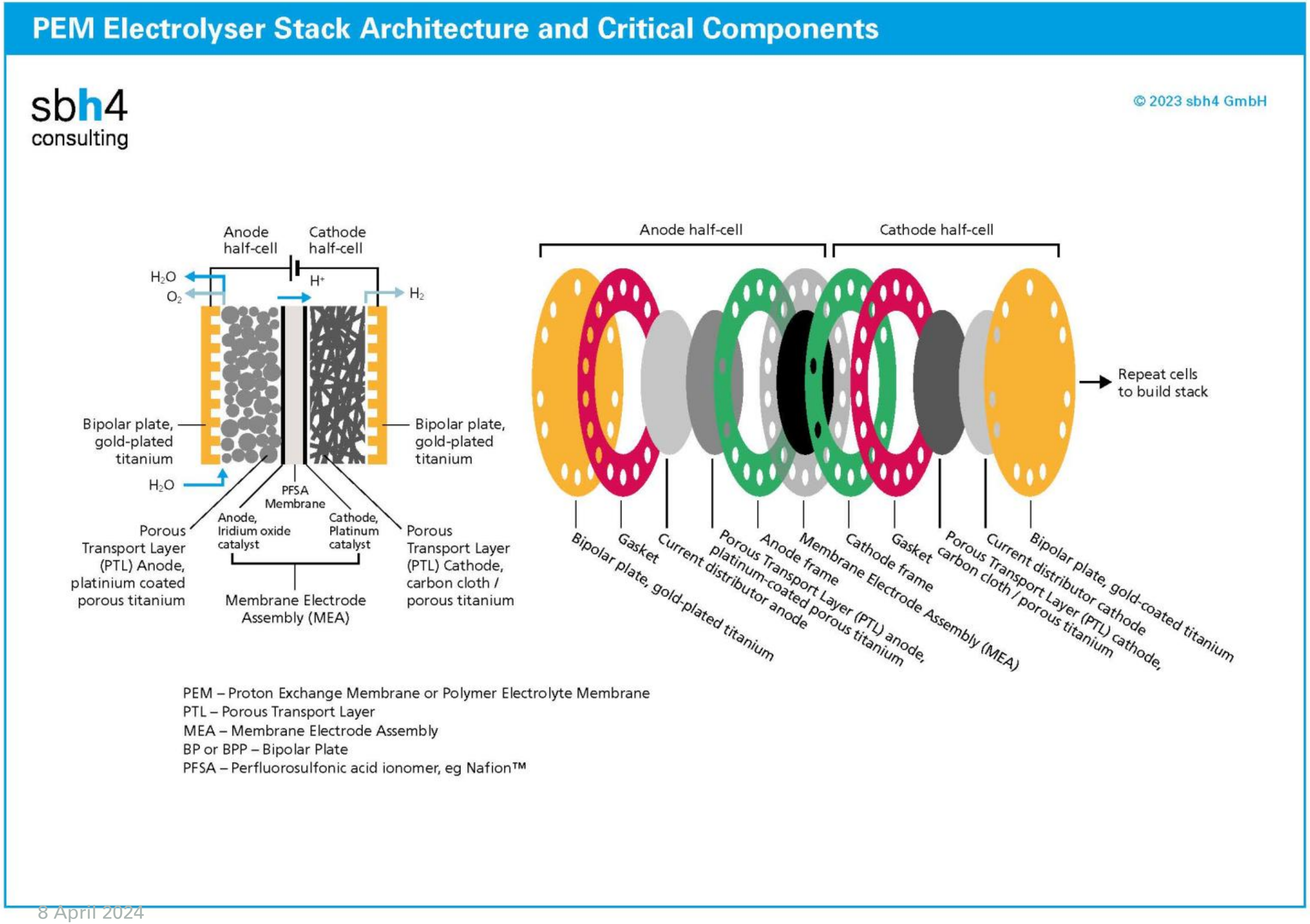
Innovations in PEM electrolysis



PEM Electrolyser Stack Architecture and Critical Components

PEM – Proton Exchange Membrane or Polymer Electrolyte Membrane
PTL – Porous Transport Layer
MEA – Membrane Electrode Assembly
BP or BPP – Bipolar Plate
PFSA – Perfluorosulfonic acid ionomer, eg Nafion™

- Classical PEM stack architecture relies on precious metals: gold (BPP coating), iridium (anode) and platinum (cathode).
- Metallic components (BPP, PTL) are built around titanium – a metal in high demand for building nuclear submarines and apple phones!
- Manufacturing is complex due to processing of flexible membrane that is boiled, then coated with the catalytic powders.
- Assembly requires mechanical compression to retain gases at 20 to 30 bar.
- Gaskets and seals are critical to avoid internal and external leakages.


borit
HYDROGEN COMPONENTS
HYDROGATE™
Advanced technology for high precision sheet metal forming
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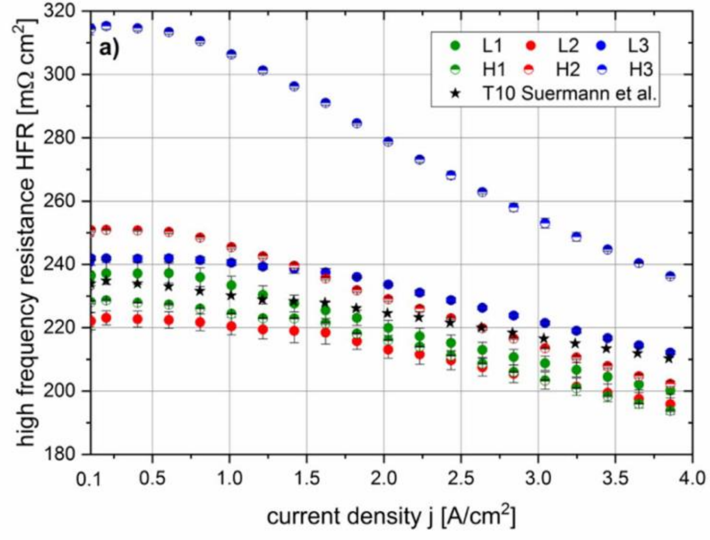
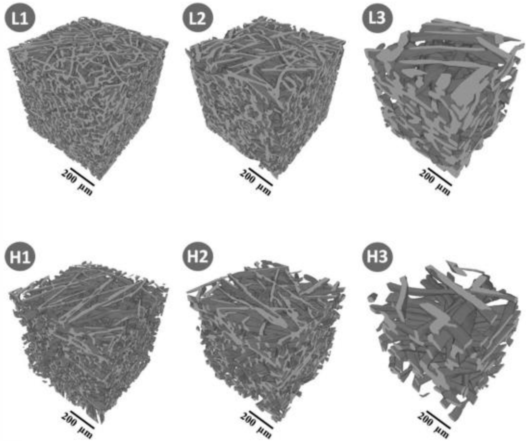
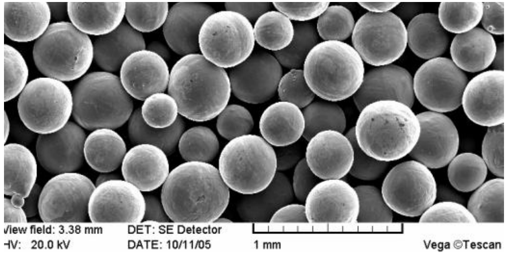
GRAEBENER
Bipolar Plate Technologies
WE MAKE Y
Fuel Cells

Sintered titanium powder mesh has historically been the standard PTL material, but sintered titanium fibres (eg Bekaert) are now established and can improve PTL and stack performance through reduced electrical resistance. Fibres also increase the membrane life, compared to powder.

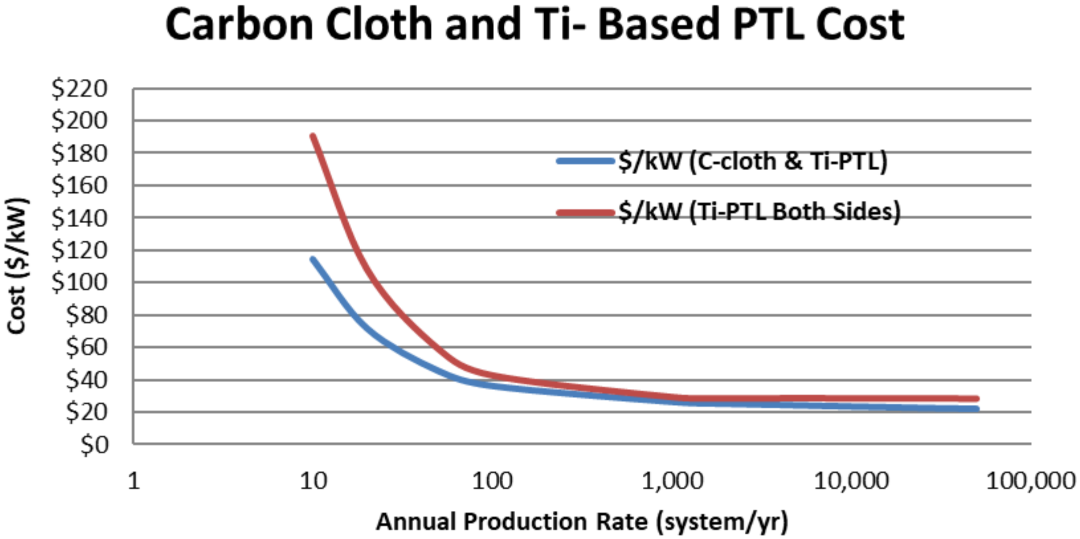






https://www.researchgate.net/publication/333360045_Polymer_Electrolyte_Water_Electrolysis_Correlating_Performance_and_Porous_Transport_Layer_Structure_Part_II_Electrochemical_Performance_Analysis
https://iopscience.iop.org/article/10.1149/2.0561904jes/pdf
https://www.semanticscholar.org/paper/Optimization-of-porous-current-collectors-for-PEM-Grigorieva-Baranova/28e162d1b4deb9e46fb14c3e0001085c62d4bf3e

Using carbon or coated carbon felts instead of titanium powders, fibres and felts for the PTL can reduce cost.



Freudenberg E35H carbon felt

Manufacturing Cost Analysis for Proton Exchange Membrane Water Electrolyzers,
Ahmad Mayyas et al, 2019, NREL/TP-6A20-72740
https://www.quintech.de/produkte/komponenten/gasdiffusionslagen/gdl-fuer-elektrolyse/e35-h/

Iridium oxide catalyses the oxygen evolution reaction. Avoidance of iridium oxide for the anode catalyst is possible, for example PMF powder from PAJARITO POWDER. But performance is reduced, and a larger membrane / electrolyser is required with additional materials usage.

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Catalysts for PEM water electrolysis

- Iridium oxide
- Low iridium catalysts
- Platinum and PGM alloys on Engineered Catalyst Supports (ECS)

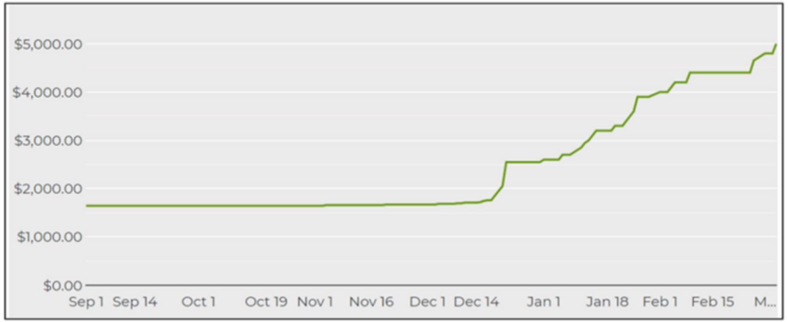
Catalysts for AEM water electrolysis

- LaSrCo
- Ni Ferrite
- Ni-Mo on ECS
- $PbRuO_x$

PAJARITO POWDER

www.PajaritoPowder.com

Iridium Price, **$5800**/toz April 2021



Platinum Price, $1132/toz March 2021

https://www.h2utechnologies.com/technology

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Innovations in PEM and alkaline electrolyser safety

For alkaline electrolysis, the hydrogen in oxygen concentration can be 1.5%. 2% would be 50% of the LEL. For safety management and electrolyser process control, a measurement range of 0 to 5% may be suitable.

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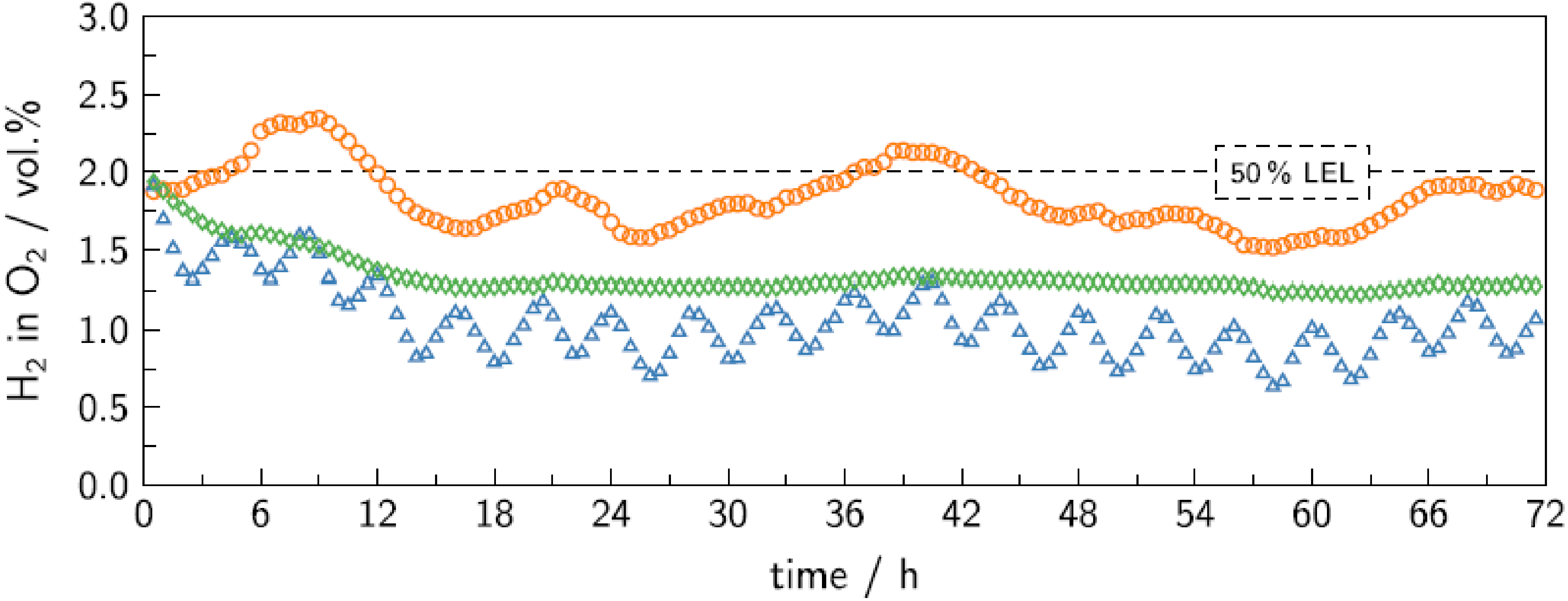
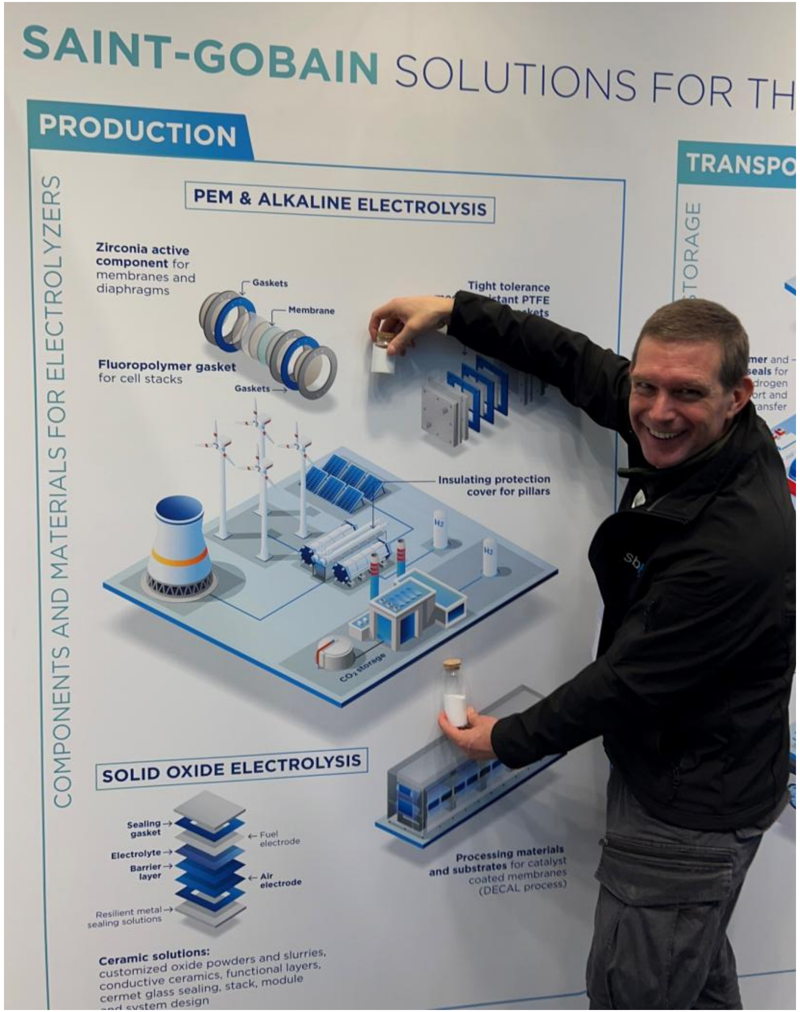


Experimental evaluation of dynamic operating concepts for alkaline water electrolyzers powered by renewable energy,
Jörn Brauns & Thomas Tuerk in Alectrochimica Acta, Dec 2021


SAINT-GOBAIN SOLUTIONS FOR TH
PRODUCTION
TRANSPO
COMPONENTS AND MATERIALS FOR ELECTROLYZERS
STORAGE
PEM & ALKALINE ELECTROLYSIS
Zirconia active component for membranes and diaphragms
Gaskets
Membrane
Fluoropolymer gasket for cell stacks
Gaskets
Tight tolerance
Insulating protection cover for pillars
H2
H2
CO2 storage
SOLID OXIDE ELECTROLYSIS
Sealing gasket
Electrolyte
Barrier layer
Resilient metal sealing solutions
Fuel electrode
Air electrode
Processing materials and substrates for catalyst coated membranes (DECAL process)
Ceramic solutions: customized oxide powders and slurries, conductive ceramics, functional layers, cermet glass sealing, stack, module and system design


ZIRFON
AGFA
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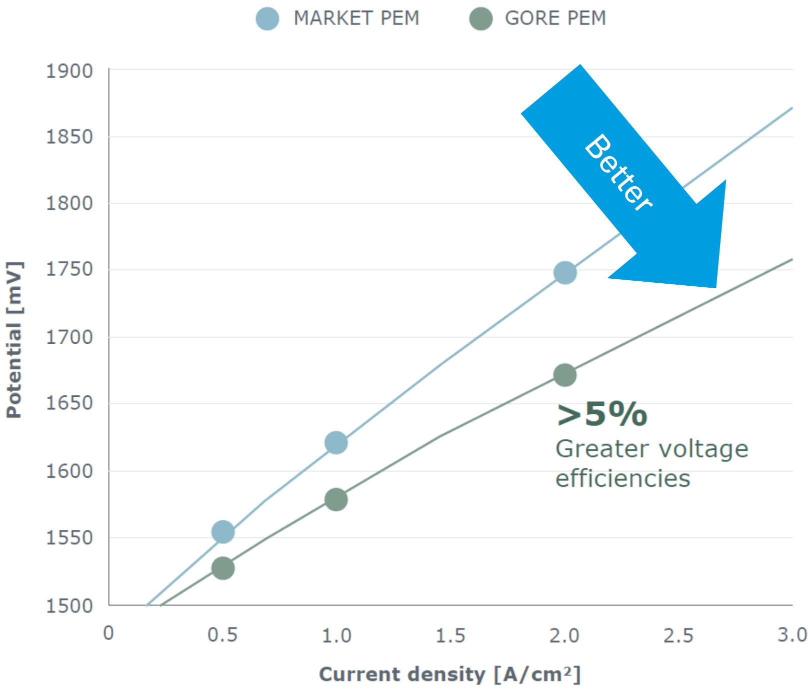
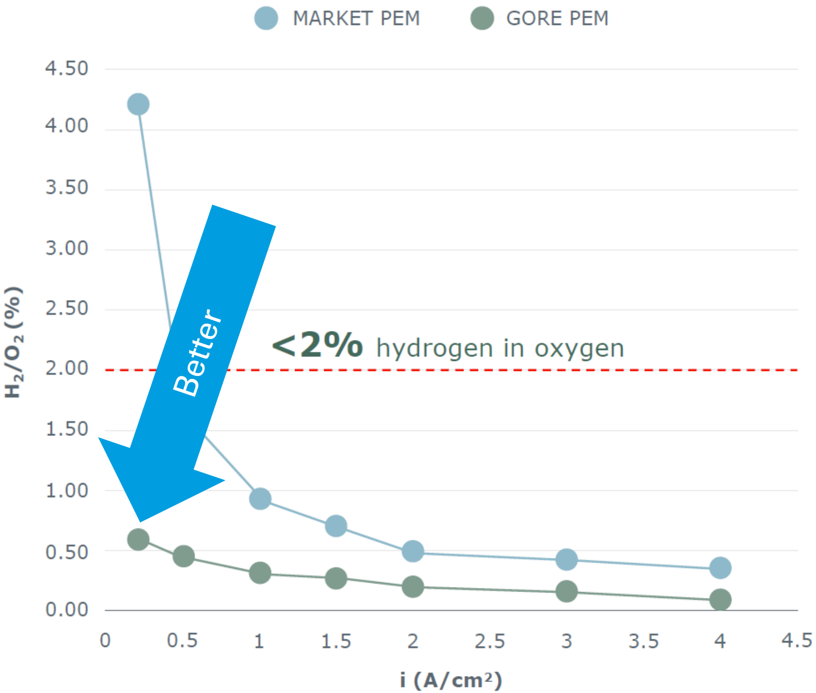
ZIRFON

Gore – making improvements to the polymer electrolyte membrane to reduce power input and improve operability at low-load conditions. Data presented is as expected for 80 °C, atmospheric pressure. This membrane is incorporated into the Siemens Energy Silyzer 300 stacks.



>5%
Greater voltage efficiencies



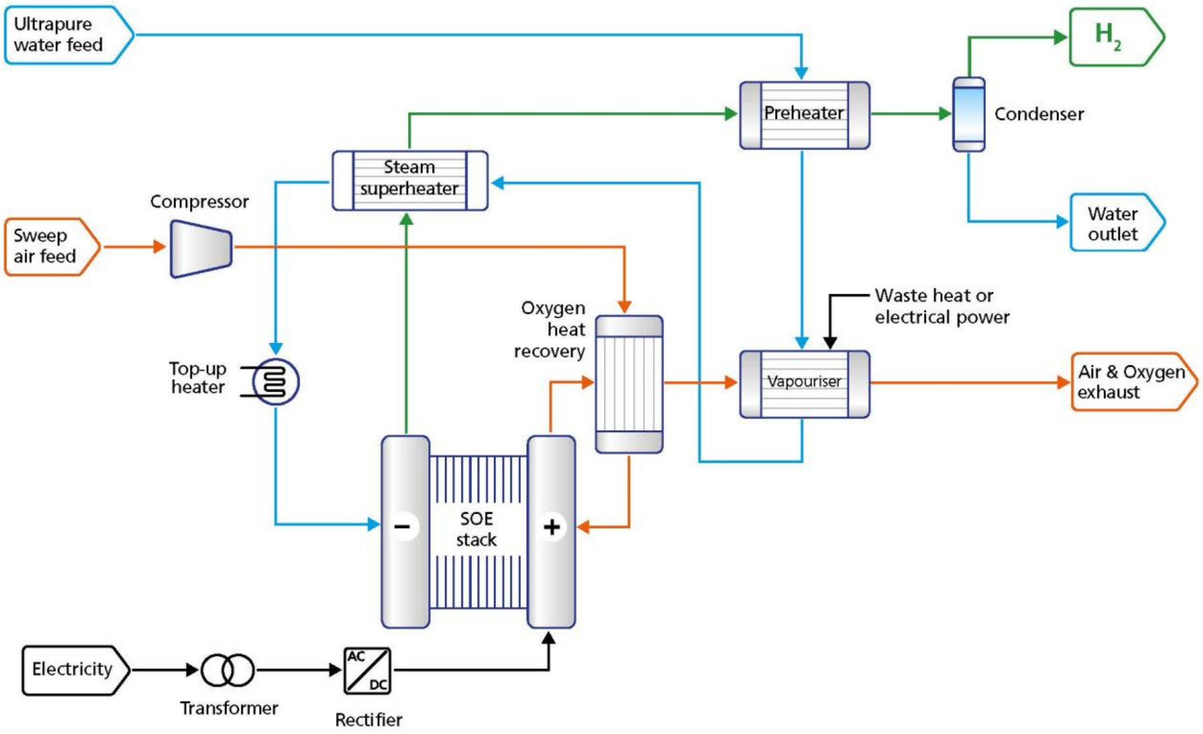
<2% hydrogen in oxygen

ADVANCED MEMBRANE DESIGN & CRITICAL FACTORS IN SCALING PEM WATER ELECTROLYSIS SYSTEMS,
Rainer Enggruber, W. L. Gore & Associates GmbH

Innovations in solid oxide electrolysis

SOE – Solid Oxide Electrolysis
SOEC – Solid Oxide Electrolysis Cell
HTE – High Temperature Electrolysis
Co-SOEC / Co-electrolysis
CO2 electrolysis / Electrolytic CO2 reduction

Solid Oxide Electrolysis process for hydrogen generation



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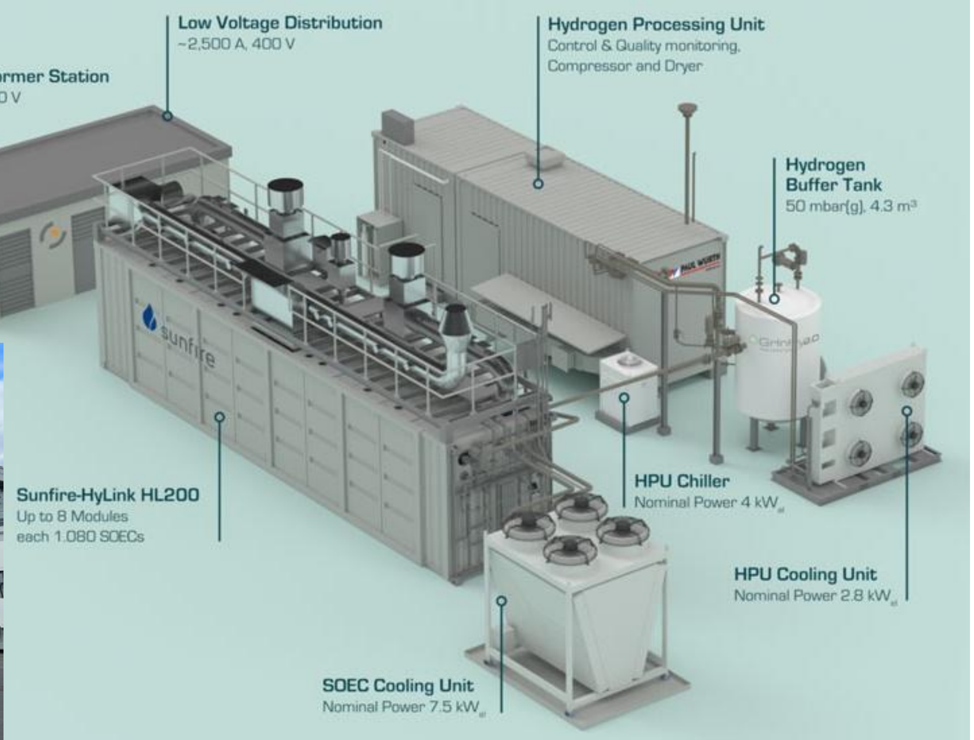
SOEC for H2 production

- With electrical steam generation, the system efficiency can around 42 kWh / kg H2
- Waste heat can be used to vaporise the water feed and reduce the electrical power consumption
- With waste heat for steam, the system efficiency can be as good as 40 kWh / kg H2 – about 20% better than many alkaline and PEM systems
- Low pressure hydrogen from the stack means compression and the associated capex and power is required, an additional 2 kWh/kg H2 may be required to compress to circa 20 bar

Sunfire – Solid Oxide Electrolysis for hydrogen production.



https://salcos.salzgitter-ag.com/de/grinhy-20/news.html?tx_pagetypenews_archive%5Baction%5D=show&tx_pagetypenews_archive%5Barticle%5D=19785&cHash=616e606007d3c39f10c6904eeae0cfeehttps://salcos.salzgitter-ag.com/de/grinhy-20/news.html?tx_pagetypenews_archive%5Baction%5D=show&tx_pagetypenews_archive%5Barticle%5D=19783&cHash=d96708c6f5e1ee4b97a9d49e92a98c81

FuelCell Energy: Solid Oxide Electrolysers in development, building on SOFC expertise.

- Capacity: 600 kg/day H2 at atmospheric pressure
- H2 purity (dry gas): 99% H2, 1%N2
- Power: 39.4 kWh/kg H2 with steam input
  - Steam (up to): 146 °C, 3.2 bar, 258 kg/hr
- Power: 43.8 kWh/kg H2 with water input
  - Water: 5,451 litres per day at < 1 µS/cm
- Footprint: 2x modules, each L40’xW8’xH10’
- Ramp rate: 10% per minute
- Flexibility: 0 to 100%

https://www.fuelcellenergy.com/platform/solid-oxide-electrolysis

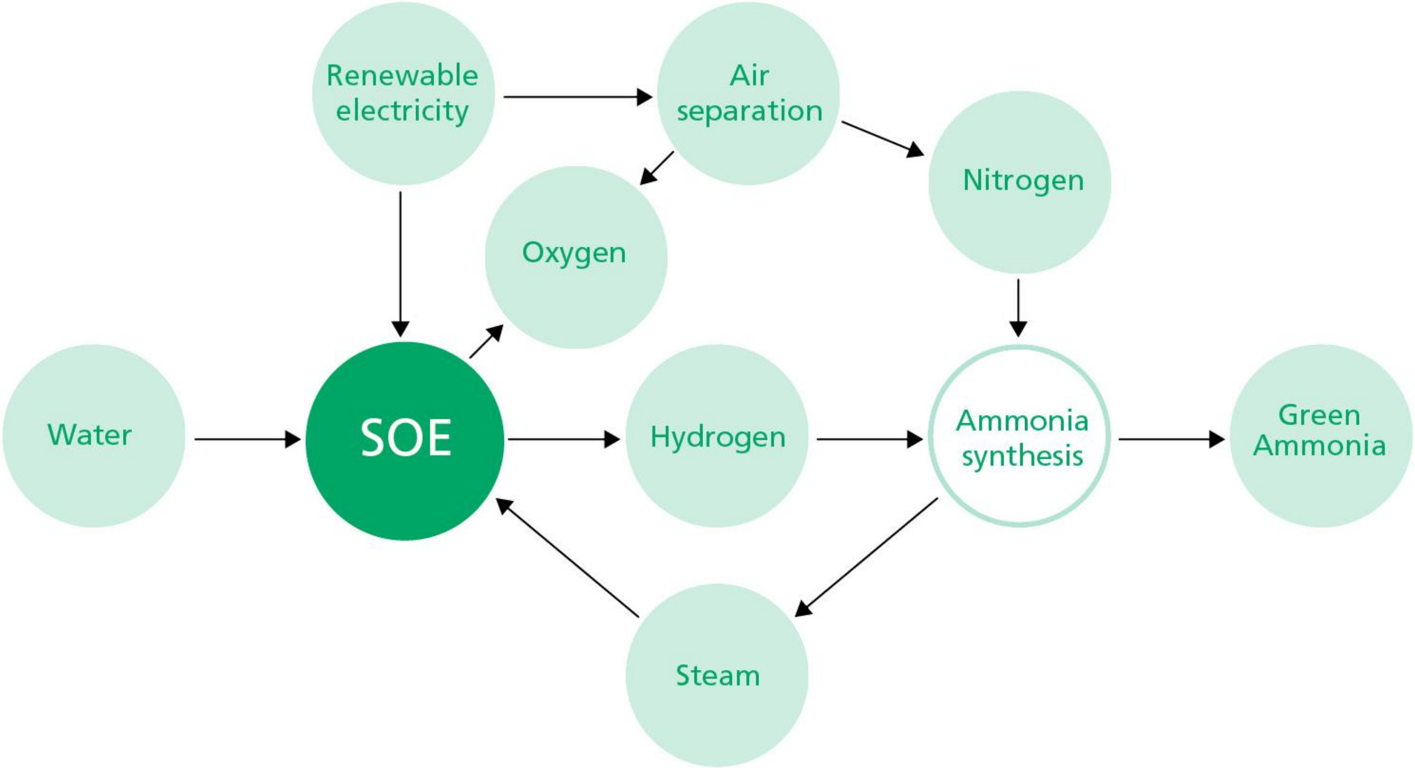
Ceres Power: Solid Oxide Electrolyser in demonstration at AVL Remscheid test centre, Germany. Further demonstration with Linde and BOSCH planned.

Module Efficiency 38kWh/kg

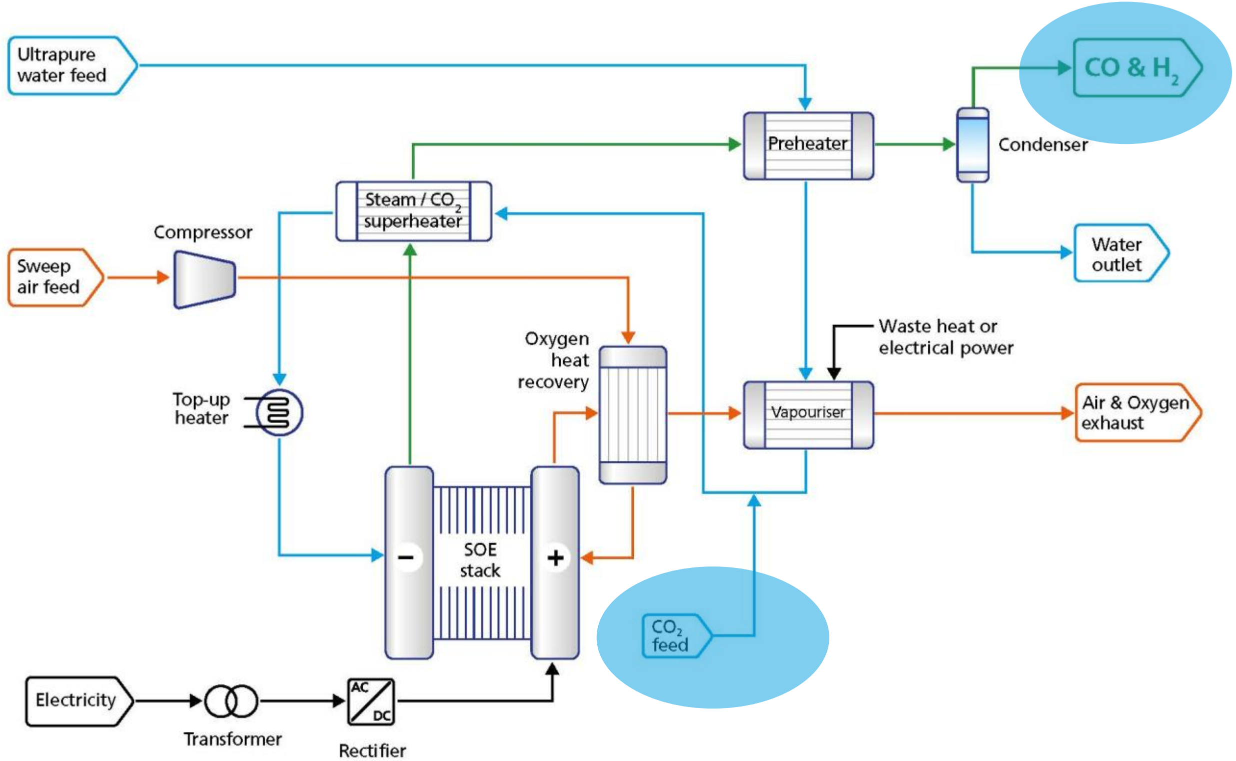
Specification	Target Value
Electrical Power Input	100kW
Hydrogen Production	65kg / day
Module Efficiency	38kWh/kg
Steam input	150°C

https://www.ceres.tech/media/image-gallery/

SOEC for hydrogen integrates well with ammonia production.



Solid Oxide Co-Electrolysis process for syngas generation



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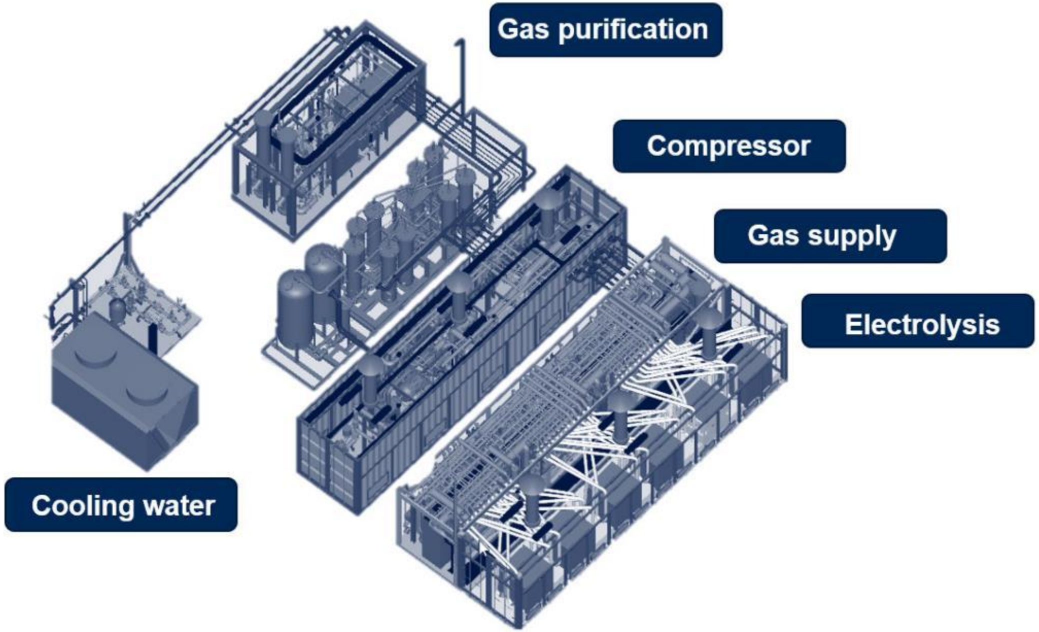
Co-SOEC

- SOEC operating in Co-SOEC mode uses similar equipment to SOEC operating in steam to hydrogen mode
- The key difference is that high purity CO2 is fed to the stack in addition to steam
- Syngas is produced
- For CO2 reduction to CO (as Topsøe operates) only CO2 is fed to the SOEC stack

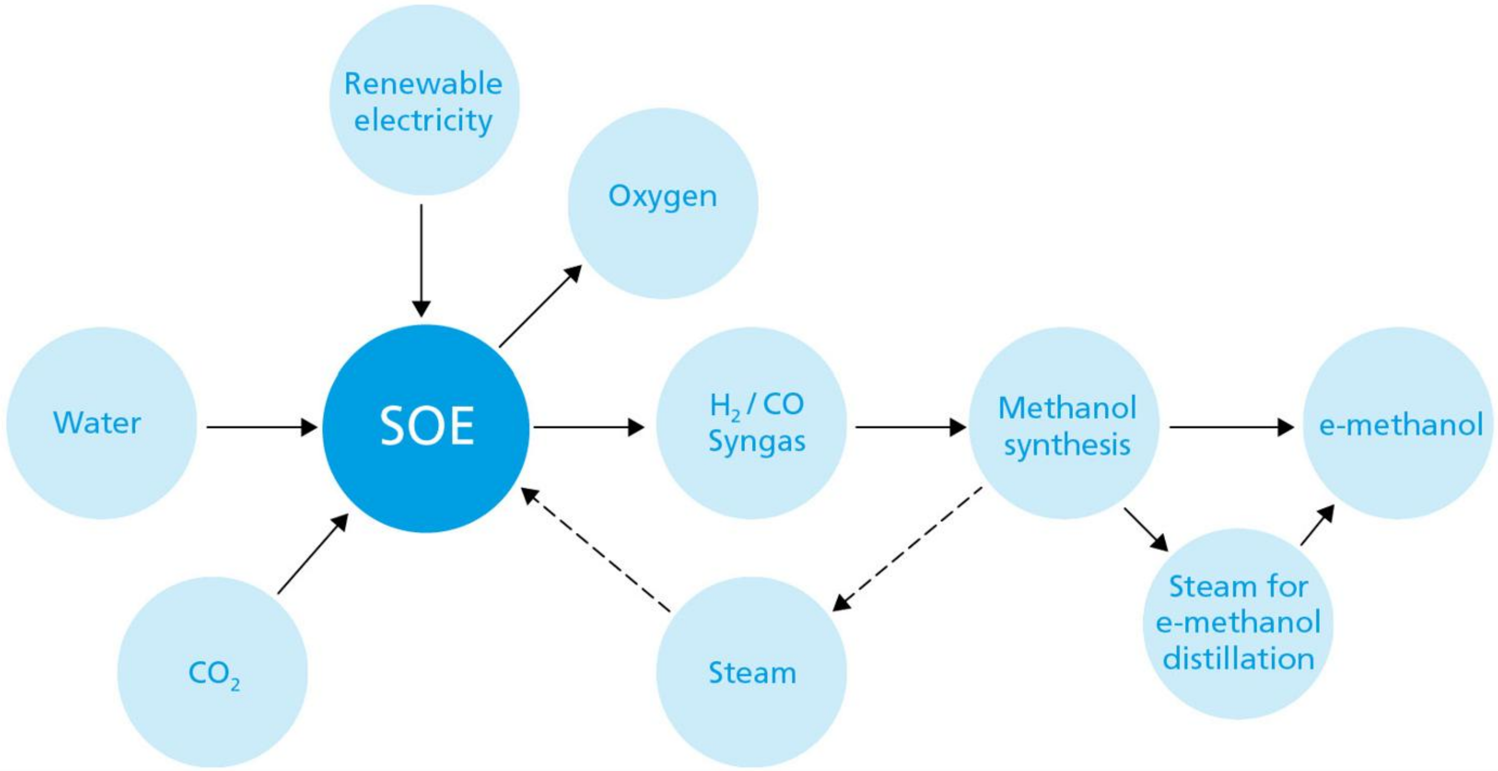
Topsøe eCOs™ , CO2 to CO reduction using electrolysis on SOEC. Topsøe leased 2 x750 kW ultrapure CO2 reduction CO production plants to DeLille Oxygen, USA.

- Electrochemical process to enable green electrons to reduce CO2 to CO
- CO can be combined with hydrogen to make syngas for methanol or FTS fuels

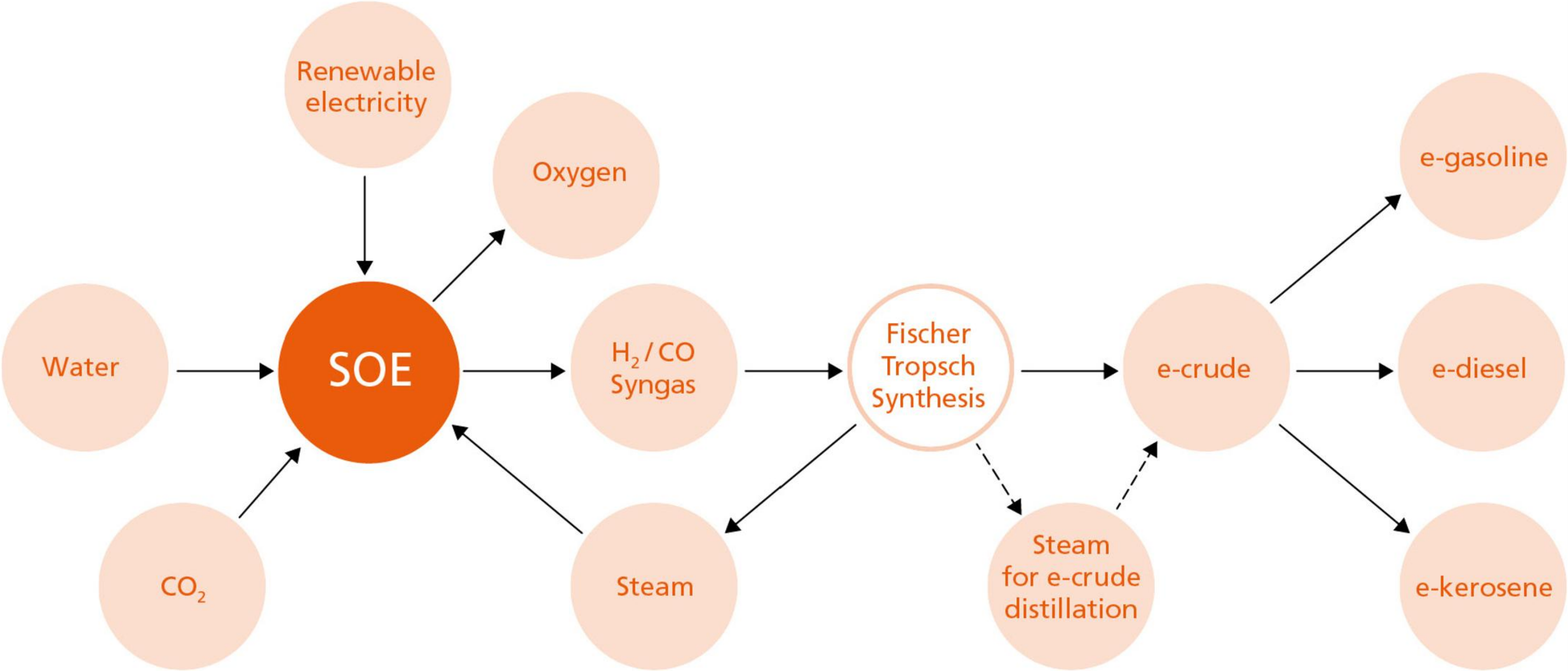


https://iopscience.iop.org/article/10.1149/MA2021-031191mtgabs

Co-SOEC for syngas production integrates well with e-methanol production. Some modern e-methanol plants use direct hydrogenation of CO2, avoiding the need to produce CO.



Co-SOEC for syngas production integrates well with Fischer Tropsch Synthesis (FTS) for Power to Liquids for e-fuels such as eSAF. Direct hydrogenation of CO2 for FTS is being researched, but not yet deployed. So, syngas with CO and H2 is required.



Oxylum / twelve

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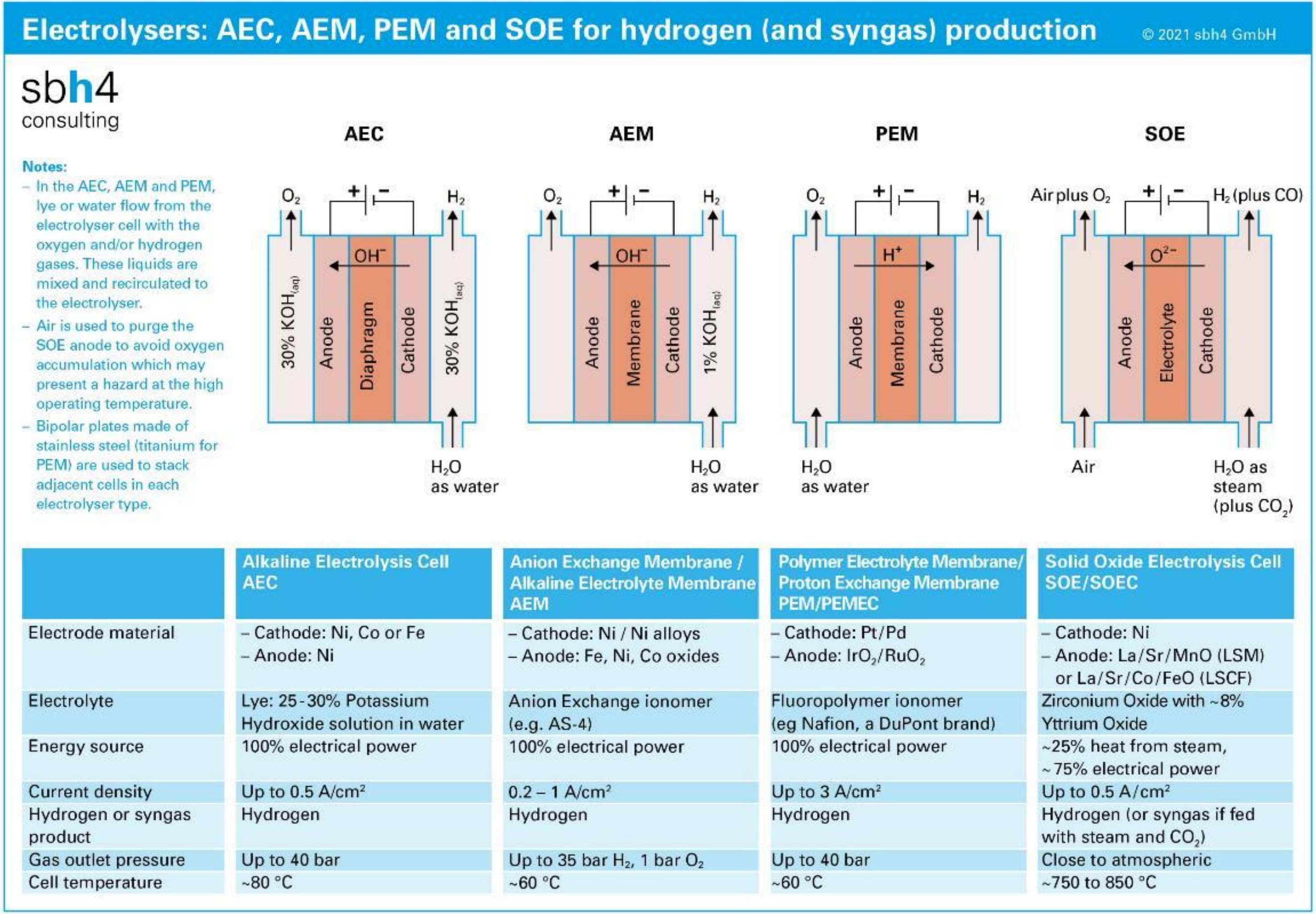
Innovations in AEM electrolysis

AEM – Anion Exchange Membrane

AEM - Alkaline Electrolyte Membrane



Electrolysers: AEC, AEM, PEM and SOE for hydrogen (and syngas) production

Notes:

- In the AEC, AEM and PEM, lye or water flow from the electrolyser cell with the oxygen and/or hydrogen gases. These liquids are mixed and recirculated to the electrolyser.
- Air is used to purge the SOE anode to avoid oxygen accumulation which may present a hazard at the high operating temperature.
- Bipolar plates made of stainless steel (titanium for PEM) are used to stack adjacent cells in each electrolyser type.

	Alkaline Electrolysis Cell AEC	Anion Exchange Membrane / Alkaline Electrolyte Membrane AEM	Polymer Electrolyte Membrane/ Proton Exchange Membrane PEM/PEMEC	Solid Oxide Electrolysis Cell SOE/SOEC
Electrode material	– Cathode: Ni, Co or Fe – Anode: Ni	– Cathode: Ni / Ni alloys – Anode: Fe, Ni, Co oxides	– Cathode: Pt/Pd – Anode: IrO_2/RuO_2	– Cathode: Ni – Anode: La/Sr/MnO (LSM) or La/Sr/Co/FeO (LSCF)
Electrolyte	Lye: 25-30% Potassium Hydroxide solution in water	Anion Exchange ionomer (e.g. AS-4)	Fluoropolymer ionomer (eg Nafion, a DuPont brand)	Zirconium Oxide with ~8% Yttrium Oxide
Energy source	100% electrical power	100% electrical power	100% electrical power	~25% heat from steam, ~75% electrical power
Current density	Up to 0.5 A/cm²	0.2 – 1 A/cm²	Up to 3 A/cm²	Up to 0.5 A/cm²
Hydrogen or syngas product	Hydrogen	Hydrogen	Hydrogen	Hydrogen (or syngas if fed with steam and CO_2)
Gas outlet pressure	Up to 40 bar	Up to 35 bar H_2, 1 bar O_2	Up to 40 bar	Close to atmospheric
Cell temperature	~80 °C	~60 °C	~60 °C	~750 to 850 °C

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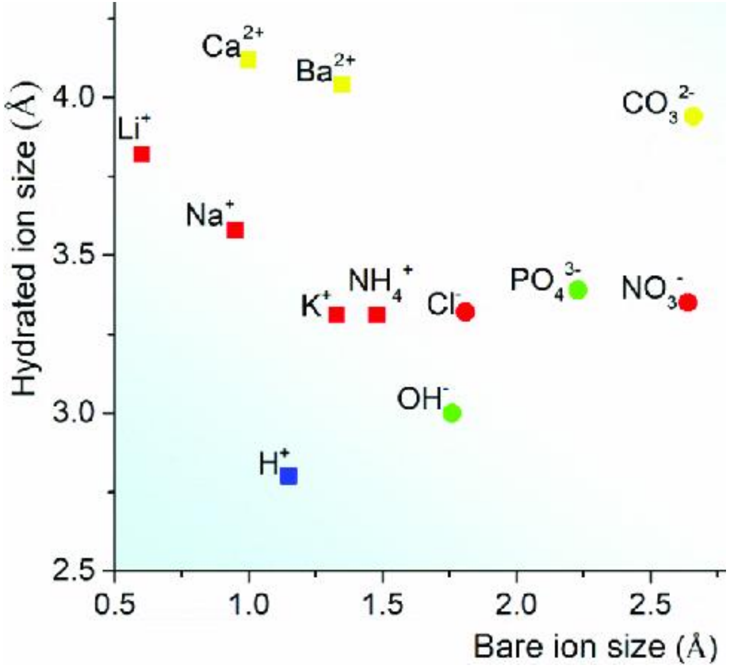
- AEM sits between alkaline (AEC) and PEM technologies
- Operating conditions are alkaline like AEC, not acidic like PEM
- Materials of construction and catalysts are low-cost, like AEC
- System has potential to be low capex
- The use of a membrane gives it characteristics close to PEM technology
- AEM aligns well with intermittent operation and variable renewable power input
- Efficiencies are not yet as good as most PEM or alkaline systems
- Key development in recent years has been to increase the stack life with improved membrane durability

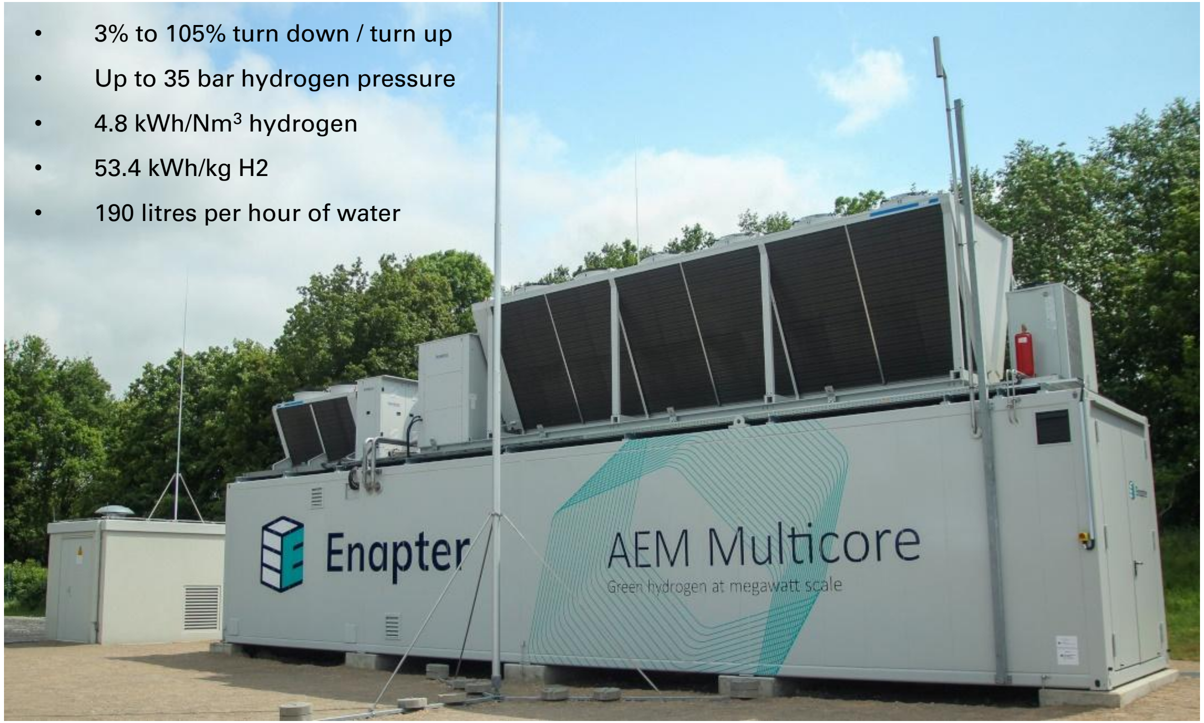
Shooting an OH- ion through a membrane is like Dirty Harry firing a Smith & Wesson model 29 bullet at a punk.



https://www.researchgate.net/publication/317425515_Metal-Organic_Framework-Derived_Nanoporous_Metal_Oxides_toward_Supercapacitor_Applications_Progress_and_Prospects

Enapter AEM Nexus, 1MW Multicore (420 modules) at Bioenergiepark Saerbeck. 210 Nm3/hr (450 kg / day) of hydrogen at 99.9% purity (99.999% with dryer).

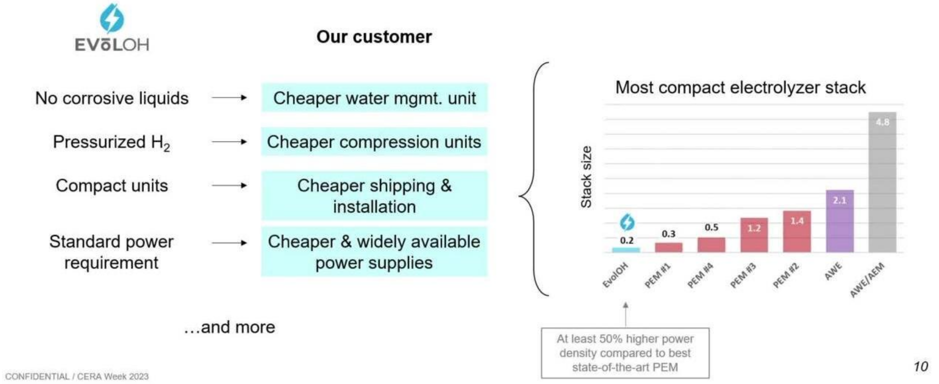
- 3% to 105% turn down / turn up
- Up to 35 bar hydrogen pressure
- 4.8 kWh/Nm^3 hydrogen
- 53.4 kWh/kg H2
- 190 litres per hour of water



https://www.enapter.com/application/development-of-megawatt-scale-aem-electrolysers#48058

Cavendish Renewable Technology – large AEM stack in development. Membrane life is extended using low temperature operation, enabled by innovative membrane catalyst coating.

EVōLOH – Carbonate AEM electrolysis. Membrane life is extended using buffered electrolyte with pH close to 7. Focus on stack production at scale and low cost. Allow EPCs to integrate the stacks into large systems.



EVōLOH

Our customer

No corrosive liquids →	Cheaper water mgmt. unit
Pressurized H_2 →	Cheaper compression units
Compact units →	Cheaper shipping & installation
Standard power requirement →	Cheaper & widely available power supplies

…and more

Most compact electrolyzer stack

At least 50% higher power density compared to best state-of-the-art PEM

CONFIDENTIAL / CERA Week 2023

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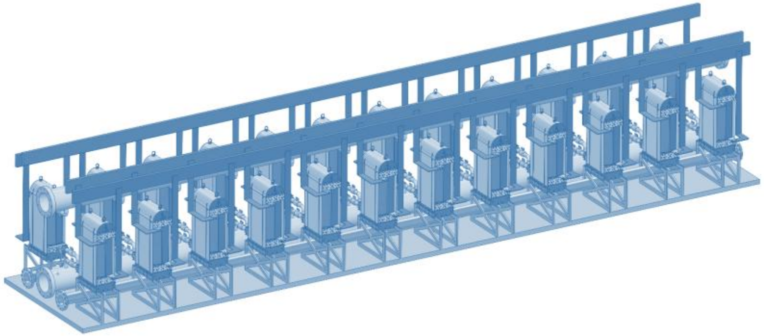
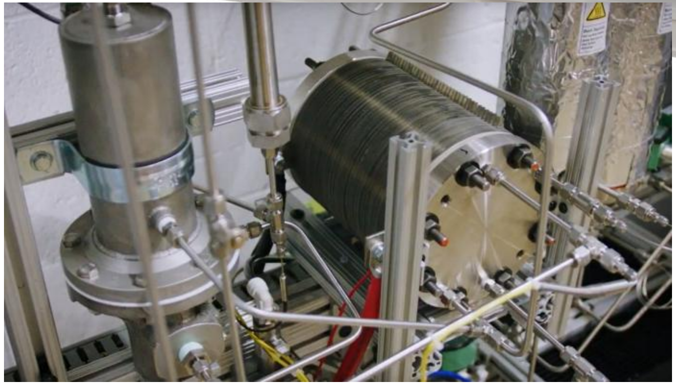
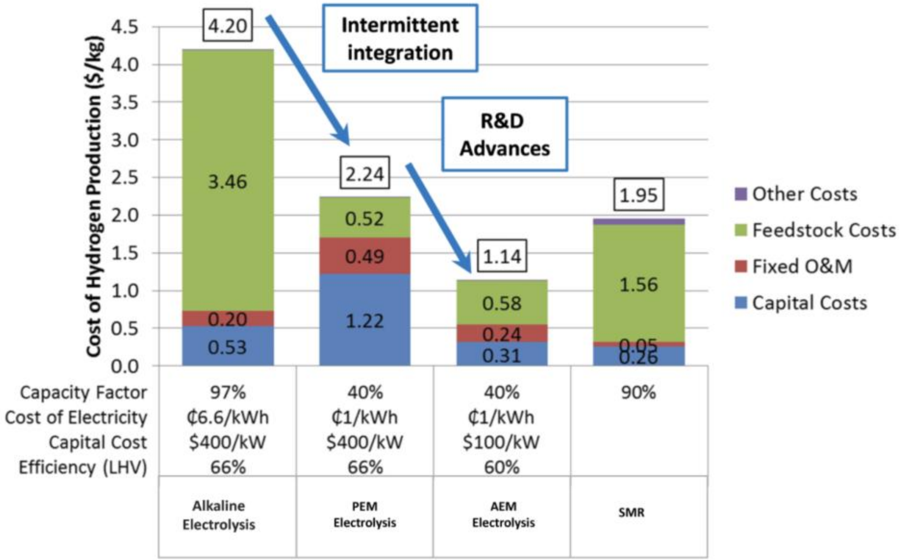


- Low-cost stack materials: aluminium, plastic, steel and carbon
- Targeting USD30 per kW for stacks (excludes BOP)
- IP surrounding the electrodes and electrode materials
- Highly manufacturable stack
- Reel to reel manufacturing
- 3.75 GW per year stack production planned
- High power density to reduce stack size
- Membrane life extended due to use of less aggressive carbonate electrolyte with pH close to 7

https://ceraweek.com/program/evoloh-8822-805228/

High pressure AEM with 200 bar hydrogen for ammonia or hydrogen mobility. POWER to HYDROGEN (P2H2) Clean Energy Bridge™.

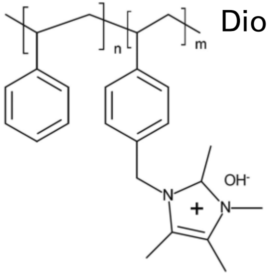




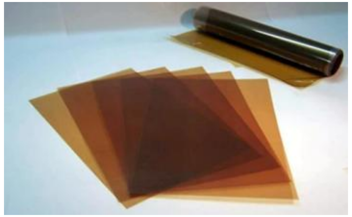
- 200 bar hydrogen generation
- Pure oxygen co-generation
- Able to integrate with variable renewables

https://power-h2.com/products/

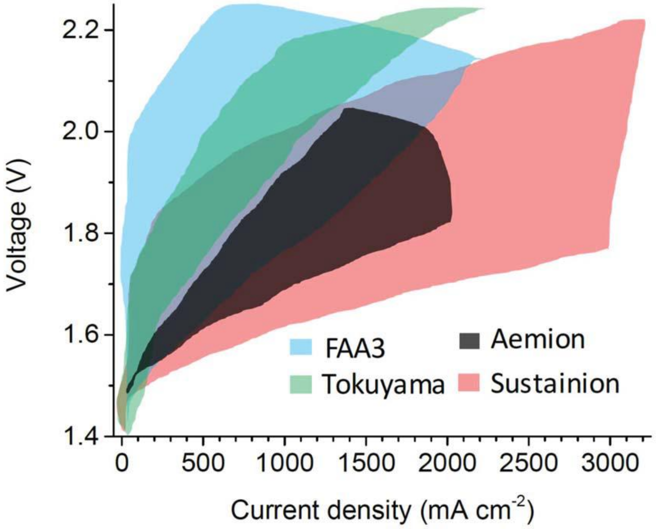
Ionomr Innovations and several others developing ‘fluoropolymer-free’ AEM membranes.



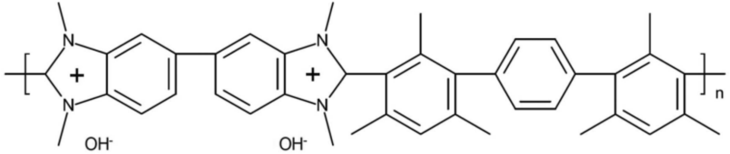
Dioxide Materials, Sustainion®

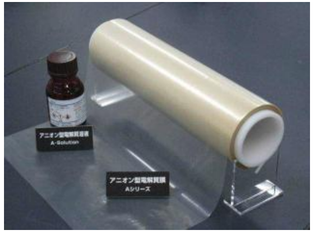


Fumatech, Fumasep FAA-3



Ionomr Innovations, Aemion+™



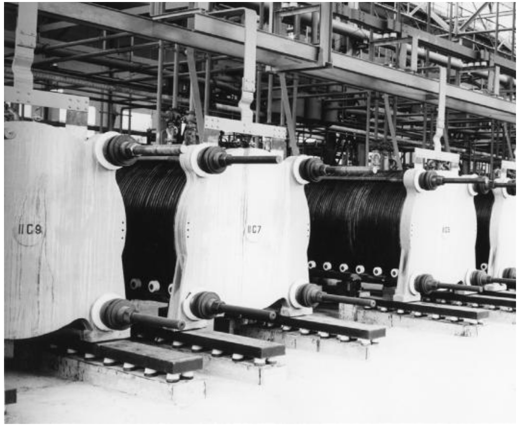


Tokuyama A901

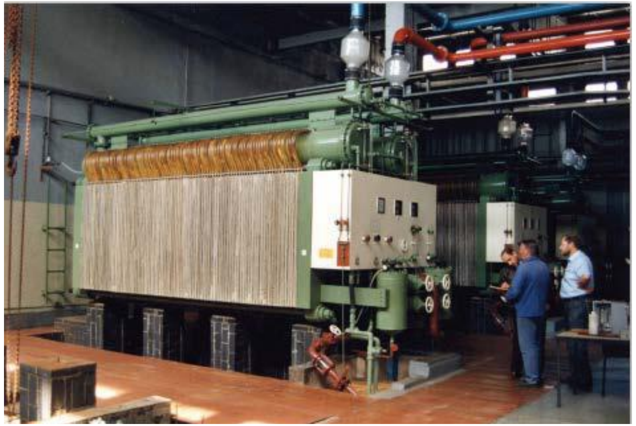
https://asmedigitalcollection.asme.org/electrochemical/article-pdf/18/2/024001/6673712/jeecs_18_2_024001.pdf
https://ionomr.com/solutions/aemion/
https://dioxidematerials.com/product/40-micron-sustainion-x37/
https://www.laborxing.com/de/products/fumasep-faa-3-pk-130-anion-exchange-membrane#

Innovation or chaos?

Alkaline electrolysis from hydropower for green hydrogen has been deployed in Norway, Egypt and Zimbabwe at 100+ MW since 1928. The target molecule in each case was ammonium nitrate. In the 1970s, cheap grey hydrogen / grey ammonia from natural gas reforming made all these facilities un-economical.



- 1949
- Hydro power from Glomfjord, Norway
- Ammonium nitrate fertilizer production
- Nel alkaline electrolysis
- 160 MW on 150 modules
- 27,100 Nm3 / hr H2 at atmospheric pressure

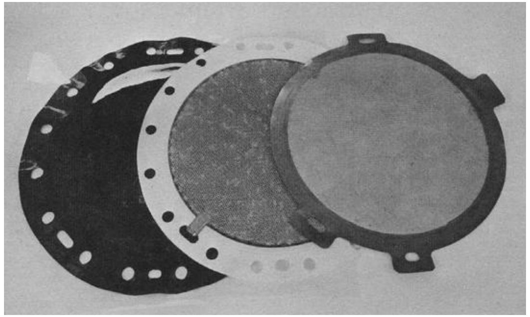


- 1973
- Kima Fertilizer plant, Egypt
- Hydro power from the Aswan dam
- BBC Electrolyzer System Oerlikon
- 144 MW alkaline electrolysis (144 modules)
- 32,000 Nm^3 / hr hydrogen at atmospheric pressure

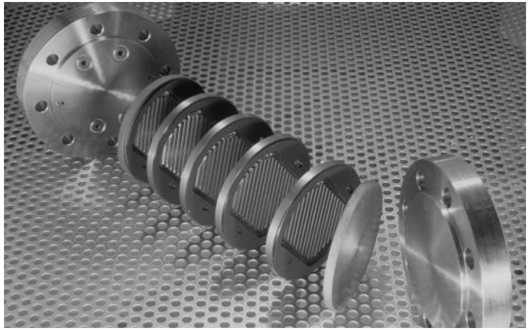
- 1973
- Sable Chemicals ammonia plant, Kwekwe, Zimbabwe,
- Hydro power from the Kariba dam
- Electrolysers from Lurgi, (now Sunfire, through IHT acquisition)
- 100MW Pressurised Alkaline (28 x 3.5MW)
- 21,000 Nm^3 / hr hydrogen at 30 bar
- Hydrogen for Ammonia source switched to rail imports from South Africa in 2015, electrolysers no longer in use

https://www.ammoniaenergy.org/wp-content/uploads/2022/11/Project-Features-November-2022-speaker-slides.pdf
https://hydrogenoptimized.com/history/
https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwjZgbDz7Yv2AhUJHOwKHVKiBIEQFnoECAYQAQ&url=http%3A%2F%2Fwww.elygrid.com%2Fwp-content%2Fuploads%2F2021%2F07%2Fevent_8th-international-symposium-hydrogen-and-energy.pdf&usg=AOvVaw38Uh2oRsQgsfPBsl54mifu
Image from NEL Hydrogen, published in Hydrogen Production by Water Electrolysis, Copyright Elsevier 2022

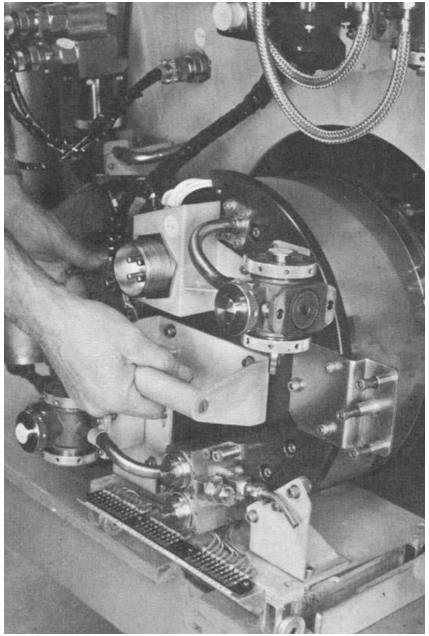
Early PEM (SPE) electrolysers were developed for oxygen supply on US Navy nuclear submarines to enable long dives. They were also used in space stations to convert water to oxygen. MW-scale PEM-based green hydrogen concepts were developed in the 1970's.



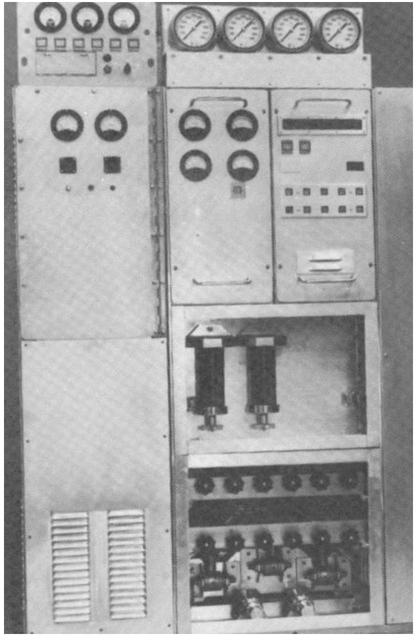
General Electric Company PEM (Solid Polymer Electrolyte, SPE) cell, late 1960s



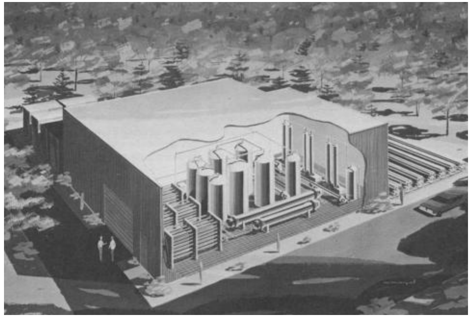
Siemens PEM stack, 1989



NASA 27-cell PEM stack, late 1960s



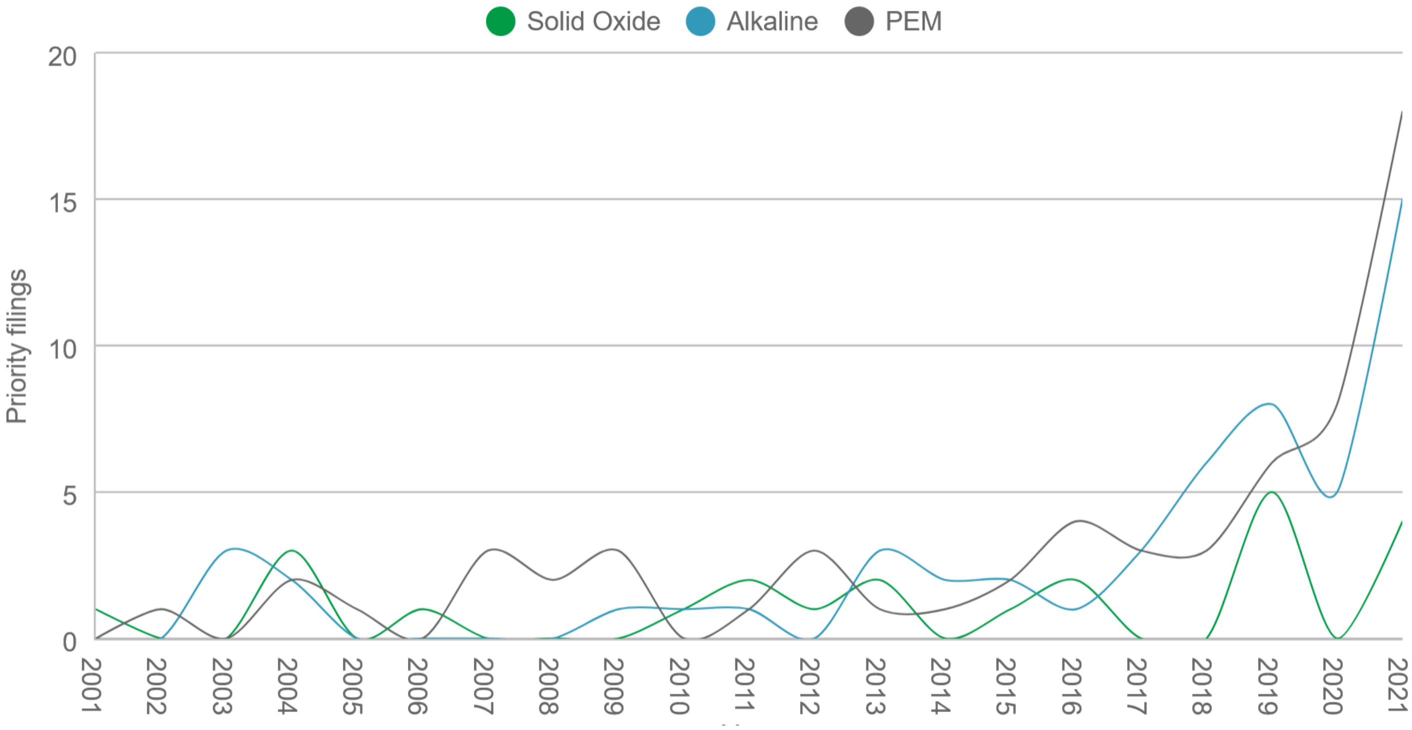
General Electric Company PEM electrolyser to produce oxygen for US navy submarines, late 1970s



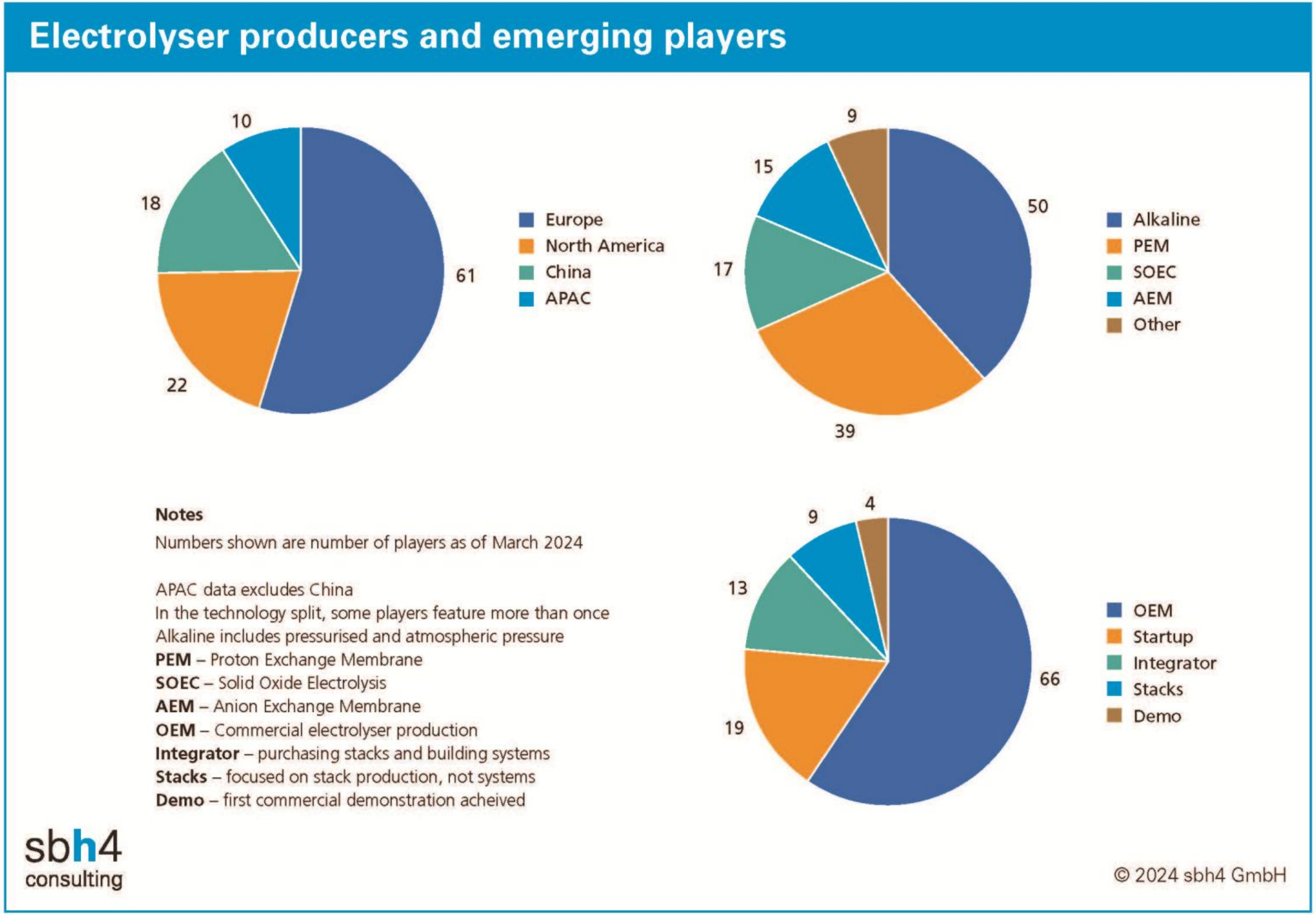
General Electric Company 73MW PEM green hydrogen conceptual plant

CONCEPTUAL DESIGN OF LARGE SCALE WATER ELECTROLYSIS PLANT USING SOLID POLYMER ELECTROLYTE TECHNOLOGY, L. J. NUTTALL, General Electric Company, 1977
STATUS OF SOLID POLYMER ELECTROLYTE FUEL CELL TECHNOLOGY AND POTENTIAL FOR TRANSPORTATION, APPLICATIONS, L. J. NUTTALL, General Electric Company, 1983
Siemens image from Hydrogen Production by Water Electrolysis, Tom Smolinka and Jürgen Garche

Alkaline and PEM electrolyser technologies are still innovating, as shown be patent filings in 2021. Will AEM and SOEC catch up through this decade?



https://appleyardlees.foleon.com/igipr3/inside-green-innovation-progress-report-third-edition/hydrogen



Electrolyser producers and emerging players

Notes

Numbers shown are number of players as of March 2024

APAC data excludes China
In the technology split, some players feature more than once
Alkaline includes pressurised and atmospheric pressure
PEM – Proton Exchange Membrane
SOEC – Solid Oxide Electrolysis
AEM – Anion Exchange Membrane
OEM – Commercial electrolyser production
Integrator – purchasing stacks and building systems
Stacks – focused on stack production, not systems
Demo – first commercial demonstration acheived

- Data that sbh4 tracks has shown a rapid growth in AEM and SOEC technology providers and startups
- AEM or SOEC startups may need 3 to 5 years to develop a commercial stack and system
- Many new PEM and Alkaline OEMs are also emerging rapidly
- Alkaline and PEM startups may need 2 to 3 years to develop a commercial offer and establish the required supply chain

Beware over-simplification! Alkaline and PEM are often declared to be mature technologies with a high TRL. Ok, so…if a new PEM or alkaline electrolyser producer emerges in 2024 using an innovative stack or system, is **their** technology, product and manufacturing mature? Or what about a new factory with new people and equipment?

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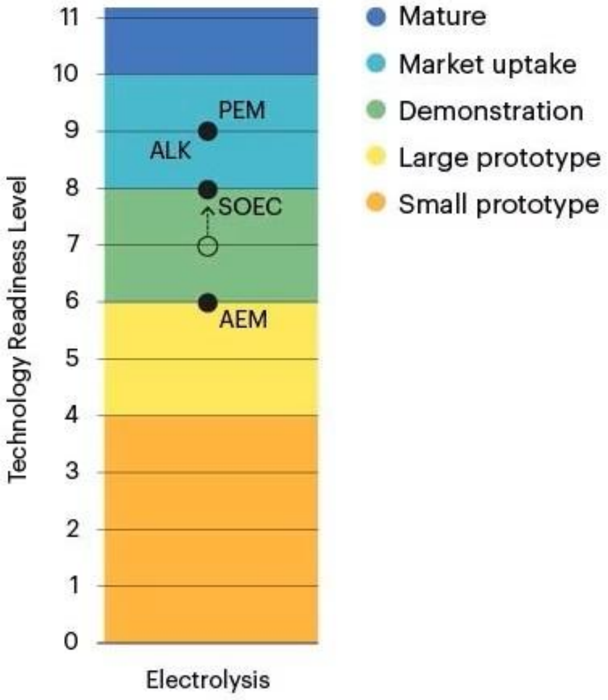
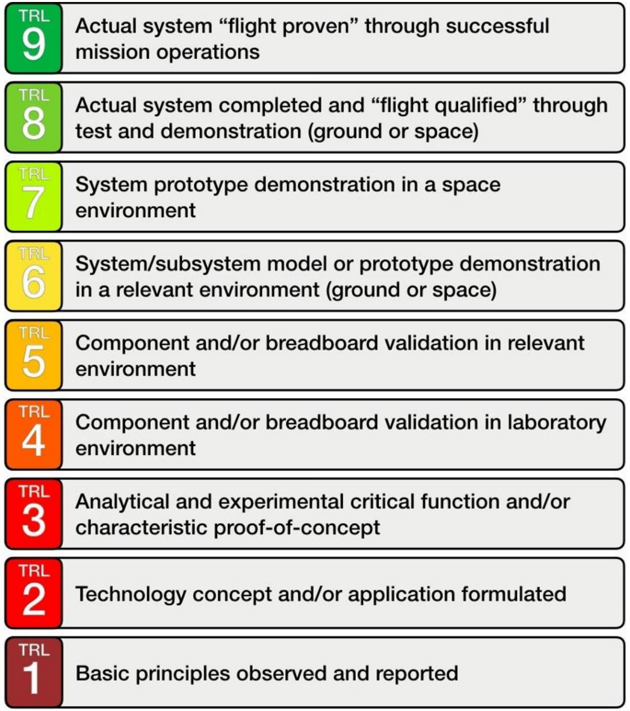
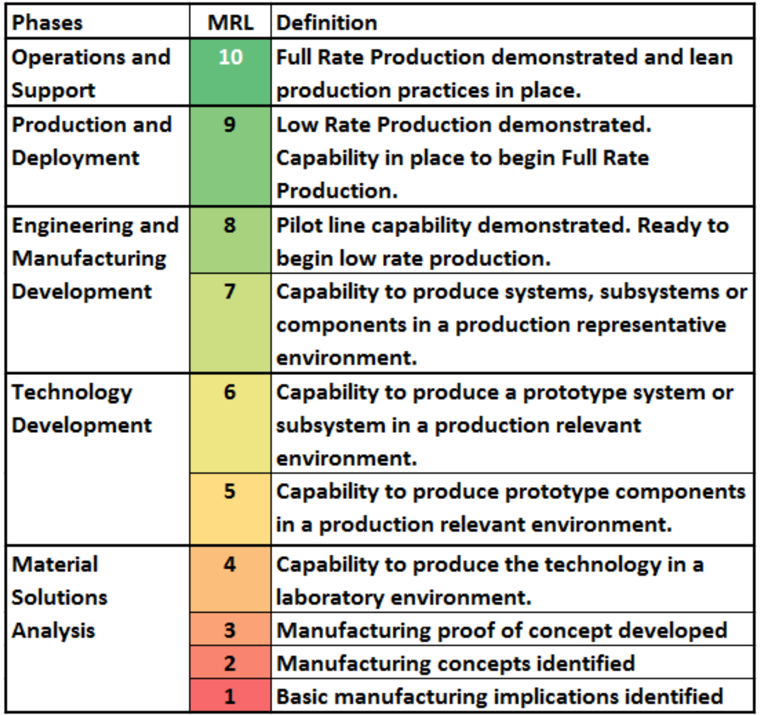


https://www.iea.org/energy-system/low-emission-fuels/electrolysers
https://www.researchgate.net/publication/368973951_Review_of_Energy_Portfolio_Optimization_in_Energy_Markets_Considering_Flexibility_of_Power-to-X/figures?lo=1

TRL is only partially meaningful at this stage of PEM and alkaline electrolyser production scale up. TRL was developed to assess aerospace systems that were never designed to be mass-produced, nor was cost the major focus. DFMA is critical to ensure success and MRL may be a relevant scale.



TRL 9	Actual system "flight proven" through successful mission operations
TRL 8	Actual system completed and "flight qualified" through test and demonstration (ground or space)
TRL 7	System prototype demonstration in a space environment
TRL 6	System/subsystem model or prototype demonstration in a relevant environment (ground or space)
TRL 5	Component and/or breadboard validation in relevant environment
TRL 4	Component and/or breadboard validation in laboratory environment
TRL 3	Analytical and experimental critical function and/or characteristic proof-of-concept
TRL 2	Technology concept and/or application formulated
TRL 1	Basic principles observed and reported

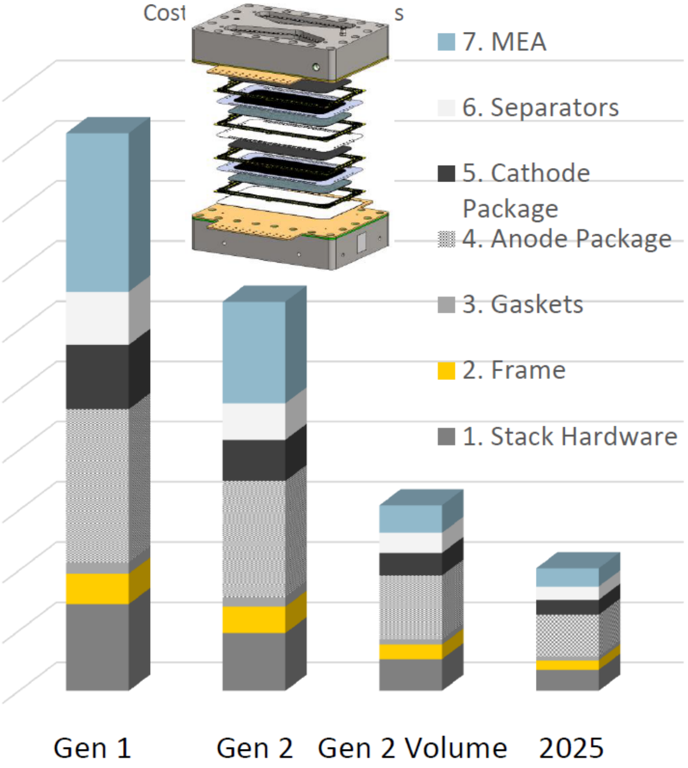


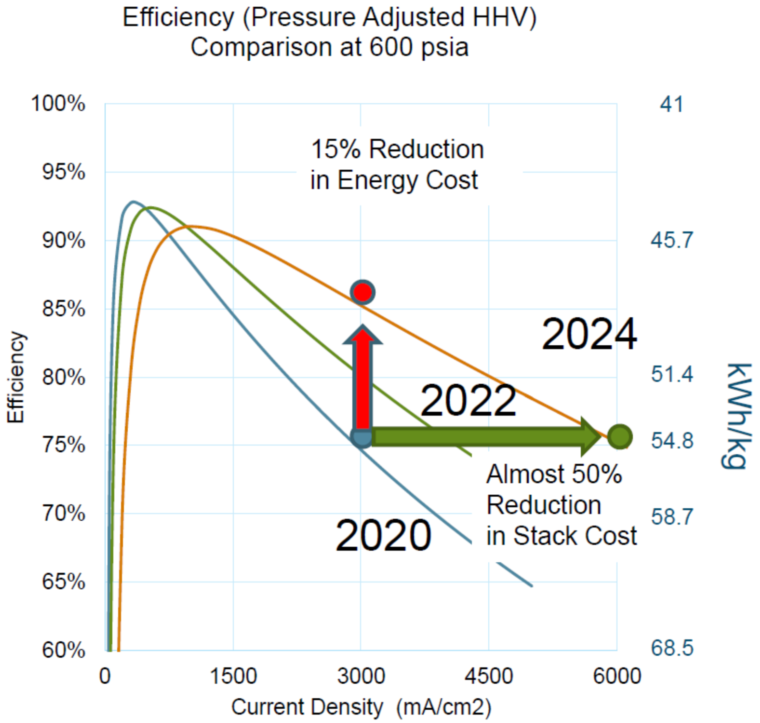
Phases	MRL	Definition
Operations and Support	10	Full Rate Production demonstrated and lean production practices in place.
Production and Deployment	9	Low Rate Production demonstrated. Capability in place to begin Full Rate Production.
Engineering and Manufacturing Development	8	Pilot line capability demonstrated. Ready to begin low rate production.
	7	Capability to produce systems, subsystems or components in a production representative environment.
Technology Development	6	Capability to produce a prototype system or subsystem in a production relevant environment.
	5	Capability to produce prototype components in a production relevant environment.
Material Solutions Analysis	4	Capability to produce the technology in a laboratory environment.
	3	Manufacturing proof of concept developed
	2	Manufacturing concepts identified
	1	Basic manufacturing implications identified

https://www.nasa.gov/general/technology-readiness-level/
https://www.zimmerpeacocktech.com/2018/08/18/sensor-and-assay-technology-readiness-levels/

Innovations in electrolyser manufacturing

Plug Power: manufacturing cost reductions from stack design changes, reduced materials wastage and manufacturing automation leading to 75% labour input reduction. Efficiency improvements achieved in parallel.





https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.energy.gov%2Fsites%2Fdefault%2Ffiles%2F2022-04%2F4-H2-AMP%2520Workshop-Plug%2520Power.pdf&psig=AOvVaw0WCXQIa9fyerD7K60OGzIP&ust=1702541878488000&source=images&cd=vfe&opi=89978449&ved=0CBUQ3YkBahcKEwjgs5n2_luDAxUAAAAAHQAAAAAQAw

Larger PEM stacks are converging to circa 1MW with a rectangular cell shape. Compared to a circular cell shape, the rectangular shape minimises wasted materials during manufacture and reduces cost.

Stiesdal, Denmark. Nitrogen shrouded, pressurised alkaline electrolyser. Rectangular stack produced by Danfoss. Standardised 3MW HydroGen unit with 46 to 49 kWh/kg H2 efficiency. Target electrolyser **system** capex €200 per kW of power.

https://www.linkedin.com/posts/henrik-stiesdal-064a9374_i-am-pleased-to-announce-that-we-have-now-activity-7126514653869879296-uDqL?utm_source=share&utm_medium=member_desktop
https://www.stiesdal.com/wp-content/uploads/2023/04/32514-Stiesdal-Hydrogen-brochure.pdf

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Innovation in electrolyser supply chains

2JCP– providing systems integration engineering services to Siemens Energy to build Silyzer 300 systems in the Czech Republic around the PEM stacks produced in Germany. This shipment ready for European Energy in Kassø.

https://www.linkedin.com/posts/2-jcp-group_greentech-renewableenergy-electrolyzers-activity-7085300309559762944-kS81?utm_source=share&utm_medium=member_desktop
https://www.linkedin.com/posts/2-jcp-group_racice-silyzer-hydrogen-activity-7059456418189385728-q7ix?utm_source=share&utm_medium=member_desktop
https://hydrogentechworld.com/siemens-energy-air-liquide-inaugurate-electrolyzer-gigafactory-in-berlin

Convion integrating Elcogen elcoStack 3000 SOEC stack modules into full electrolyser systems.

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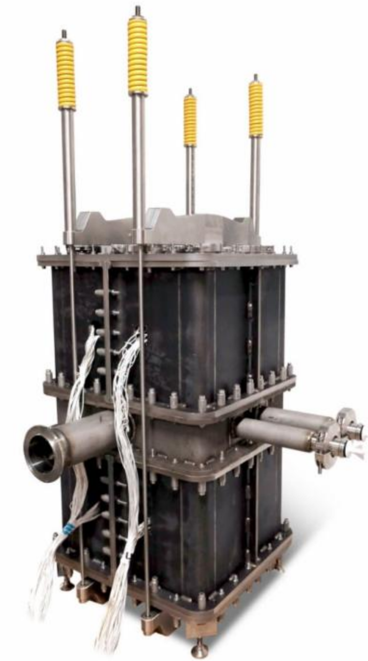
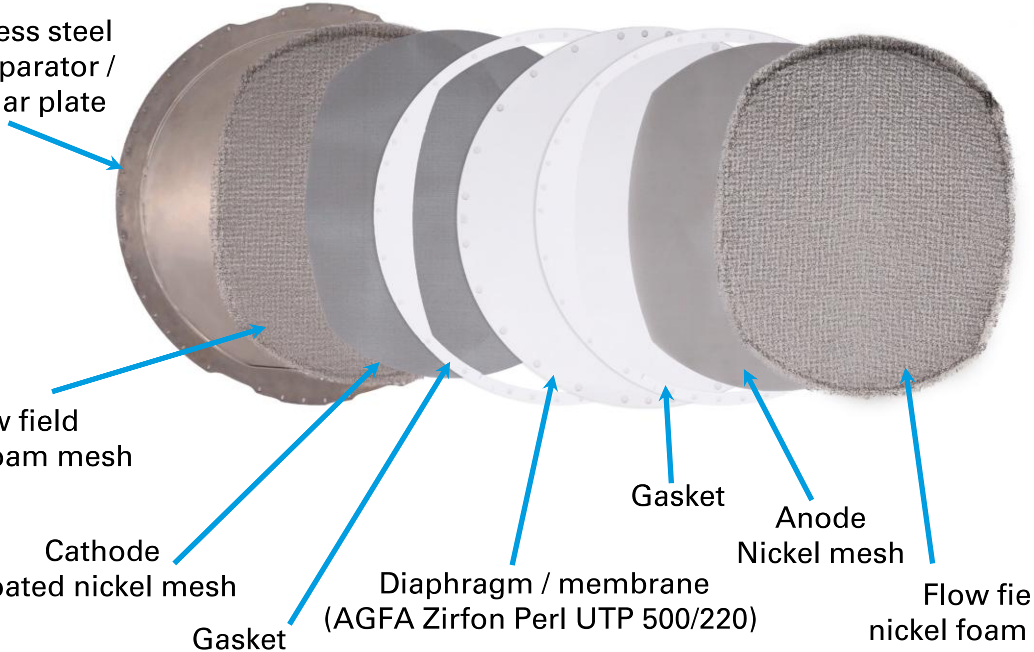


https://convion.fi/convion-and-elcogen-celebrate-a-key-development-milestone-in-green-hydrogen-production-technology/
https://elcogen.com/products/solid-oxide-stack-modules/

McPhy and De Nora technology partnership. Alkaline cell with 8-layer architecture and components. Used in McPhy PA electrolysers.



Stainless steel cell separator / Bi-polar plate

Flow field nickel foam mesh

Cathode Coated nickel mesh

Gasket

Diaphragm / membrane (AGFA Zirfon Perl UTP 500/220)

Gasket

Anode Nickel mesh

Flow field nickel foam mesh

https://www.denora.com/dam/jcr:3e2377ae-20bf-492f-9c14-80b129364bf5/AWE.pdf?refid=b5e5a867-4cbe-43e8-84a2-746a37a47b5b

Andritz operating as EPC player to integrate Hydrogen Pro stacks into systems for projects in Europe, eg Salzgitter Flachstahl GmbH 100MW SALCOS® green steel project.

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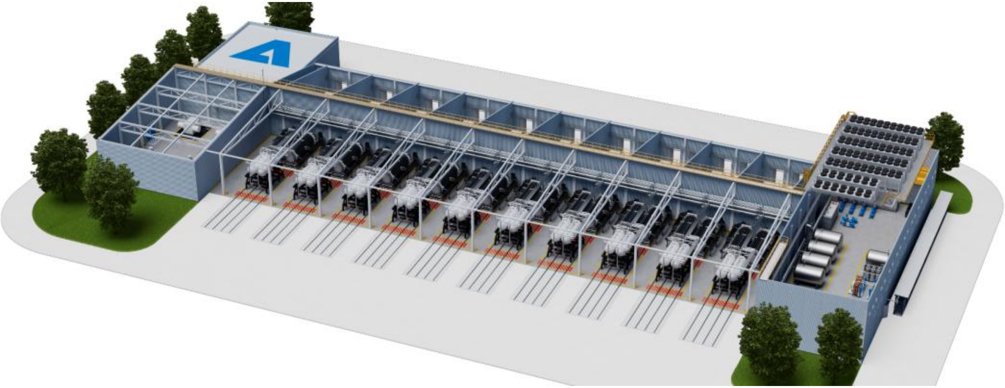
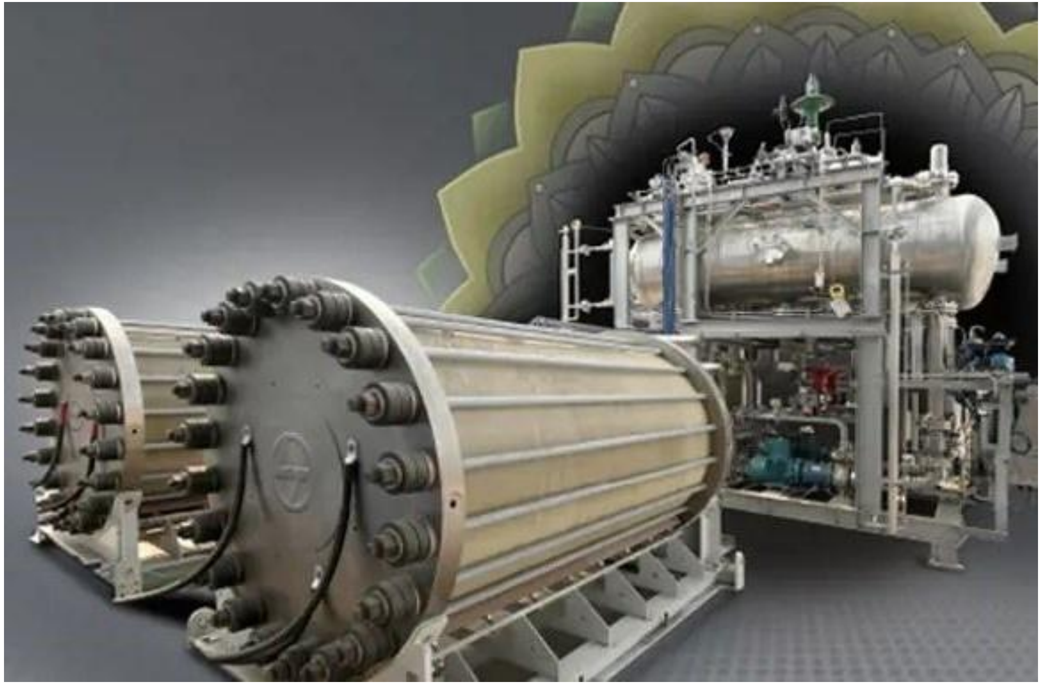


https://www.andritz.com/newsroom-en/metals/2023-09-20-salzgitter-group

https://www.andritz.com/newsroom-en/news/2023-04-19hydrogenprogroup

Larsen & Toubro producing pressurised alkaline electrolysers in India under license from McPhy.



https://hydrogentechworld.com/lt-commissions-first-indigenously-manufactured-hydrogen-electrolyser
https://www.lntgreen.com/projects/green-hydrogen-plant/

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Introduction to Stephen B. Harrison

Stephen B. Harrison is the founder and managing director at sbh4 GmbH in Germany. His work focuses on decarbonisation and greenhouse gas emissions reduction. E-fuels, hydrogen, ammonia and CCTUS are fundamental pillars of his consulting practice.

In support of the European Commission through CINEA in 2023, Stephen evaluated seven CCS, hydrogen and e-fuels submissions to the Third Innovation Fund. The fund allocated €2 billion to large-scale decarbonisation projects in Europe.

Stephen has served as the international expert and team leader for three ADB projects related to CCTUS and renewable hydrogen deployment in Pakistan, Palau and Viet Nam. He has also supported the IFC and work bank on e-fuels and green hydrogen strategy development projects in Namibia and Pakistan. In 2021, he specified more than 2GW of electrolyser capacity for green hydrogen projects.

With a background in industrial and specialty gases, including 27 years at BOC Gases, The BOC Group and Linde Gas, Stephen has intimate knowledge of e-fuels, hydrogen, ammonia and carbon dioxide from commercial, technical and operational perspectives. For 14 years, he was a global business leader in these FTSE100 and DAX30 companies.

Stephen has extensive buy-side and sell-side M&A due diligence and investment advisory experience in the energy and clean-tech sectors. Private Equity firms and investment fund managers and green-tech start-ups are regular clients. He also supports operating companies in their mission to decarbonise their scope 1, 2 and 3 GHG emissions.

Stephen served on the Scientific Committee for CEM2023 in Barcelona and chaired the session related to CEM from clean energy systems. Stephen was session chair for the e-fuels and hydrogen propulsion track at the Bremen Hydrogen Technology Exhibition in September 2023. He was also conference chair at the CO2 utilisation Summit in Hamburg in 2023. Stephen also served on the Technical Committee for the Green Hydrogen Summit in Oman in December 2022 and the Advisory Board of the International Power Summit in Munich in September 2022.