Hy-SPIRE/PROMETEO webinar

Compact SOC stack design for low temperature electrolysis application

Stefan Diethelm, Dario Montinaro (SOLYDERA)

Dante Fronterotta, Hangyu Yu, Cédric Frantz, Jan Van herle (EPFL)

25 years of Solid Oxide technology development and manufacturing

2000
HTCeramix founded

2006
SOFCpower founded, Acquisition HTceramix

2015
Acquisition Ceramic Fuel Cells

2017
Development of the 1.7kW G8 SOFC stack

2020
Start of stack industrial plant in Pergine (ITA)

2022
New name and company strategy for the H2 economy

2024
Industrialization of larger G8X stack up to 10kW in SOFC

Research and Innovation Centers

Mezzolombardo
ITALY

Yverdon-les-Bains
SWITZERLAND

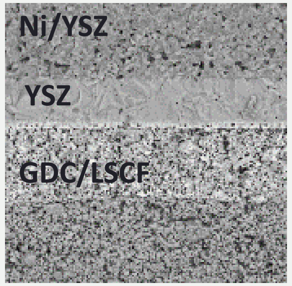
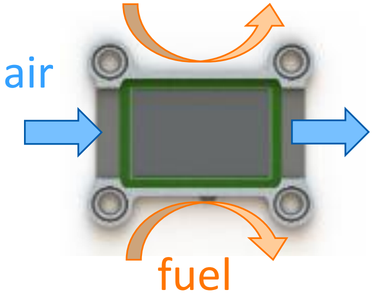
Melbourne
AUSTRALIA

25/75 MW/year Industrial plant

Pergine Valsugana, **ITALY**

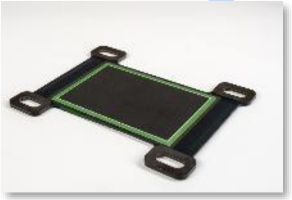
Head Quarter
Industrial Cell & Stack Production

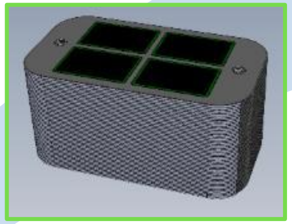
Proven stack technology

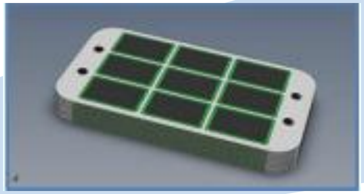
TECHNOLOGY		• **planar anode supported cells with a very thin electrolyte, allows operation in a wide temperature range (650-800°C)** • **Proprietary sealing material for tightness & robustness** • **Optimized interconnect coatings for extended lifetime**
STACK DESIGN		• Proprietary **parallel flow design** for optimal temperature distribution, maximum stack lifetime and robustness • Interconnect produced by standard automotive manufacturing process • Uniform and stable interconnect geometry for **high Fuel Utilization and Steam Conversion**
TRACK RECORDS		• Proven operation in SOFC, SOE, co-electrolysis and reversible mode • Stack efficiency up to **75%** in SOFC (2015) and **97%** in steam electrolysis (2020) • Average less than **0.2%** efficiency drop per 1’000 h in the field • Scale up stack power up to **10 kW** in a single tower (**30 kW** in SOE)

Current scale-up approach for high performance & low risk

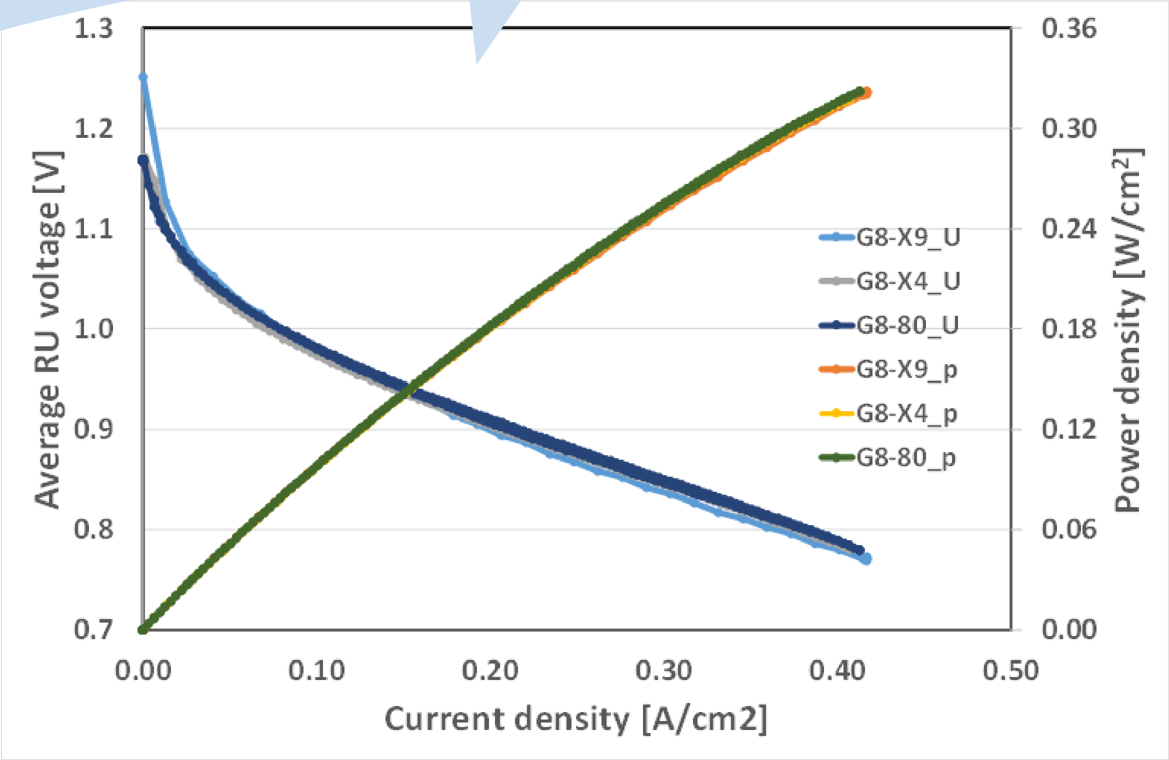
- ✓ Same cells
- ✓ Same sealing & contact solutions
- ✓ Interconnect scale-up based on same design & manufacturing process







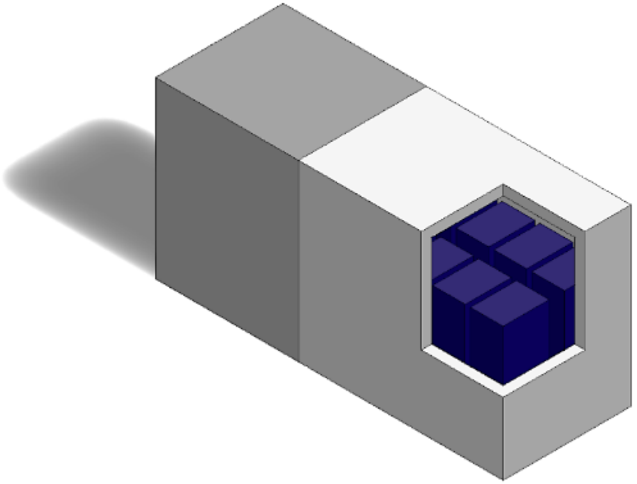
...

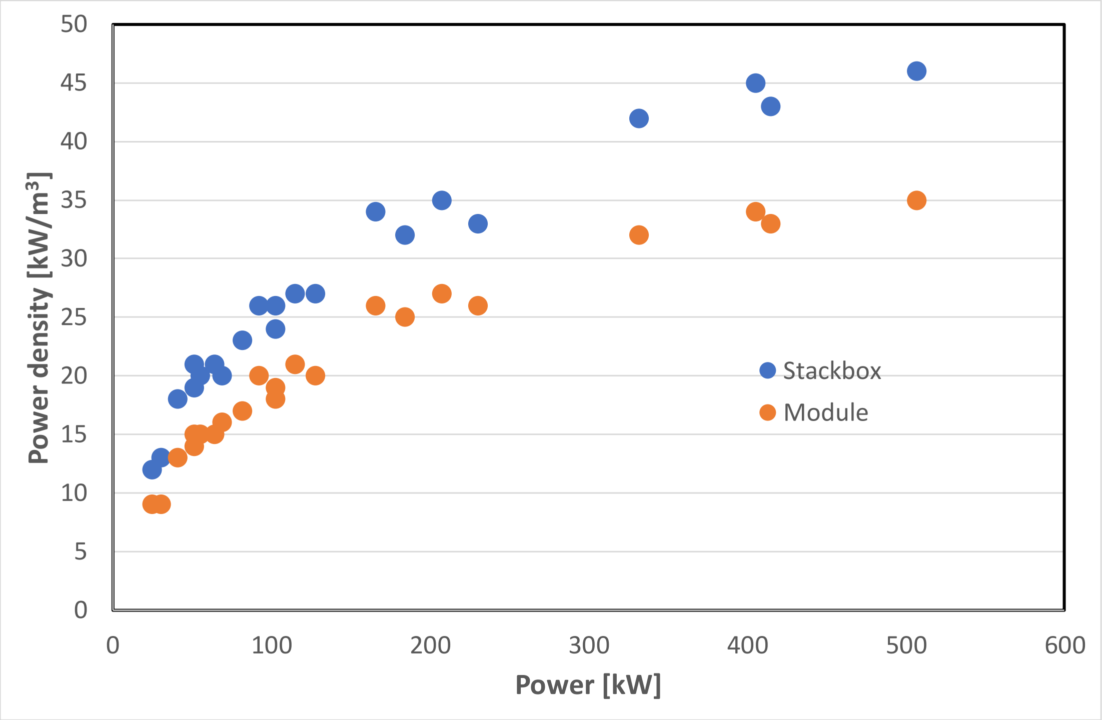


Increase in power density

G8: 1.7/4.5 kW
70 RE, 80 cm²/RE
124 W/L

G8X: 10/30kW
100 RE, 320 cm²/RE
171W/L +38%





Hy-SPIRE project:

integration of metal- and electrode-supported SOE cells for operation at 550-700 °C

Specific objectives:

- increasing stack compactness to allow rapid start-up and cycling (e.g. hot idle ramp in minutes)
- integrate metal supported cells
- corrosion testing of metal components (substrates and interconnects)
- lower temperature operation

Work tasks

Single cell performance of H-SOEL and O-SOEL + **Short stack** performance of H-SOEL and O-SOEL → **CFD model** calibration → **Stack design** refinement for H-SOEL and O-SOEL

Electrode optimization

Techno-economic analysis + Life cycle assessment

HySPIRE SRU model

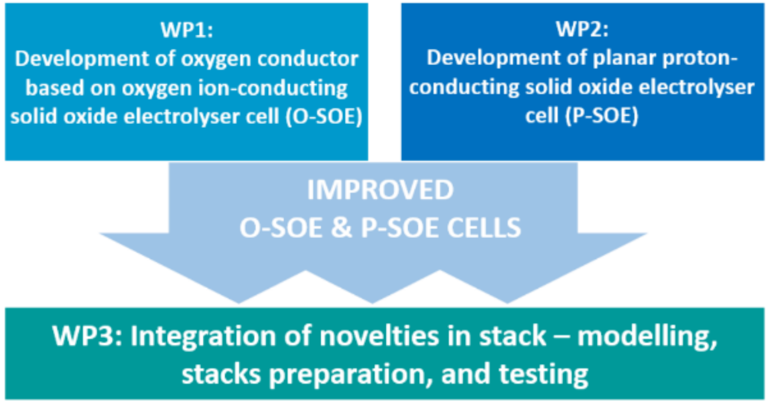
Develop a **3D model** of a **Stack Repeating Unit (SRU)** with **dynamics capabilities**

- Fuel electrode/Metal-supported O-SOE
- Fuel electrode/Metal-supported P-SOE

The **SRU** is **centrally positioned unit** in the stack, exposed to the **highest thermal gradients** and **near-adiabatic conditions.**

Optimization targets:

- Thermal behaviour study
- Transients
- Stack compactness (15% reduction target)
- Load and thermal cycling
- Limit temperature to 700 °C



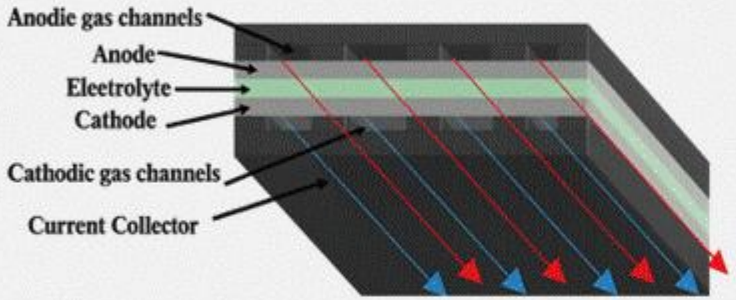
SOE geometry and meshing

- Model development geometries:
  1. Simplified 3D planar
  2. Reduced simplified 3D
  3. 2D Planar
  4. Final 3D (SolydEra G8)

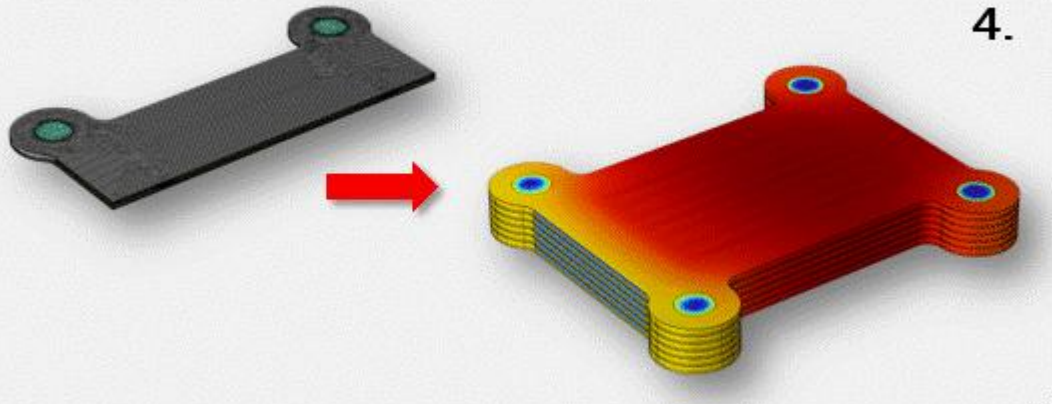
- Co-flow

- tetrahedral mesh for higher accuracy and enhanced edge and corner resolution

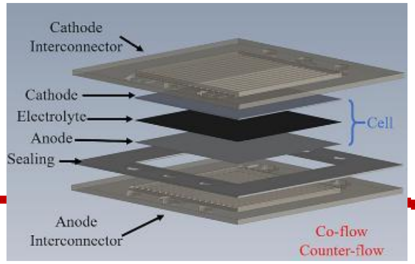
1-2.



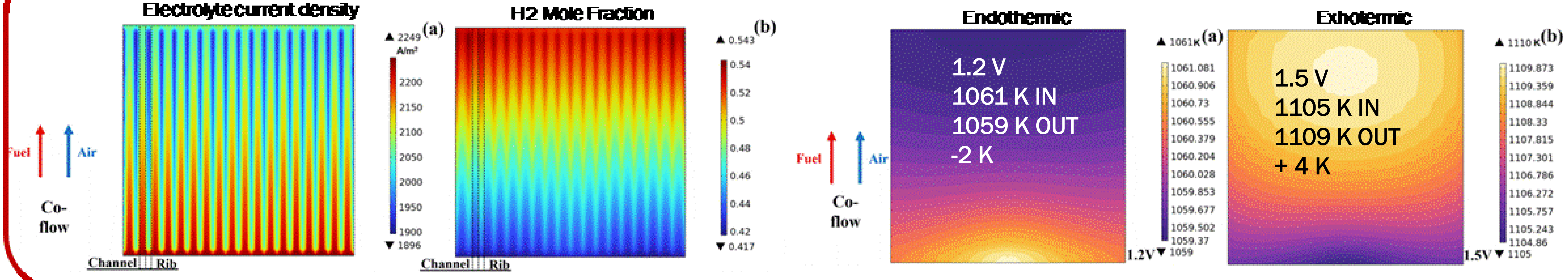
4.



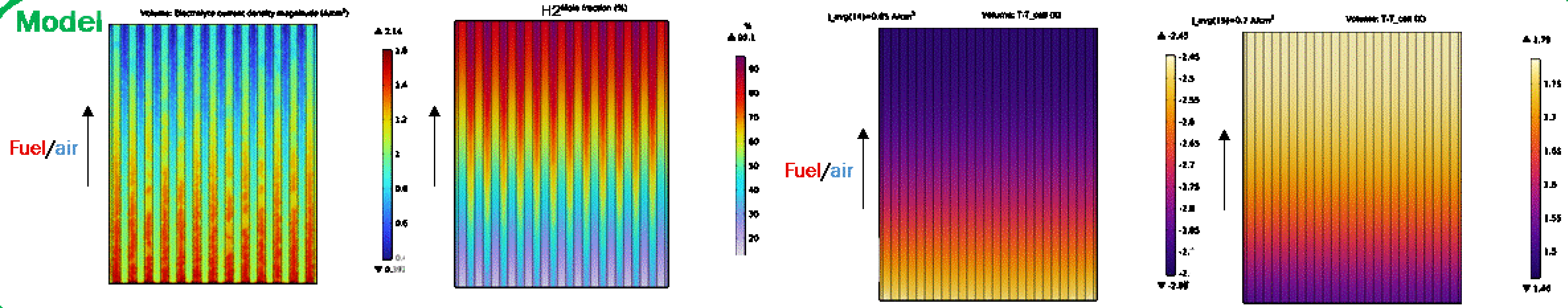
Model qualitative validation



Literature



Model



[1] Liu, C., Dang, Z., & Xi, G. (2023). Numerical study on thermal stress of solid oxide electrolyzer cell with various flow configurations. Applied Energy, 349, 122041.
https://doi.org/10.1016/j.apenergy.2023.122041

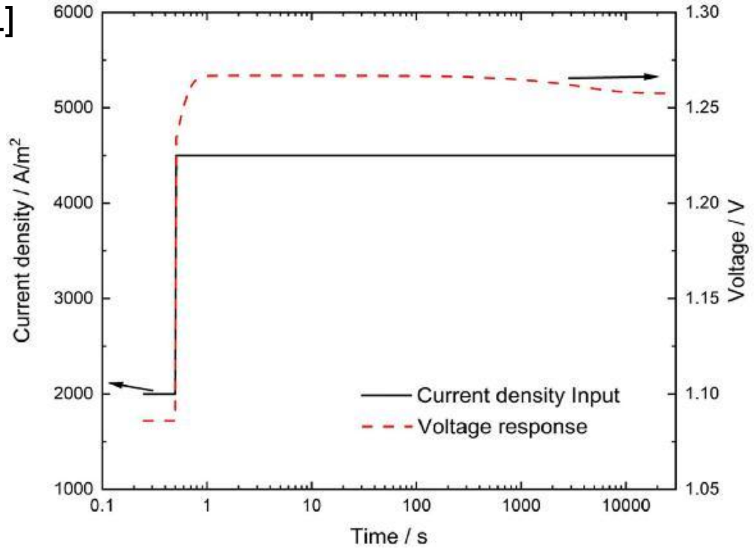
SOE qualitative validation

- current step – galvanostatic
- input T 800 °C
- SolydEra geometry

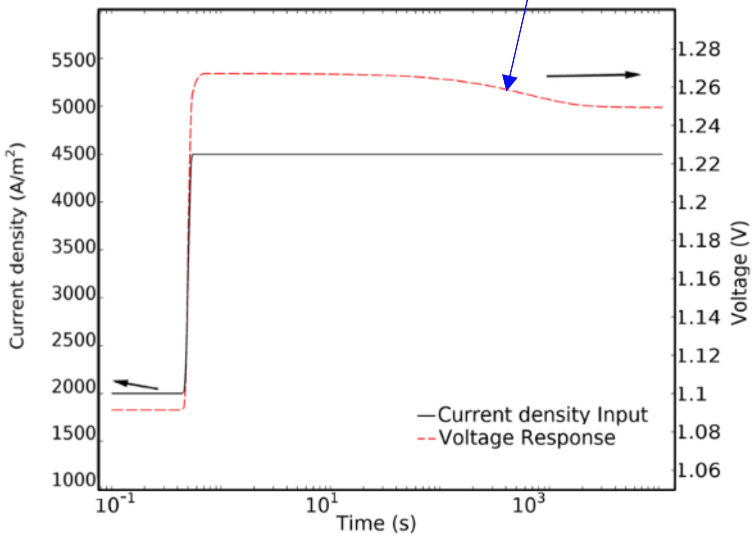
$0.2 \rightarrow 0.4\ A/cm^2$ step
⇒ voltage step from 1.1 V to 1.27 V
⇒ heating
⇒ voltage drops after 2 min and stabilizes in 30'

Literature

[1]



Our model



[1] Tiancheng Cui et al. "Transient thermomechanical response of an electrolyte supported planar solid oxide electrolysis cell under dynamic loading conditions". In:Energy and AI 21 (Sept. 1, 2025), url: https://www.sciencedirect.com/science/article/pii/S2666546825001223

Model calibration

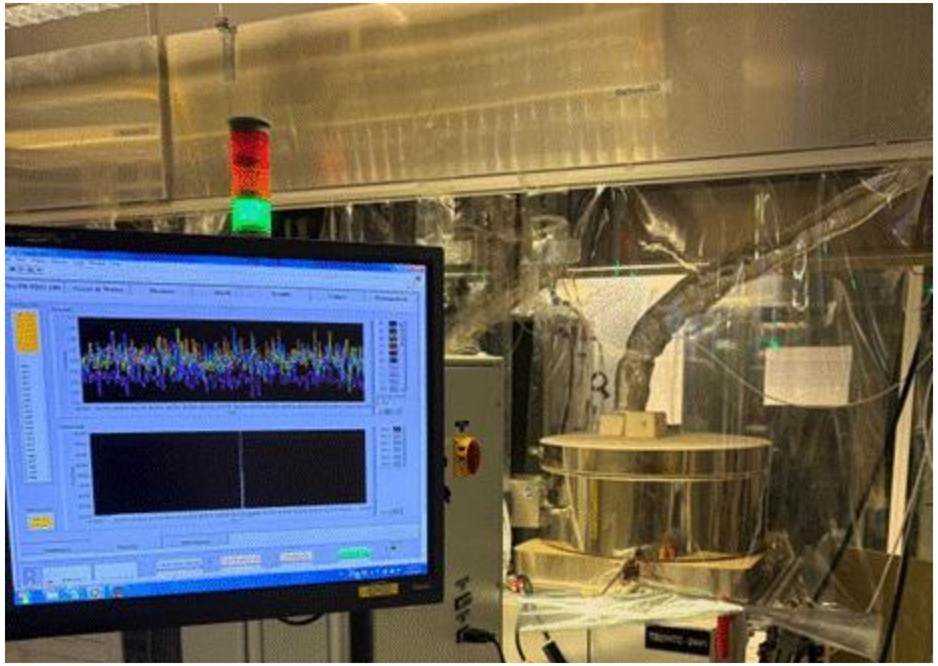
Calibration using experimental data measured on short-stacks (6 RE)

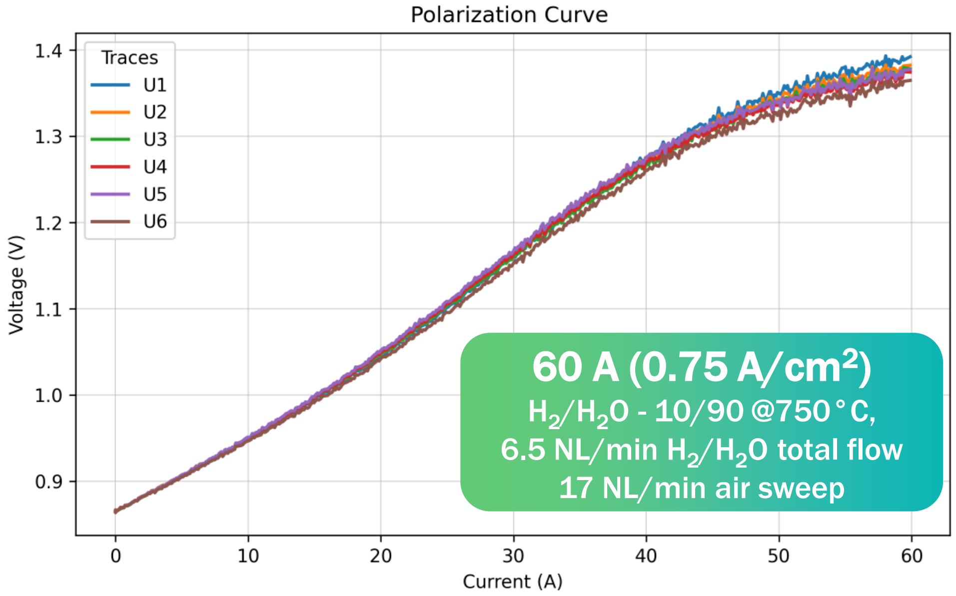
Stationary test protocol (28 experiments)

- Stack temperature
- Fuel flow, composition
- Air flow and composition
- Max. polarisation current
- iV, EIS

Dynamic test protocol (18 experiments)

- Dynamic response following variation of
- Fuel flow, composition
- Air flow and composition





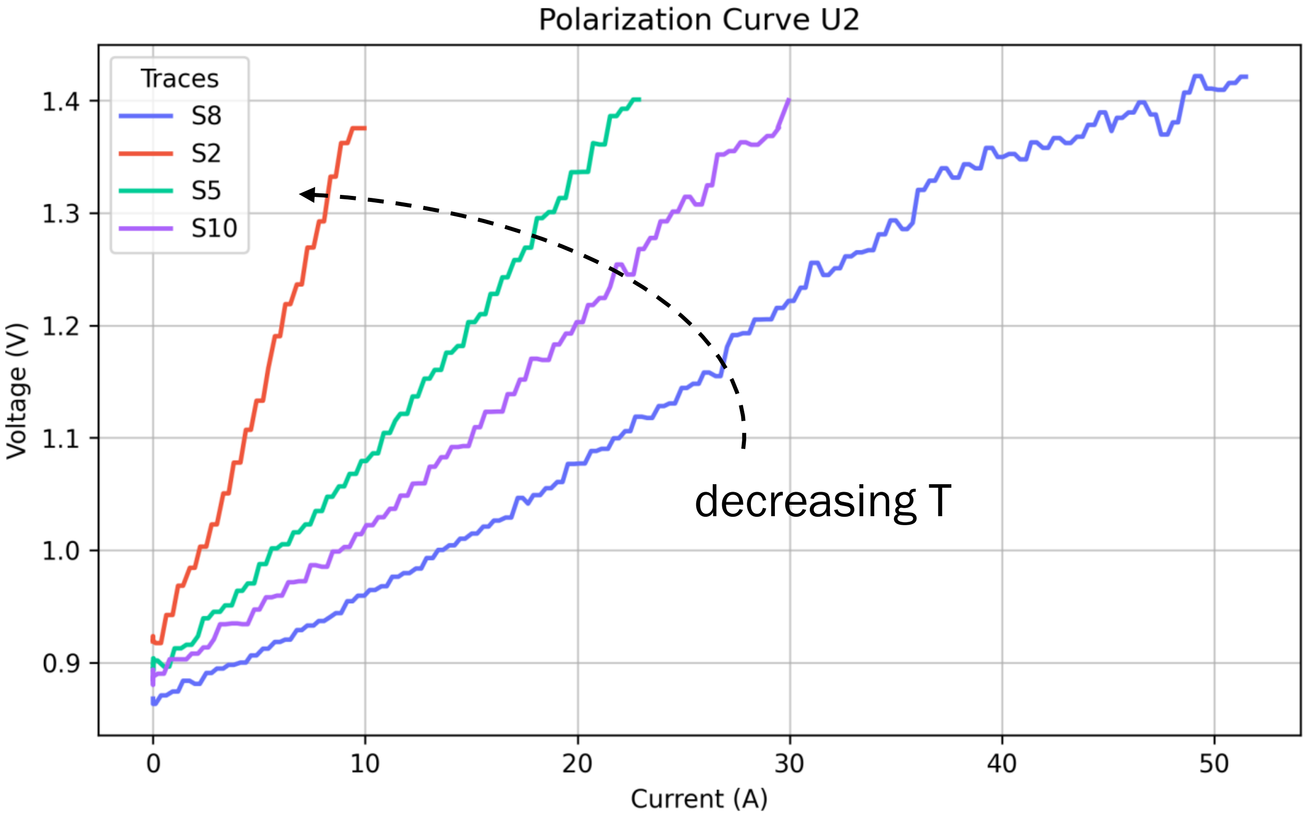
Experimental plan - Stationary protocol

SolydEra SS 6RU SOEC Stationary Experimental Plan f = fuel side a = air side	R.	T [°C]	Fuel side m_{H2O} [g/min]	$V_{H2,f}$ [NL/min]	$V_{N2,f}$ [NL/min]	Air Side V_{N2+} [NL/min]	V_{air} [NL/min]	Mole fractions $x_{H2O,f}$	$x_{H2,f}$	$x_{N2,f}$	$x_{O2,a}$	$x_{N2,a}$	Other flow rates $V_{H2O,f}$ [NL/min]	$V_{O2,a}$ [NL/min]	$V_{N2,a}$ [NL/min]	V_f [NL/min]	Current limit $I_{90\%SUF}$ [A]	$I_{100\%SUF}$ [A]	Tests verification iV	$EIS_{0\%}$	$EIS_{25\%}$	$EIS_{50\%}$	$EIS_{75\%}$	$EIS_{100\%}$
	Ch.SOFC	750	0.000	1.728	1.152	0	32	0	0.4	0.6	0.21	0.79	0	6.720	25.3	2.9	37.8	42.0	Full	X				
	Ch.SOE	750	2.696	0.40	0	0	17	0.9	0.1	0	0.21	0.79	3.6	3.57	13.43	4	72.2	80.2	Full	X				
3^3 design (Activation energies, pre-exponential factors, anodic/cathodic charge transfer coefficients)	S1	615	2.546	0.60	0	0	17	0.85	0.15	0	0.21	0.79	3.4	3.57	13.43	4	68.2	75.8	Full	X		X		X
	S2	615	2.696	0.40	0	0	17	0.9	0.1	0	0.21	0.79	3.6	3.57	13.43	4	72.2	80.2	Full	X	X	X	X	X
	S3	615	2.846	0.20	0	0	17	0.95	0.05	0	0.21	0.79	3.8	3.57	13.43	4	76.2	84.7	Full	X		X		X
	S4	675	2.546	0.60	0	0	17	0.85	0.15	0	0.21	0.79	3.4	3.57	13.43	4	68.2	75.8	Full	X		X		X
	S5	675	2.696	0.40	0	0	17	0.9	0.1	0	0.21	0.79	3.6	3.57	13.43	4	72.2	80.2	Full	X	X	X	X	X
	S6	675	2.846	0.20	0	0	17	0.95	0.05	0	0.21	0.79	3.8	3.57	13.43	4	76.2	84.7	Full	X		X		X
	S7	750	2.546	0.60	0	0	17	0.85	0.15	0	0.21	0.79	3.4	3.57	13.43	4	68.2	75.8	Full	X		X		X
	S8 (n)	750	2.696	0.40	0	0	17	0.9	0.1	0	0.21	0.79	3.6	3.57	13.43	4	72.2	80.2	Full	X	X	X	X	X
	S9	750	2.846	0.20	0	0	17	0.95	0.05	0	0.21	0.79	3.8	3.57	13.43	4	76.2	84.7	Full	X		X		X
Extra	S10	700	2.696	0.40	0	0	17	0.9	0.1	0	0.21	0.79	3.6	3.57	13.43	4	72.2	80.2	OCV	X	X	X	X	X
a,b,m coefficients	S11	750	2.097	1.0	0.20	0	17	0.7	0.25	0.05	0.21	0.79	2.8	3.57	13.43	4	56.2	62.4	OCV	X				
	S12	750	2.097	0.80	0.40	0	17	0.7	0.2	0.1	0.21	0.79	2.8	3.57	13.43	4	56.2	62.4	OCV	X				
	S13	750	2.097	0.40	0.80	0	17	0.7	0.1	0.2	0.21	0.79	2.8	3.57	13.43	4	56.2	62.4	OCV	X				
	S14	750	2.097	0.20	1.00	0	17	0.7	0.05	0.25	0.21	0.79	2.8	3.57	13.43	4	56.2	62.4	OCV	X				
	S15	750	1.872	0.40	1.10	0	17	0.6250	0.1	0.275	0.21	0.79	2.5	3.57	13.43	4	50.1	55.7	OCV	X				
	S16	750	1.723	0.40	1.30	0	17	0.5750	0.1	0.325	0.21	0.79	2.3	3.57	13.43	4	46.1	51.3	OCV	X				
	S17	750	1.573	0.40	1.50	0	17	0.5250	0.1	0.375	0.21	0.79	2.1	3.57	13.43	4	42.1	46.8	OCV	X				
	S18	750	1.236	0.40	1.95	0	17	0.4125	0.1	0.4875	0.21	0.79	1.65	3.57	13.43	4	33.1	36.8	OCV	X				
	S19	750	2.696	0.40	0	11.333	5.667	0.9	0.1	0	0.07	0.93	3.6	1.19	4.4767	4	72.2	80.2	OCV	X				
	S20	750	2.696	0.40	0	10.524	6.476	0.9	0.1	0	0.08	0.92	3.6	1.36	5.1162	4	72.2	80.2	OCV	X				
	S21	750	2.696	0.40	0	8.905	8.095	0.9	0.1	0	0.1	0.9	3.6	1.70	6.3952	4	72.2	80.2	OCV	X				
	S22	750	2.696	0.40	0	4.857	12.143	0.9	0.1	0	0.15	0.85	3.6	2.55	9.5929	4	72.2	80.2	OCV	X				
Diffusion Limitations	S23	750	2.696	0.40	0	0	10.000	0.9	0.1	0	0.21	0.79	3.6	2.10	7.9000	4	72.2	80.2	Full	X		X		X
	S24	750	2.696	0.40	0	0	35.000	0.9	0.1	0	0.21	0.79	3.6	7.35	27.6500	4	72.2	80.2	Full	X		X		X
	S25	750	1.048	0.1556	0	0	17.0	0.9	0.1	0	0.21	0.79	1.4	3.57	13.43	1.5556	28.1	31.2	Full	X		X		X
	S26	750	3.600	0.53	0	0	17.0	0.9	0.1	0	0.21	0.79	6	3.57	13.43	6.5340	120.3	133.7	Full	X		X		X

Experimental plan - Dynamic protocol

SolydEra SS 6RU SOEC Dynamic Experimental Plan f = fuel side a = air side		Fuel side			Air Side		Mole fractions					Other flow rates				
R.	T [°C]	m_{H2O} [g/min]	$V_{H2,f}$ [NL/min]	$V_{N2,f}$ [NL/min]	V_{N2+} [NL/min]	V_{air} [NL/min]	$x_{H2O,f}$	$x_{H2,f}$	$x_{N2,f}$	$x_{O2,a}$	$x_{N2,a}$	$V_{H2O,f}$ [NL/min]	$V_{O2,a}$ [NL/min]	$V_{N2,a}$ [NL/min]	V_f [NL/min]	What to do (recording V(t), T(t), I(t))
D1	615	2.696	0.400	0.000	0	17	0.9	0.1	0	0.21	0.79	4	3.570	13.4	4.0	Ramp 615→750°C @ 1 °C/min,
D5	615	2.846	0.20	0	0	17	0.95	0.05	0	0.21	0.79	3.8	3.57	13.43	4	Ramp 615→750→615 °C @ 1 °C/min
D7	615	2.696	0.40	0	0	17	0.9	0.1	0	0.21	0.79	3.6	3.57	13.43	4	Current sweep Steps: 0 → 0.25 → 0.50 → 0.75 → 1.00 A cm^{-2}, each held 6–8 min. For each step level, repeat with 3 rise times: ~0.5 s, ~5 s, ~30 s (controller-limited).
D8	750	2.696	0.40	0	0	17	0.9	0.1	0	0.21	0.79	3.6	3.57	13.43	4	Current sweep Steps: 0 → 0.25 → 0.50 → 0.75 → 1.00 A cm^{-2}, each held 6–8 min. For each step level, repeat with 3 rise times: ~0.5 s, ~5 s, ~30 s (controller-limited).
D9	750	1.048 -> 4.494	0.1556 -> 0.6667	0.000	0	17	0.9	0.1	0	0.21	0.79	1.4-> 6	3.570	13.4	1.6	Fuel-flow/utilization step. Fuel flow rate from Min → Max → Min, holds 10 min
D12	700	2.696	0.40	0	0	17	0.9	0.1	0	0.21	0.79	3.6	3.57	13.43	4	Square wave ±10% of bias current, that from 0.45 A cm^{-2} and 0.55 A cm^{-2} oscillates in a
D13	700	2.696	0.40	0	0	17	0.9	0.1	0	0.21	0.79	3.6	3.57	13.43	4	Fixed operating conditions, short term degradation. Length >24h, max possible.
D14	700	2.696	0.40	0	0	17	0.9	0.1	0	0.21	0.79	3.6	3.57	13.43	4	Ramp air flow rate from Min → Max → Min, holds 10 min
D16	700	2.6961->1.3817	0.4->0.205	0->1.95	0	17	0.9->0.46	0.1->0.05	0->0.4875	0.21	0.79	3.6->1.845	3.570	13.4	4.0	Fuel-flow/utilization step. N2 fuel flow rate from Min → Max → Min, holds 10 min
D17	700	2.696	0.40	0	0->11.3333	17->5.6667	0.9	0.1	0	0.21->0.07	0.79->0.93	3.6	3.57	13.43	4	Air-flow/utilization step. N2 air flow rate from Min → Max → Min, holds 10 min
D18	700	2.696	0.40	0	0	17	0.9	0.1	0	0.21	0.79	3.6	3.57	13.43	4	Ramp 750→700°C @ 0.5 °C/min 12A
D19	615	2.696	0.40	0	0	17	0.9	0.1	0	0.21	0.79	3.6	3.57	13.43	4	Ramp 750→615°C @ 1 °C/min 9A

SOE Experimental – Performance at lower T

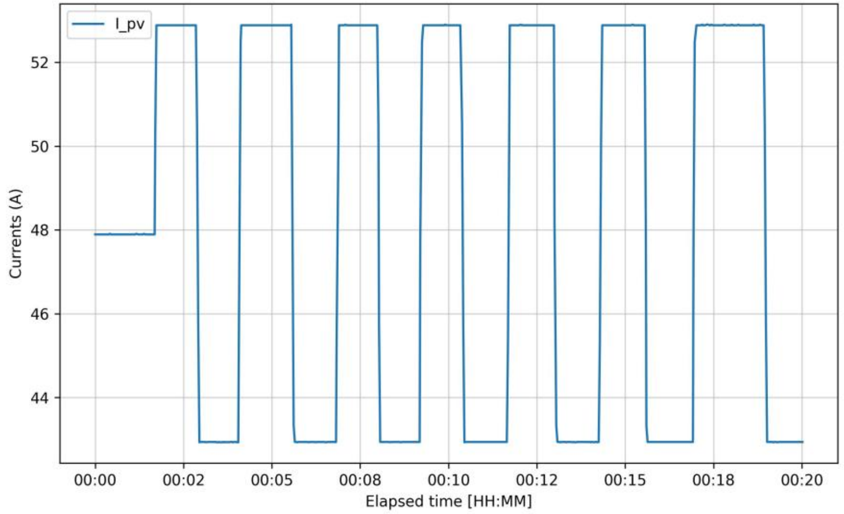


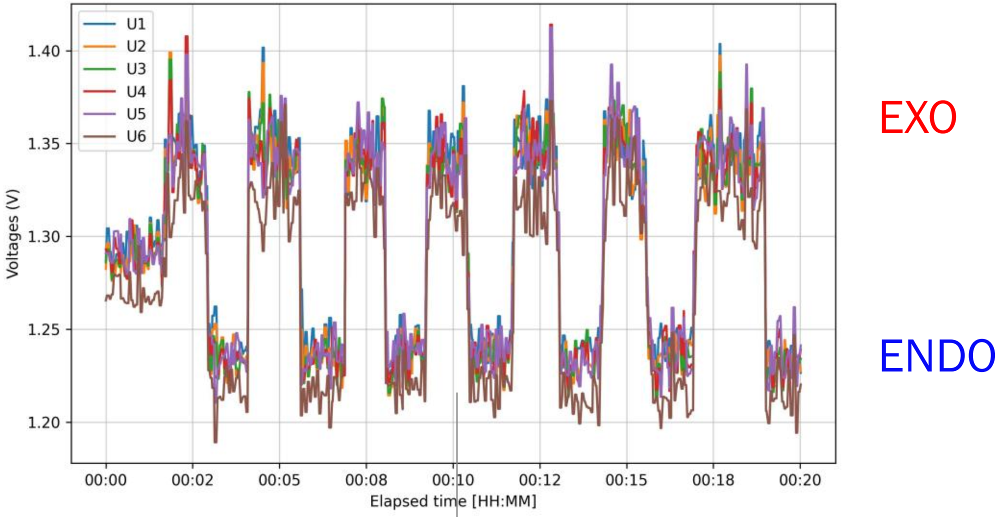
750°C
700°C
675°C
615°C

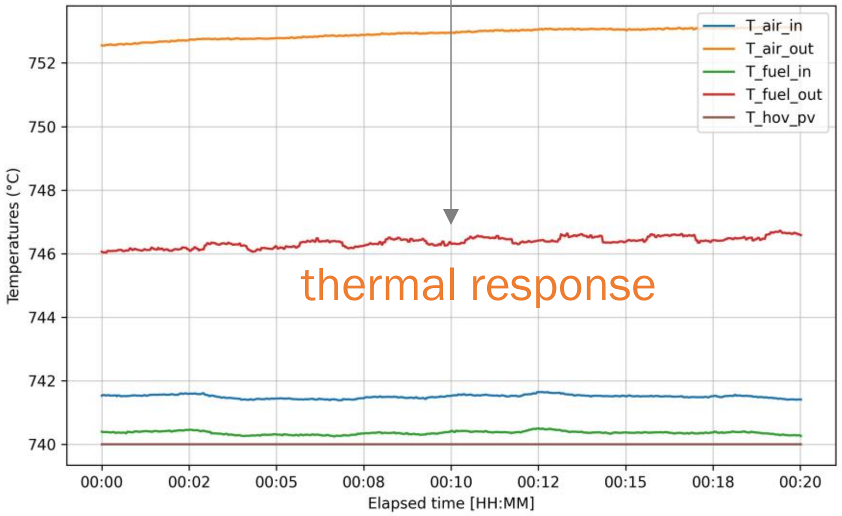
H_2/H_2O 10/90 4 NL/min H_2/H_2O total flow
17 NL/min air sweep
8 A/min ramp

SOE Experimental – Dynamic example

@750°
H_2/H_2O 10/904 NL/min H_2/H_2O total flow
17 NL/min air sweep



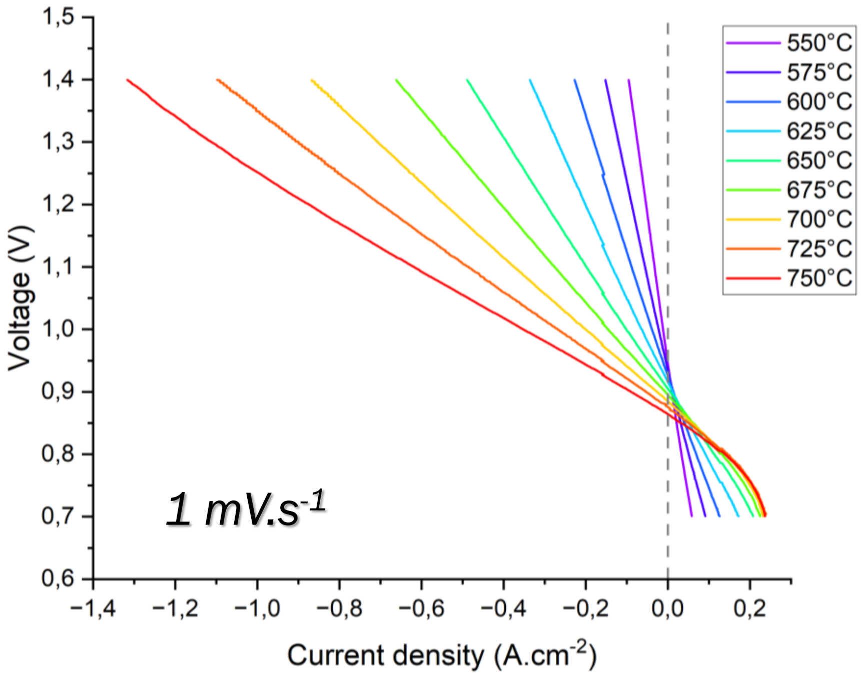




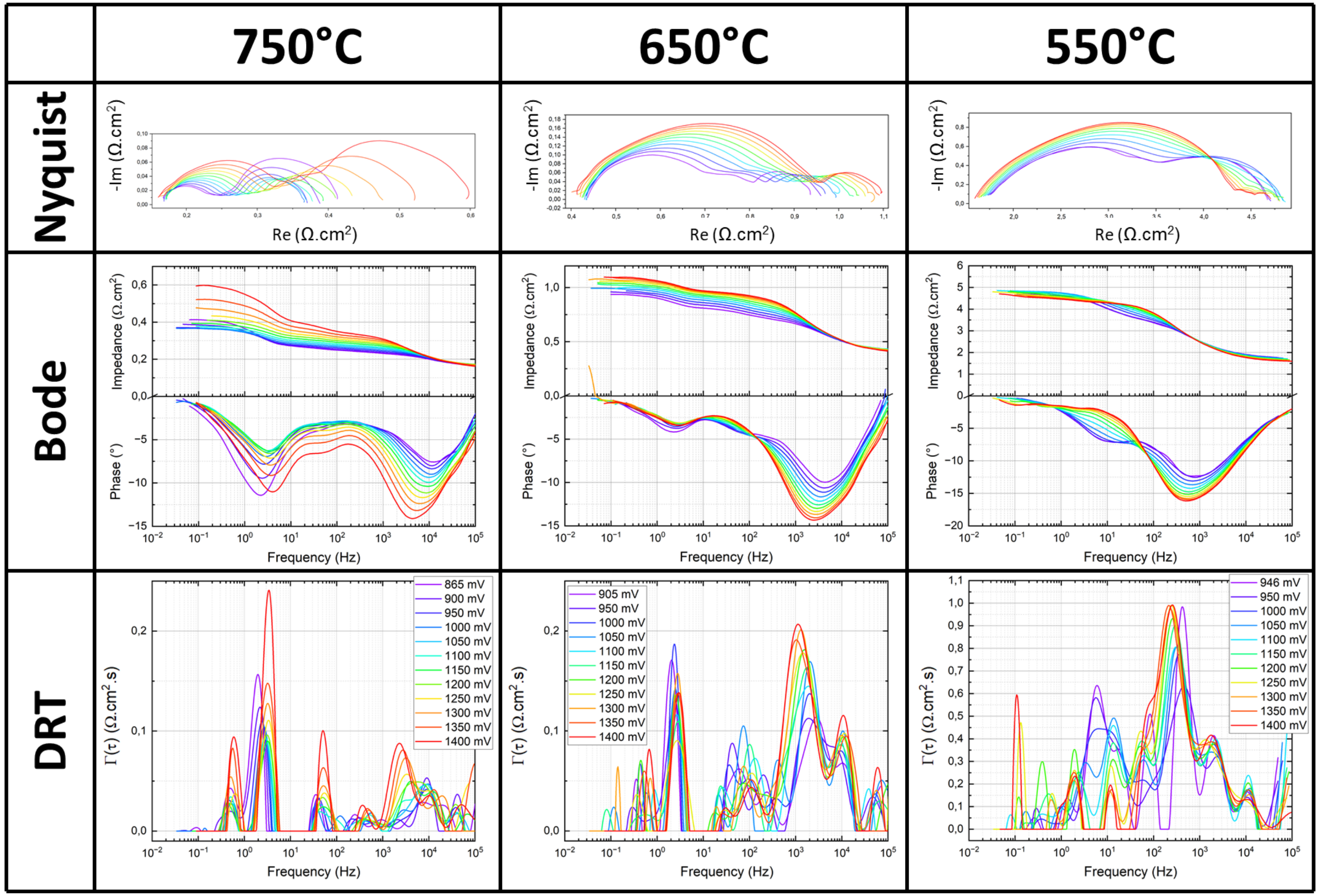
Square-wave current profile starting from thermoneutral conditions (48 A), with ±5 A modulation to reach exothermal (53 A) and endothermal (43 A) regimes.

O-SOEL (cell) performance at different T

- Total fuel flow: 15.9 sccm.cm^{-2}
- H_2:H_2O = 1:9
- Air flow: 39.8 sccm.cm^{-2}



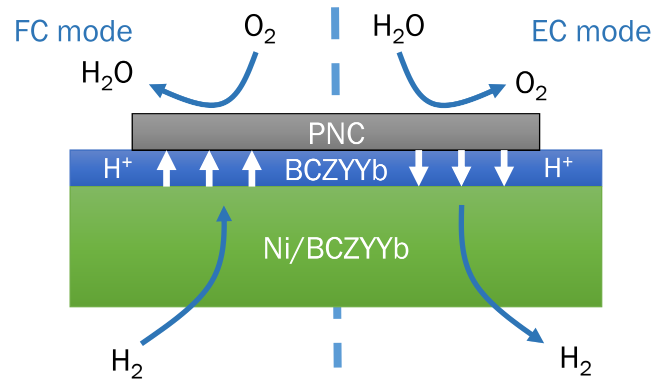
10 mV amplitude and 21 steps/decade

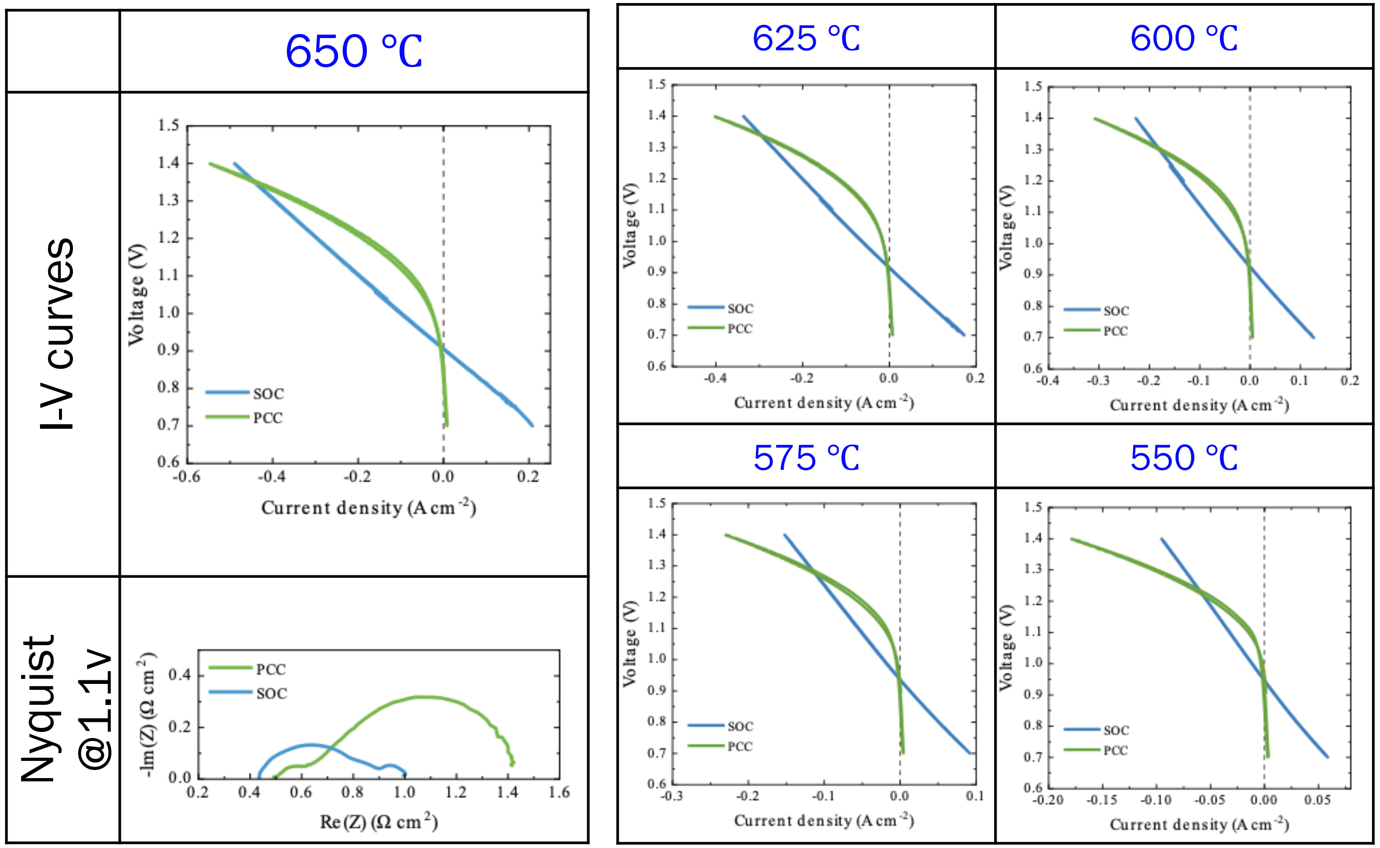


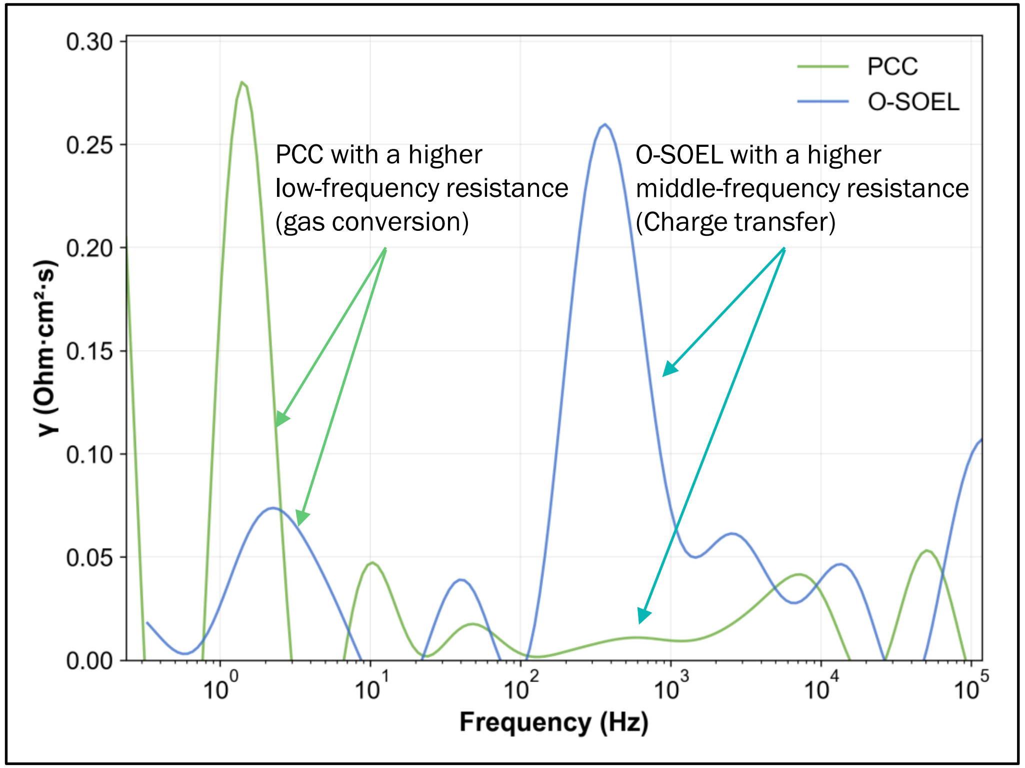
O-SOEL vs. PCC cell performance

PCC better at ≤650 ºC than O-SOE

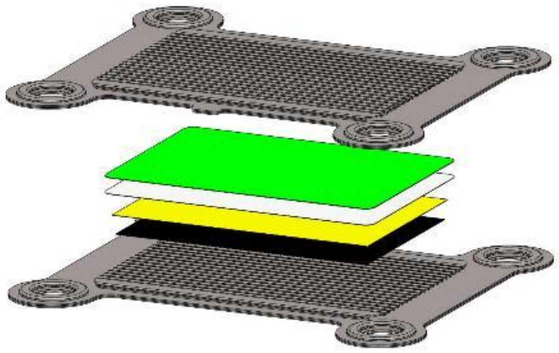
- Fuel: 50% H_2 – 47% N_2 – 3% H_2O, total 200 ml/min
- Air: 2.1% O_2 – 7.9% N_2 – 90% H_2O, total 200 ml/min



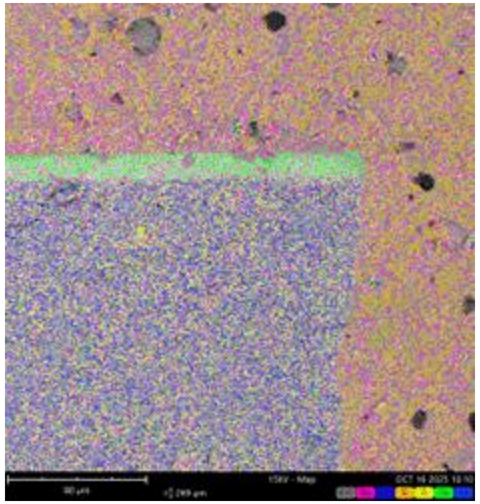




Integration of new ESC and MSC in SolydEra stack technology



- The stack manufacturing firing cycle will prevent oxidation of the metal support
- The sealing material is fine-tuned, and the design modified
- Contact layers on the steam-side are adapted



Thank you for your attention!

Hy-SPIRE

www.hy-spire.eu