AEM-ELEKTROLYSE UND HOCHTEMPERATUR-ELEKTROLYSE

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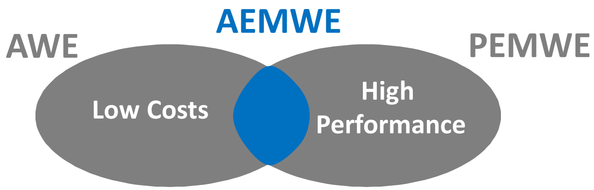
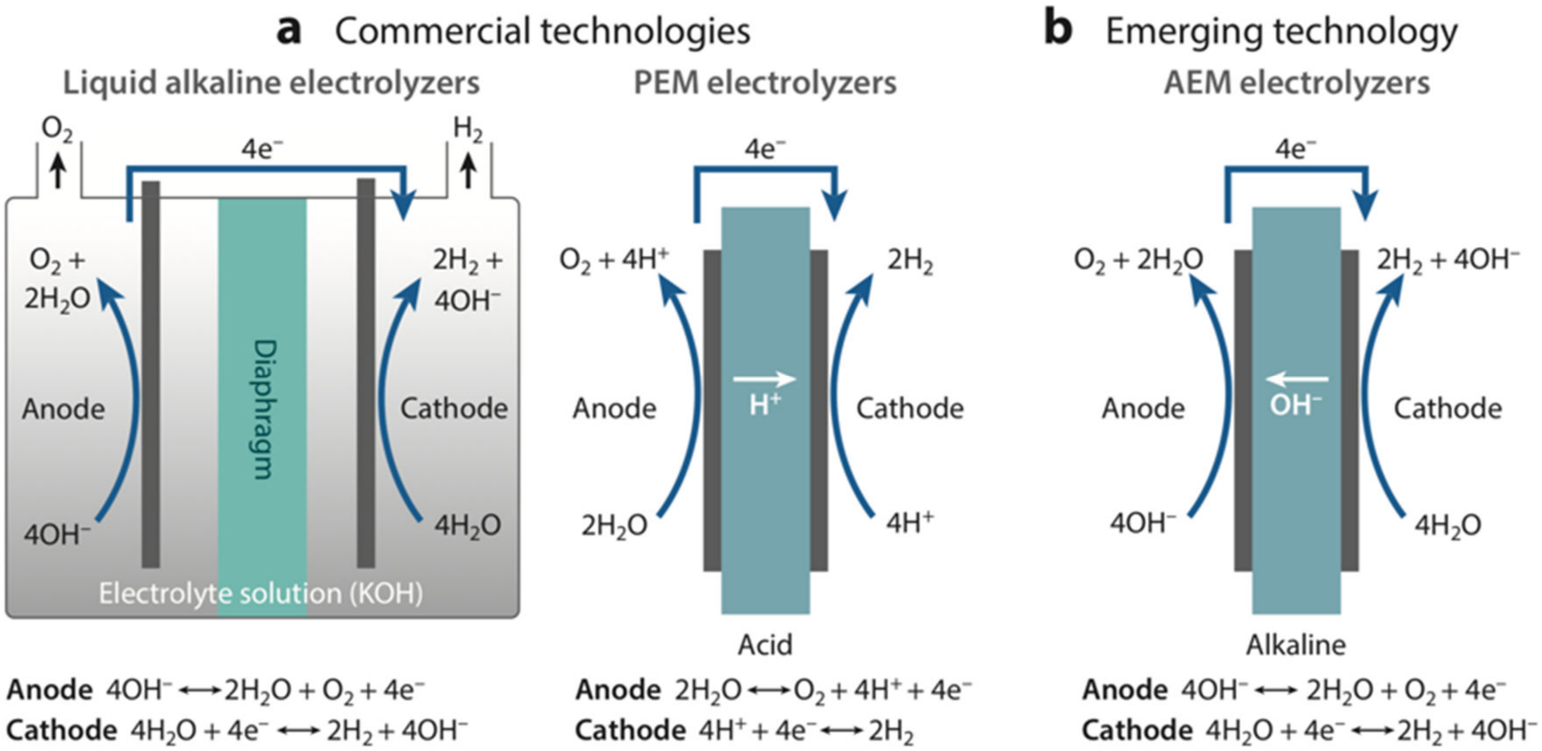
Workshop Elektrolyse-Technologie, e-mobil 12.12.23

AEM-Elektrolyse Prinzip



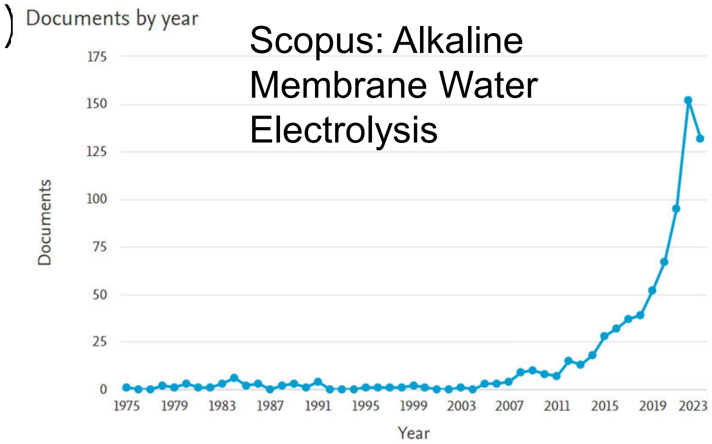


K. Ayers et al. Annu. Rev. Chem. Biomol. Eng. 10 (2019) 219–239

Potenziale und Herausforderung der AEM-Elektrolyse

Potenzielle Vorteile:

- Höher Leistungsfähigkeit versus AEL (niedriger Innenwiderstand)
- Verbesserte Gasreinheit bei Druckbetrieb
- Verbesserte Gasreinheit in der Teillast
- Keine Edelmetalle notwendig, Potential für PFAS-frei
- Möglichkeit niedriger KOH-Konzentrationen (niedrige Kosten der BoP)
- Niedrige Werkstoffkosten versus PEM-Elektrolyse



Diskutierte Nachteile / Herausforderungen

- Niedrige Performanz versus PEM-EL
- Langlebigkeit und Stabilität der OH^--leitenden Polymere
- Niedrige Performanz mit reinem Wasser
- Niedrige Reife – ein kommerzieller Anbieter Enapter 30.000 h spezifizierte Lebensdauer

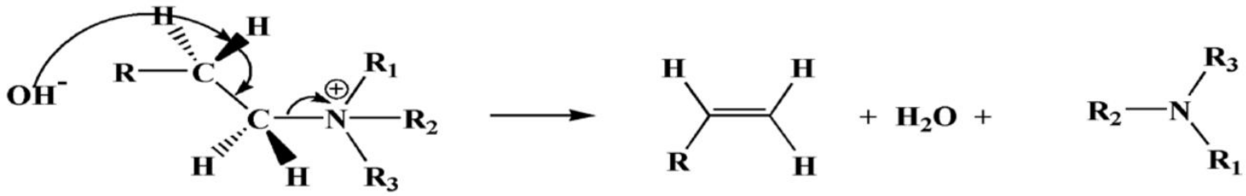
Folie 3

FKA1 Friedrich, Kaspar Andreas; 09.09.2023

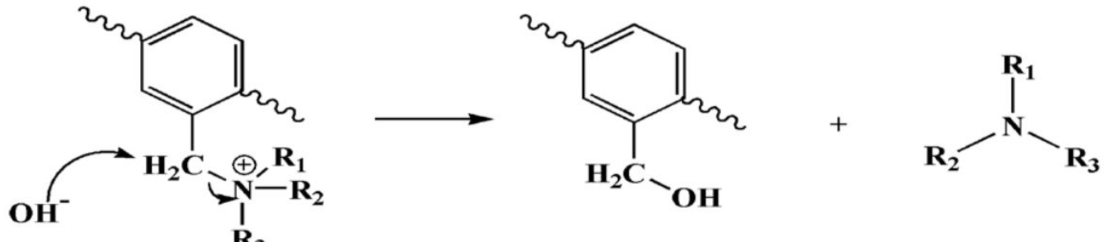
Herausforderung Stabilität:

- Zwei gut bekannte chemische Reaktionen führen zum Abbau des Polymers:

Hoffman Elimination



Nucleophilic substitution

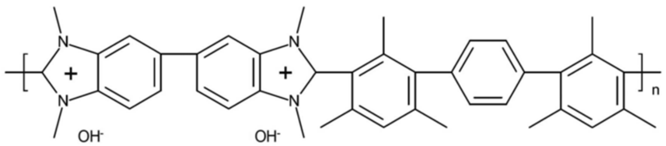


Mögliche Strategien zur Stabilisierung:

- Vernetzung, um Rotation der labilen Gruppe zu vermeiden
- Ammonium-Gruppe an einer langen Kohlenstoffkette zu binden
- Sterischer Schutz der Funktionalen Gruppe

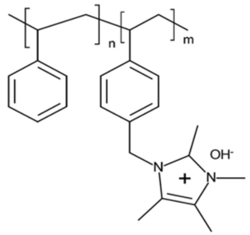
Hydroxid-leitende Membranen als Grundlage der AEM-Elektrolyse

- Tokuyama: Struktur nicht veröffentlicht, Kohlenwasserstoffmembran mit quarternärer Ammonium-Gruppe, gute Stabilität
- Fumatech FAA3: polyaromatisches Polymer mit Etherbindungen in der Hauptkette mit quartären Ammoniumgruppen; mechanisch verstärkt
- Ionomr: AEMION™: methyliertes Polybenzimidazole



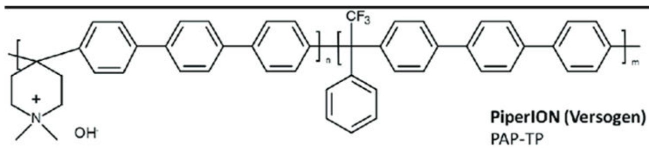
HMT-PDMBI (hexamethylterphenyl-polydimethylbenzimidazolium)

- Dioxide Materials: Sustainion™.

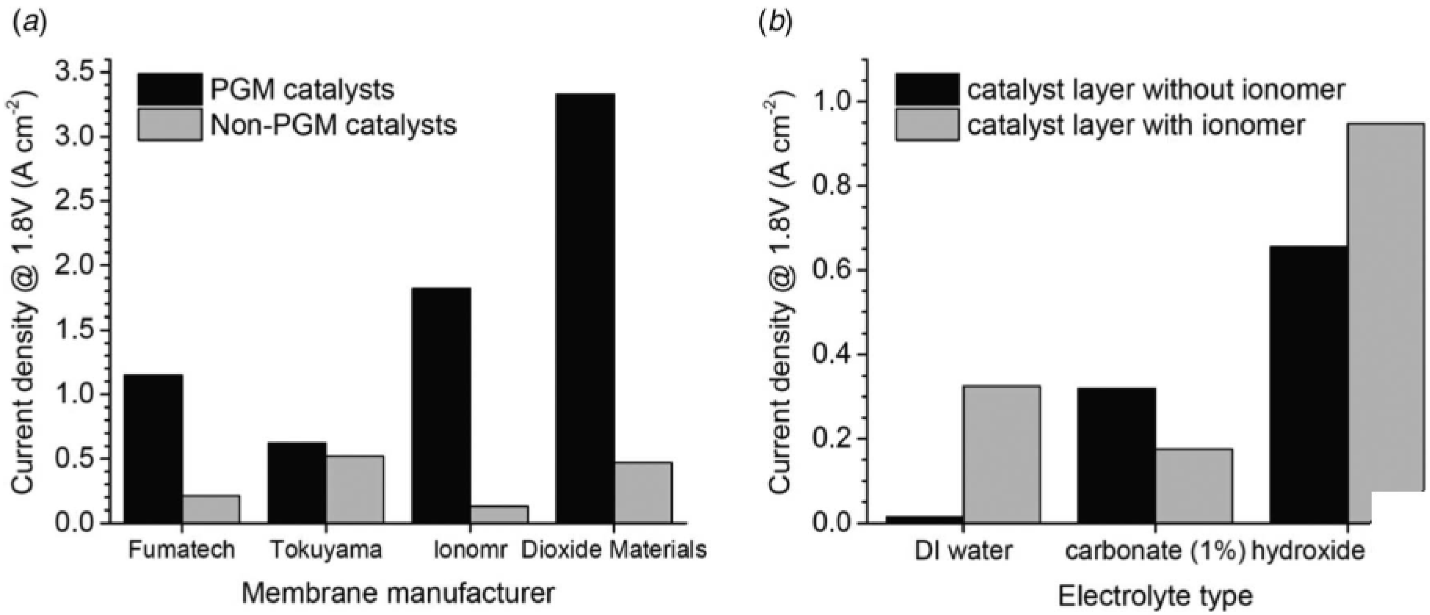


Similar to poly(4-vinylbenzylchloride-co-styrene)

- Versogen: PiperION™ Poly(aryl piperidinium)-Polymere

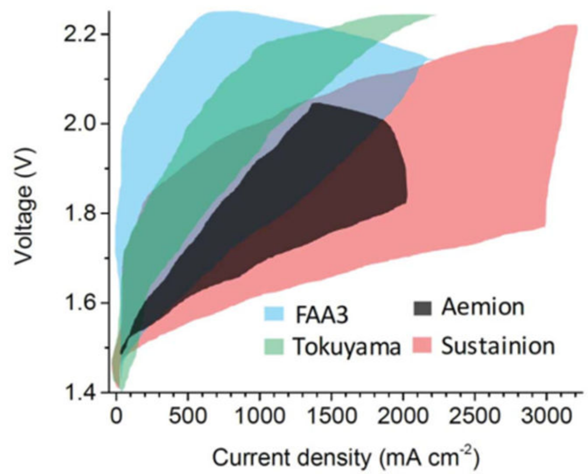


Leistungsfähigkeit mit kommerziellen Polymeren in der AEM-Elektrolyse



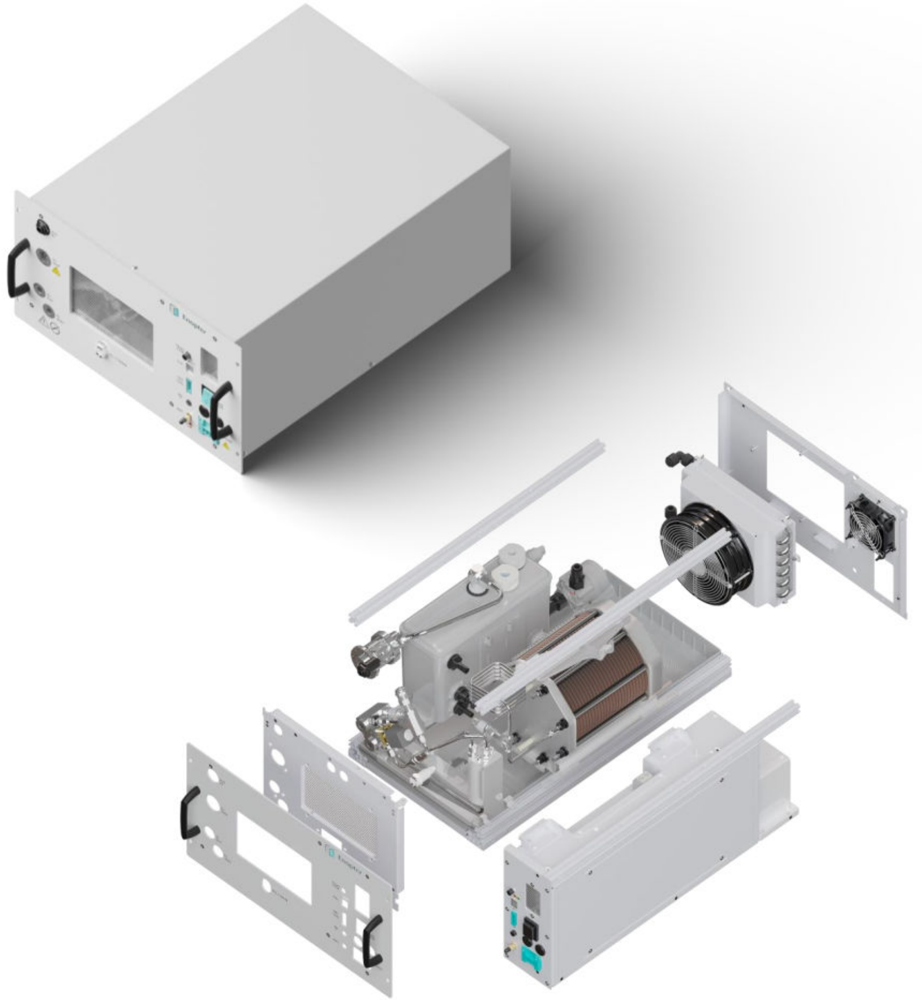
- Hohe Leistungsfähikgkeit mit PGM vgl.bar PEM-EL
- Ohne PGM noch niedrigere
- KOH notwendig für hohe Leistungsfähigkeit

Source: Henkensmeier et al., *J. Electrochem. En. Conv. Stor*. (2021), 18(2): 024001, doi.org/10.1115/1.4047963



Kommerzielle Systeme von Enapter

- Hydrogen Production: 500 NL/hr or 0.5 Nm^3/hr
- Power Consumption: 2.4 kW
- Efficiency: 4.8 kWh/Nm^3
- Hydrogen Purity: 99.9% or 99.999% (with optional dryer)
- Output Pressure: 35 bar
- Modular and scalable



Quelle: Enapter

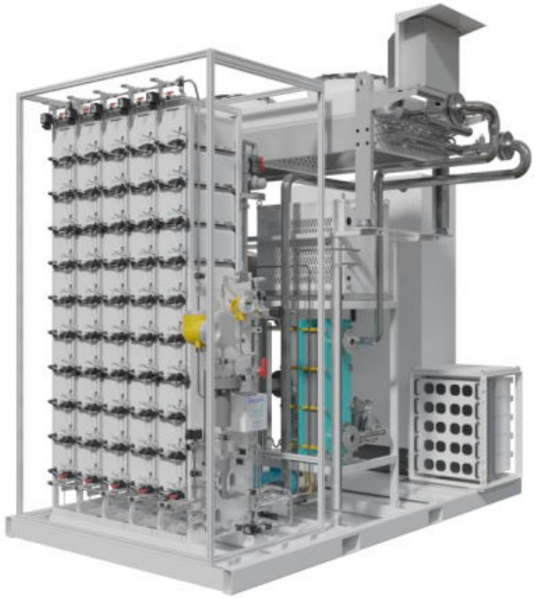
Modularisiertes Konzept – Serienfertigung des Grundmoduls

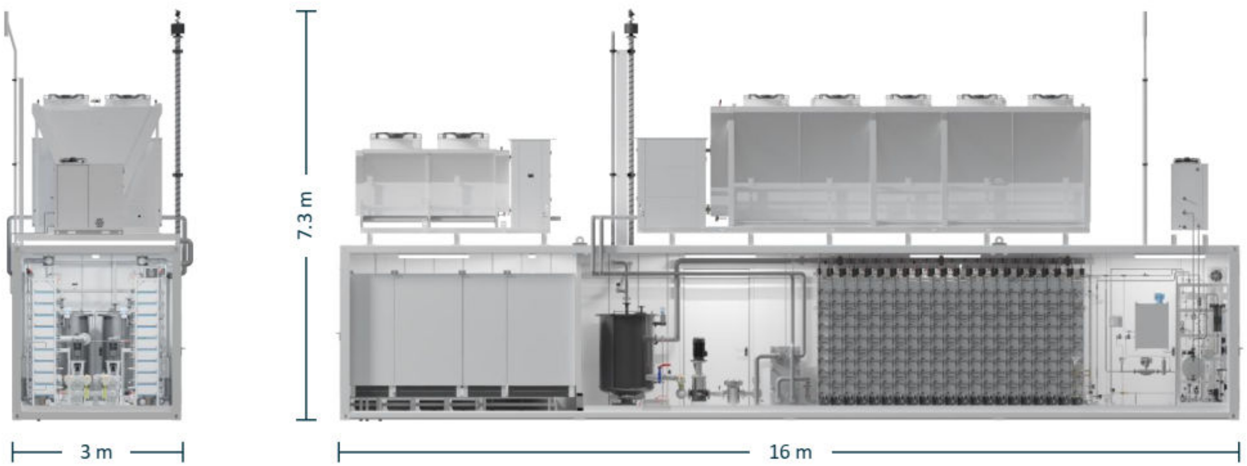
DLR

120 KW

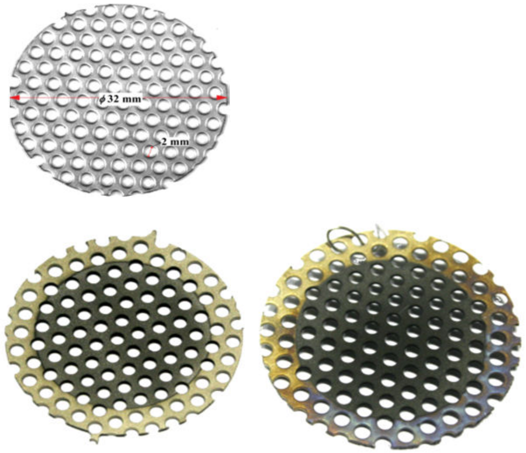
1008 KW

Enapter

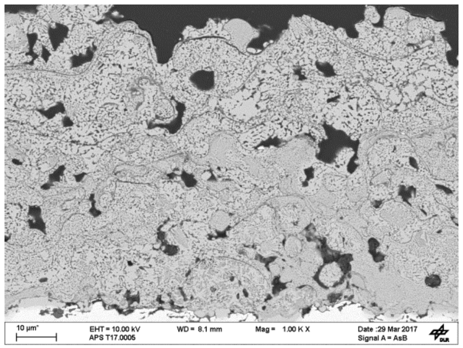




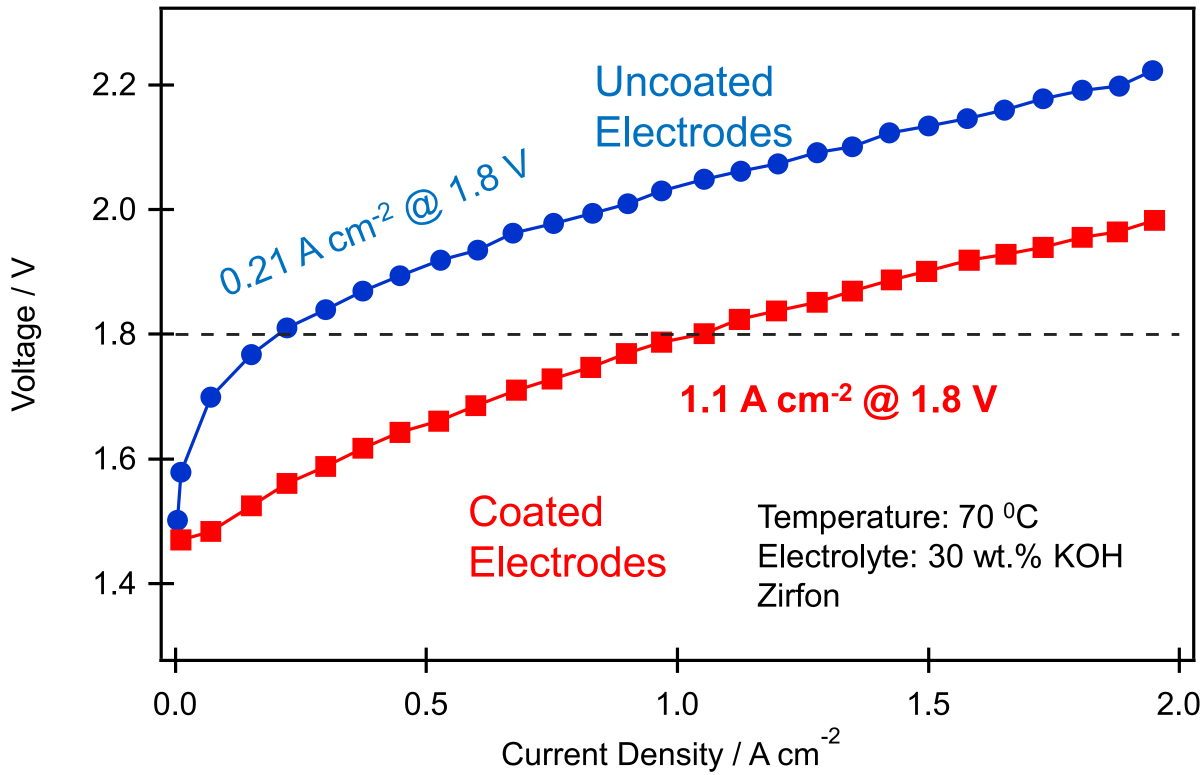
Raney Ni –Beschichtungen am DLR



as-sprayed activated



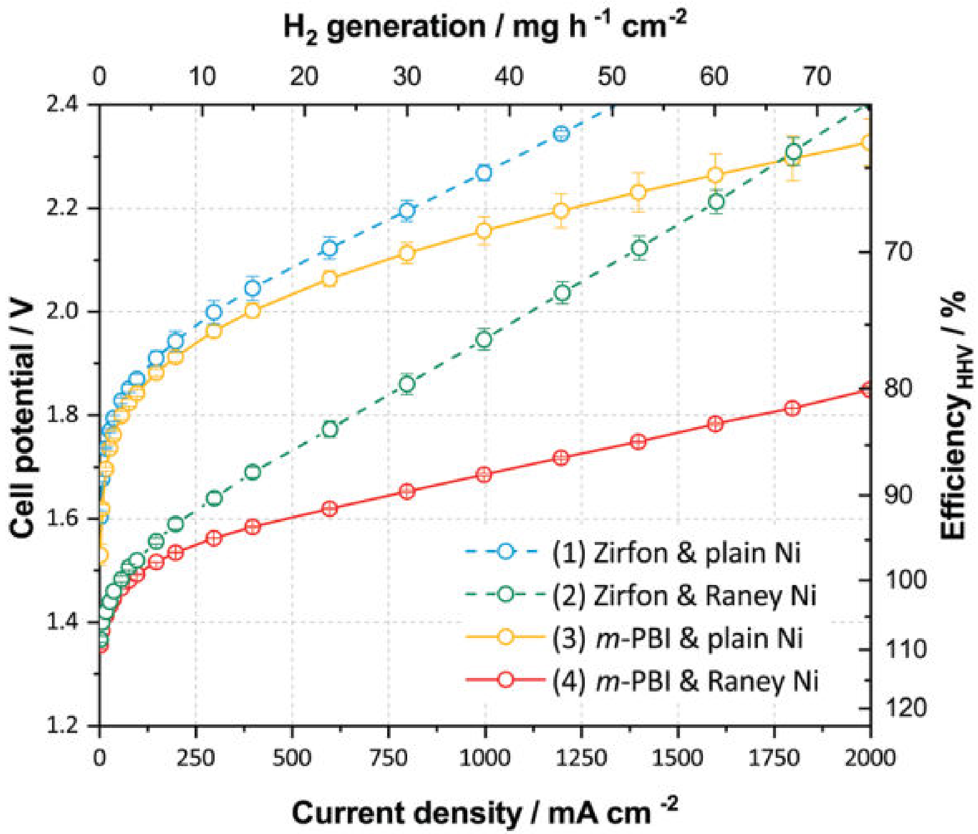
Structure of activated electrodes



APS coatings can increase performance significantly which lowers OPEX

“Ionensolvatisierende Membranen: Hohe Stromdichten mit Raney-Ni möglich

Collaboration with DTU and FZJ



Source: Kraglund et al.Energy & Environmental Science (2019)

Electrochemical cell performance in 24 wt% KOH and 80 °C

(1) Ni-foam/Zirfont PERL diaphragm/Ni-perforated plate;

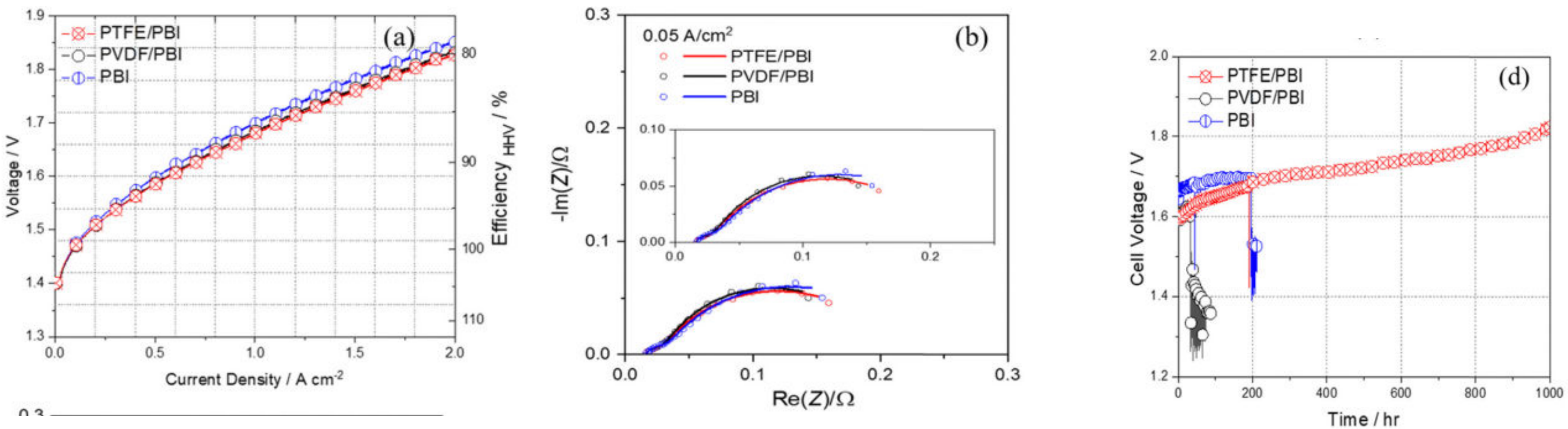
(2) RANEY type-NiMo/Zirfon PERL diaphragm/RANEY-type-Ni;

(3) Ni-foam/40 mm m-PBI membrane/Ni-perforated plate

(4) RANEY-type-NiMo/40 mm m-PBI membrane/RANEY-type-Ni.

Stabilisierung der PBI Membranen mit PTFE-Verstärkung

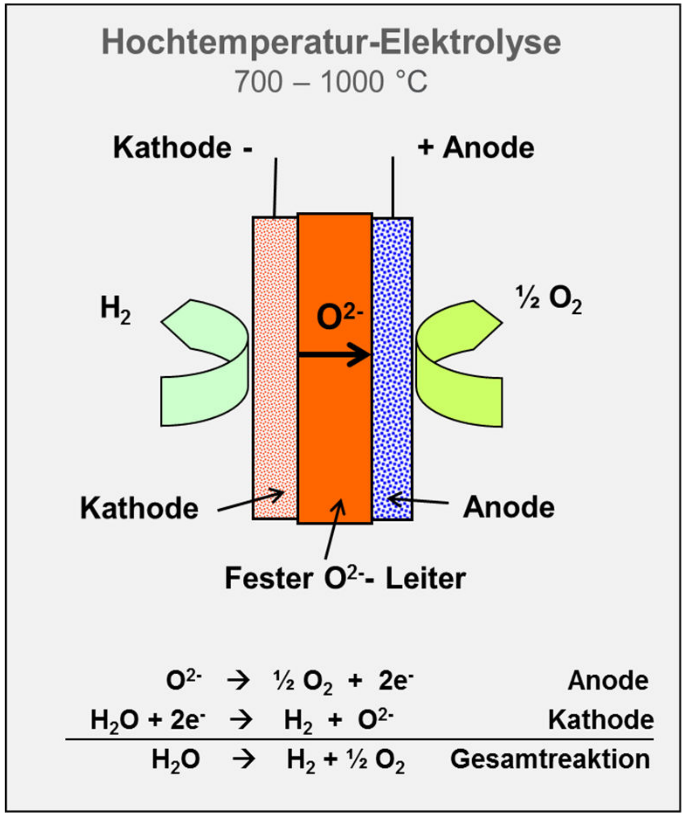
Electrochemical characterization of the AEL cell with RANEYs Nickel electrodes, with PTFE/PBI, PVDF/PBI and commercial PBI membranes in 24 wt% KOH at 80 1C:



Trisno et al., Energy Environ. Sci., 2022, 15, 4362

chronoamperometric measurements at a constant current density of 0.5 A cm^{-2}

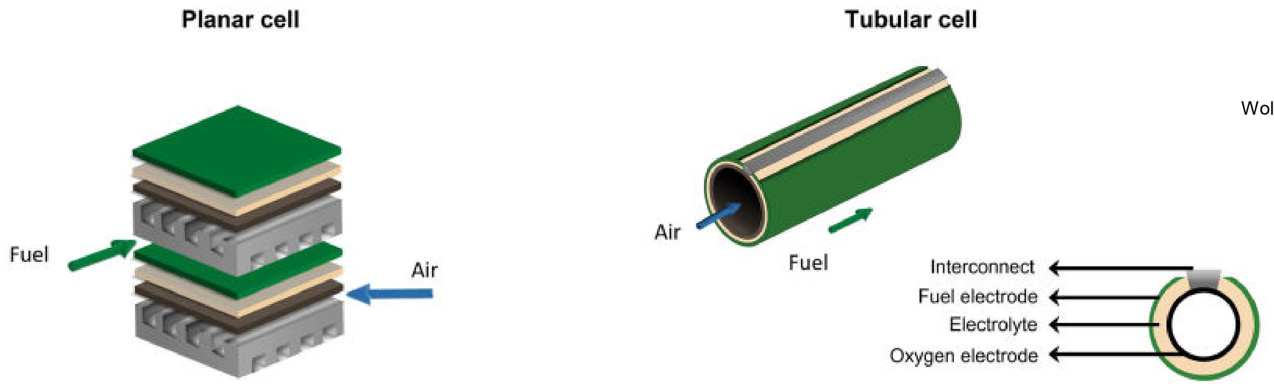
Hochtemperatur Festoxidzelle (SOC)

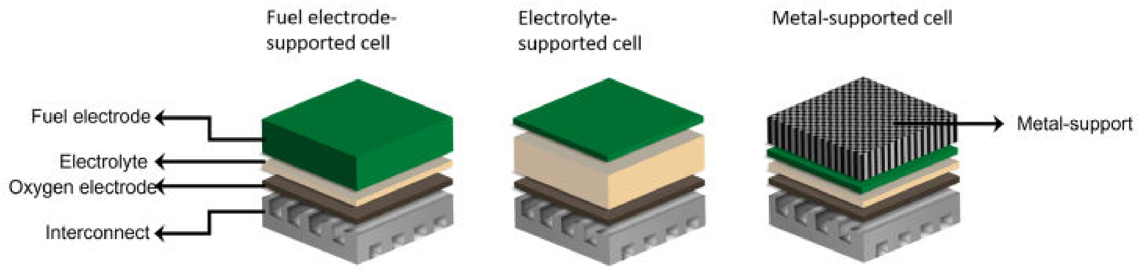


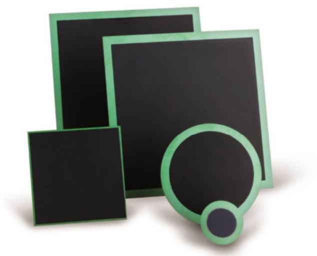
Betriebstemperatur > 600 °C
Brennstoffflexibilität
Keine Edelmetalle
Reversibilität BZ/EL
Ko-Elektrolyse: CO_2-Reduktion + Wasserspaltung

Hochtemperatur Festoxidzelle (SOC) - Zelle

Wolf *et al.* J. Mater. Chem. A, 2023, 11, 17977–18028

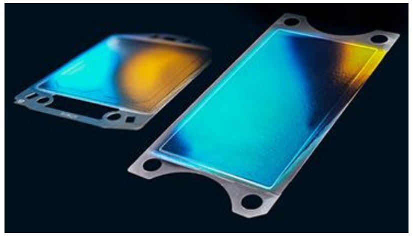






Source: Elcogen

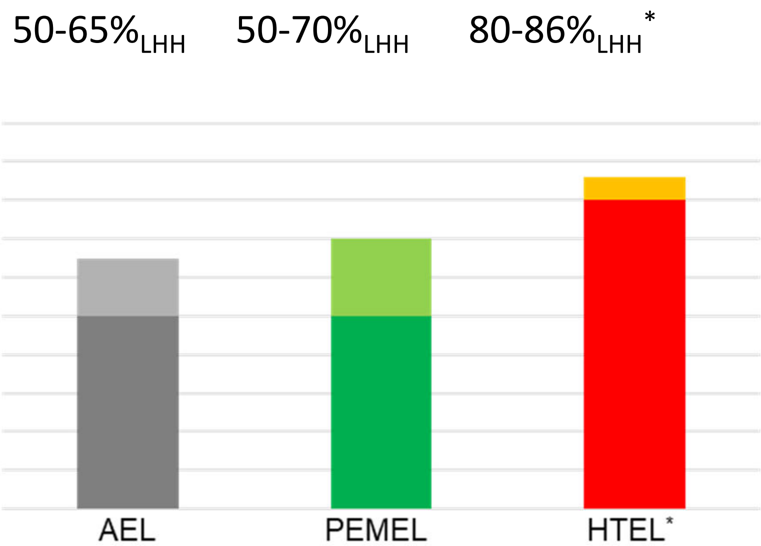
Source: Kerafol



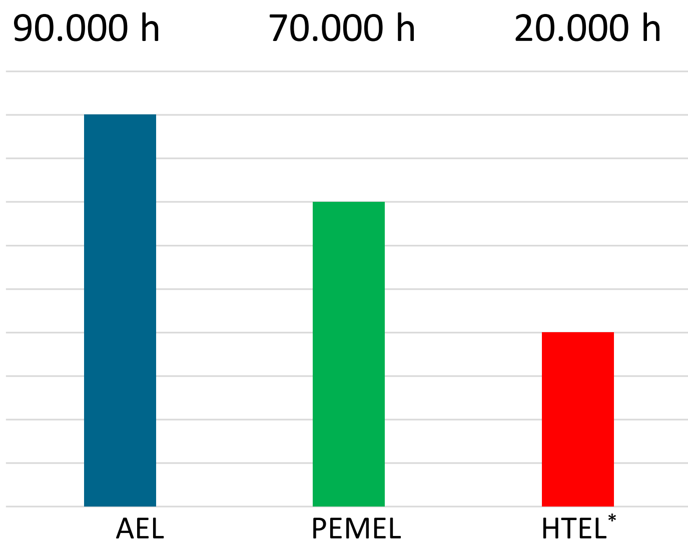
Source: Ceres

Electrolysis State-of-Art

Technical Efficiencies (plant)



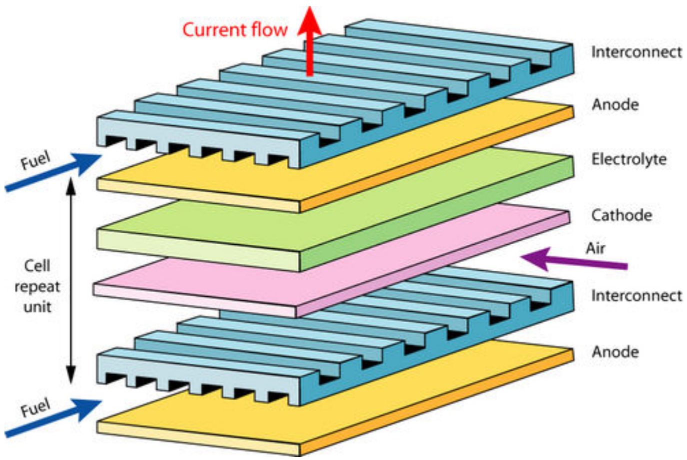
Stack Durability (reported)



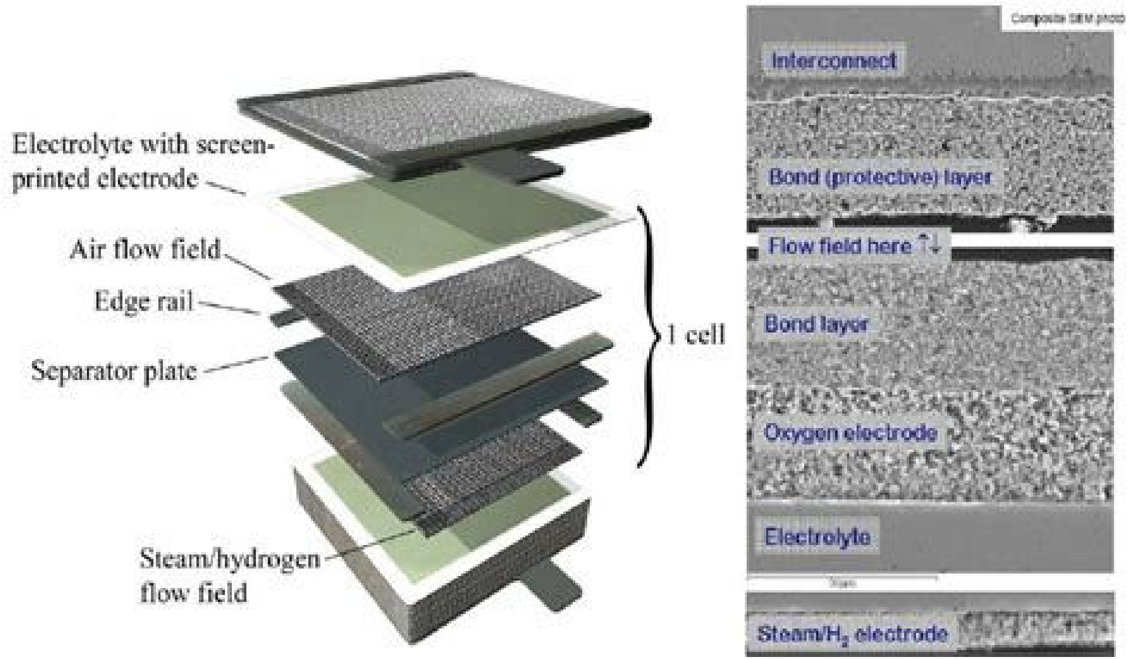
*With Steam generation

Source: H2-Giga

Hochtemperatur Festoxidzelle (SOC) – Komponente Wiederholeinheit



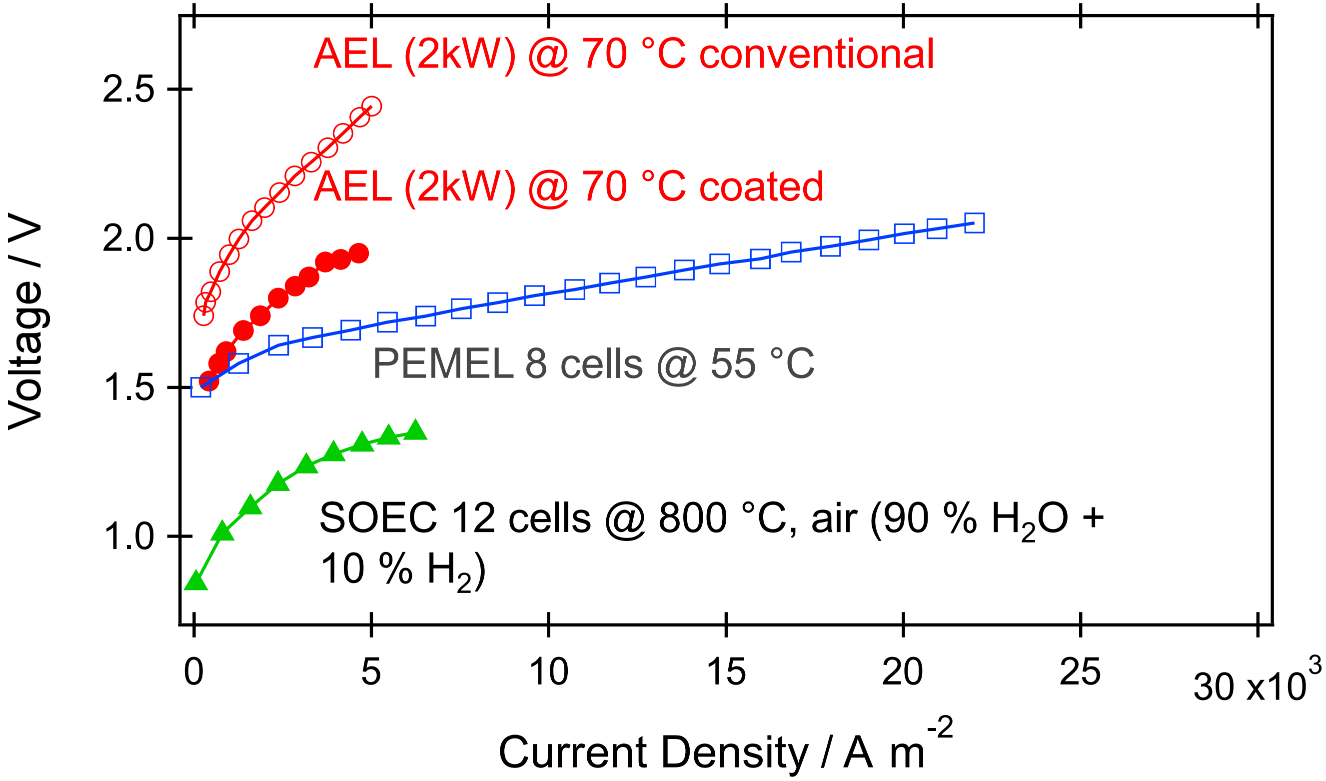
Source: University of Cambridge



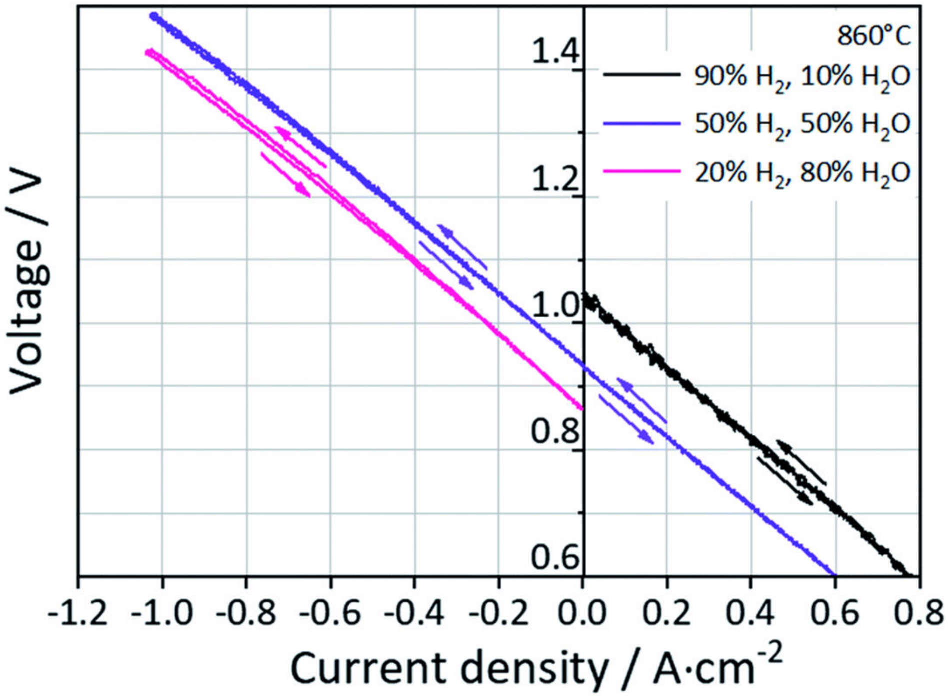
Source: M. S. Sohal *et al.* Idaho National Lab.

Vergleich der Elektrolyse-Technologien

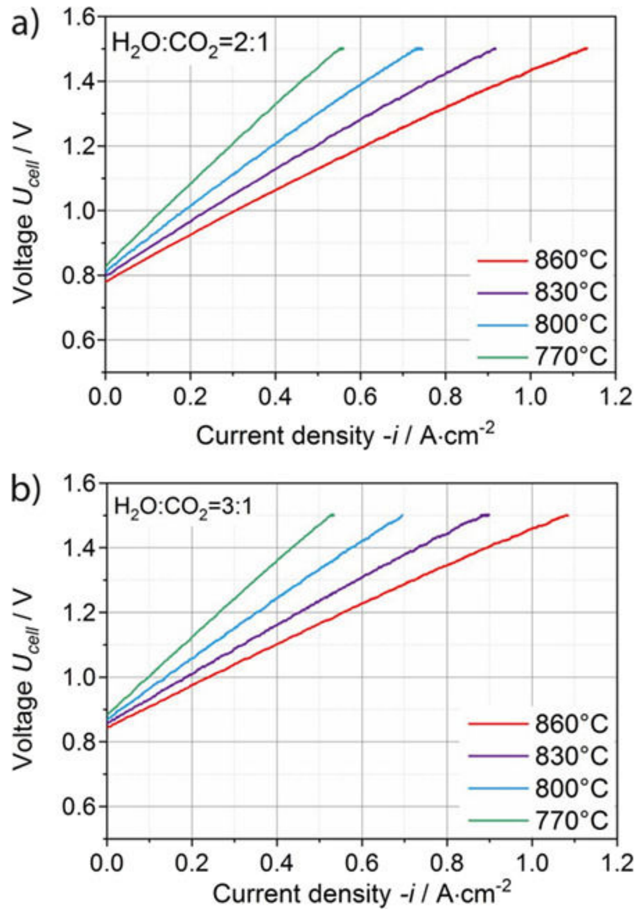
- Short stack comparison of different technologies



Hochtemperatur Festoxidzelle (SOC) – Komponente Zelle



Amaya Dueñas *et al.* J. Mater. Chem. A, 2021,9, 5685-5701

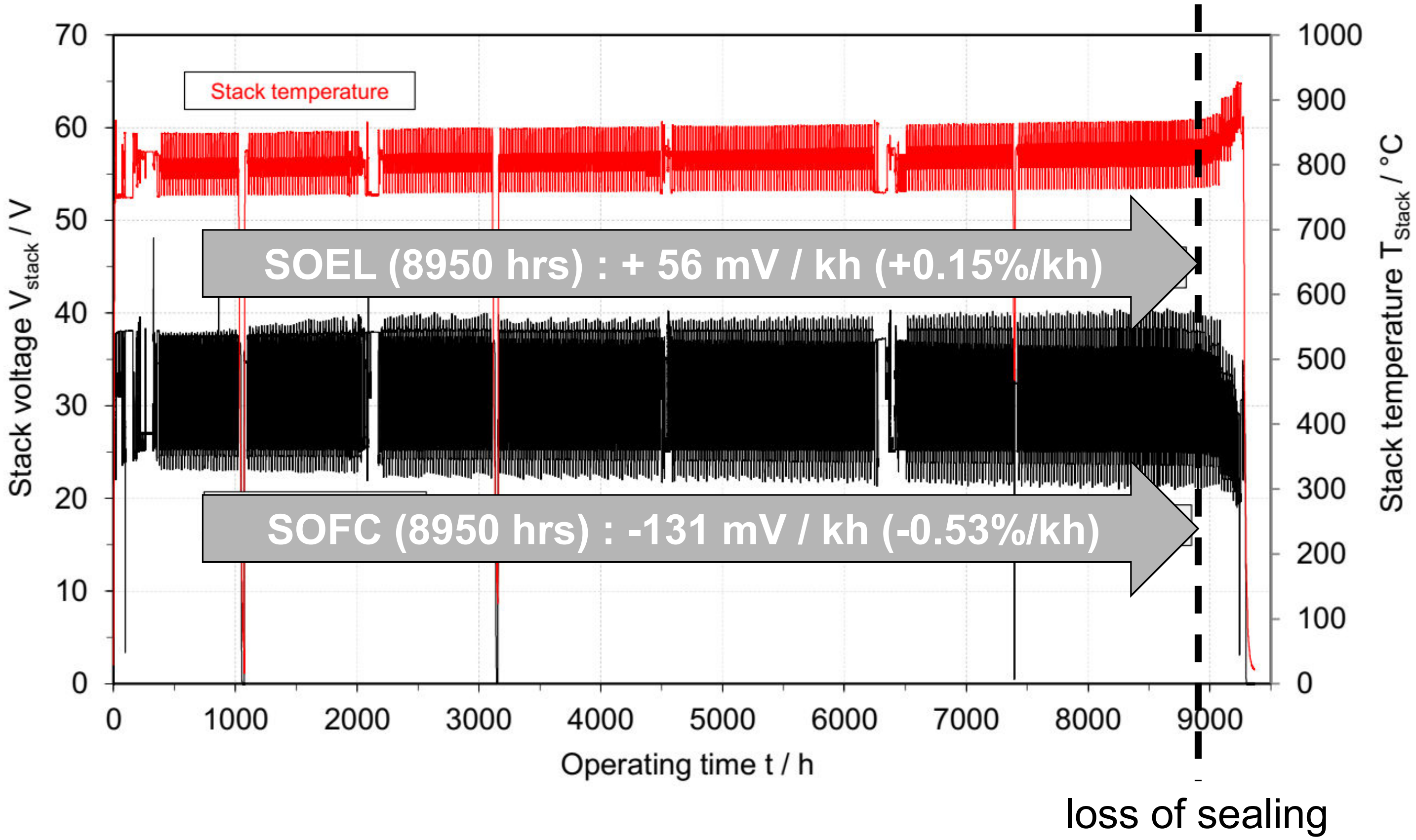


Amaya Dueñas *et al.* Chem. Ing. Tech.2020,92, No. 1–2, 45–52

Hochtemperatur Festoxidzelle (SOC) – Komponente
Stapel / Stack

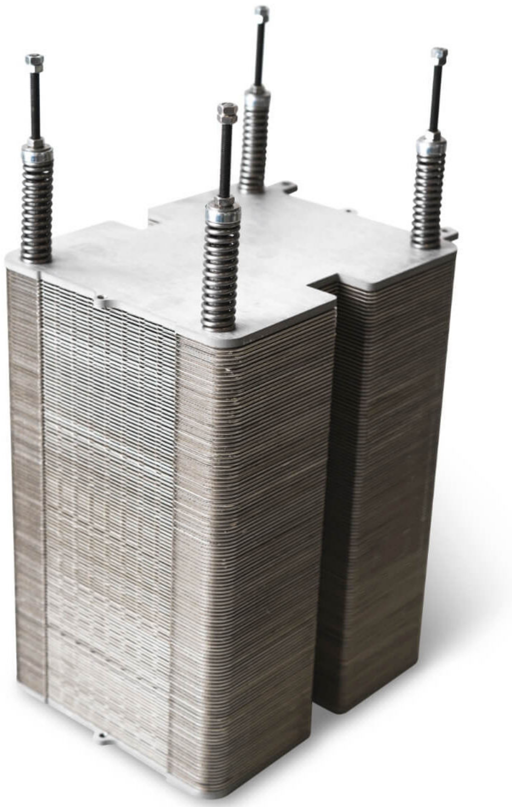
Source: Sunfire

30 Ebene Stack



M. Lang et al., 2021, ECS Trans. 103, 2041, 10.1149/10301.2041ecst

Hochtemperatur Festoxidzelle (SOC) – Komponente Stapel / Stack

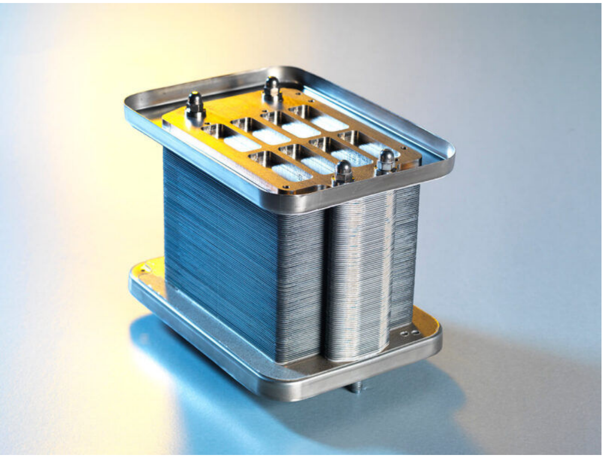


Source: Elcogen

Source: Sunfire

E&KOA

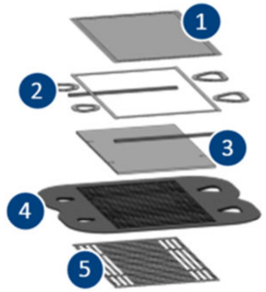
1-10kW



Source: Ceres

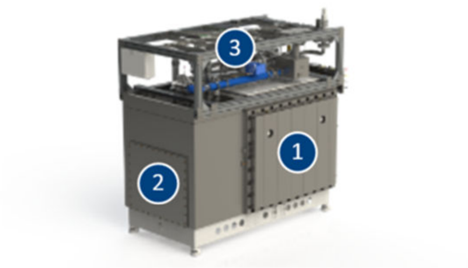
Hochtemperatur Festoxidzelle (SOC) – Komponente von Zellen bis Systeme

Cell	x 30	Stack	x 60	Module	x 12	System
0.125 kW		3.7 kW		225 kW		2.7 MW



1. Membrane electrode assembly
2. Glass sealing
3. Nickel foam
4. Sheet metal cassette
5. Cathode contact

1. End plates
2. Cells
3. Stack tensioning

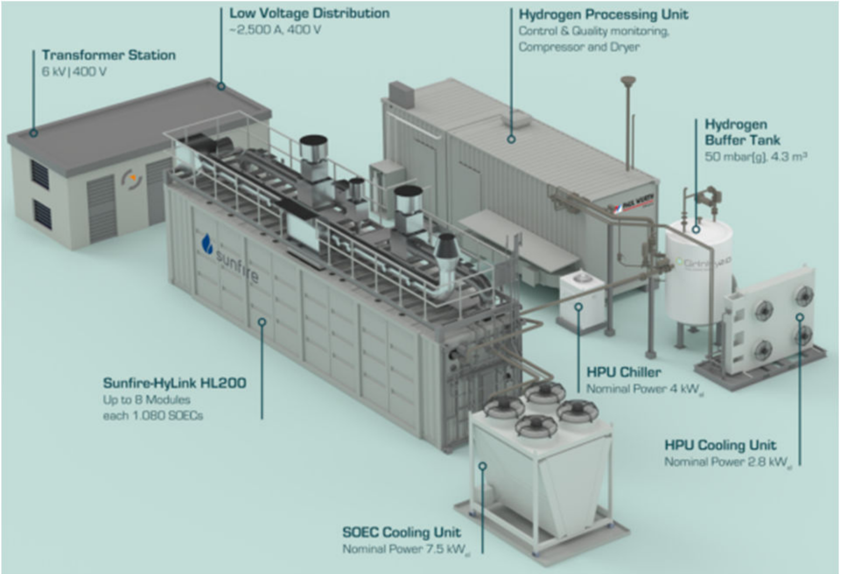


1. Stack unit
2. Gas processing unit (GPU)
3. Supply and discharge unit (SDU)

1. Block (= 4 modules)
2. Fluid interface unit (FIU)
3. Power electronics

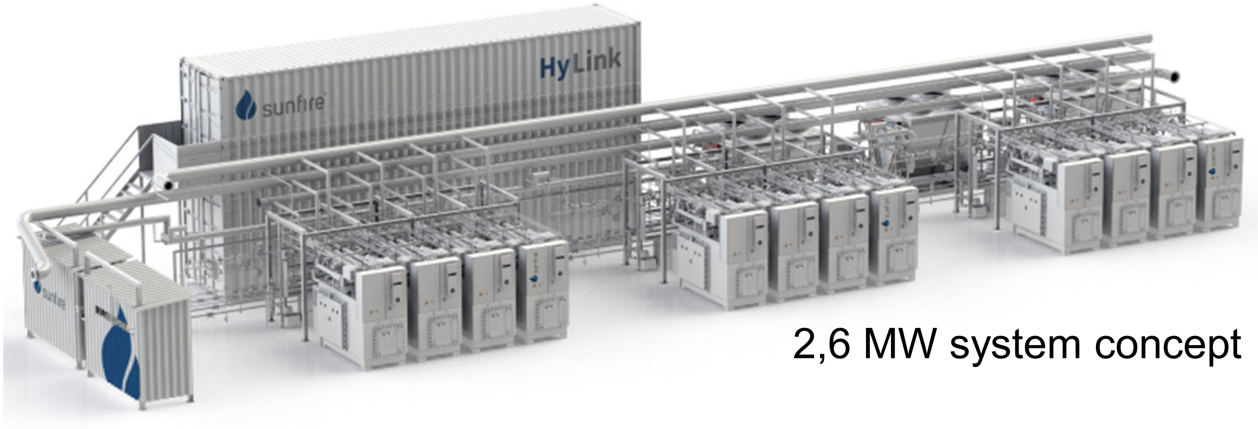
Source: Sunfire

Elektrolyseur-Systeme



1 MW

225kW module



2,6 MW system concept

Elektrolyseur-Systeme

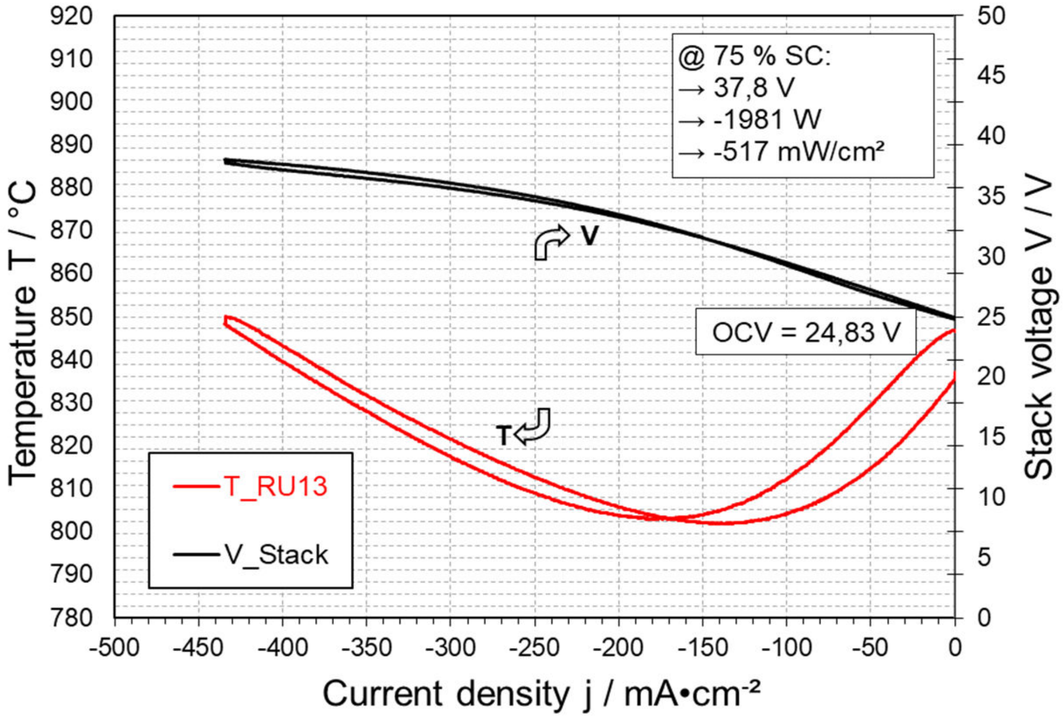
2,6 MW Sunfire @ Neste Biofuels Refinery
Rotterdam, NL

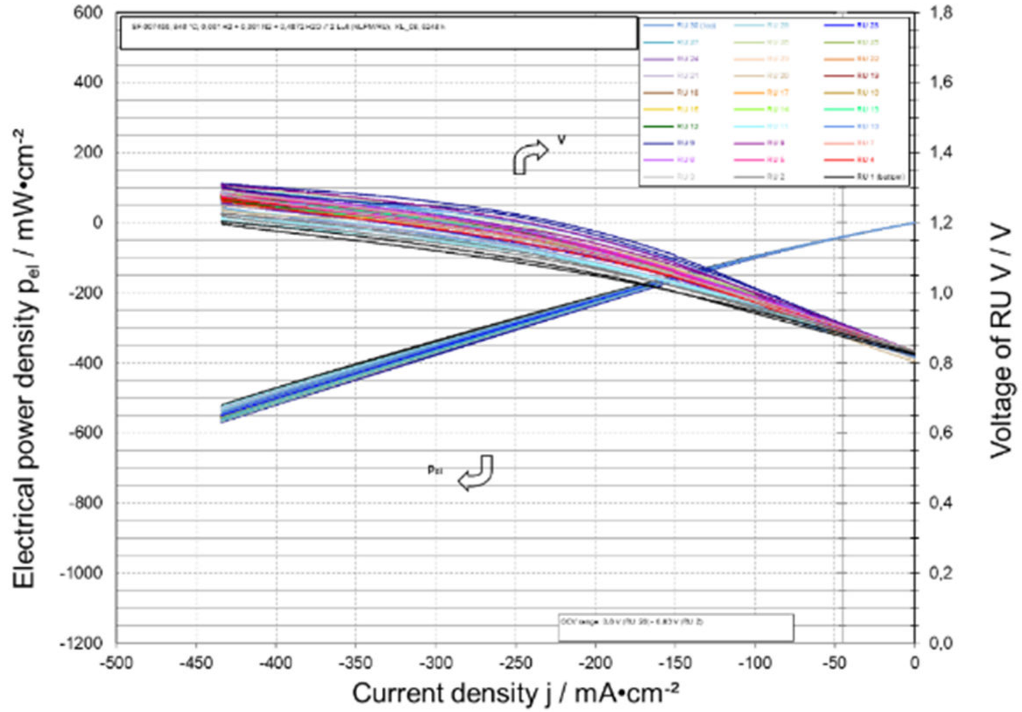
4 MW Bloomenergy @ NASA‘s Ames Research Center
California, US

VIELEN DANK FÜR IHRE AUFMERKSAMKEIT

DLR

Hochtemperatur Festoxidzelle (SOC) – Komponente
Stapel / Stack





Source: DLR

Elektrolyse