Advances in Alkaline Water Electrolyzer Technology: Enhancing Efficiency and Dynamic Performance

German Aerospace Center (DLR)

Dr. Fatemeh Razmjooei

Deutsches Zentrum
für Luft- und Raumfahrt
German Aerospace Center

DLR at a glance is the national centre for

- *Aerospace*
- *Energy*
- *Transportation research of Germany*

The German Aerospace Center (DLR)

The headquarters is located in Cologne and also has multiple other locations all over the Germany.

- ca. 10000 employees at 30 location in Germany
- > 30 Locations
- ca. 55 institutes

- International offices in Brussels, Paris, Tokyo and Washington D.C.

- Research Covers different areas
  - Space
  - Energy
  - Transport
  - Security

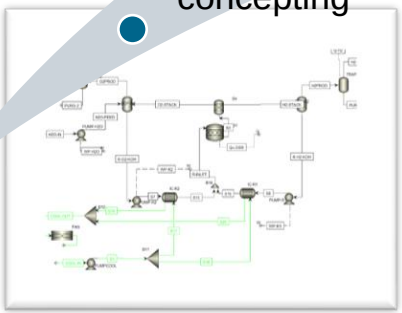
Roadmap: Advancing alkaline-based Electrolyzer Technology for Green Hydrogen Production

Ultimate Goal

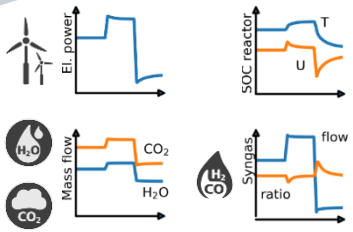
Produce efficient, low-cost, clean hydrogen through an advanced alkaline electrolyzer system, addressing the challenges across the full value chain

Key tools & Capabilities including Validation Infrastructures

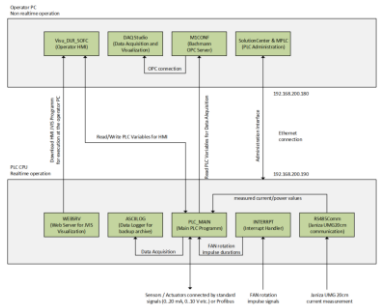
Process system concepting



Transient process system simulations



Control System design



Experimental reactor investigations

Process system experiments

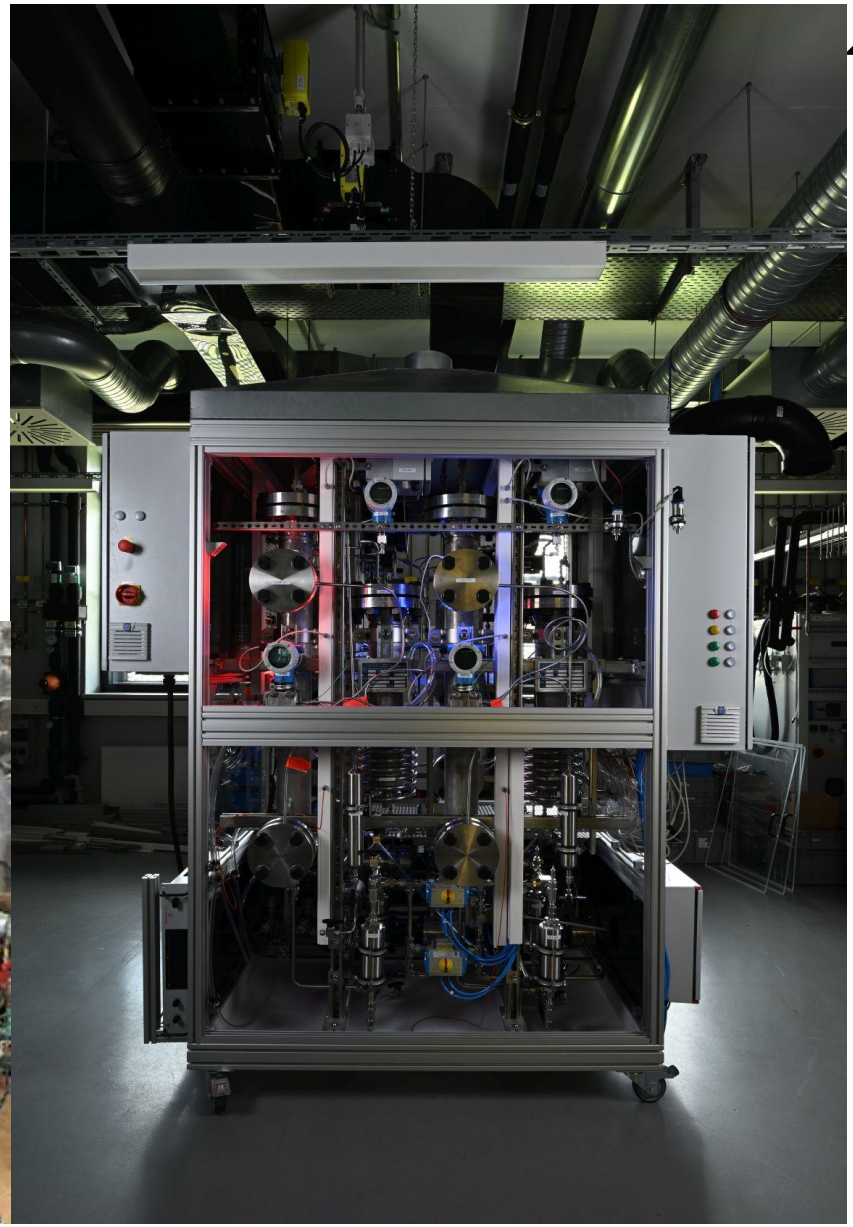
Infrastructures

- Electrolysis Capacity
- 2 Stacks, 2 kW each
- Possibility of two channel, stack operation
- Operation Conditions
- p ≤ 4 bar
- T ≤ 90°C
- Electrochemical impedance analysis on AEL module level
- Online gas analysis

Target: building up AEL electrolyser in the size of MW scale in Baden-Württemberg

Infrastructures

- Stack Test Stand
- Stacks up to 10 kW
- Operation Conditions
- p ≤ 100 bar
- T ≤ 120 °C
- Impedance analysis and automated 24/7 operation is possible

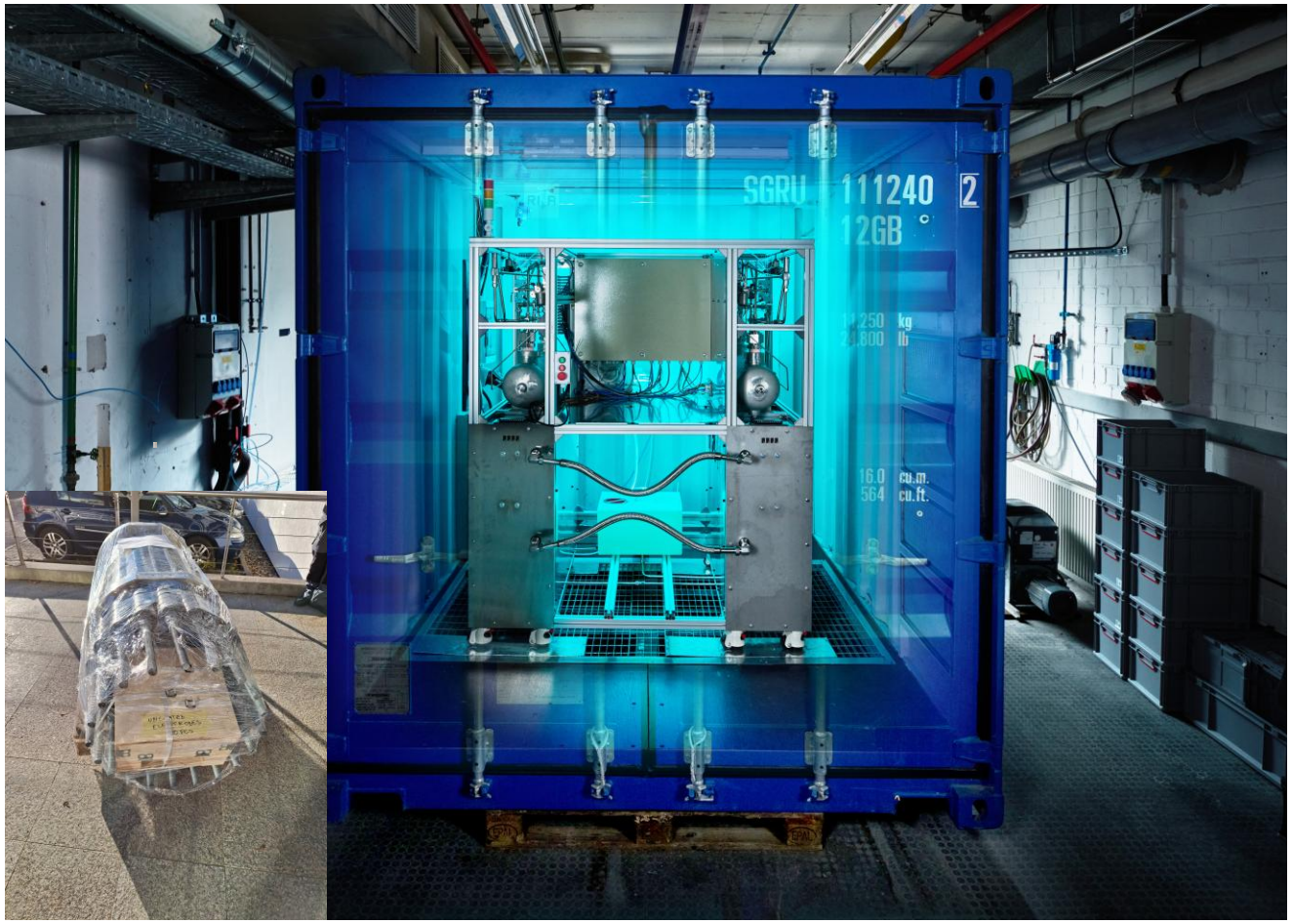


HERA project

- Support of development demonstrator system with 550 kW_{el}
- plant integration concept for integration with waste- and biogas

Infrastructures

- Stack Test Stand
- Stacks up to 50 kW
- Operation Conditions
- p ≤ 50 bar
- T ≤ 80 °
- Automated 24/7 operation possible.
- Impedance analysis planned for 2024



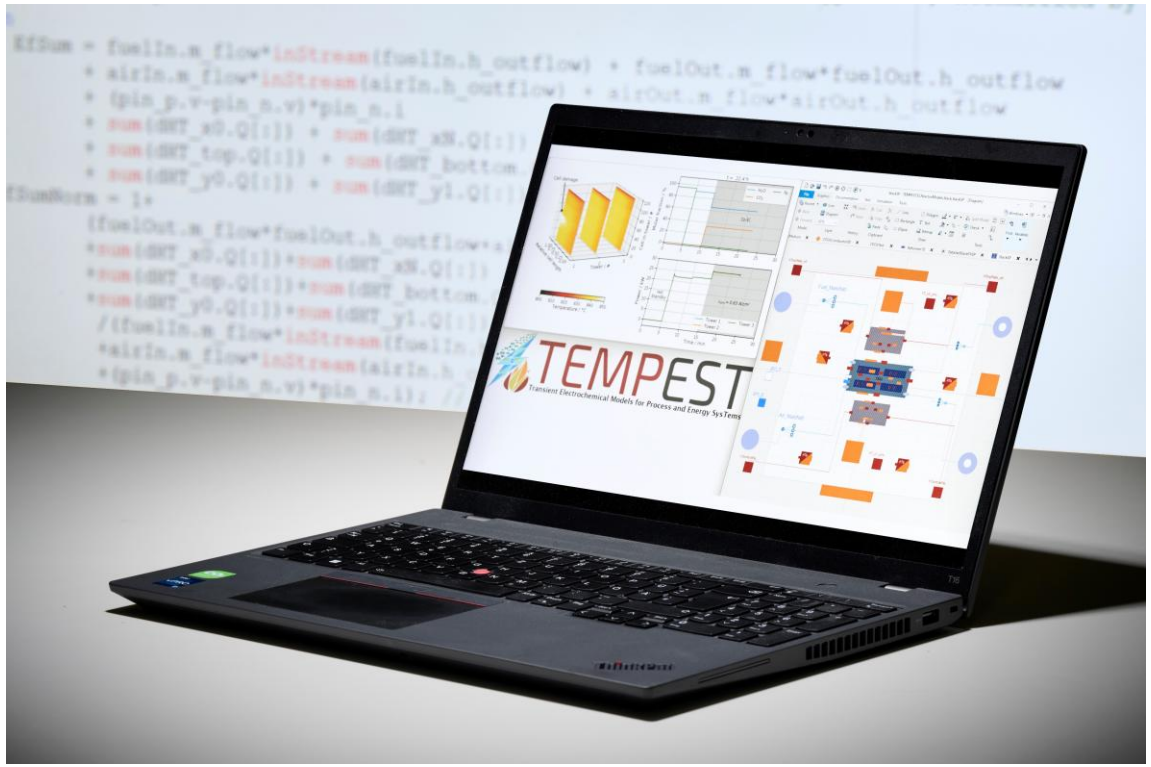
H2Mare project

- offshore generation of green hydrogen and other Power-to-X products

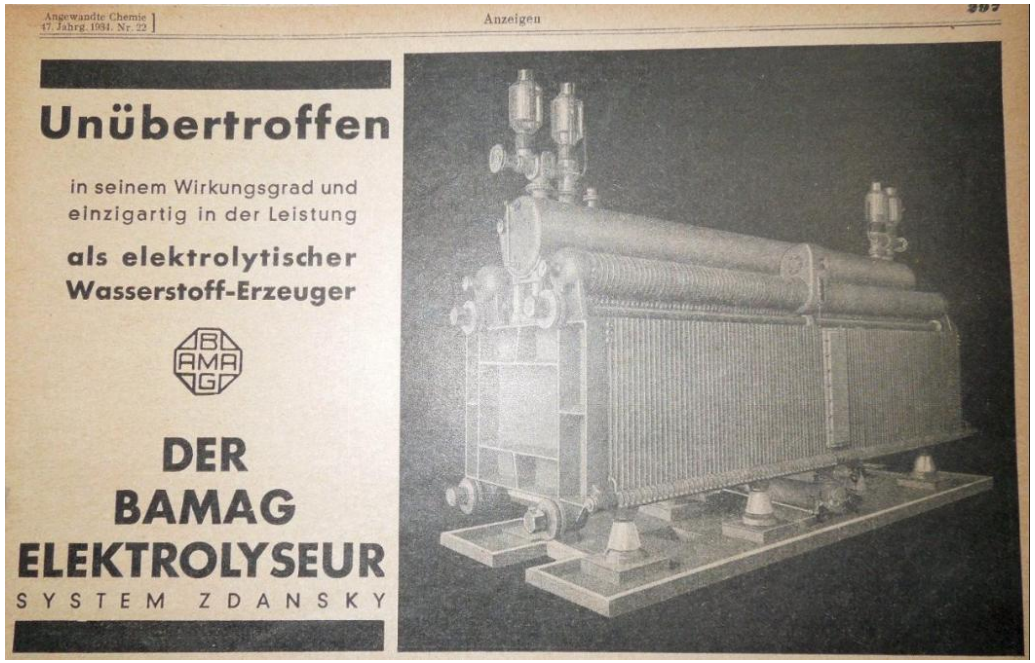
Transient simulation capabilities using TEMPEST platform

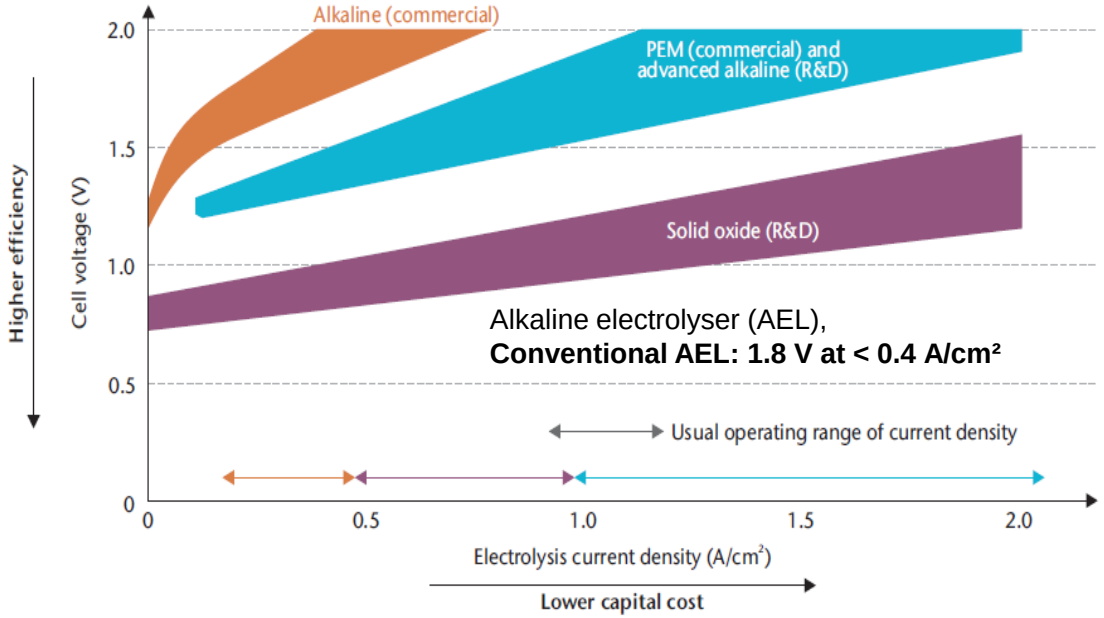
In the transient simulation, the entire system, consisting of stack and BOP components is modelled using the DLR modelling framework TEMPEST (**Transient Electrochemical Models for Process and Energy Systems**). It is implemented in Modelica and provides the possibility to model energy systems with 0D or 1D electrochemical reactors.

The model has a purpose: to determine the influence of various parameters on the performance and to develop control strategies.



State-of-the-art alkaline water electrolysers





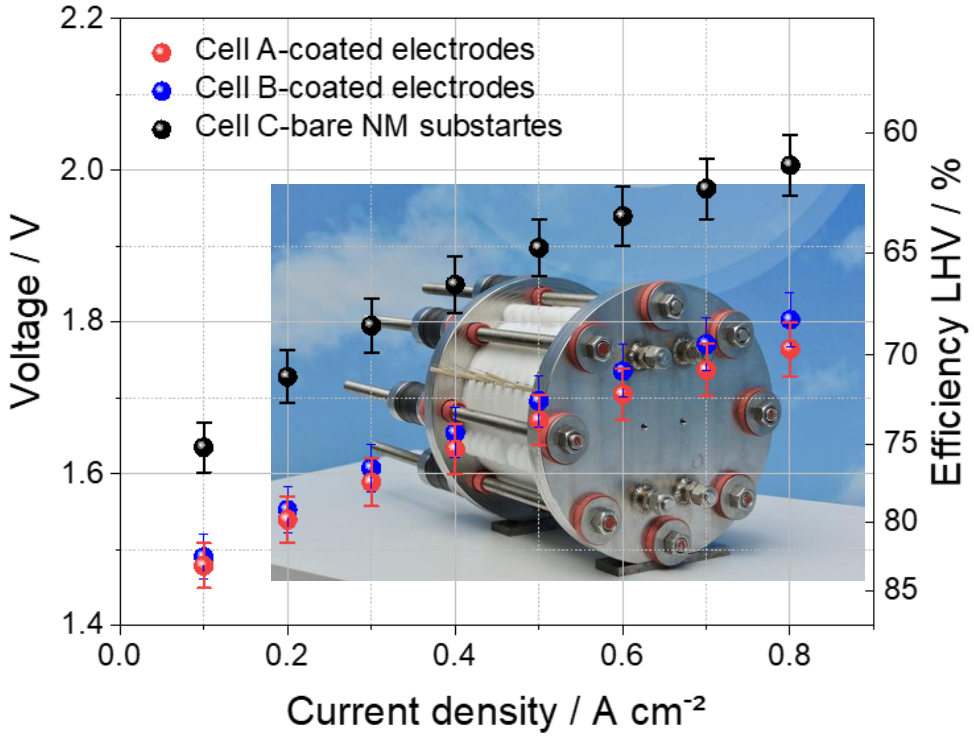
Note: A/cm² = ampere per square centimetre.

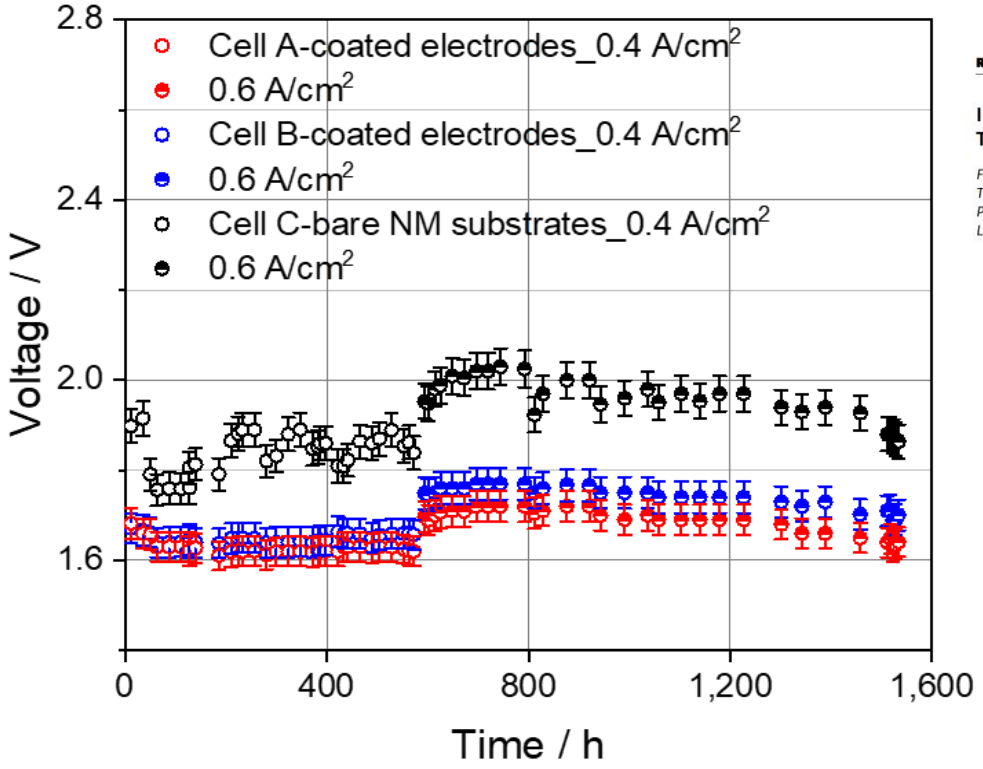
Source: adapted from Decourt et al. (2014), *Hydrogen-Based Energy Conversion, More Than Storage: System Flexibility.*

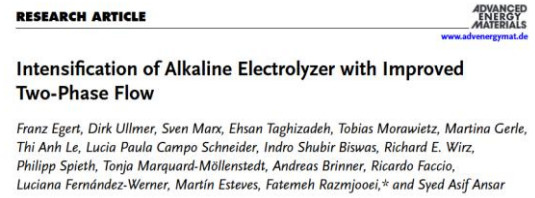
- No precious metals required
- Low cost technology
- Mature technology

- Low current density and effieciency
- Low dynamic
- Gas purity limits part load

Maintaining the performance under long-term operation



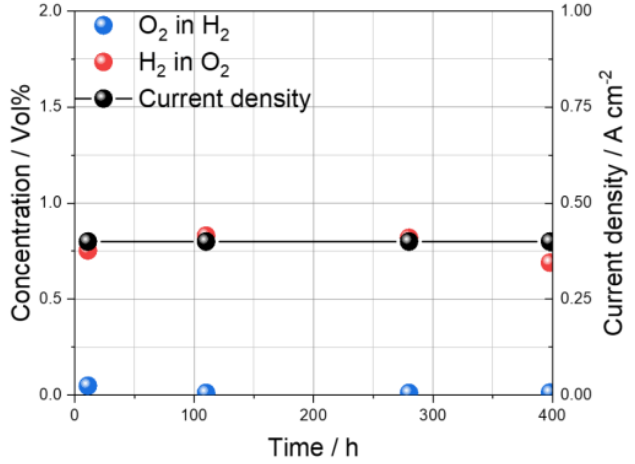



RESEARCH ARTICLE

ADVANCED ENERGY MATERIALS
www.advenergymat.de

Intensification of Alkaline Electrolyzer with Improved Two-Phase Flow

Franz Egert, Dirk Ullmer, Sven Marx, Ehsan Taghizadeh, Tobias Morawietz, Martina Gerle, Thi Anh Le, Lucia Paula Campo Schneider, Indro Shubir Biswas, Richard E. Wirz, Philipp Spieth, Tonja Marquard-Möllenstedt, Andreas Brinner, Ricardo Faccio, Luciana Fernández-Werner, Martín Esteves, Fatemeh Razmjooei, and Syed Asif Ansar*

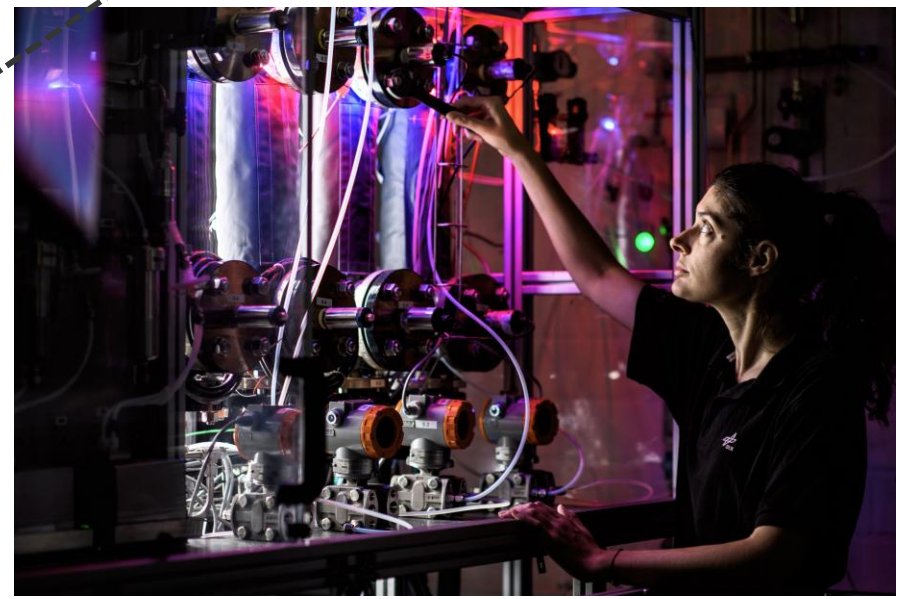


- By optimizing the operational strategies, such as protecting current or the adjusting the flow rate, the thermal overshoot was avoided and no degradation was observed up to nearly 1600 hr
- The same results was achieved for the gas purity, which stayed constant over the long-term operation

Current density and Efficiency

Cell to short stack testing

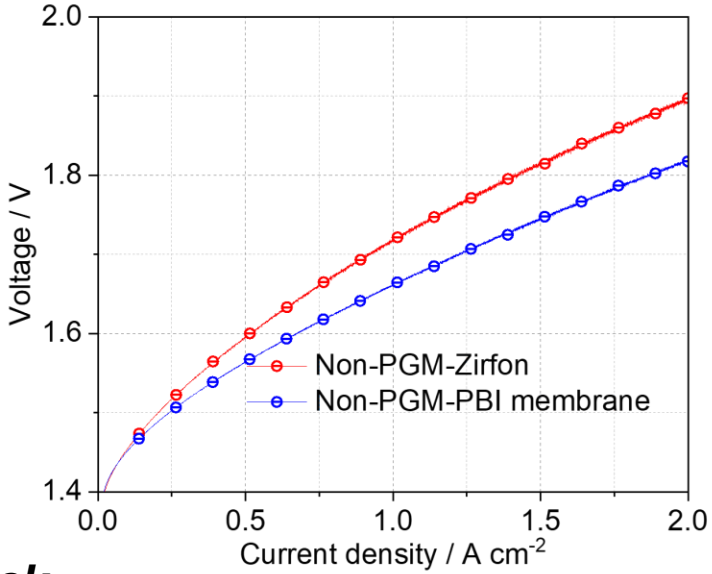
Cell voltage measurement

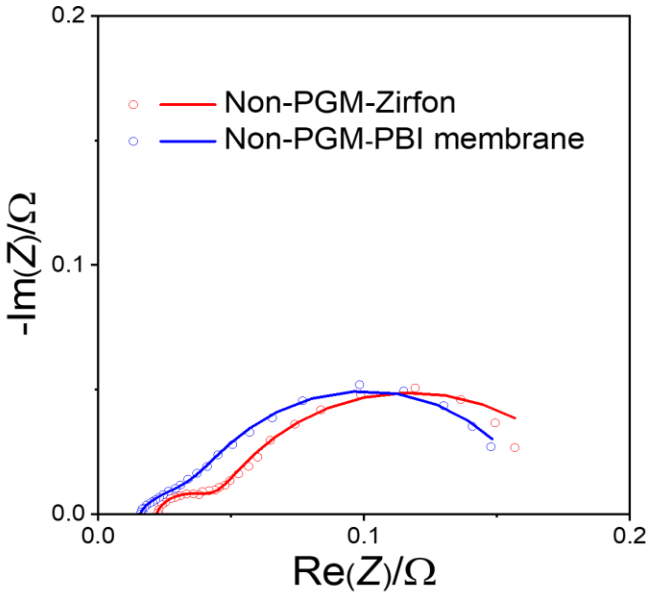


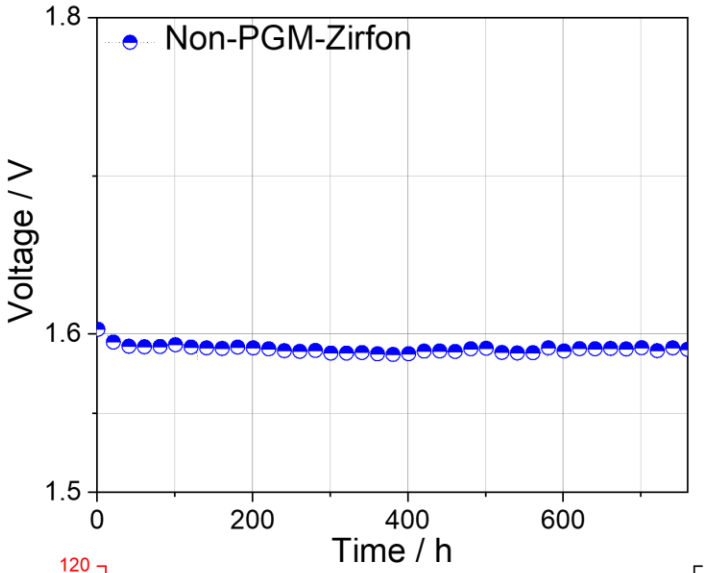
Combination of high performance non-precious based electrodes and SoA Zirfon and PBI-based membrane

Current density and durability at a constant loads

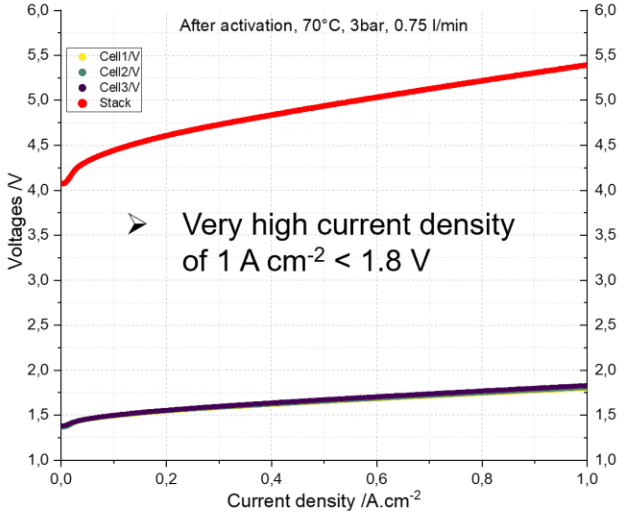
Cell

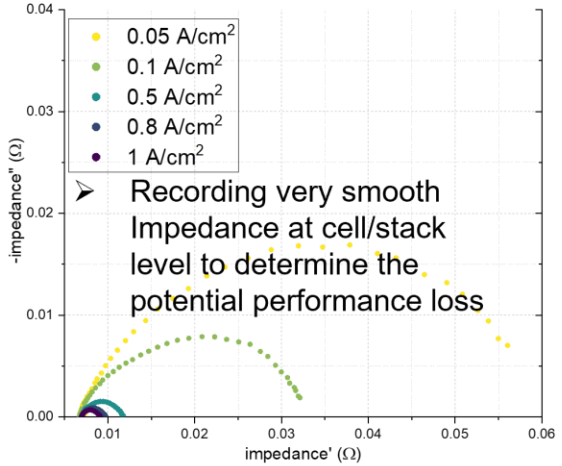


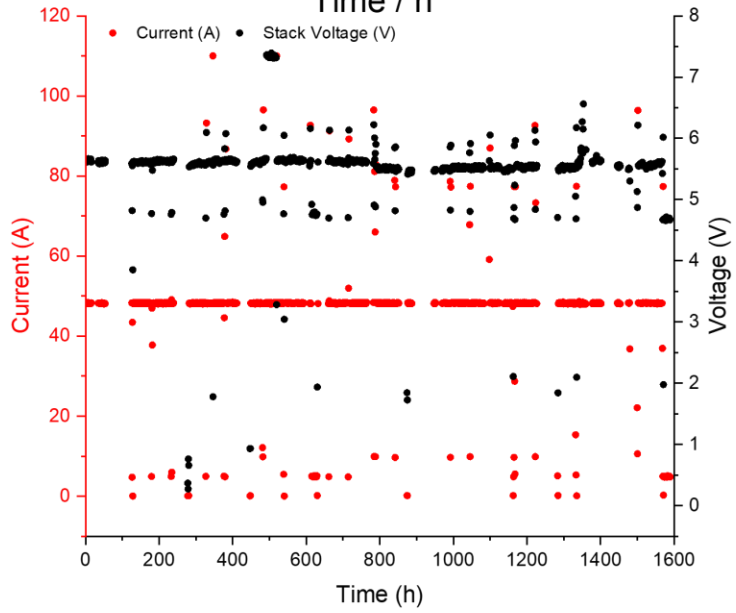




Stack

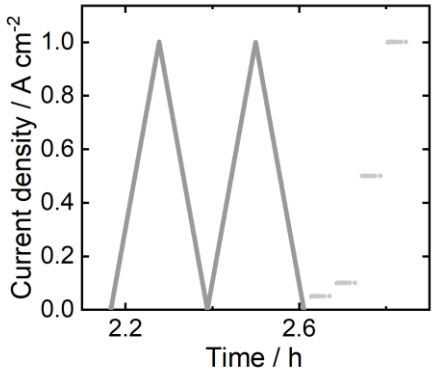


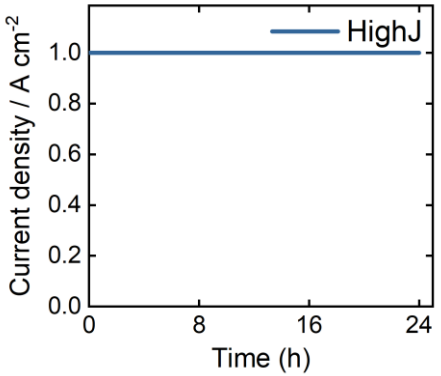


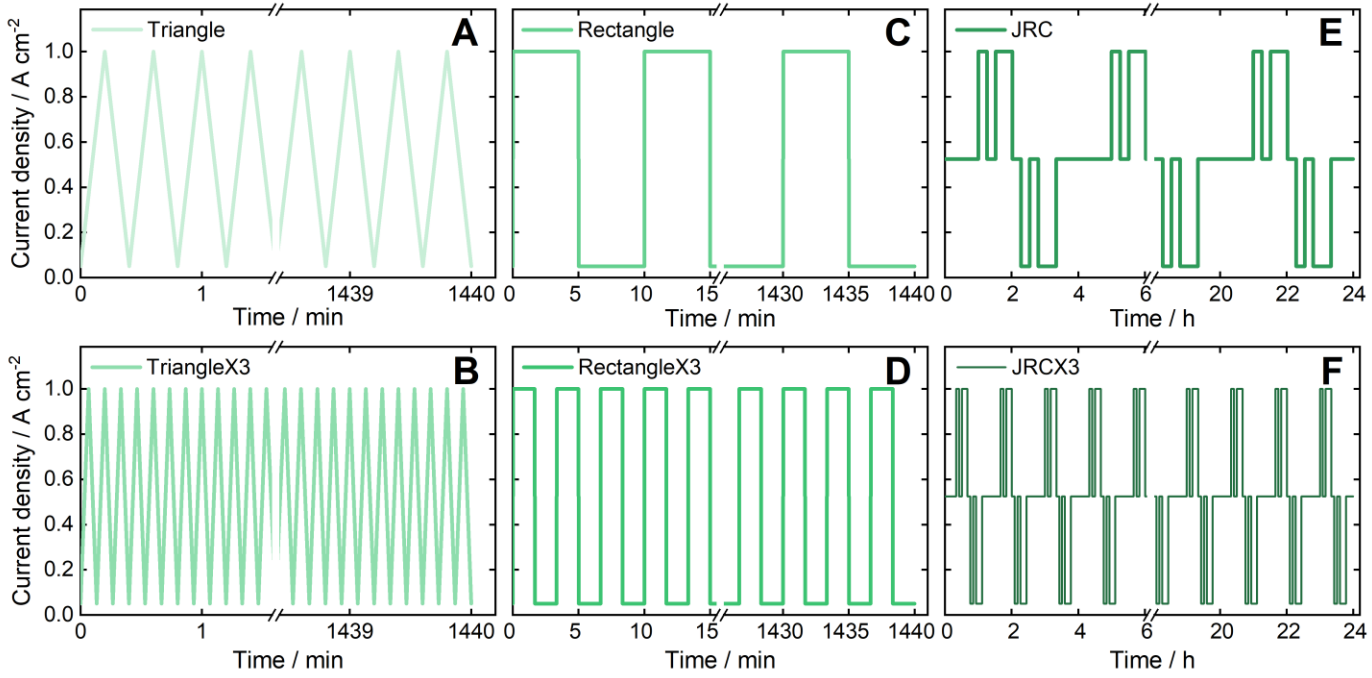


Effect of transient operation on efficiency and durability

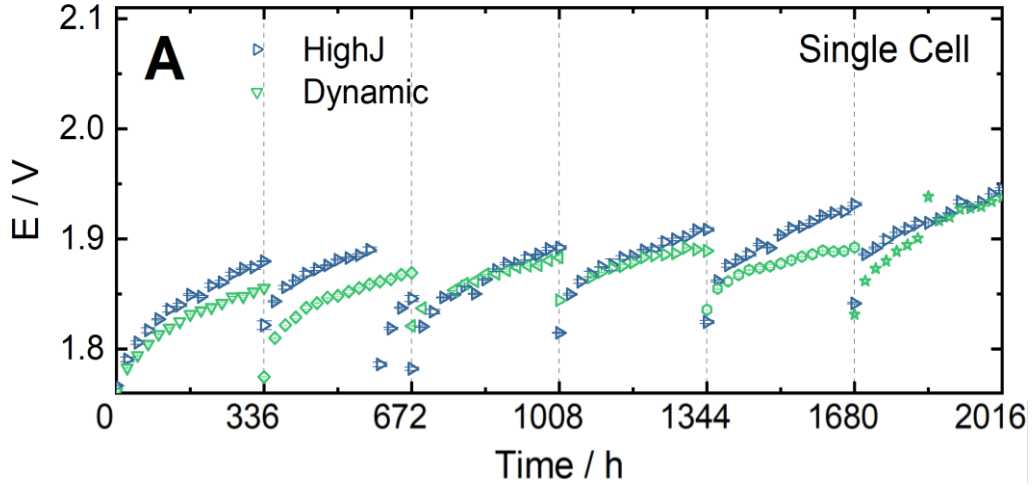
- Performance test every 24 hours
- 24-hour HighJ protocol for 0 - 12 weeks
- Six 24-hour Dynamic protocol







- E at 1 A cm^{-2} every 24 hours

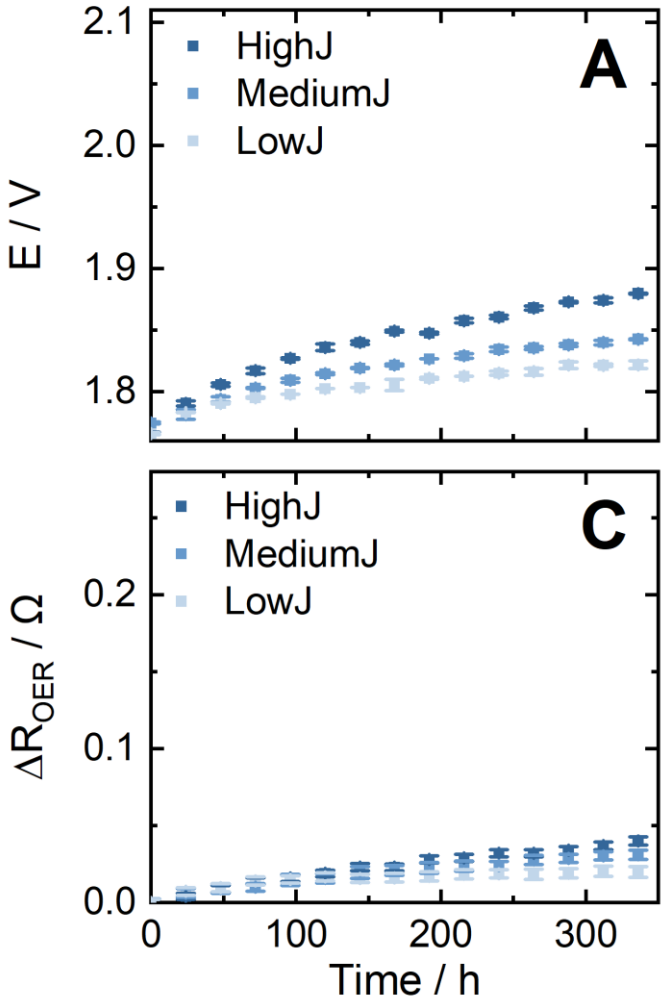


0 - 2 weeks: A – Triangle

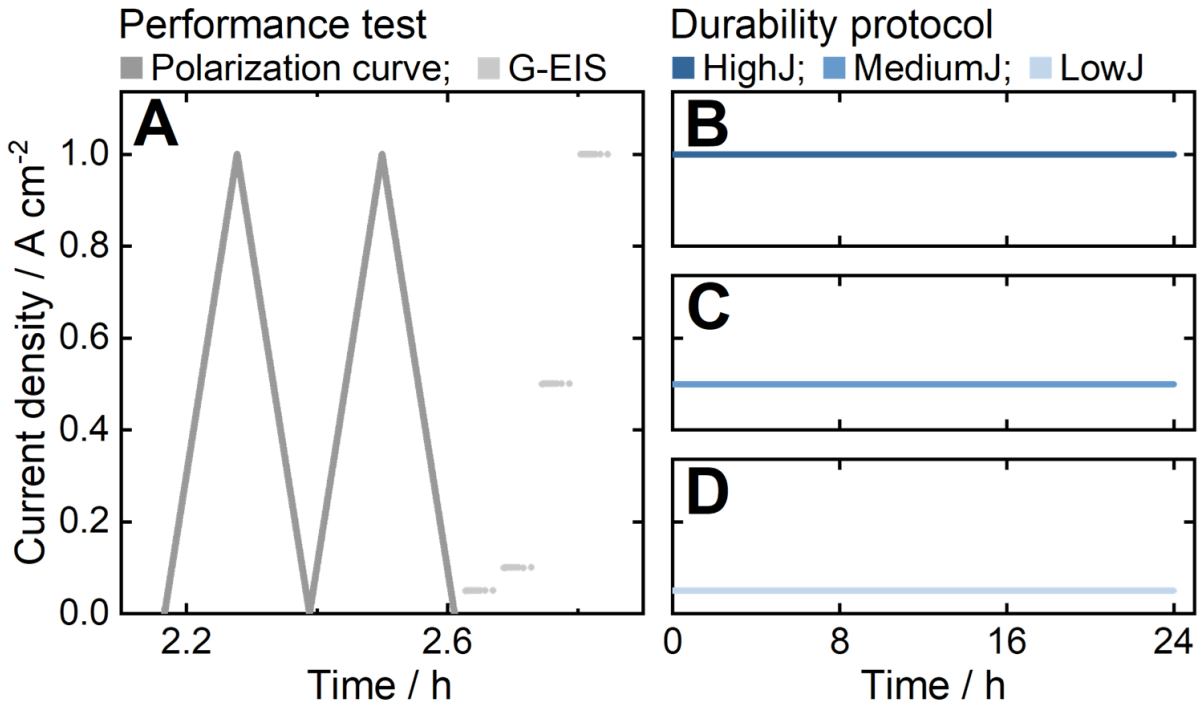
2 - 4 weeks: B – TriangleX3

4 - 6 weeks: C – Rectangle

Effect of transient operation on efficiency and durability

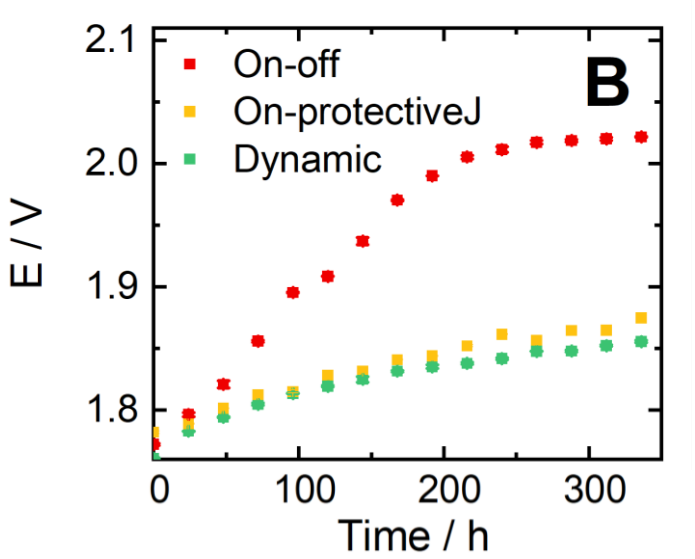


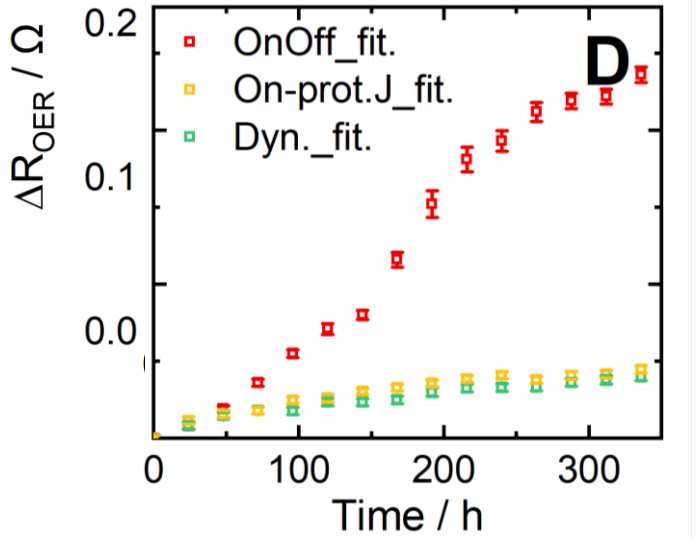
- Experimental



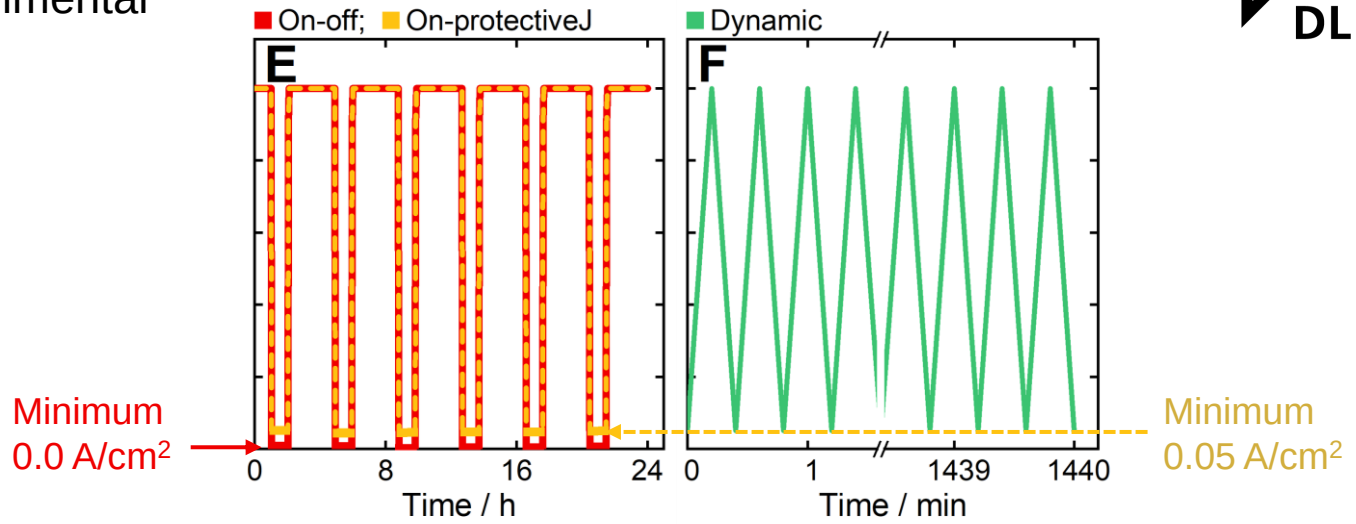
- Findings
  - E and ΔR_{OER} rise faster when a higher constant j is applied

Effect of transient operation on efficiency and durability



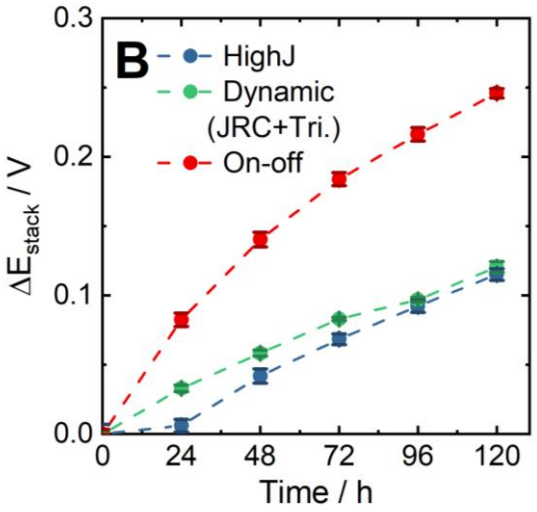


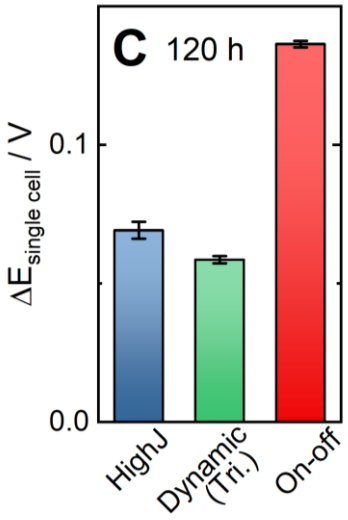
- Experimental



- Findings
  - E and ΔR_{OER} rise faster when a higher constant j is applied
  - Dramatic detrimental effect of the reverse current during the On-off protocol
  - Protective minimum load does prevent dramatic degradation
  - The trends of ΔR_{OER} resemble that of ΔE

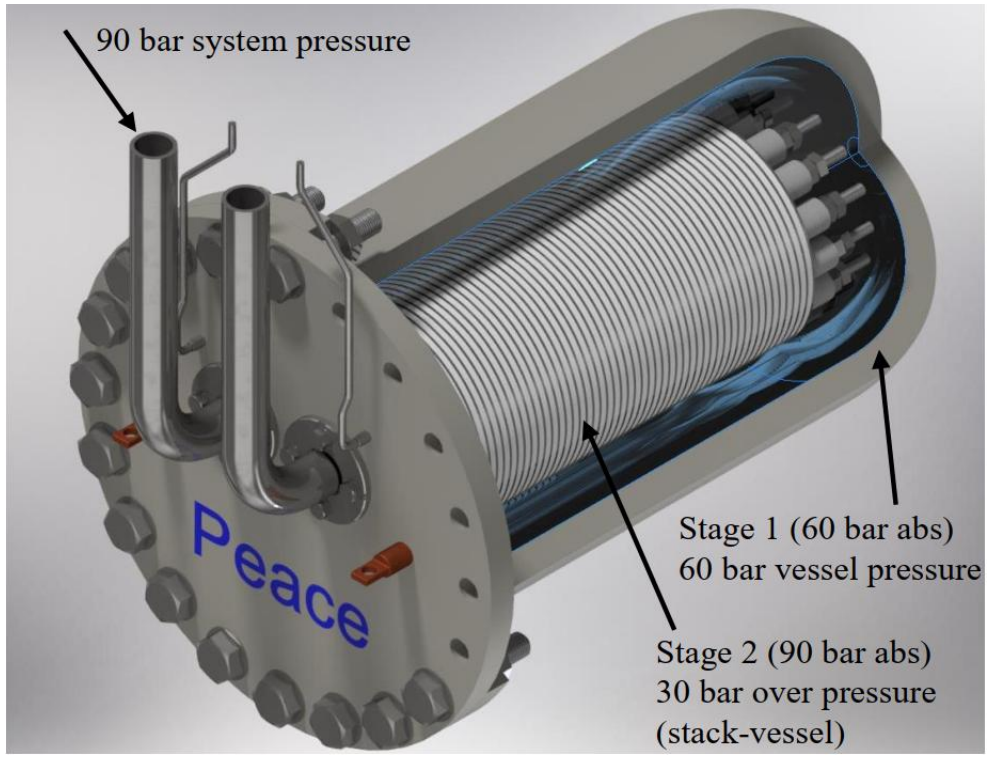
Effect of transient and intensive operation on Stack





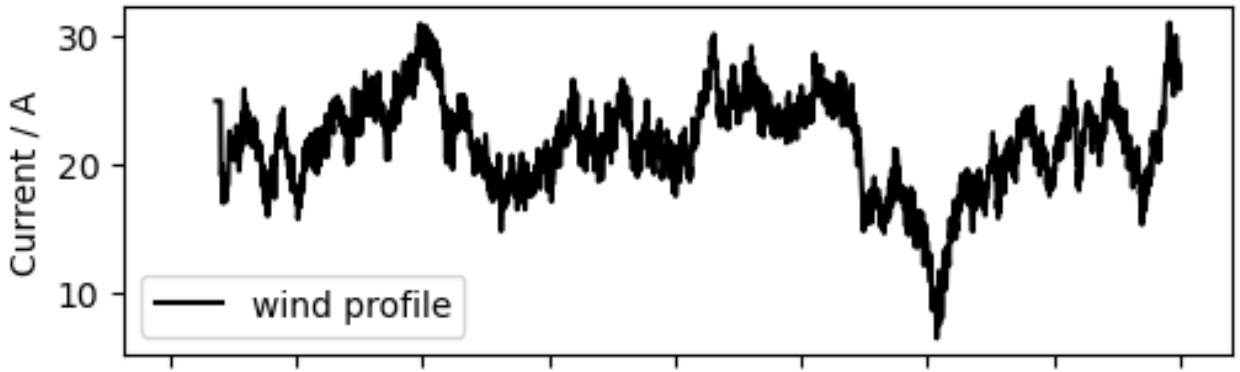
- Findings
  - Stack degradation rate: On-off >> Dynamic ≈ HighJ
  - The stack results align with the single-cell results.

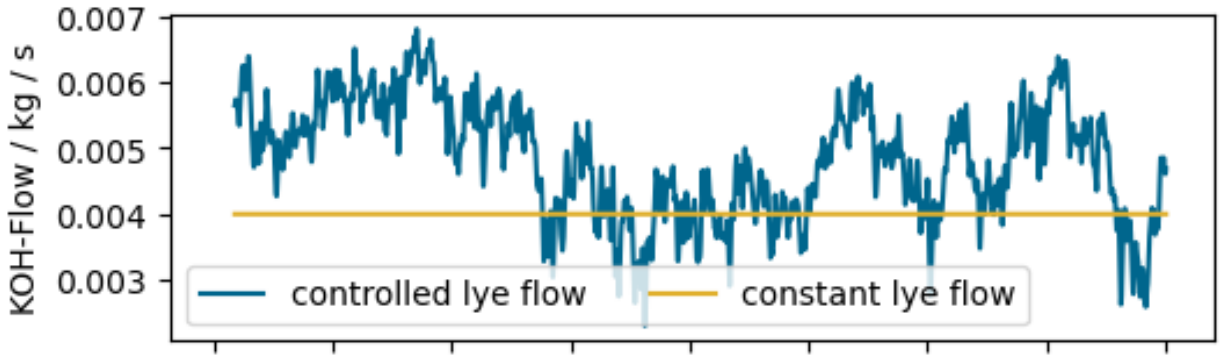
Future tasks:test validation in 50 kW high pressurised system



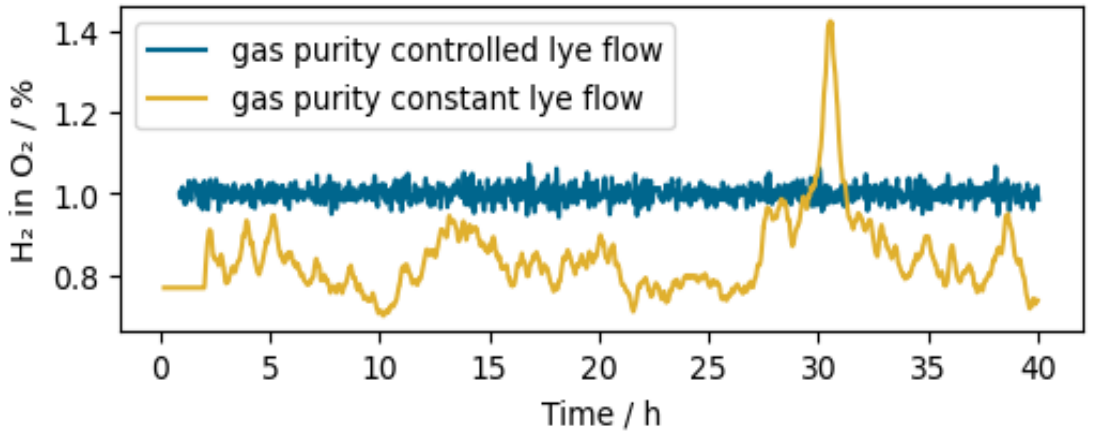
Addressing the high gas impurity under transient operation, from the operational strategies perspective

Fluctuated Wind Profile





Applying controlled operational strategies

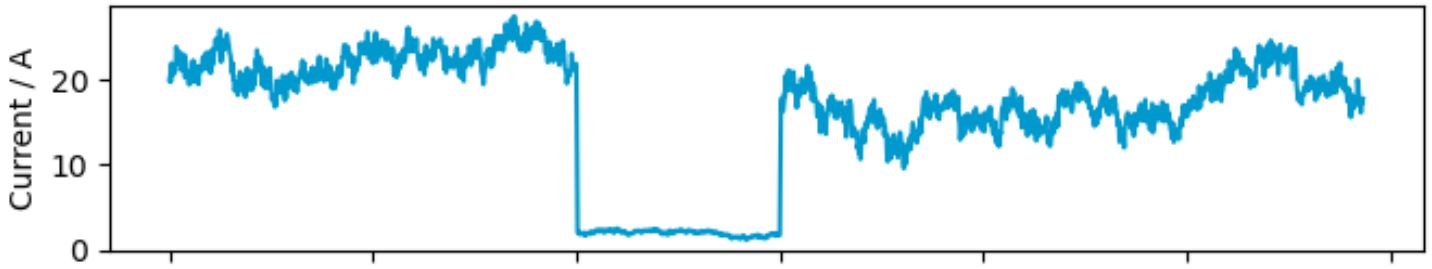


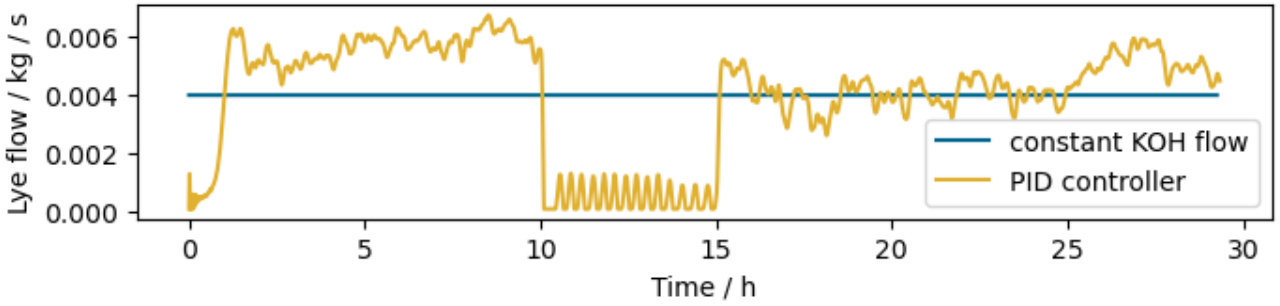
Gas Purity Fluctuations

Transient simulation capabilities using TEMPEST platform

Under nearly shutdown conditions

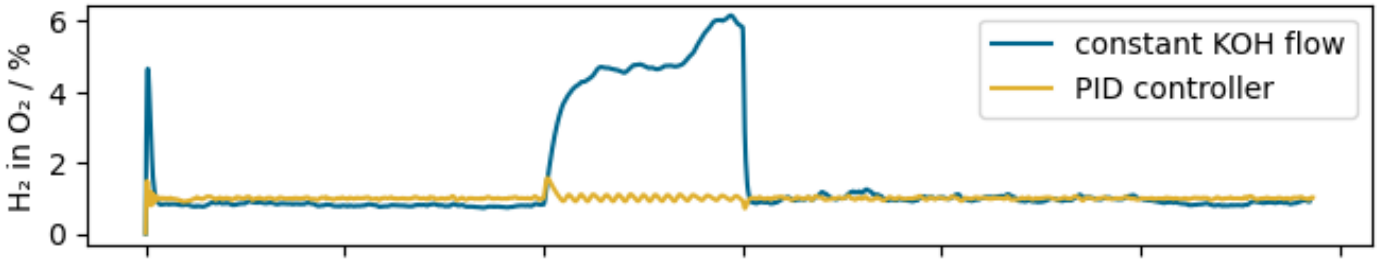
Fluctuated Wind profile



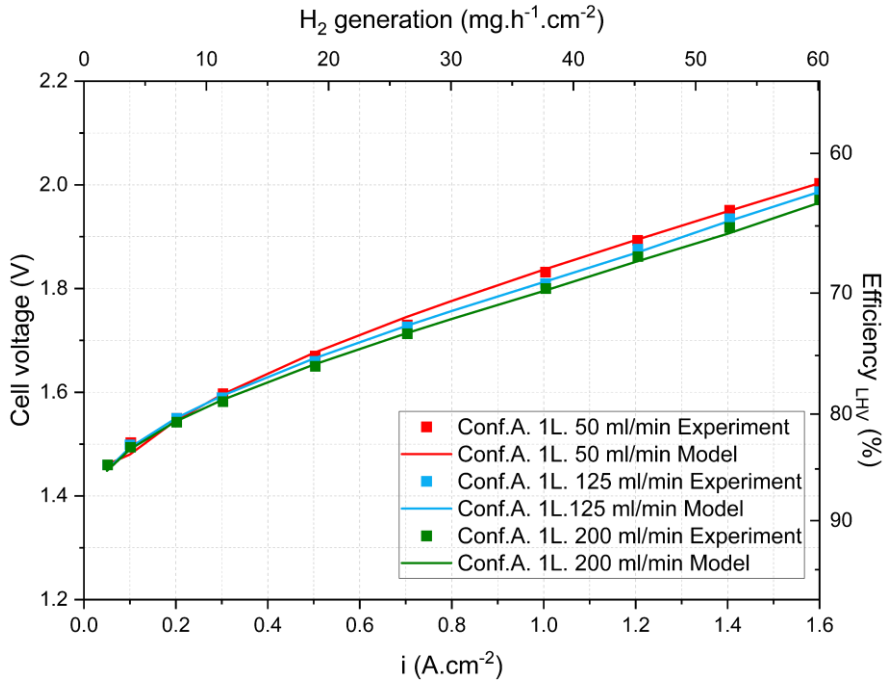


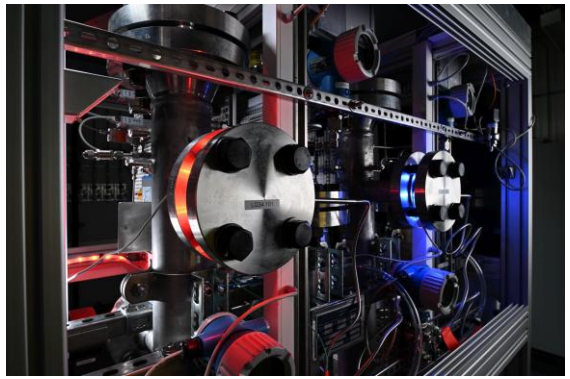
Applying controlled operational strategies

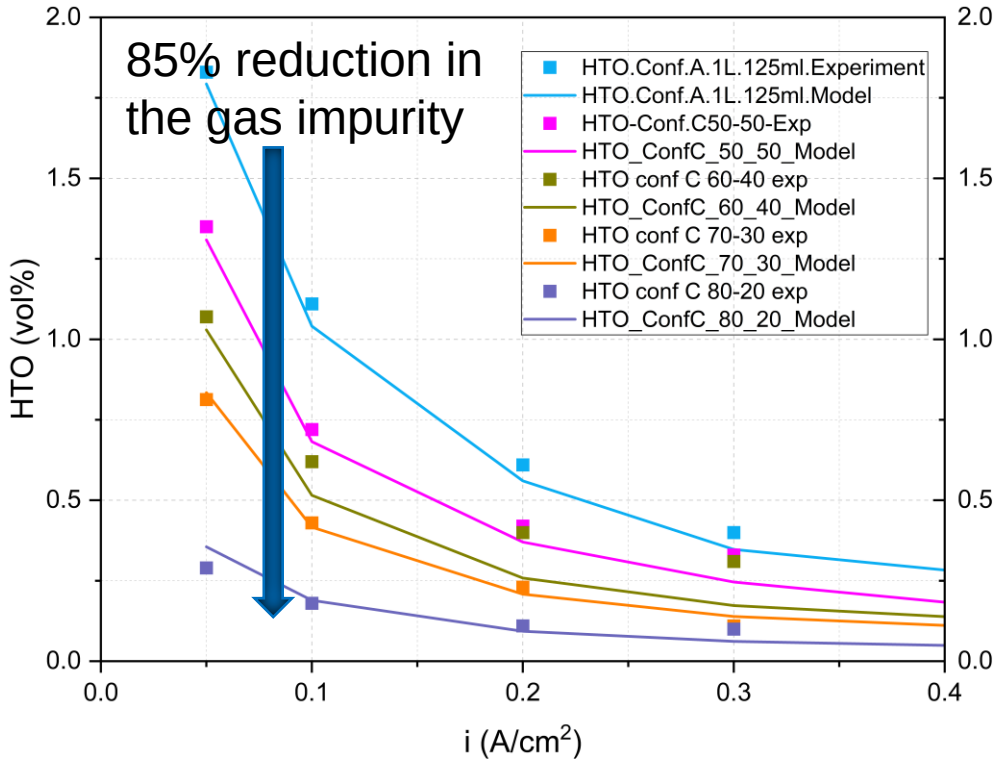
Gas Purity Fluctuations



Transient operation capabilities by optimizing Balance of Plant (BOP)







Under publication, *Confidential*

- Significantly lowering the gas impurity and shifting the part load to the lower current by optimizing the BOP
- At the same time keeping the efficiency high at very high current density

Conclusion:

- Increasing the current density and the efficiency is a material focus, however, marinating the efficiency high under dynamic operation is a system question

- Degradation under transient operation is accelerated by increasing the current density
- operation, however, it is severely affected under on-off condition

- The degradation under transient operation including on-off condition can be controlled and minimized by applying a small protecting current

- Gas purity could improve through applying optimized operation strategies by controlling the lye flow and optimizing the BOP design

Thank you for your attention

Acknowledgment:

PEACE project
H2GiGA-Degrad EL3 and AEL4Giga

For more information on TEMPEST:
Poster session : Transient simulation of AEL from atmospheric to high pressure
Hans Wiggenhauser

Contact Information:

Fatemeh.razmjooei@dlr.de