



Experimental validation of a 10kW alkaline stack by ENDURE harmonized testing protocols

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PRIVATE, NON-PROFIT RESEARCH CENTER, CREATED IN 2003 TO PROMOTE THE USE OF HYDROGEN AS AN ENERGY VECTOR



1,200 m² building with offices, laboratories and a unique workshop prepared to work with large H₂ equipment.



635 kW wind
100 kW PV
62 kW PV (self-consumption)



AEL 250 kW, industrial scale
AEL 20 kW, test bench
AEL 48 kW, 8 Nm³/h @8 bar
PEMEL 5 kW, 1 Nm³/h @6 bar
AEMEL 15 kW, 2 Nm³/h @35 bar



7 kg (4000 L) @35 bar
23 kg (900 L) @350 bar



HIGGS - R&D Blending H₂/GN



Hyundai Nexo & Kangoo ZE



The project - ENDURE

Start: 01/01/2024

Duration: 36 months

Budget: 2.5 M€

The idea:

Develop a PGM-free **alkaline electrolyser stack with PEM-like performance and low degradation rate** within a Hydrogen Europe project (GA:101137925).

The innovations:

- Develop monolithic porous transport electrodes (PTE).
- Perform multi-level computational fluid dynamics modelling.
- Develop novel PGM-free high performance electrocatalysts.

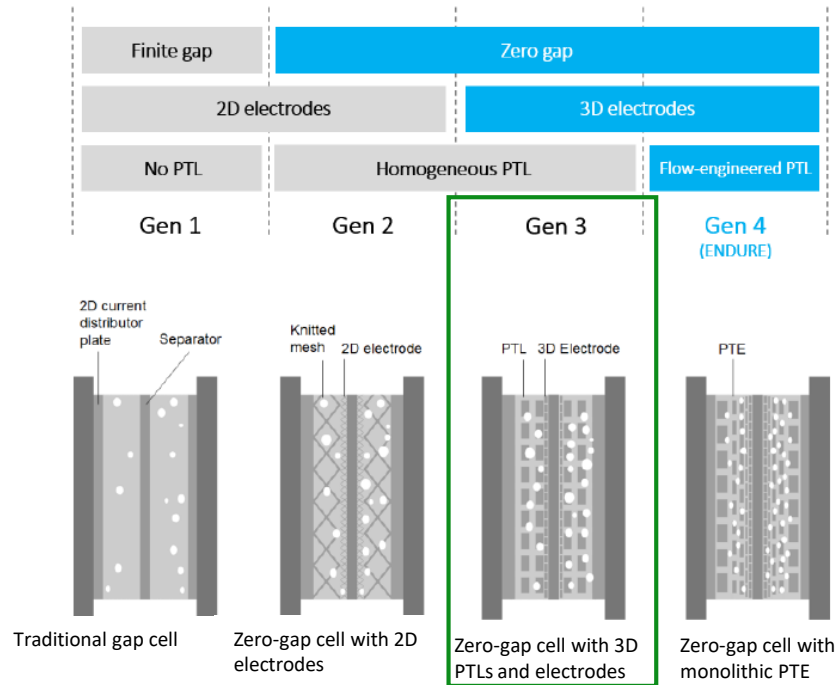
- **Validate performance at stack level** (100 and **1000 cm²**) using self developed testing protocols.



Baseline 1000 cm² stack performance validation

Stack and test bench

The baseline stack



- ~1000 cm² active area
- Zirfon UTP Perl 500
- Non-treated Ni-foam electrodes and porous transport layer (PTL)
- Zero-gap configuration
- 7 cells



The test bench



- 20 kW, 60 barg and 120 °C.
- Mixed electrolyte circuit.
- Unattended operation.
- Electrochemical Impedance Spectroscopy (EIS) – PULSENICS
- Temperatures, pressure, differential pressures, KOH flow,...

Testing protocol used and developed

Find operating window

(I) 1st fingerprint
(50h)

- Permutations:
 - 5 – 30 barg
 - $J_{\min} - 1 \text{ A/cm}^2$
 - 0.12 – 0.37 ml/min.cm²
- 80°C average temperature
- 30 wt% KOH
- Measurements:
 - Cell voltages
 - HTO & OTH
 - EIS analysis

Assess degradation

(II) Long-term
galvanostatic test (400h)

- Galvanostatic test:
 - 30 barg
 - 1 A/ cm²
 - TBD in (I)
- 80°C average temperature
- 30 wt% KOH
- Measurements:
 - Cell voltages
 - HTO & OTH
 - EIS analysis

Compare behavior

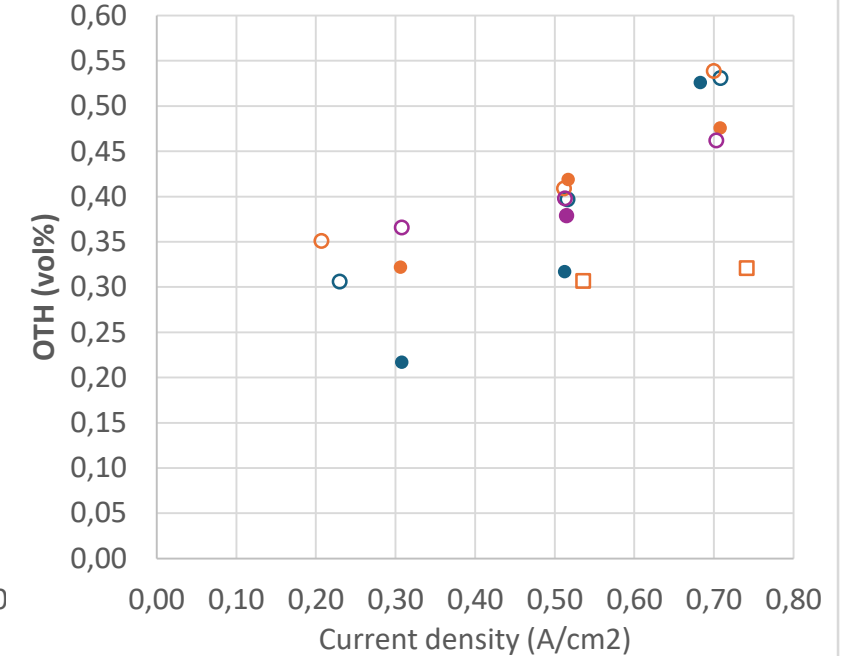
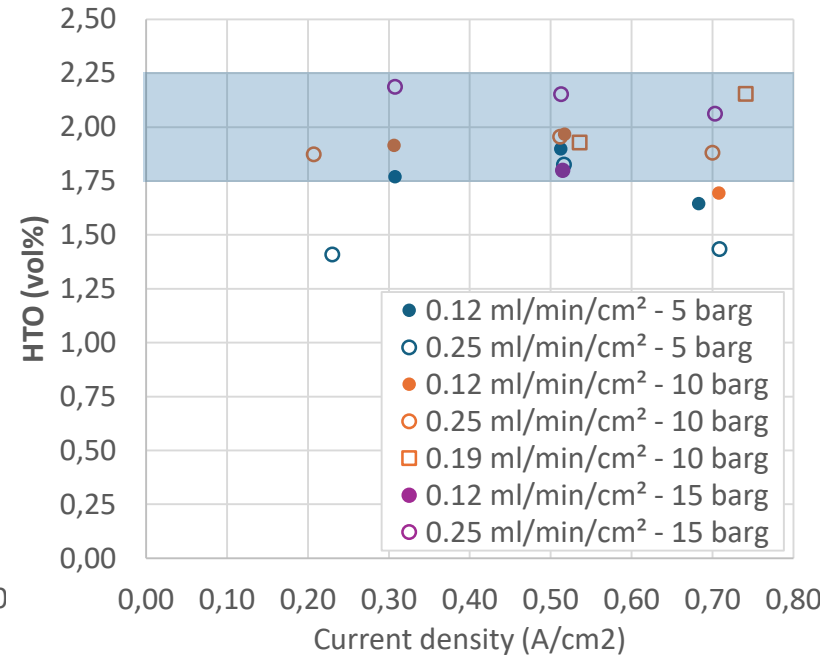
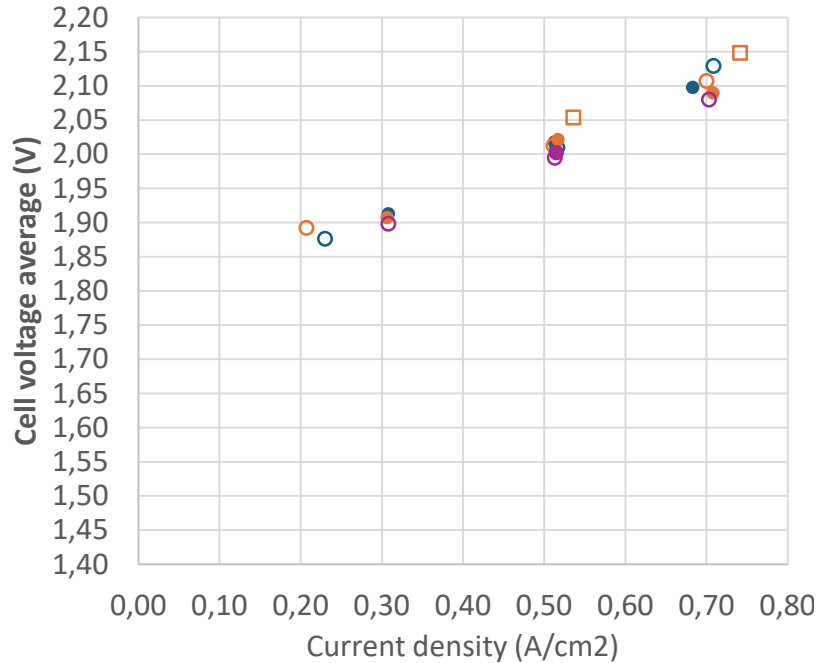
(III) 2nd fingerprint (50h)

- Permutations:
 - 5 – 30 barg
 - $J_{\min} - 1 \text{ A/cm}^2$
 - 0.12 – 0.37 ml/min.cm²
- 80°C average temperature
- 30 wt% KOH
- Measurements:
 - Cell voltages
 - HTO & OTH
 - EIS analysis

Results and discussion

1st fingerprint tests - *Find operating window*

30%wt KOH – 80±5 °C average temperature – half-cell flow



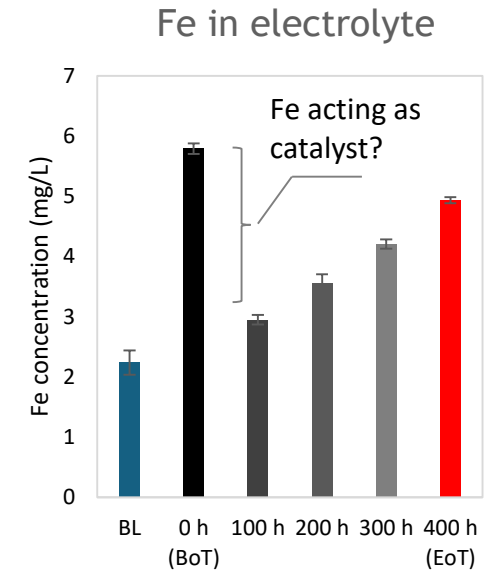
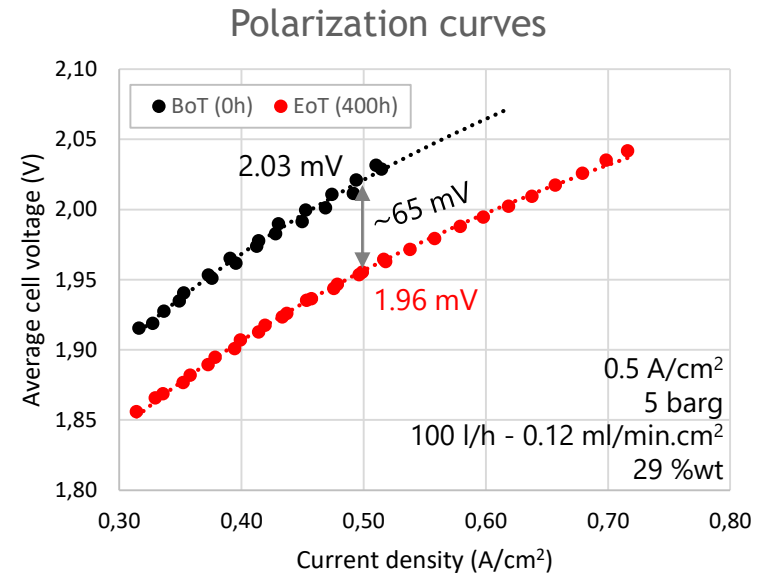
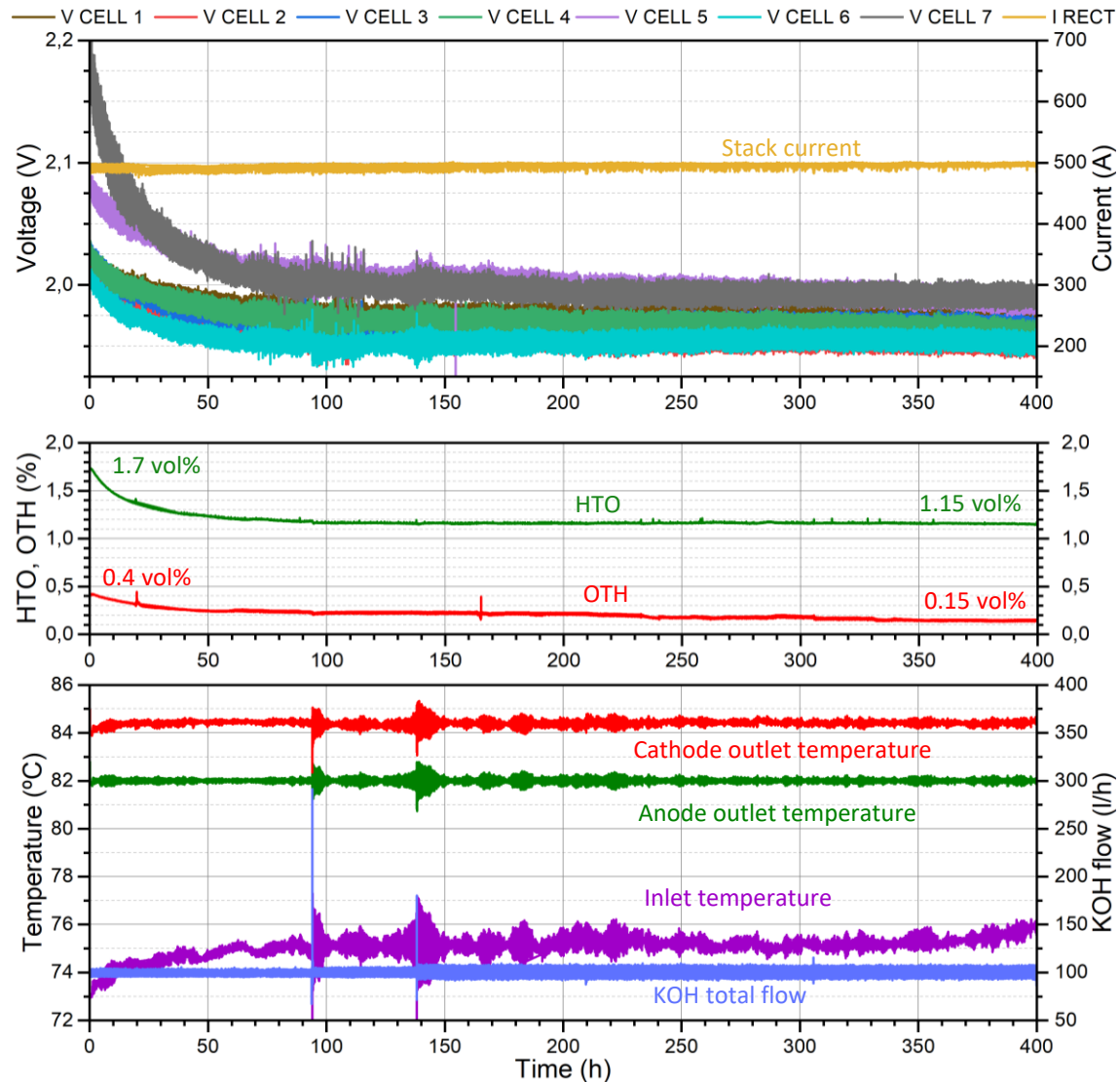
- Tests performed at different current densities (**0.2 – 0.7 A/cm²**), pressures (**5 – 15 barg**) and KOH flows (**0.12 – 0.25 ml/min.cm² – half-cell**).
- Cell voltage, HTO and OTH were measured. No EIS analysis.
- High **HTO** values (close and above **2vol%** - safety threshold) **limited** the **testing window**.

Long term galvanostatic test:

- Current density: 0.5 A/cm²
- Pressure: 5 barg
- KOH flow: 0.12 - ml/min.cm² – half-cell

Results and discussion

Long term galvanostatic test - voltage and crossover - *Assess degradation*

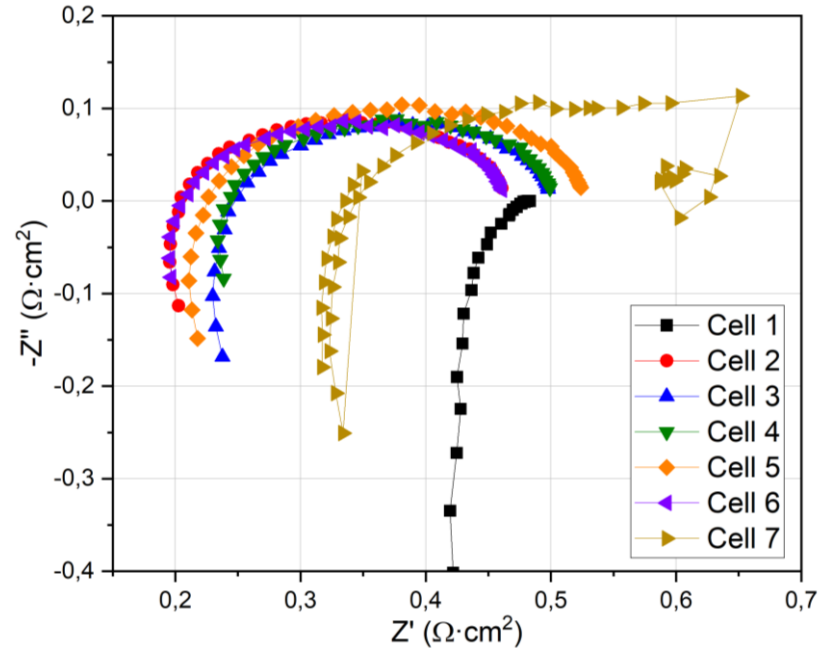


- Difference between cell voltages (5 and 7) are seen during the first 200h of test.
- Cell voltages show a decreasing tendency with time stabilizing at ~200 h ($V_{avg} \sim 1.96$ V) coherent with break-in period (and Fe concentration reduction in electrolyte?)
- A voltage drop of ~ 65 mV is observed between BoT and EoT polarization curves.
- HTO and OTH also show a decrease.

Results and discussion

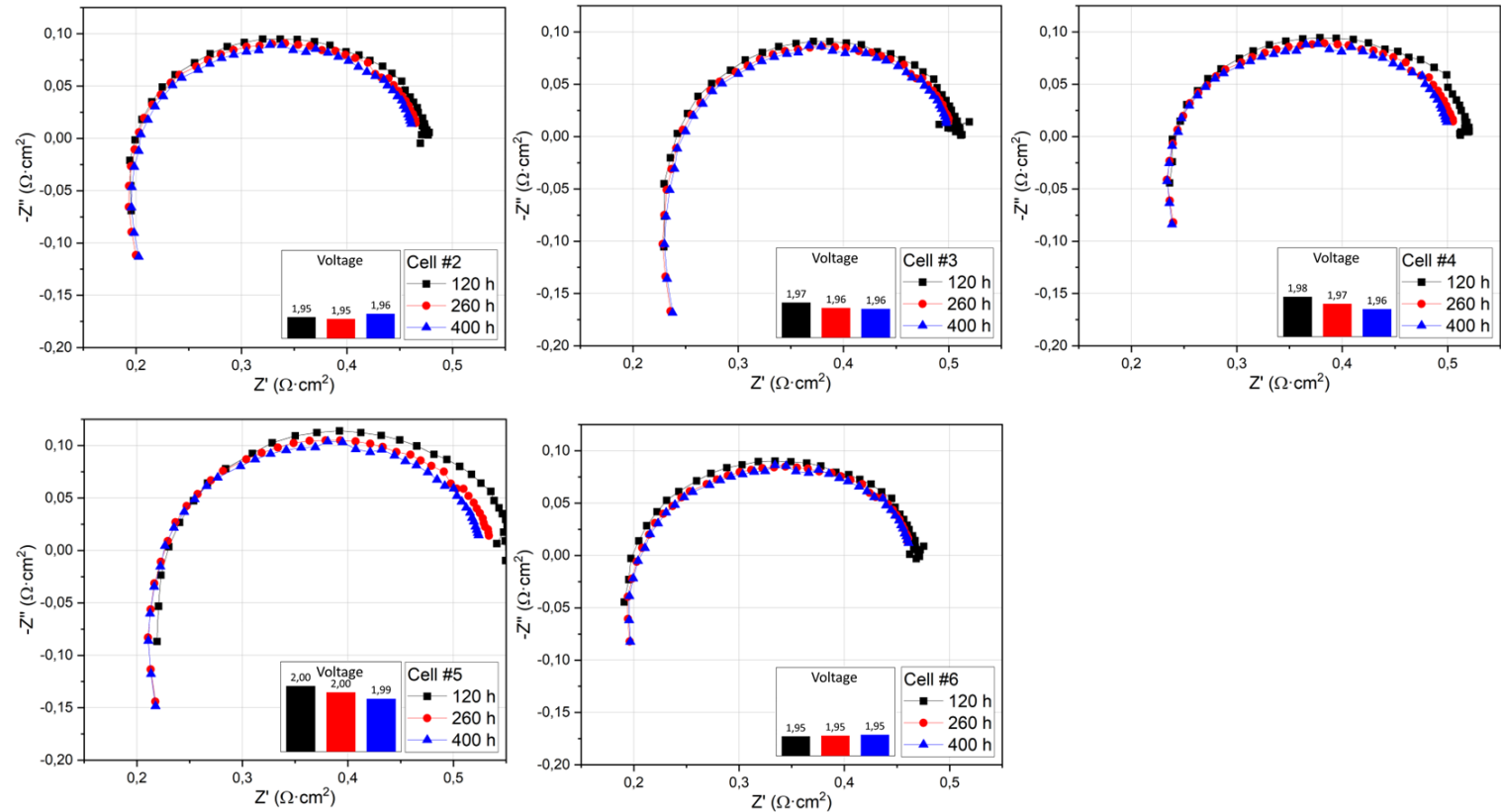
Long term galvanostatic test - EIS analysis - *Assess degradation*

Nyquist plot EoT - 400 h



- Kramer-Kronig test show low RMSE (<1%) – good data quality.
- HFR (High Frequency Resistance) span from 0.20 to 0.25 $\Omega\cdot\text{cm}^2$ (for inner cells).
- Edge cells show different behavior.

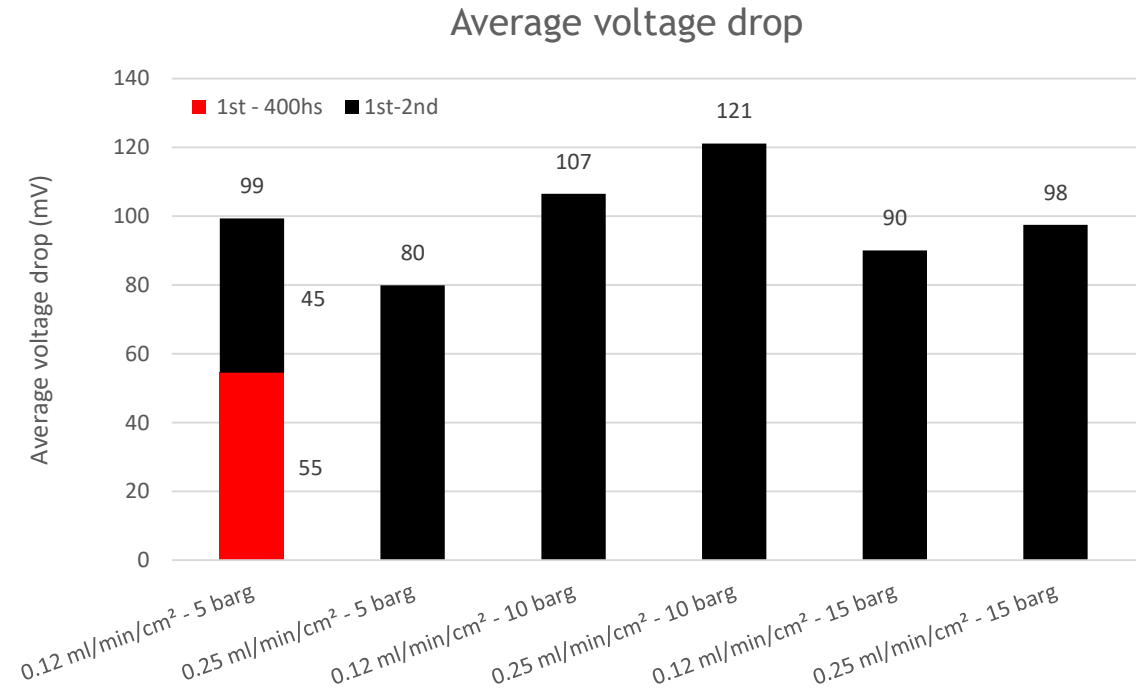
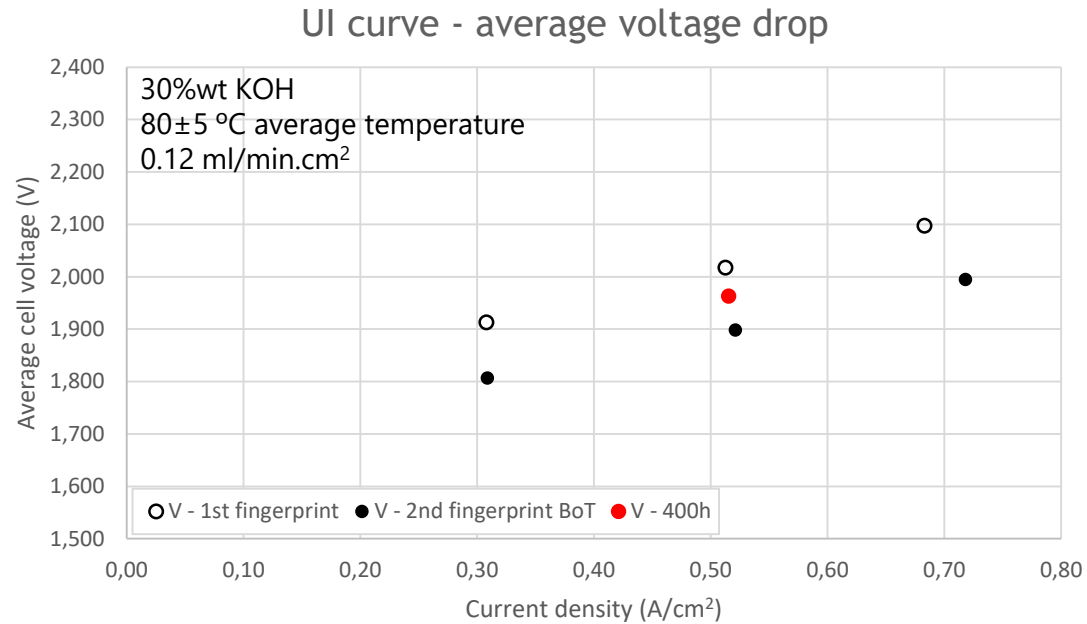
Nyquist plot evolution



- No EIS analysis is available before 120h.
- Very small HFR variation.
- Decrease of polarization resistance evidencing electrodes kinetic improvement.

Results and discussion

2nd fingerprint tests - *compare behaviour*

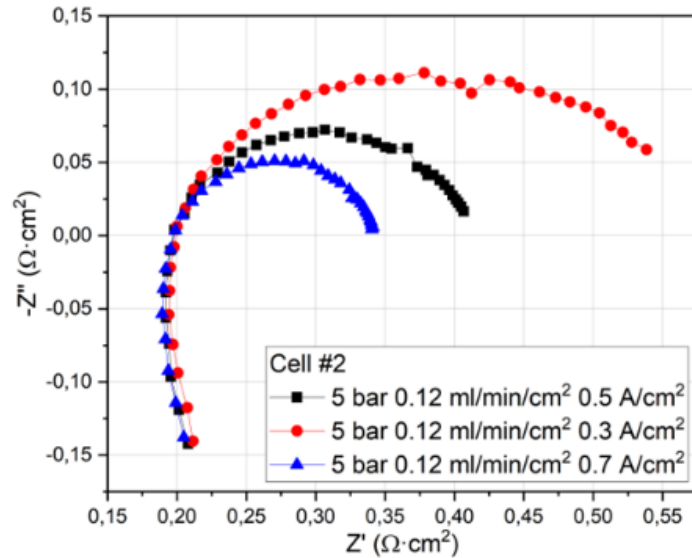


- A voltage drop is observed when comparing the results from the 1st and 2nd fingerprint at all operating conditions.
- The average **voltage drop** spans from **80 – 121 mV**.
- Further voltage drop is observed after the OFF-ON cycle after the long-term galvanostatic test and 1st tests of 2nd fingerprint evidencing reversible degradation.

Results and discussion

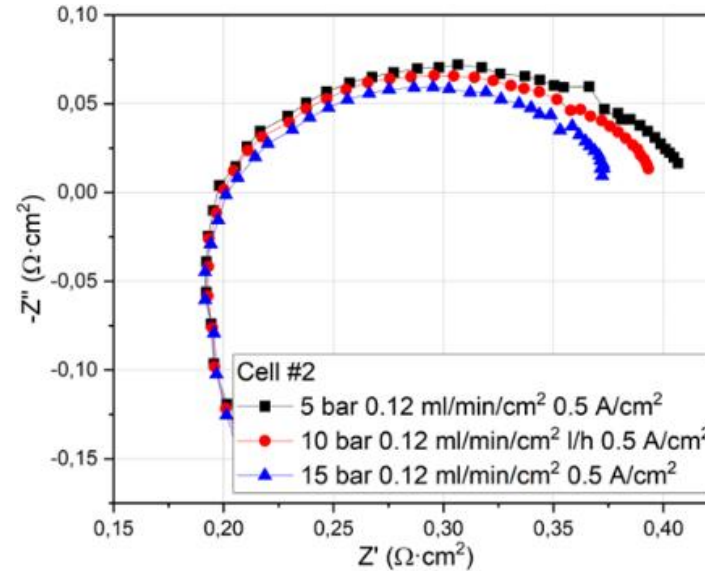
2nd fingerprint tests - EIS analysis

Current density sweep



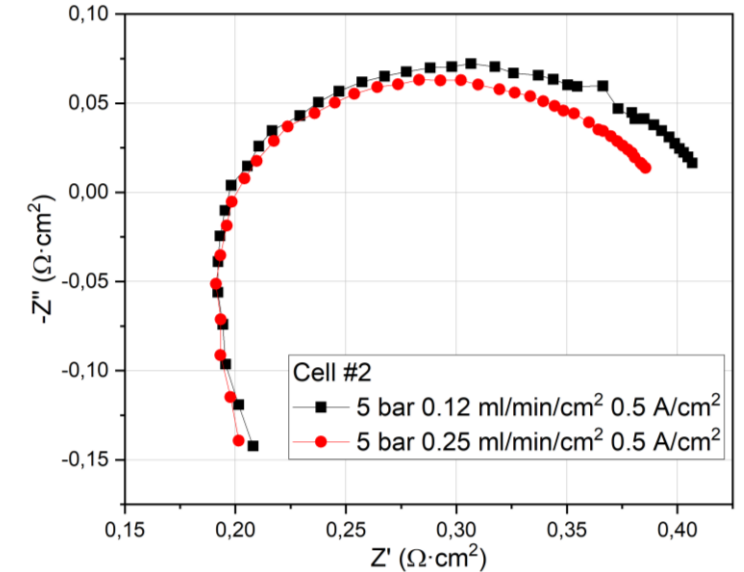
- HFR remains stable (ohmic resistance may not be affected by the increase of bubbles).
- Decrease of polarization resistance and capacitive behavior at higher current densities.

Pressure sweep



- HFR remains stable (bubble size reduction may not be affecting ohmic resistance).
- Decrease of polarization resistance at higher pressures.

KOH flow sweep



- HFR remains stable (bubble evacuation not affected by flow).
- Decrease of polarization resistance at higher KOH flows.

Conclusions and takeaways

- The baseline 10 kW short stack (zero gap with 3D electrodes and PTLs) was successfully tested implementing the testing protocols developed within ENDURE.
- The operating window of the stack-testbench was assessed and a 400 h galvanostatic test was conducted at 0.5 A/cm² and 5 barg (due to high crossover ~ 2 vol%) yielding in V_{cell} **1.96 V @ 0.5 A/cm²**.
- **No permanent degradation** was observed after **573 operating hours and 45 ON-OFF cycles** while the **break-in period** seems to be **100-200 h of constant operating conditions**.
- An EIS analysis was performed in a cell-by-cell basis allowing a detailed behavior analysis.

Thank you!

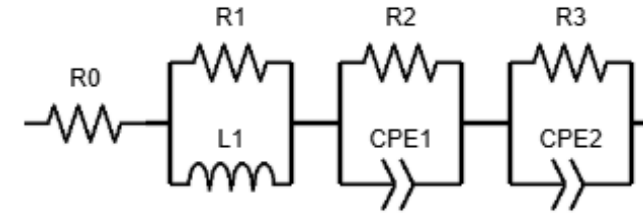
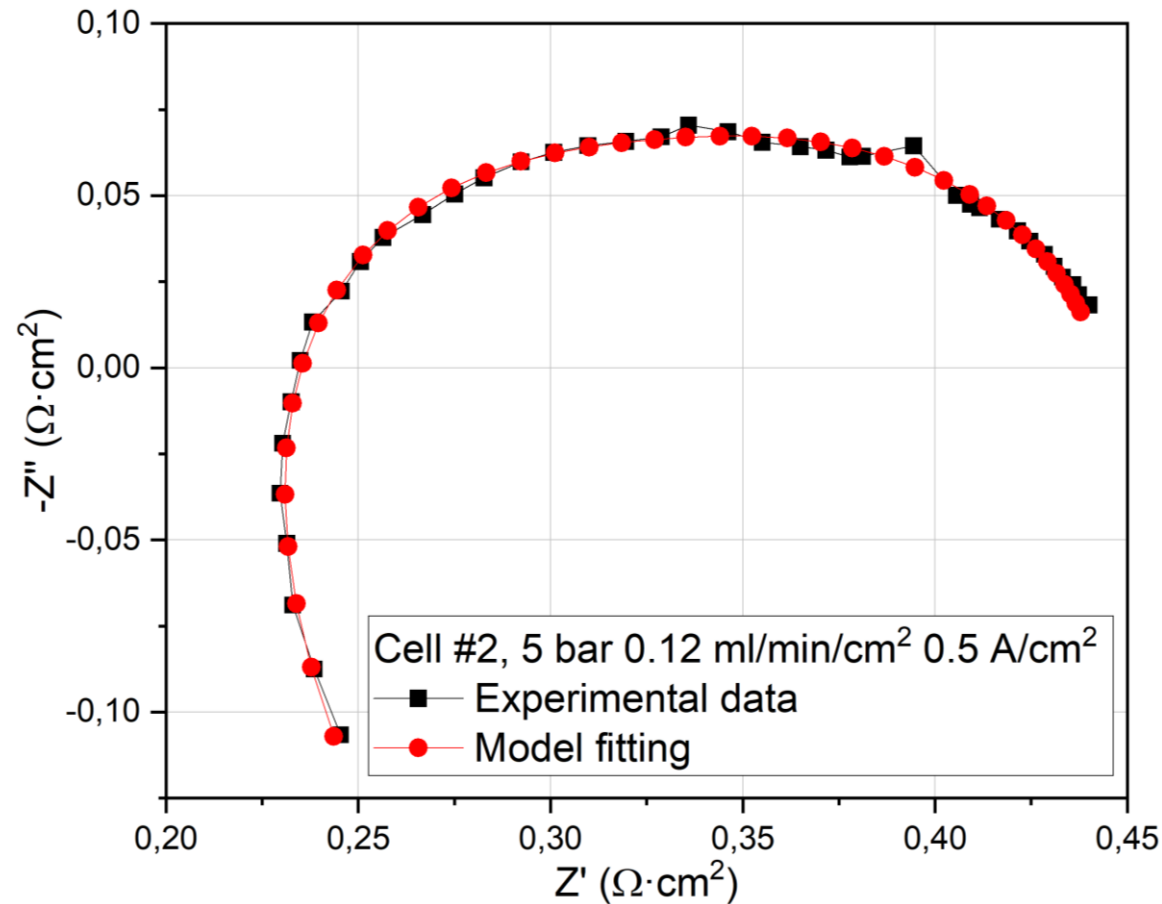
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Backup slides

Equivalent electrical circuit modelling



R0 – HFR related

R1 and L1 – inductive behavior

R2 and CPE1 (Q1) – cathode electrochemical processes

R3 and CPE2 (Q2) – anode electrochemical processes

Cell	Operating conditions	RMSE	R0 (Ω·cm ²)	R1 (Ω·cm ²)	L1 (nH)	R2 (Ω·cm ²)	Q1 (C) / α1 (-)	R3 (Ω·cm ²)	Q2 (C) / α2 (-)
2	120	0.007	0.17	1.09	1.77	0.23	2.07 / 0.85	0.09	11.89 / 0.94