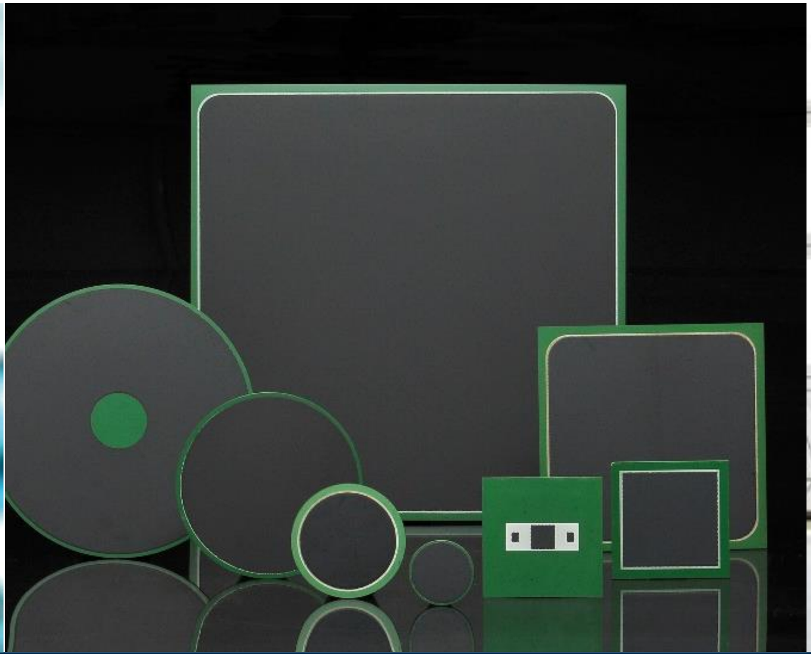


SOLID OXIDE CELLS FOR ELECTROLYSIS AND POWER GENERATION

15.11.2023 | CHRISTIAN LENSER

Member of the Helmholtz Association

JÜLICH
Forschungszentrum
Wandel gestalten

OVERVIEW

- The need for green H_2 in Europe (and worldwide)
- Why SOC? Benefits and disadvantages
- SOC research at IEK-1

WHY THE INTEREST – „NO-REGRET“ HYDROGEN

Green molecules needed?	Industry	Transport	Power sector	Buildings
No-regret	· Reaction agents (DRI steel) · Feedstock (ammonia, chemicals)	· Long-haul aviation · Maritime shipping	· Renewable energy back-up depending on wind and solar share and seasonal demand structure	· Heating grids (residual heat load *)
Controversial	· High-temperature heat	· Trucks and buses ** · Short-haul aviation and shipping · Trains ***	· Absolute size of need given other flexibility and storage options	
Bad idea	· Low-temperature heat	· Cars · Light-duty vehicles		· Building-level heating

- Green H_2 is <u>necessary</u> to decarbonize certain parts of the energy and production sectors
- Focus on use as chemical agent (e.g. steel) or chemical feedstock (e.g. e-fuels, fertilizer)
- Electrolysis (“water-splitting”) is a good way to get green H_2

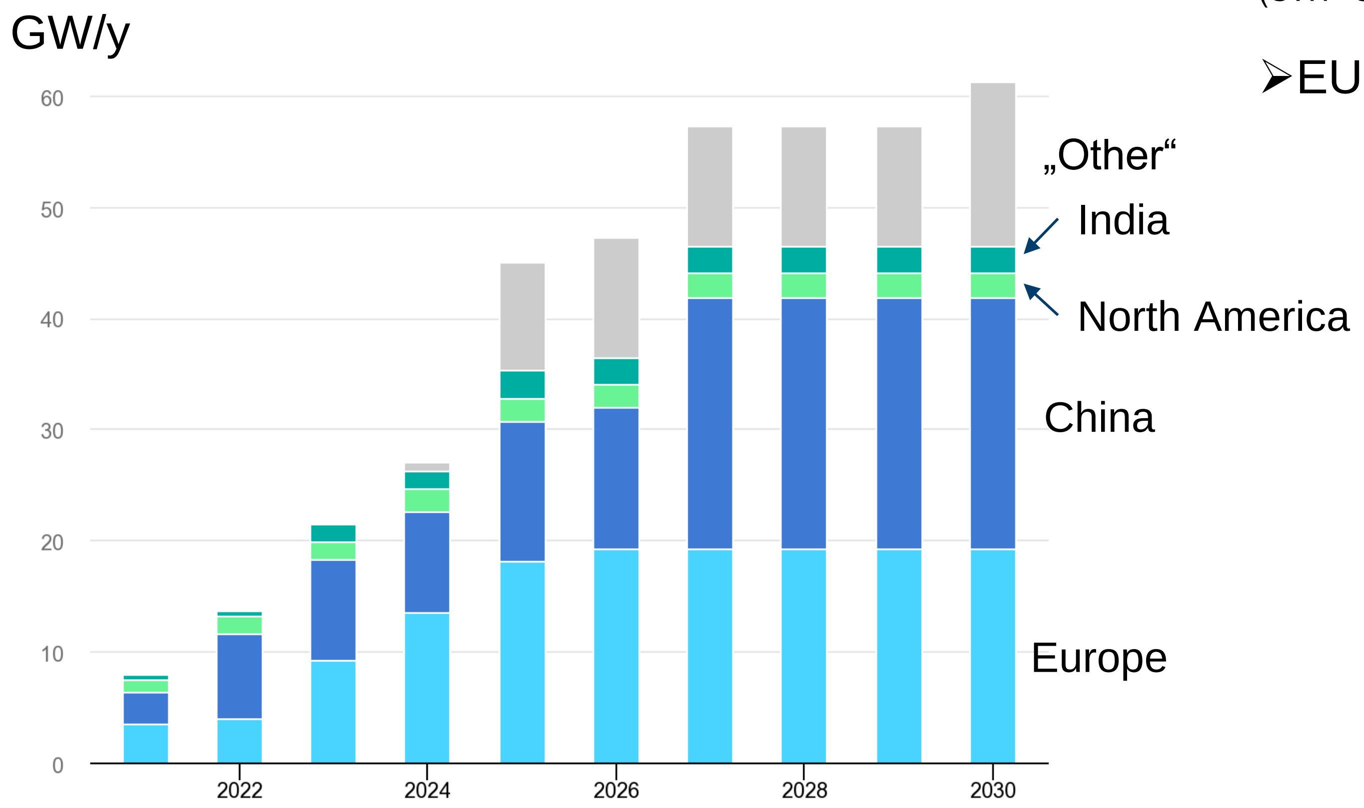
Source: „12 Insights on Hydrogen“, Agora Energiewende, Berlin (2021)

ELECTROLYSIS TECHNOLOGIES

TECHNOLOGY	PRINCIPLE	TEMPERATURE	EFFICIENCY	DEVELOPMENT LEVEL	ADVANTAGES	LIMITATIONS
AEL (Alkaline Electrolysis)	METALS; OXYGEN; HYDROGEN; ⊕; ⊖; OH^-; ALKALINE AQUEOUS SOLUTION (BASE+WATER)	80°C – 50°C	BROUGHT ENERGY; PRODUCED <65%; LOST	IN USE ON A LARGE SCALE WORLDWIDE	- HIGH LONG-TERM STABILITY - LOW INVESTMENT COSTS - NO RARE NOBLE METALS	- HIGH INERTIA - LOWER EFFICIENCY
PEM (Proton Exchange Membrane)	NOBLE METALS; HYDROGEN; OXYGEN; ⊕; ⊖; H+; WATER; ACID!; SOLID POLYMER	80°C – 50°C	BROUGHT ENERGY; PRODUCED <70%; LOST	COMMERCIALLY READY (WOW; SOON!; PRE-ORDER)	- GOOD DYNAMIC BEHAVIOR - FAST COMPENSATION OF FLUCTUATING CURRENT QUANTITIES	- HIGH INVESTMENT COSTS - NOBLE METALS ARE NECESSARY
SOEC (Solid Oxide Electrolyzer Cell)	OXYGEN; HYDROGEN; ⊕; ⊖; O^{2-}; WATER (VAPOR); SOLID OXIDE	900°C – 500°C	BROUGHT ENERGY; PRODUCED >90%; LOST	BETWEEN RESEARCH AND INDUSTRY	- COUPLING OF ELECTRICITY AND HEAT - ELECTROLYSIS OF CO_2	STABILITY (NI DEPLETION, ELECTRODE DETACHMENT) (BOOM)

ELECTROLYSIS: NOW - 2030

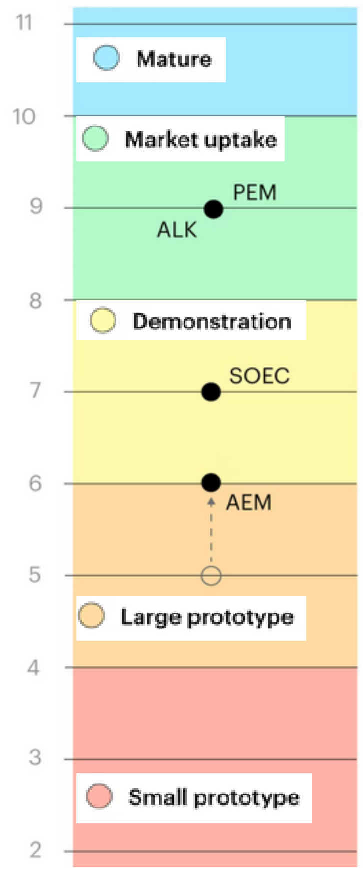
Planned electrolyser manufacturing capacity by region, 2021-2030



https://www.iea.org/data-and-statistics/charts/planned-electrolyser-manufacturing-capacity-by-region-2021-2030

“The electrolysis capacity currently installed in the EU will need to increase almost 900-fold within just eight years.”
(SWP Comment “Electrolysers for the Hydrogen Revolution, 2022)

➢EU target is 120 GW installed capacity by 2030



TRL Electrolysis

https://www.iea.org/reports/electrolysers

ELECTROLYSER PROJECTS IN EU AND WORLD

"World's largest green hydrogen project!"

Project	Rated power (MW)	Technology	Manufacturer	Use case
Shell Holland Hydrogen 1	200	Alkaline	ThyssenKrupp Nucera	ChemPark
H2 Green Steel (SE)	700	Alkaline	ThyssenKrupp Nucera	Steel industry
NEOM (SA)	2200	Alkaline	ThyssenKrupp Nucera	Export
European Energy & others (DK)	> 250	PEM	Plug Power	e-fuels
Kuga (CN)	260	PEM	Longi, Peric and Cockerill Jingli Hydrogen	refinery
Prosgrunn (NOR)	24	PEM	ITM Power	green ammonia
MultiPLHY (Rotterdam)	2.6	SOEC	Sunfire	Neste refinery
NASA (USA):	4	SOEC	Bloom Energy	Research

OVERVIEW

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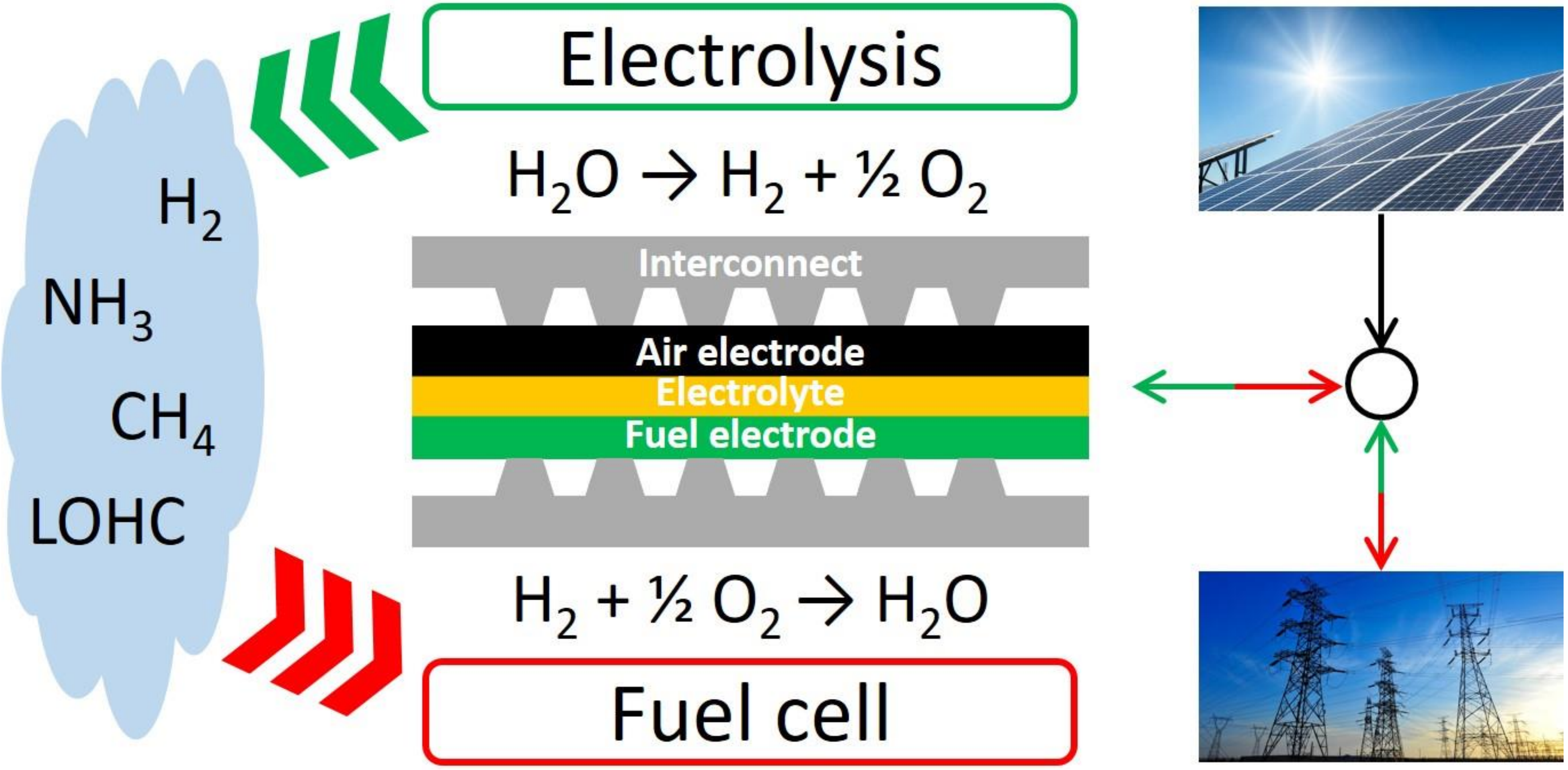
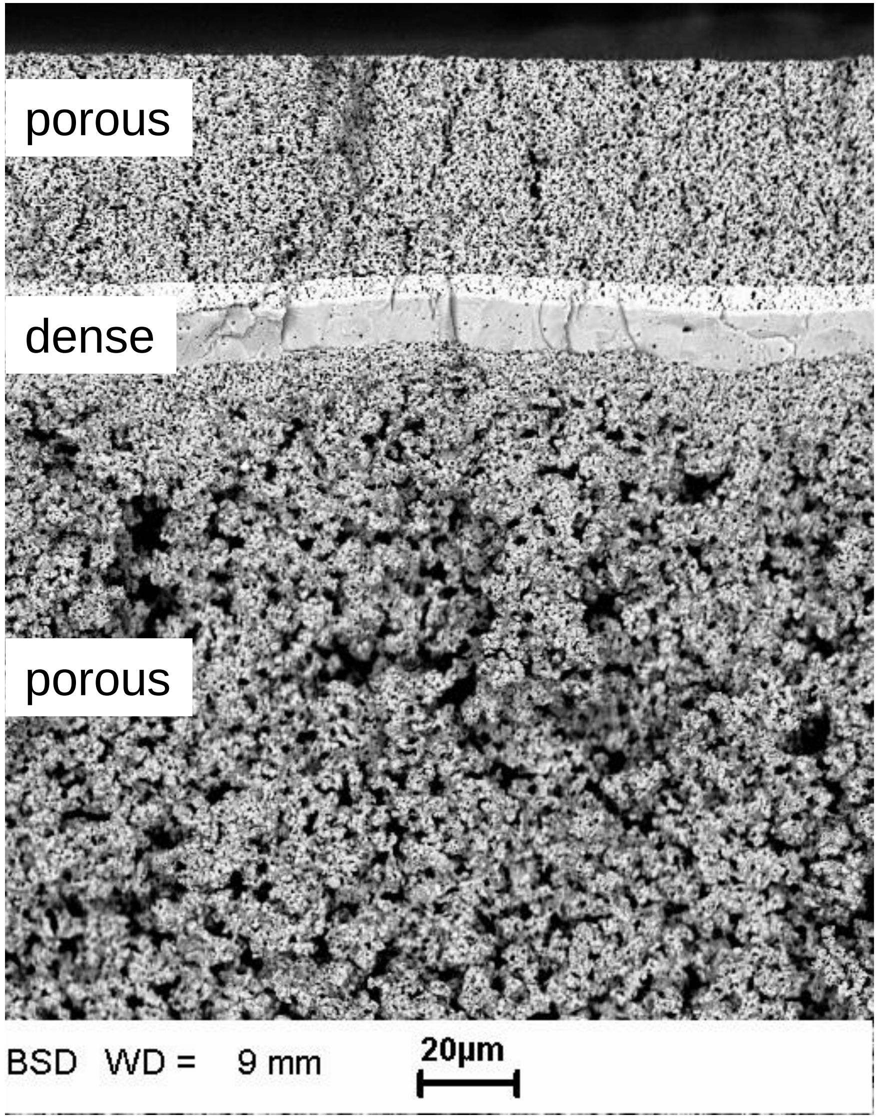
SOLID OXIDE CELLS – WHAT IS IT?

- Fuel cells and electrolyzers are electrochemical energy conversion devices

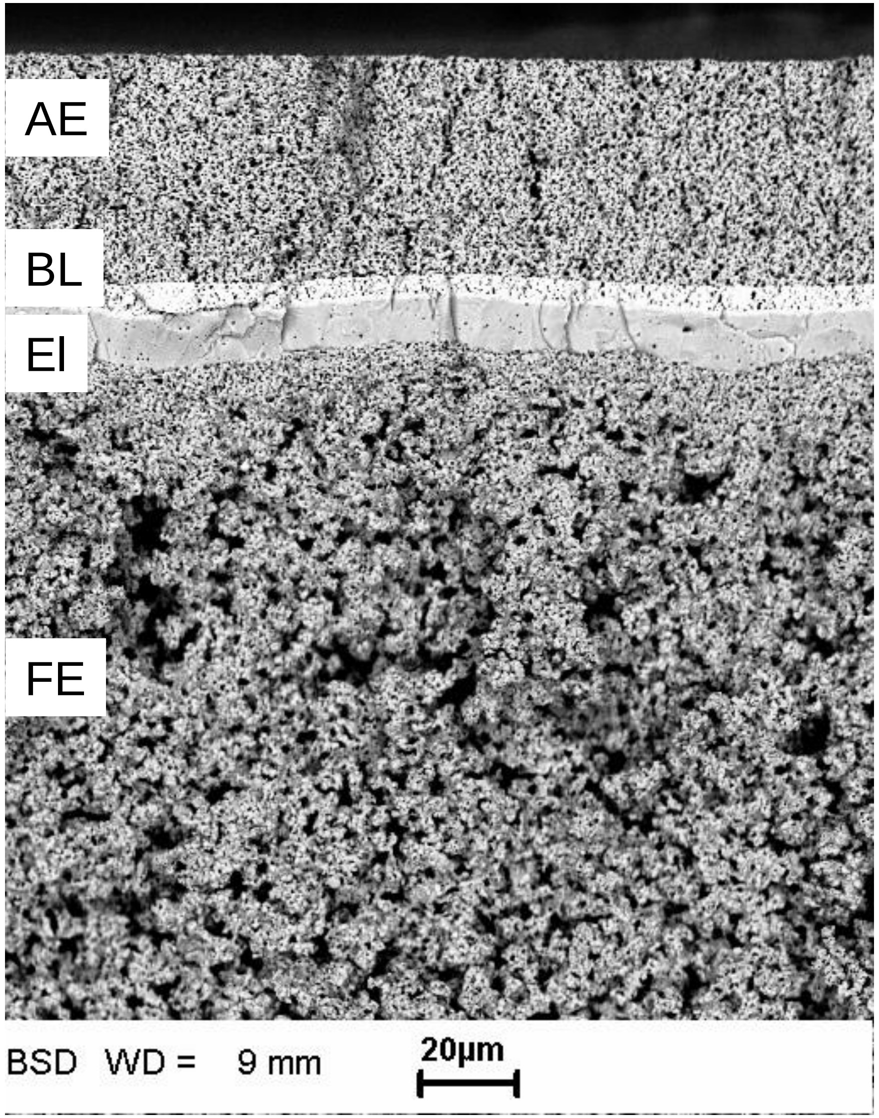


SOLID OXIDE CELLS – WHAT DOES IT LOOK LIKE?



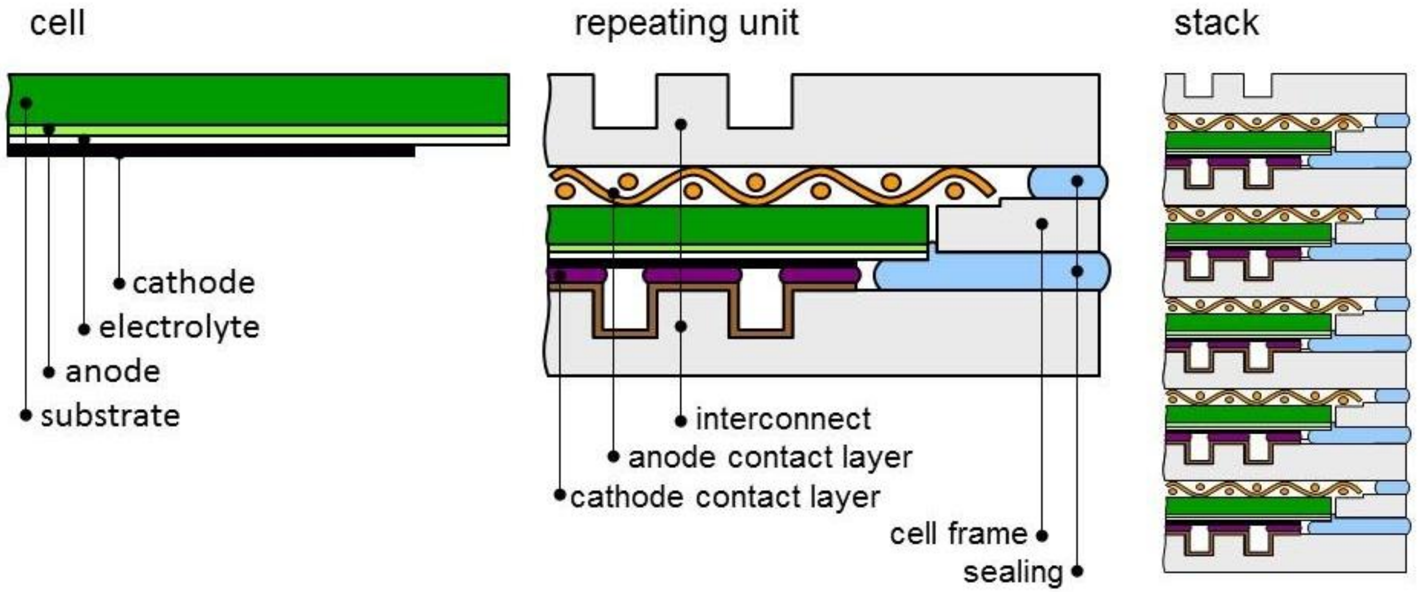
- SOC are ceramic multilayer structures
- Each layer has a dedicated function, e.g.
  - Mechanical support
  - Electrochemical reactions
  - Ion transport and gas separation
- Different cell designs exist
  - Electrolyte-supported (~ 850 °C)
  - Electrode-supported (~ 700 °C)
  - Metal supported (< 700 °C)

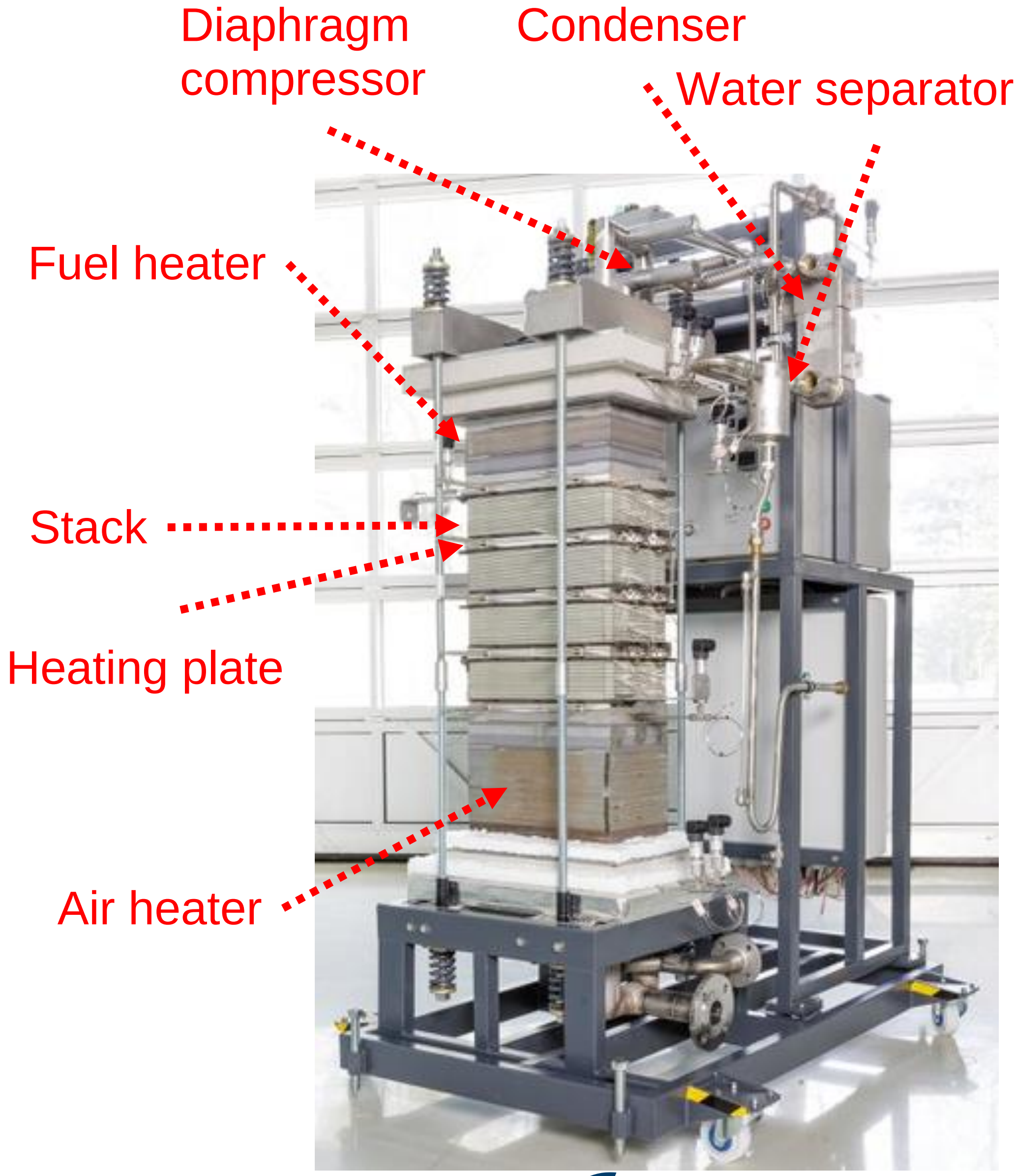
SOLID OXIDE CELLS – MATERIAL SELECTION



- Air electrode: LSCF: $La_{1-x}Sr_xCo_{1-y}Fe_yO_{3-\delta}$ (**LSCF**) or $La_{1-x}Sr_xCoO_{3-\delta}$ (**LSC**)
- Diffusion barrier layer: $Gd_{0.2}Ce_{0.8}O_{1.9}$ or $Gd_{0.1}Ce_{0.9}O_{1.95}$ (**GDC20 / GDC10**)
- Electrolyte: $(Y_2O_3)_{0.08}(ZrO_2)_{0.92}$ or $Y_{0.148}Zr_{0.852}O_{1.926}$ (**YSZ**)
- Fuel electrode / support: Ni / YSZ cermet

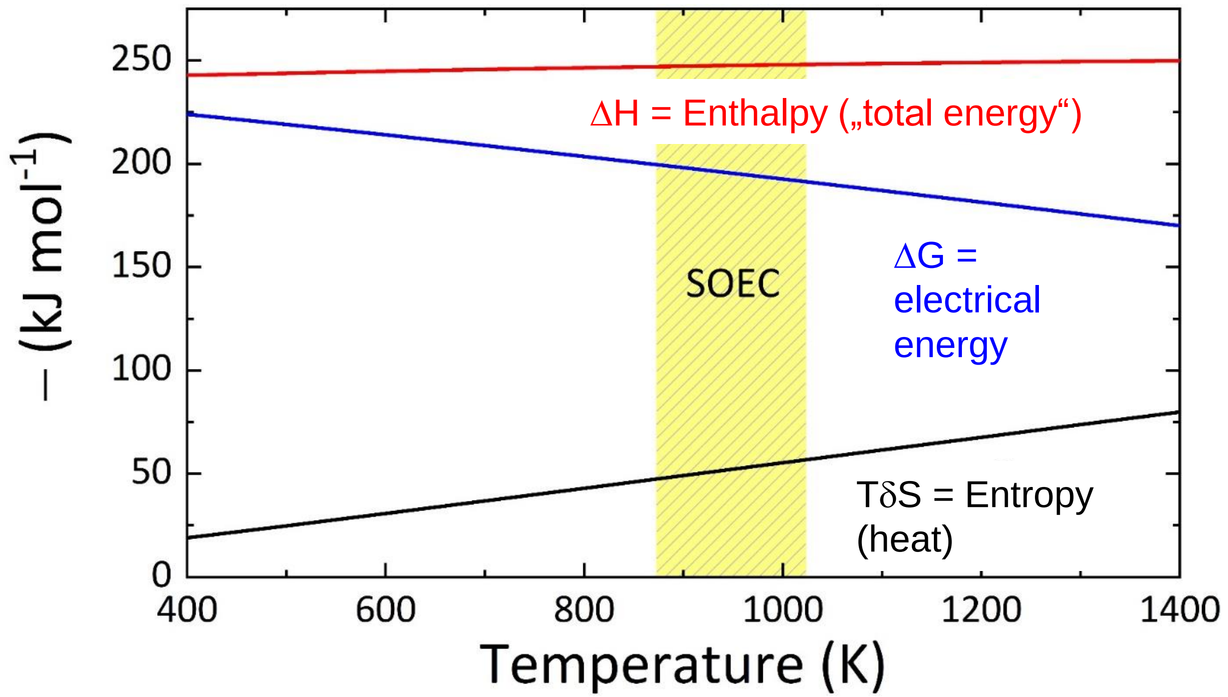
CELL – STACK – SYSTEM





HIGH TEMPERATURE – PRO AND CON

Thermodynamics



Electricity demand decreases with increasing temperature!

Pro

- High efficiency possible
- Integration with high-temperature processes is beneficial
- Fuel flexibility: hydrogen, carbohydrates, CO
- (relatively) High tolerance against impurities
- Reversible operation – SOFC and SOEC in one system!

Con

- Operation conditions are demanding for materials (corrosion!)
- Long start-up times -> stationary operation
- High cost & low availability
- Difficult scaling (fragile cells)

OVERVIEW

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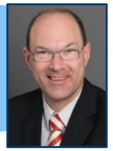
Solid Oxide Cells @ Juelich

IEK-1
Materials Synthesis and Processing

Ceramics, cells, functional layers

Head: Prof. Dr. Olivier Guillon
SOCs: Prof. Dr. Norbert H. Menzler



IEK-13
Theory and Computation of Energy Materials

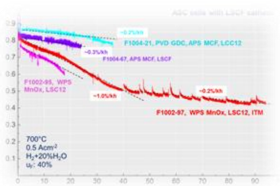
Materials modelling

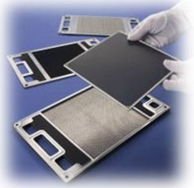
Head: Prof. Dr. Michael Eikerling
SOCs: Dr. Thomas Kadyk

IEK-2
Microstructure and Properties

Metals, kinetics, thermodynamics

Head: Prof. Dr. Ruth Schwaiger
SOCs: Dr. Dmitry Naumenko





IEK-9
Fundamental Electrochemistry

Development, charact. & opt. of cells, stacks & systems

Head: Prof. Dr. Rüdiger A. Eichel
SOCs: Dr. L.G.J. (Bert) de Haart
Dr. Felix Kunz

ZEA-1
Engineering and Technology

Stack assembly, sealing/welding

Head: Prof. Dr. Ghaleb Natour
SOCs: DI Nikolaos Margaritis

Solid Oxide Cells @ IEK-1

People

Division head

Team leaders

Secretary

Scientists

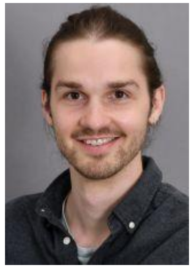




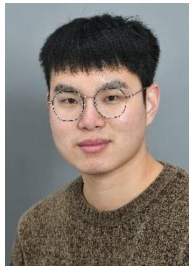
Technicians

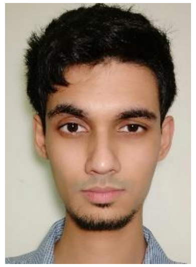


PhD students

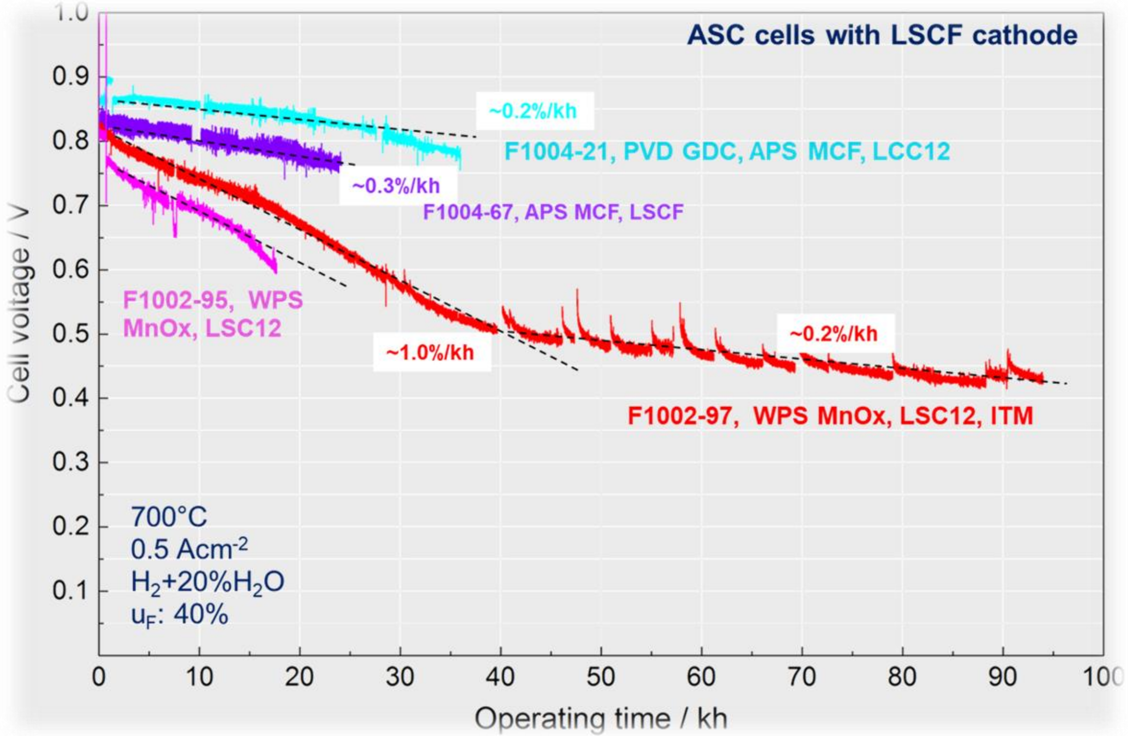



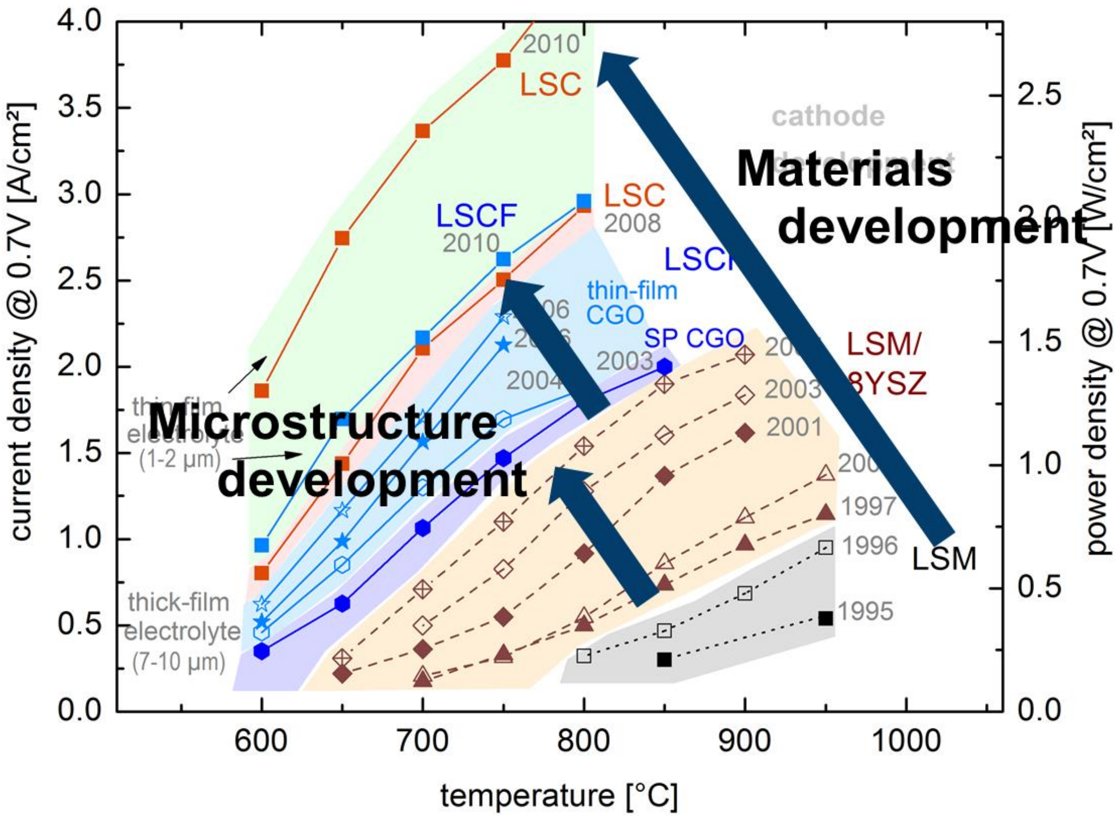






HIGHLIGHTS: SOC IN JÜLICH



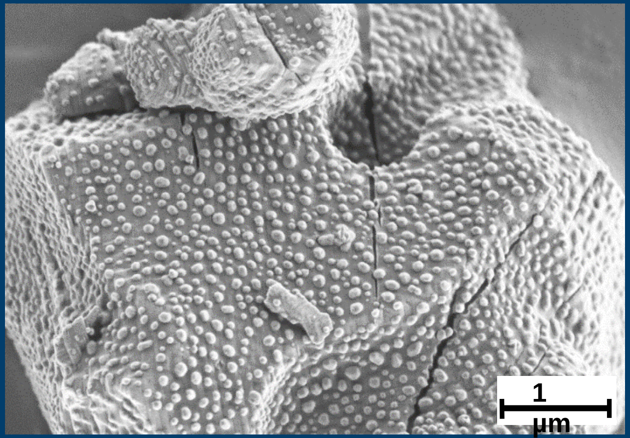


- Long-term testing of short stacks
- World-record in longest runtime of any fuel cell (> 11 years; 93 kh)

- Cell development since ~ 1995
- Increased power density > 10-fold through optimization of materials and microstructures

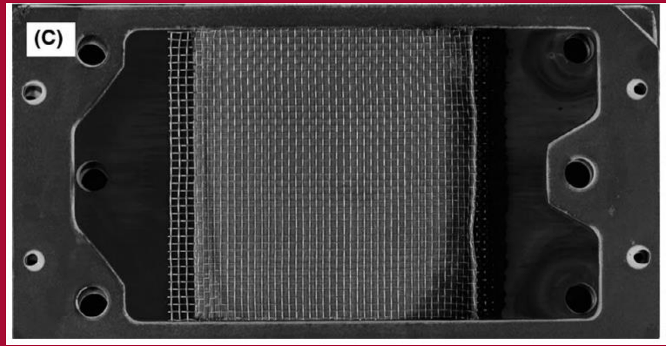
JÜLICH Forschungszentrum

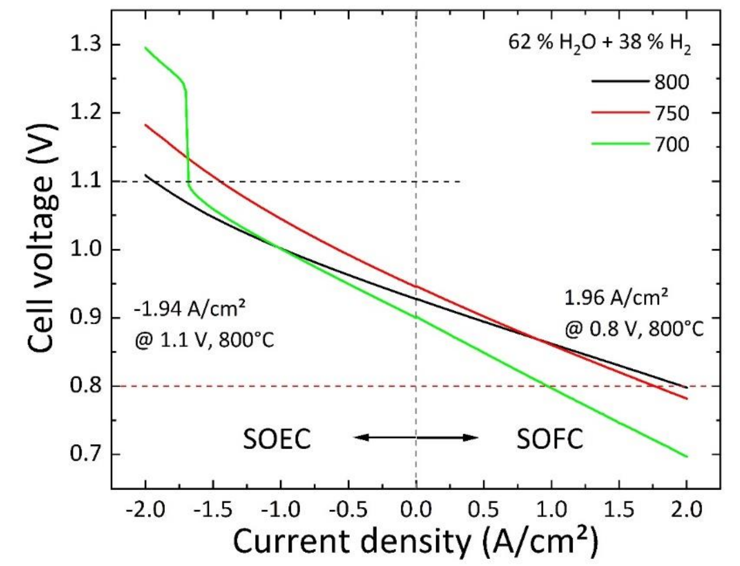
OXIDE-ION CONDUCTING CELLS



Materials & Microstructures

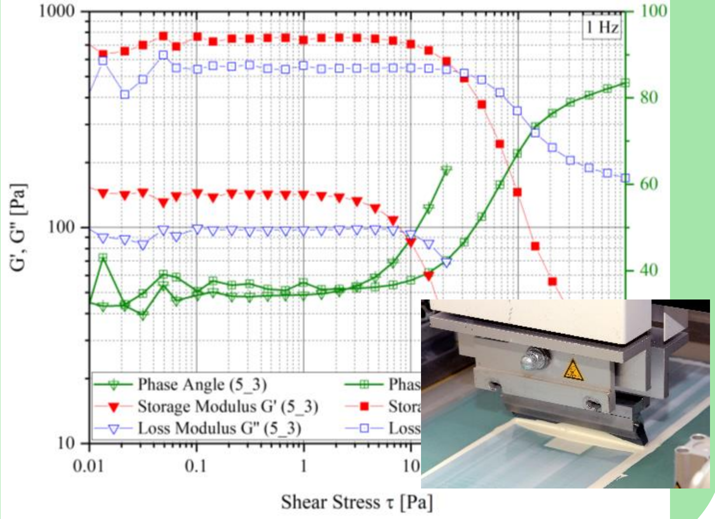
- Oxide-ion conducting materials for electrode and electrolytes
- Processing into layered ceramic systems
- Material interactions
- Testing and characterization



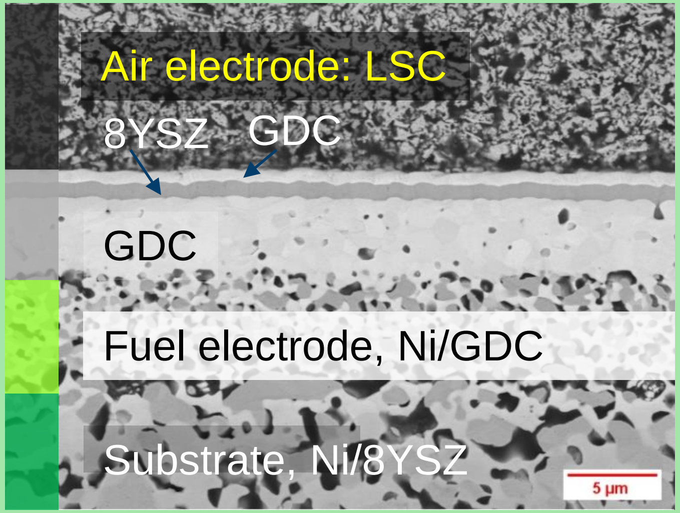


Testing and application, e.g.
- Electrolysis
- Syngas

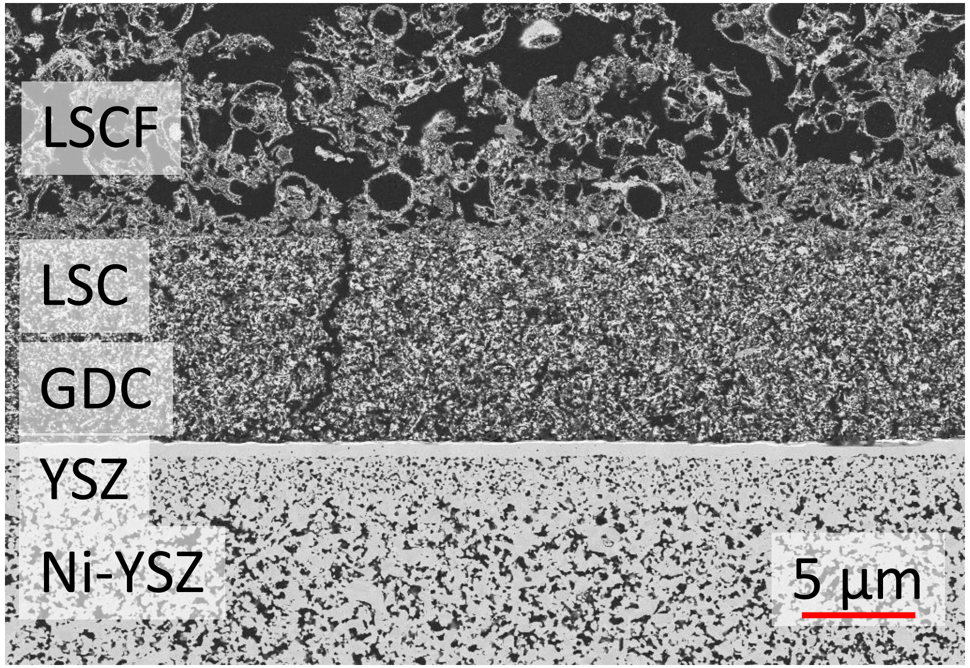
Processing

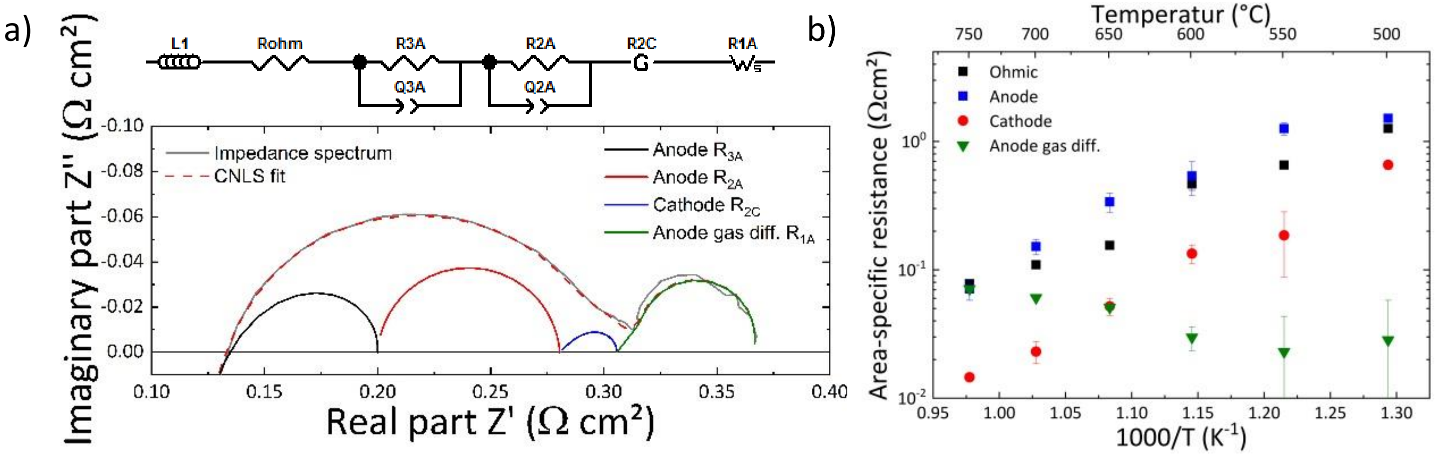


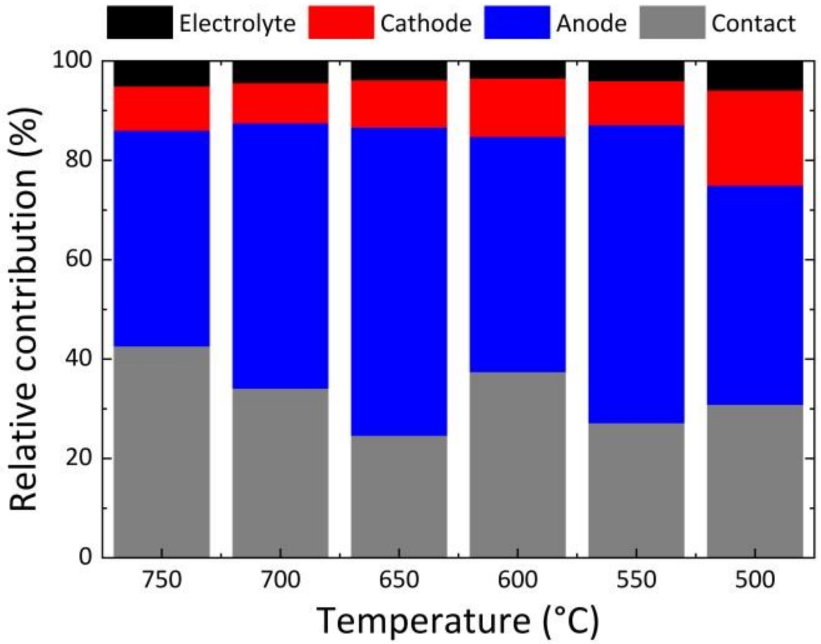
Cell architecture



HIGH-PERFORMANCE SOFC







YSZ electrolyte (2 µm via sol-gel)
GDC barrier (0.5 µm via PVD)

- Best cells from Jülich at the time (2020)

C. Lenser et al., Journal of Power Sources, 474 (2020) 228671

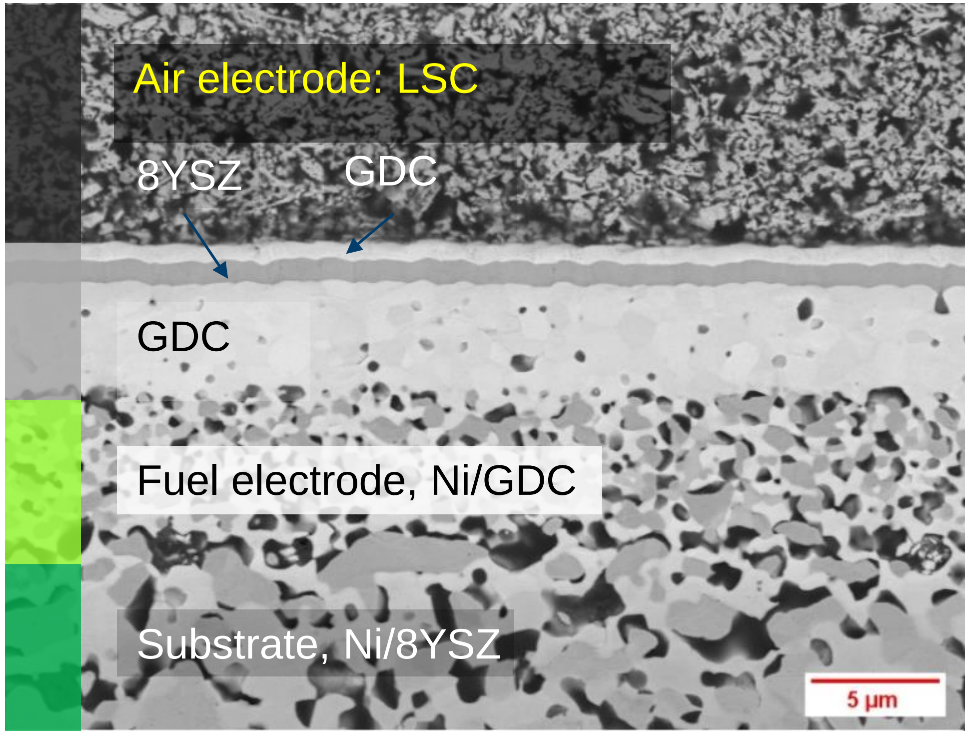
Performance @0.5 A/cm², 700 °C

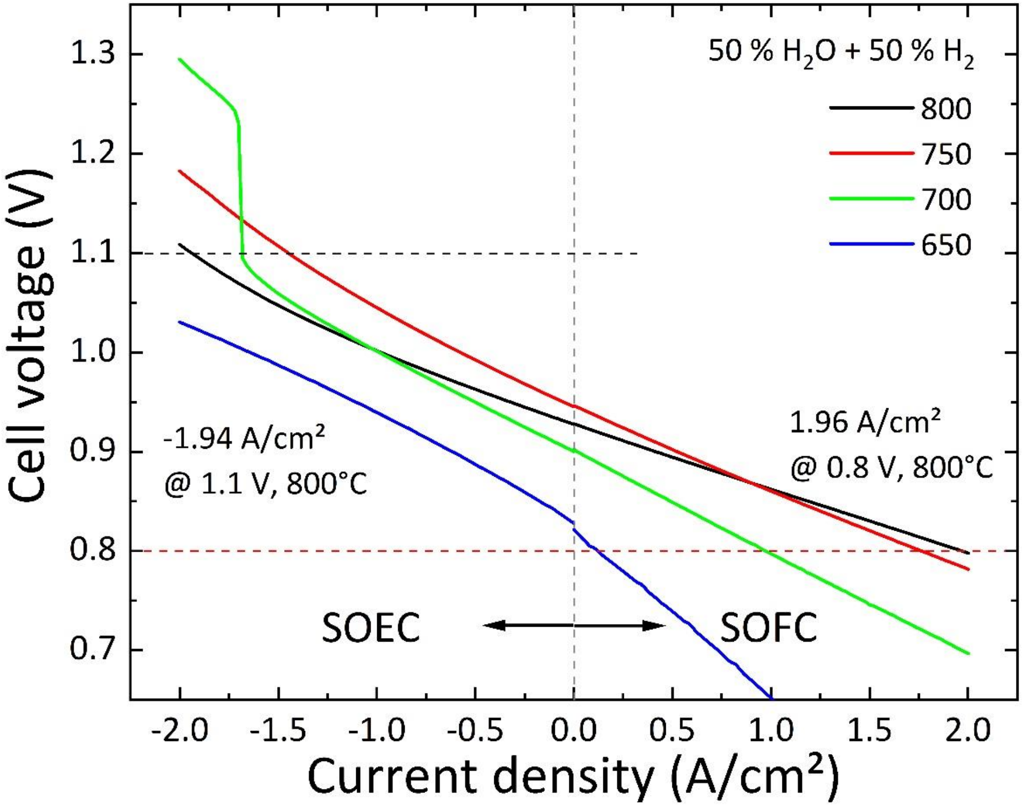
Cell test: 928 mV

Stack test: 876 mV

Limited by contact resistance in stack!

HIGH-PERFORMANCE SOEC





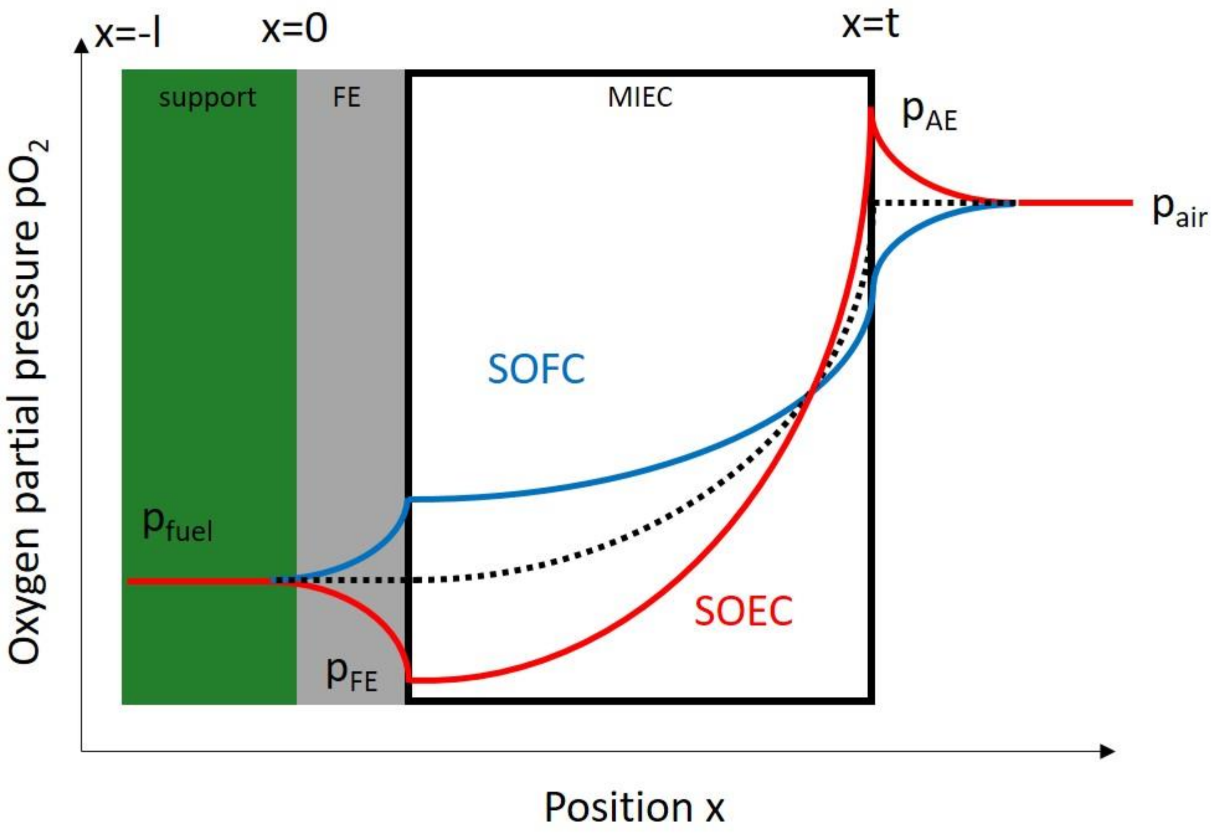
- Ni-GDC fuel electrode requires GDC electrolyte
- YSZ electron blocking layer necessary
- ➢ Three layer electrolyte

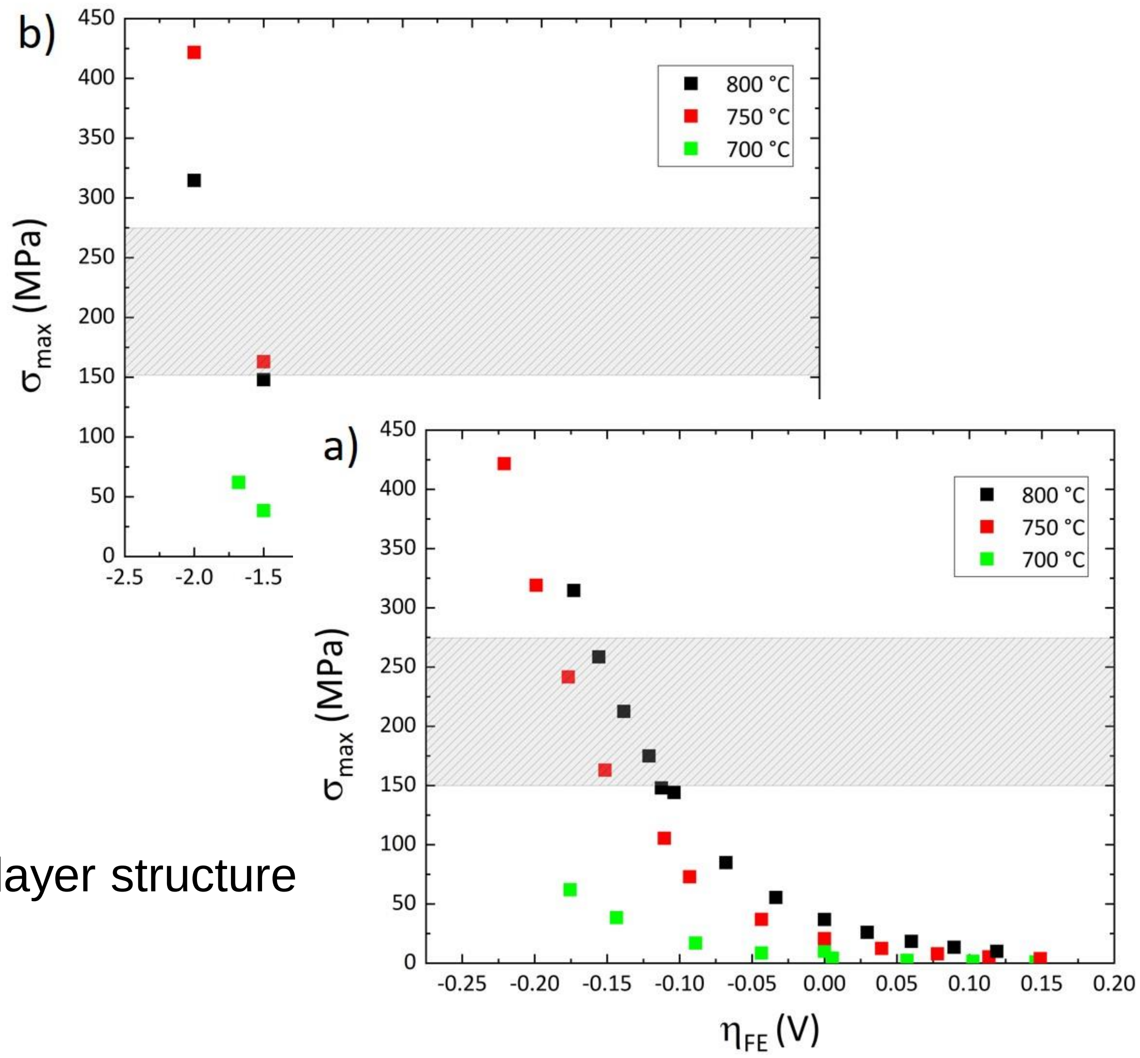
- Very high performance
- Cell failure at high electrolysis current at intermediate temperature

- ➢ Best cells from Jülich at the time (2023)

J. Zhang et al., Journal of the American Ceramic Society, 106 (2022) 93-99.

ELECTRO-CHEMO-MECHANICAL ANALYSIS





- 1-D model of electro-chemo-mechanical stresses in multilayer structure
- Failure point determined by fuel-electrode overpotential
- Optimization of microstructure is key!

C. Lenser et al., Journal of Power Sources, 541 (2022) 231505.

THANK YOU FOR YOUR ATTENTION

CHRISTIAN LENSER