A Component-specific approach towards Accelerated stress testing for PEMWEs

29th September 2023

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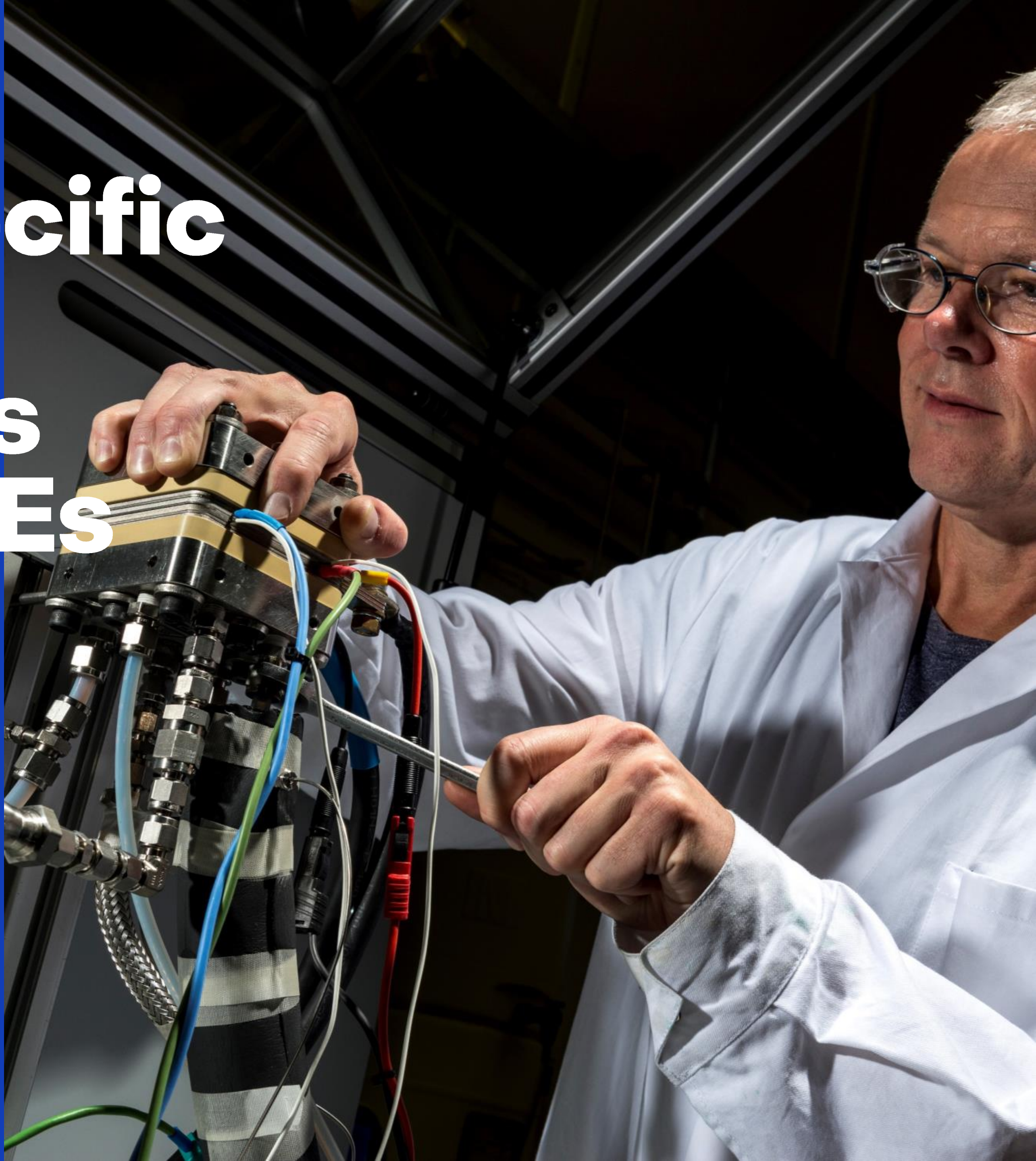
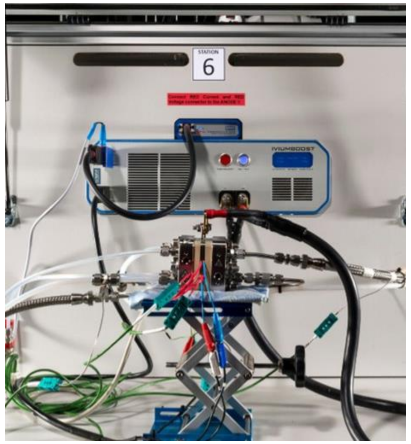


TNO: Netherlands Organisation for Applied Scientific Research

1 cm^2

ASTs Testing stations

10 cm^2



R&D CELL MANUFACTURING & CELL/SHORT STACK TESTING

PEM, SOE, AEM + testing for Alkaline

Hydrohub
Groningen

Faraday Lab
Petten

2500 cm^2

STACK AND BALANCE-OF-PLANT TESTING

PEM (50 kW, full-scale cells) and Alkaline in consortium with end-users

Accelerated Stress and Life Tests

Understand and Prevent **cell degradation**

ACCELERATED STRESS TESTS (ASTs)

I. Harsh stressor
II. Target specific components
III. Trigger one degradation mechanism on a shorter time scale (500 hours)

Screening for the best electrolyzer component *(e.g. vs. state-of-art component)*

Estimate the Durability of the component *(needs "acceleration multiplier")*

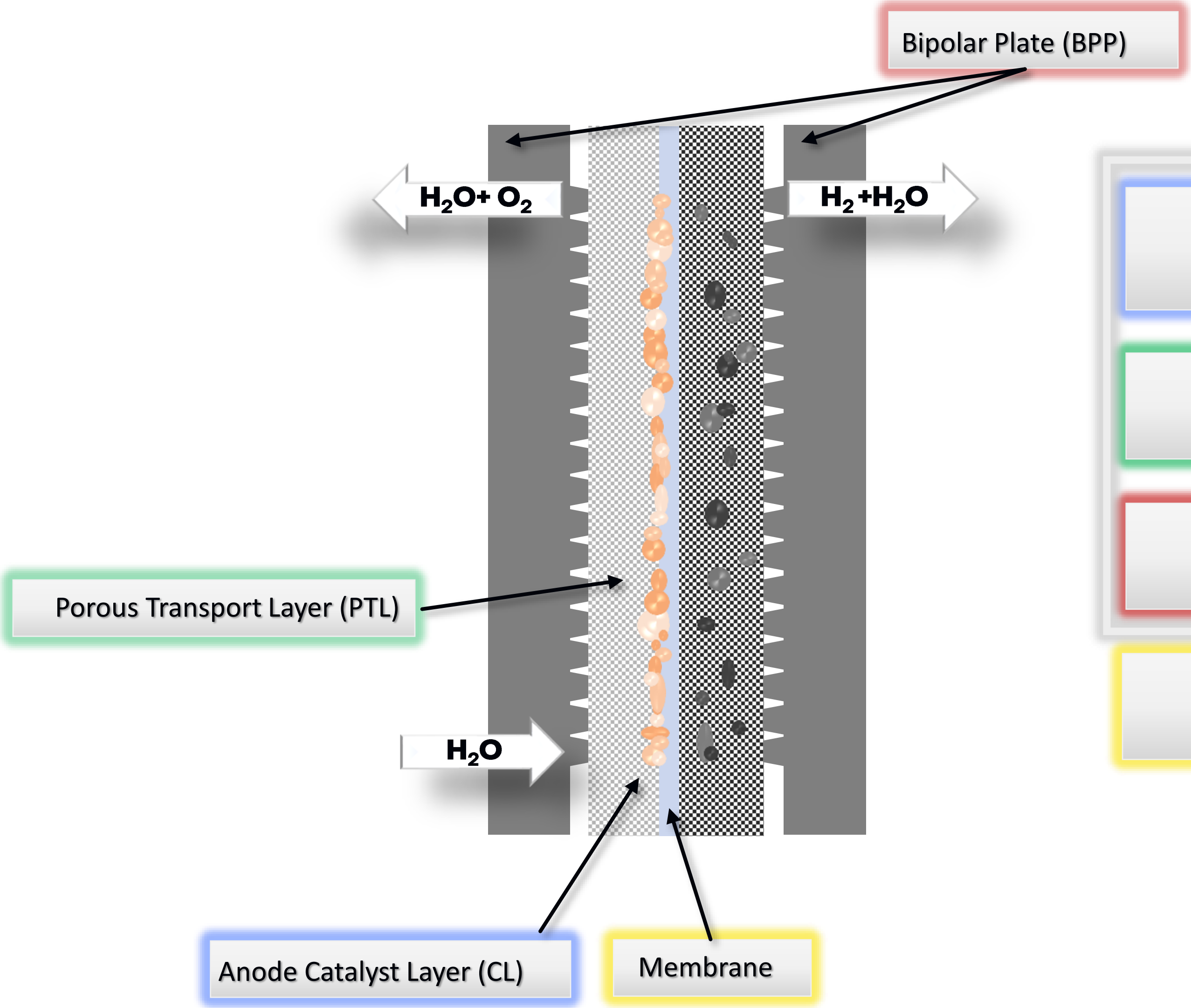
Current Focus

ACCELERATED LIFE TESTING (ALTs)

I. Mild stressors
II. Generic cell test
III. Mimic real life conditions for one use case on a longer time scale (> 1000 hours).

Estimate the Durability of the whole cell *(needs "acceleration multiplier")*

Component-Specific Irreversible Losses



Current Focus

ANODE KINETICS LOSS due to Anode Thinning & Increase Polarization Resistance

Increase Ohmic resistance of POROUS TRANSPORT LAYER

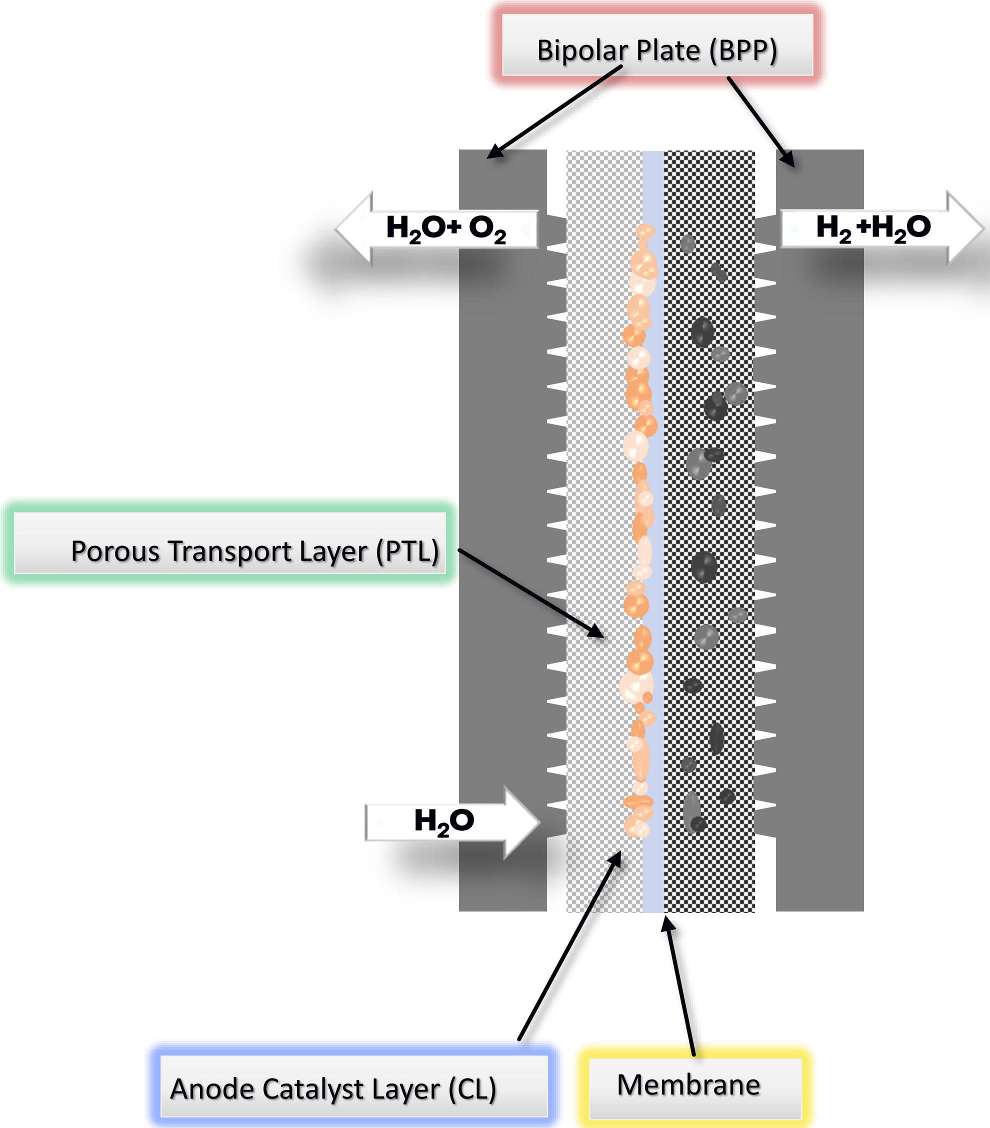
Increase Ohmic resistance of BIPOLAR PLATE

MEMBRANE THINNING & LOCALIZED PINHOLES

*Cathode kinetics is rapid and low degradation is expected, hence outside the current scope.

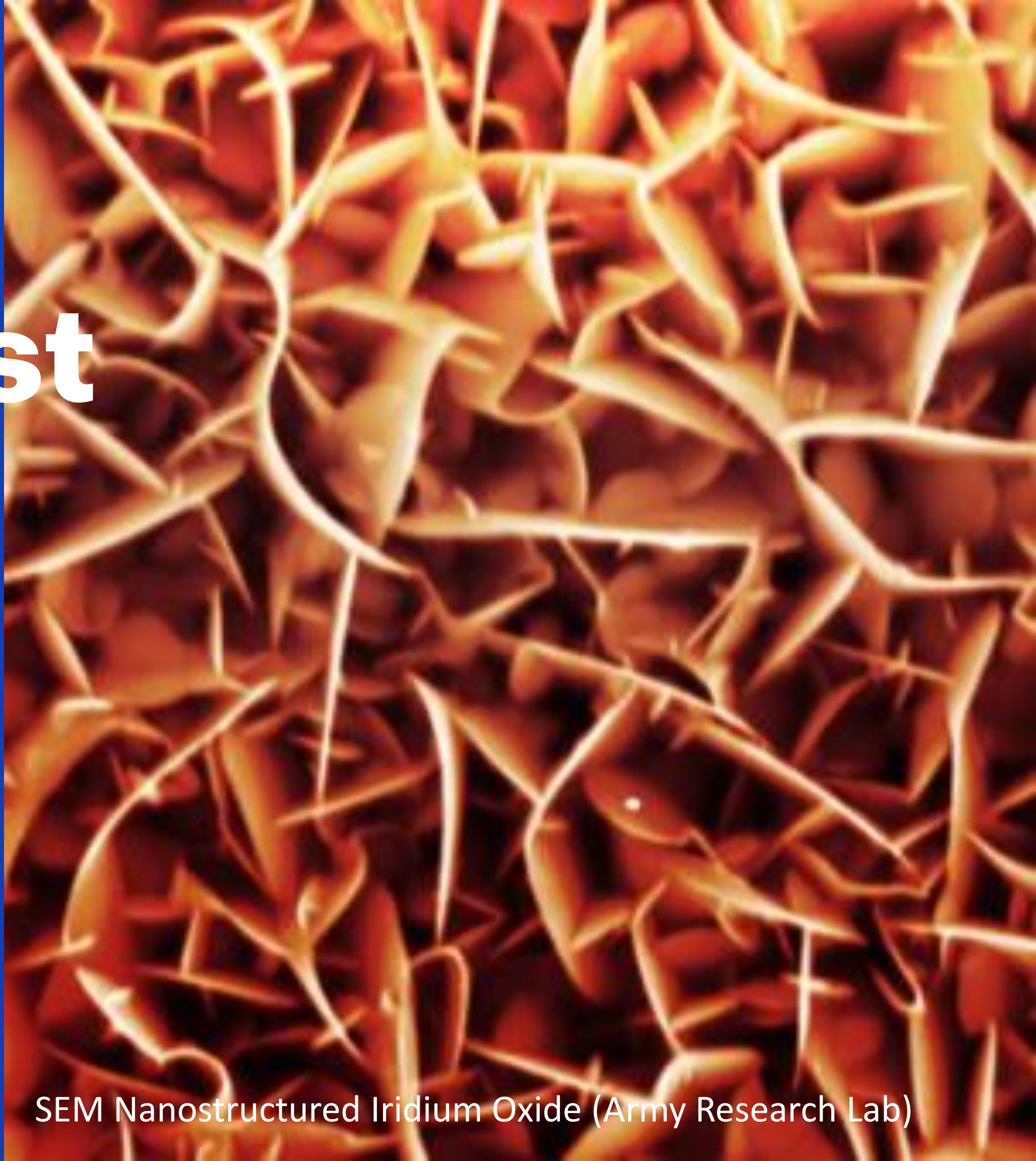
Stressors and Targets

Stressor				
High temperature (> 60ºC)	Anode CL	PTL	BPP	Membrane
Low current (≤0.3 A cm^{-2})	Anode CL			Membrane
Dynamic (On/Off)	Anode CL			Membrane
I-V cycling (1.5V – 2.2 V)	Anode CL			
High voltage (> 2.2. V)	Anode CL	PTL	BPP	
Low humidity	Anode CL			Membrane



Anode Catalyst Layer

ASTs

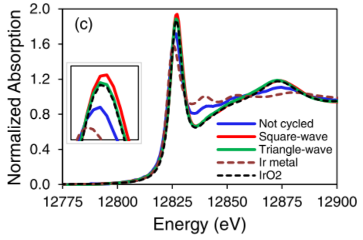


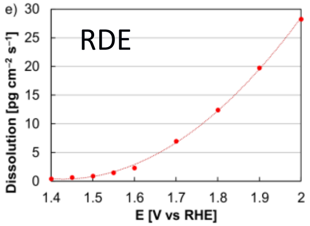
SEM Nanostructured Iridium Oxide (Army Research Lab)

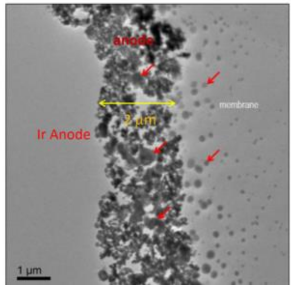
AST Protocol Anode CL- Anticipated Effects

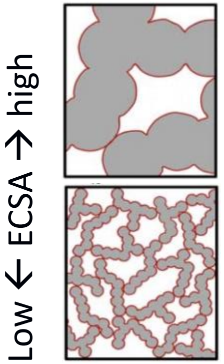
- Change in Oxidation State
- Iridium Dissolution
- Migration
- Coarsening
- Change in Morphology

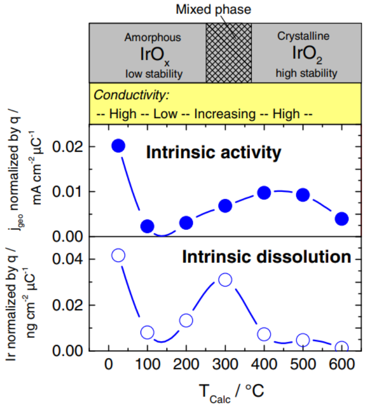
ANODE CL Degradation











Alia et al.J. Electrochem. Soc **169** 054517 (2022)
Alia et al. J. Electrochem. Soc. **163** F3105 (2016)
Alia et al. J.Electrochem. Soc, **166** (15) F1164-F1172 (2019)
Ayers et al. J.Electrochem. Soc. Interface **30** 67 (2021)
Padgett et al. J. Electrochem. Soc., **170** 084512 (2023)
Geiger et al 2016 J. Electrochem. Soc. 163 F3132
Weiß et al. Journal of The Electrochemical Society, **166** (8) F487 (2019)

Stressors and Aspects Covered

ASTs

I. Harsh stressor

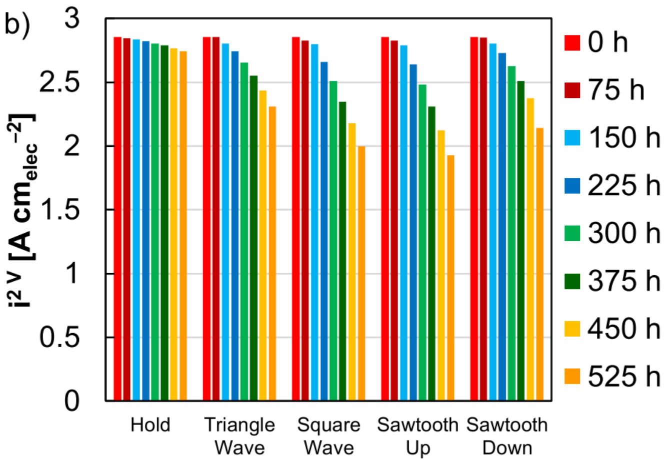
II. Target-specific components

III. Trigger one degradation mechanism on a shorter time scale (500 hours)

NREL

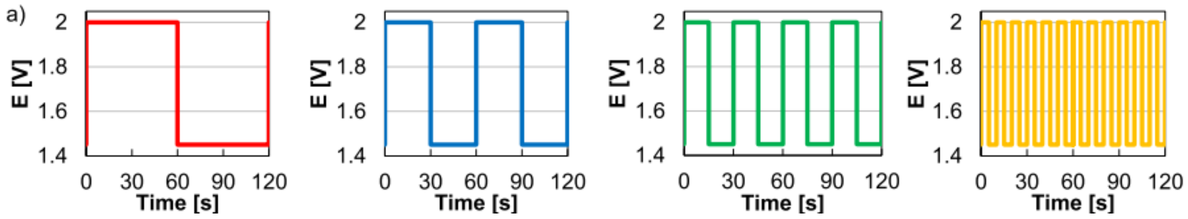
Load cycling

Stressor waveforms



1.4V/2V

Cycle time

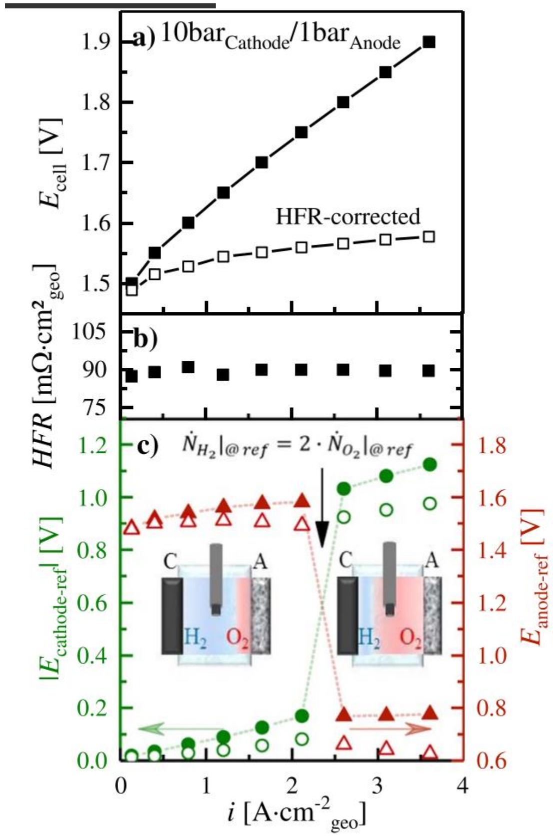


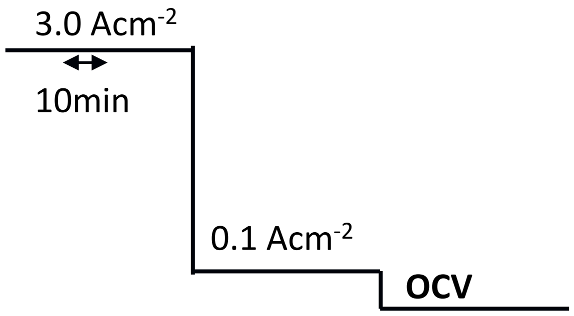
Alia et al. J.Electrochem. Soc, **166** (15) F1164-F1172 (2019)

Technische Universität München

Load cycling

START & STOP





Weiß et al. Journal of The Electrochemical Society, **166** (8) F487 (2019)

Weiß et al. Journal of The Electrochemical Society, **168** 114511 (2021)

TNO's AST Protocol: Anode CL

APPROACH

I. Evaluate effect of load cycling

II. Shutdown behaviour

Anode CL

- Anode CL: 0.8 mg/cm^2. Needs to be optimized to lower loading.
- Cathode CL: 0.5 mg/cm^2 Pt
- PTL and BPP: Pt-coated Titanium.
- Membrane: Nafion115 , at T< 80ºC, and MilliQ water.

EX-SITU measurements

Pristine Witness sample
SEM,TEM,
XPS/XANES,
XRF
Conductivity

CONDITIONING

80ºC, 2 barg

1. Heat to 40ºC for 0.5 h
2. Heat to 80ºC for 5 h
3. Apply 2 V for 24 h
4. Record an *I-V* curve (80ºC)
5. Cool down to T_x for 0.5 h

IN-SITU measurements

60ºC, 2 barg (BoL)

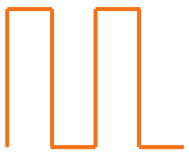
I-V: 1.55 – 2.275 V
PEIS: 1.55 V, 1.65V, 25-0.5 kHz

STRESSOR

x6 (1000 hours)

60ºC, 2 barg

I-V Square waves
1.4 ⇄ 2.275 V
t_{step}= 60 s
5000 cycles (166 h)



IN-SITU measurements

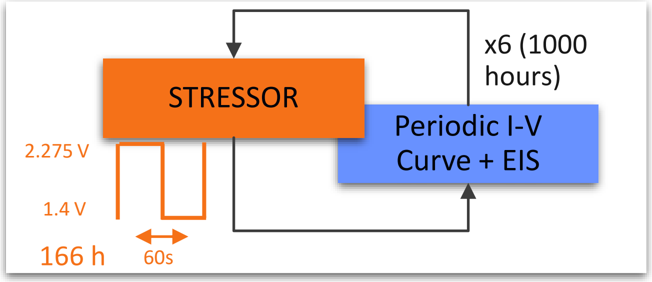
60ºC, 2 barg (EoL)

I-V: 1.55 – 2.275 V
PEIS: 1.55 V, 1.65V, 100-0.5 kHz
ICP-MS, ICP-OES

EX-SITU measurements

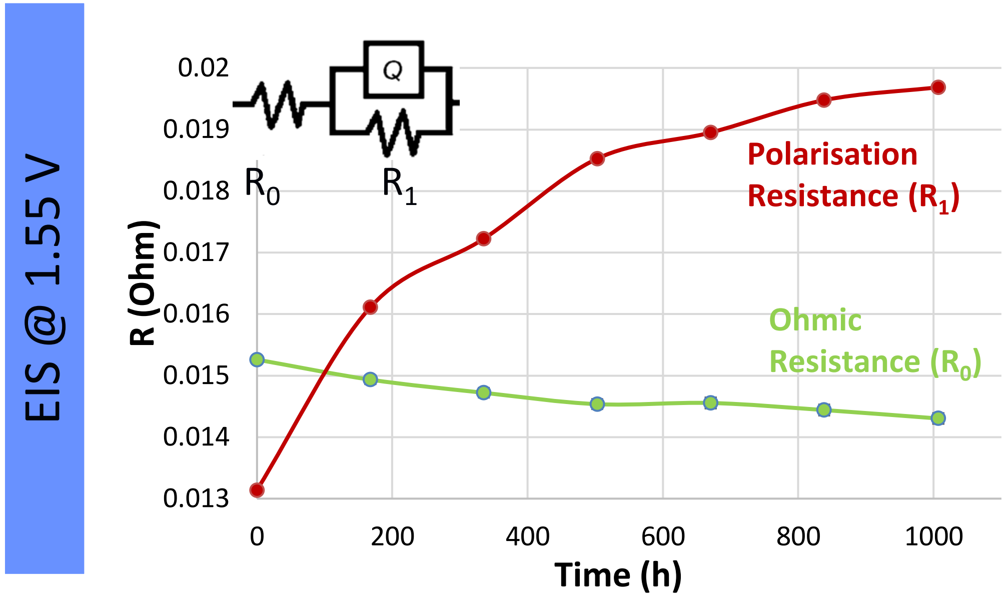
Aged sample
SEM,TEM,
XPS/XANES,
XRF
Conductivity

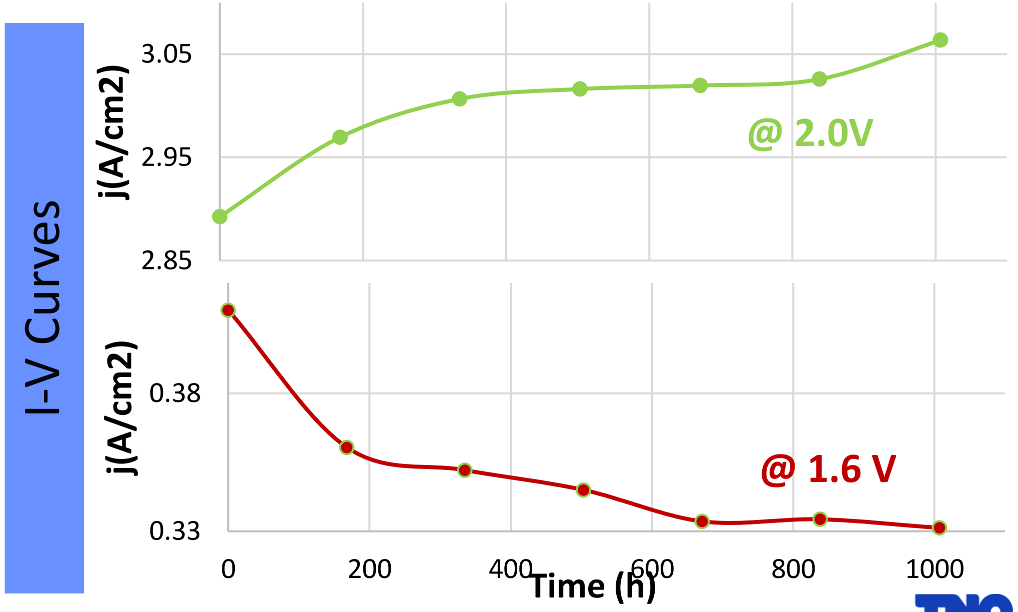
Results 1000h AST-Anode CL



Over time, we measured two opposite trends:

- Polarization resistance increases (Current decreases) →kinetic activity loss
- Ohmic resistance decreases (Current increases)→ membrane thinning/creep or PTL/CL interface conductivity





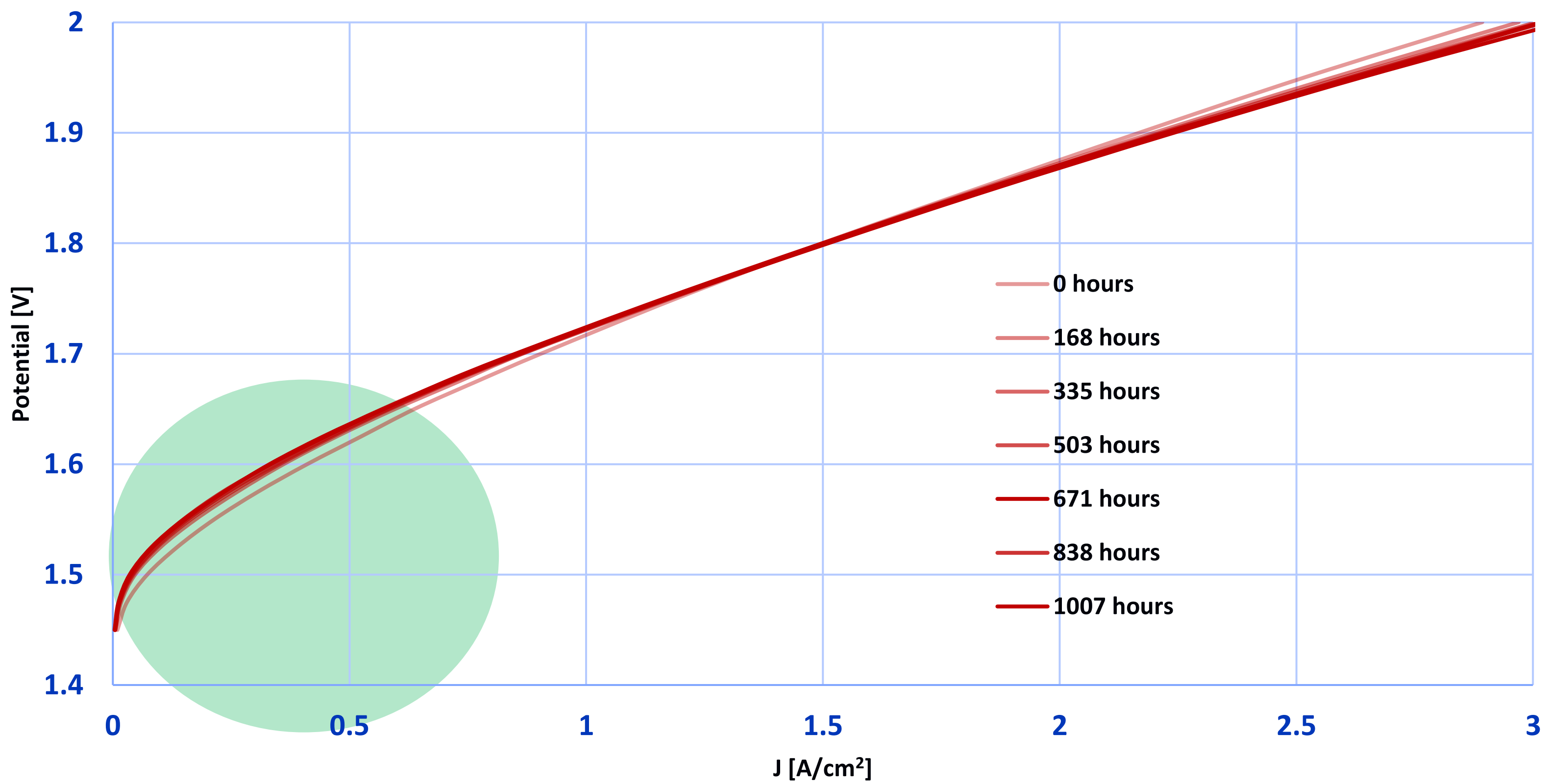
Conclusions & Future Perspective

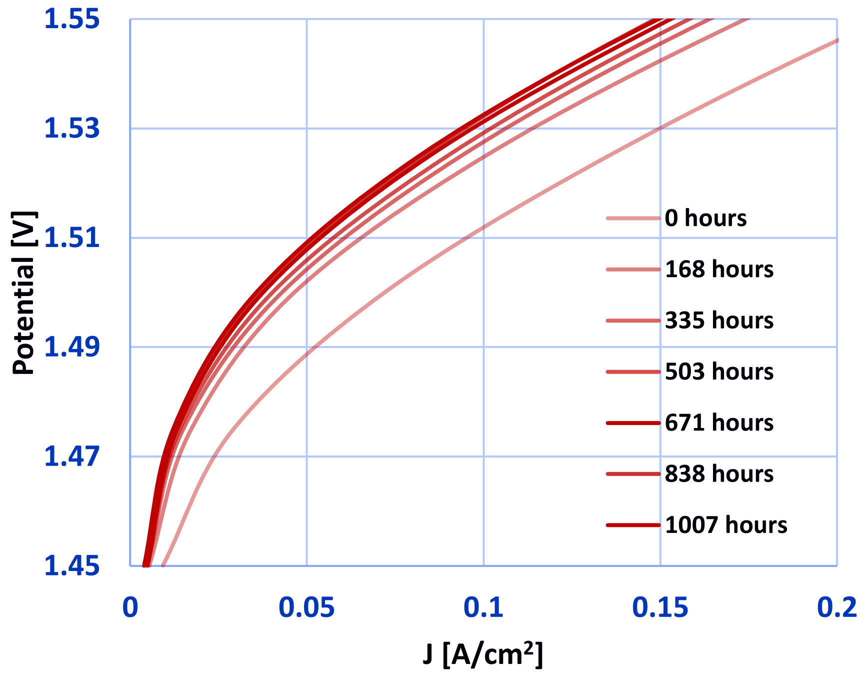
- We have developed component-specific ASTs to steer component R&D
- Efficient anode catalyst utilization (lower loading) is important for scale up.
- Catalyst durability will become an increasingly important topic for lower catalyst loadings.
- TNO's AST for the Catalyst Layer with Voltage cycling effectively degrades the anode CL

Next steps

- In-situ measurements will be complemented by ex-situ characterisations.
- Cycling frequency of stressor waveform.
- Further reduction in catalyst loading.
- Study the effect of shutdown behavior.

Results 1000h AST – Polarisation Curves

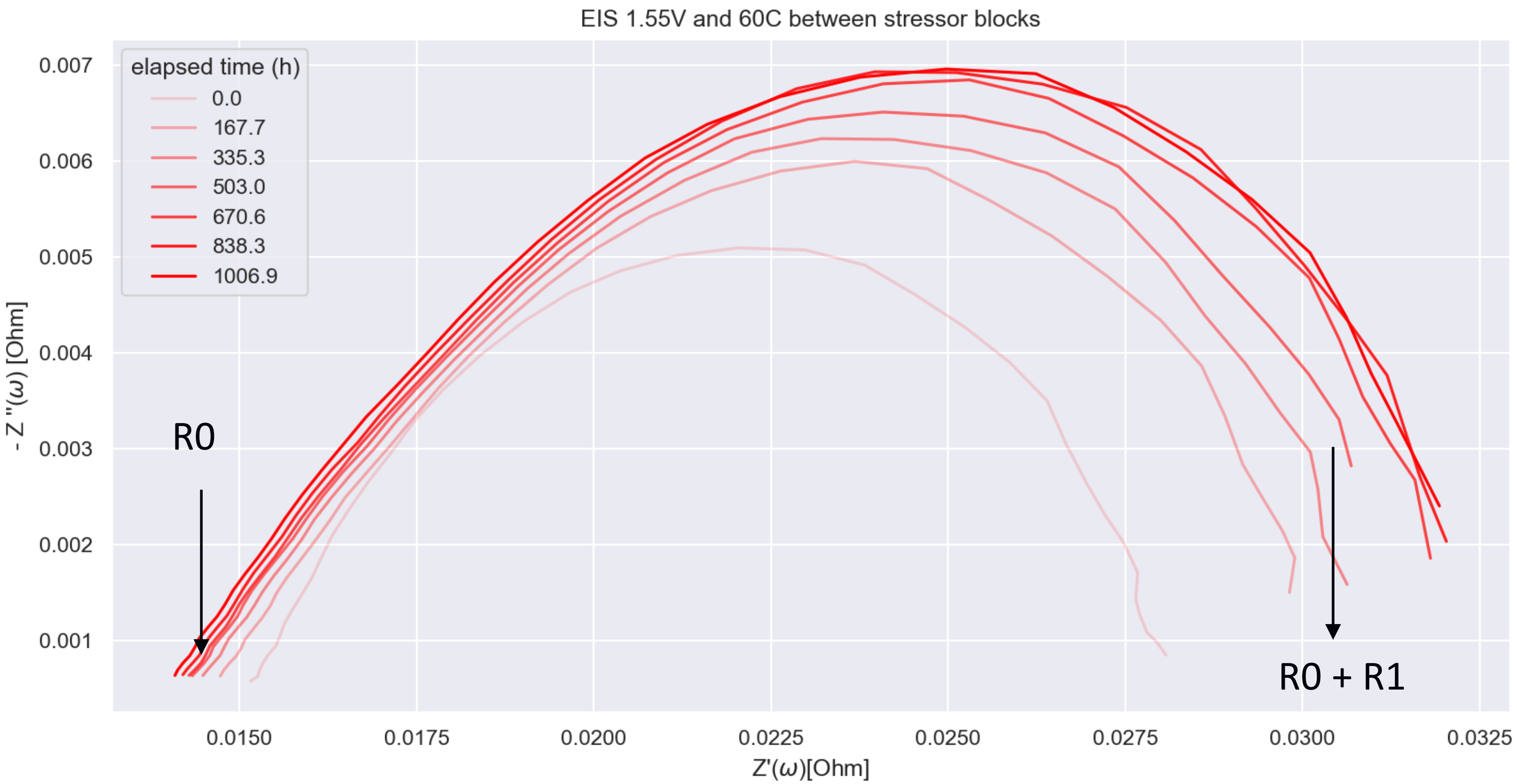


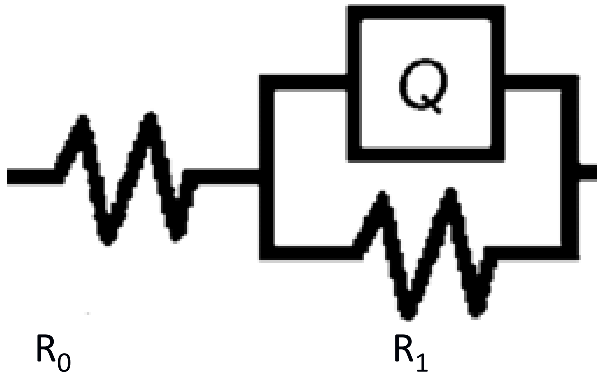


Two opposite trends are observed for the measured current:

1. Repeated cycling increases kinetic overpotential
2. Ohmic losses decrease over time

Results 1000h AST – Impedance Spectra





Two opposite trends are observed for the measured resistance:

- Polarization resistance increases →kinetic loss.
- Ohmic resistance decreases→ membrane thinning/creep or PTL/CL interface conductivity