Fraunhofer ISE

Fuel Cell Systems @ Fraunhofer ISE

Ulf Groos, Head of Department Fuel Cell Systems
Fraunhofer Institute for Solar Energy Systems
Freiburg, 2022
www.h2-ise.com
www.ise.fraunhofer.com

Fuel Cell Systems: Core Competences

Fully engaged for our clients

1. Facts & Figures
2. Modeling
3. Production Research
4. Ex-situ Analytics
5. In-situ MEA Characterization
6. In-situ Stack Characterization
7. Testing of Balance-of-Plant Components

01

Facts & Figures

Fraunhofer ISE

Scientifically Sound R&D Services

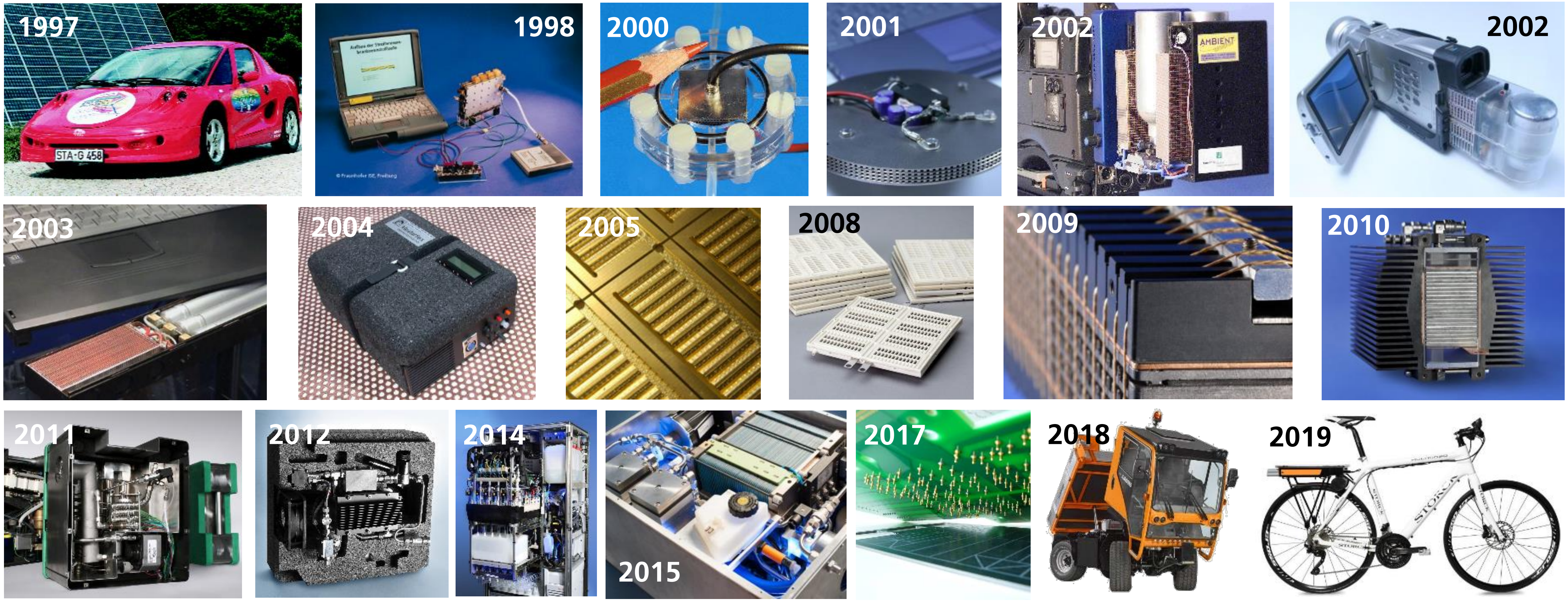
Our customers rely on our results

Department Fuel Cell Systems

1. > 24 researchers plus students
2. 3.8 Mio € annual budget (w/o investments) and 40% direct revenue by industry contract research (2021)
3. >500 m² laboratory area with 12 single cell test stations, 4 short stack test stations, 1 system test site, 2 climate chambers (all fully automated for 24/7 operation)
4. Focus on transport application (LT PEMFC)

Enjoy our virtual lab tour:
https://www.ise.fraunhofer.de/en/business-areas/hydrogen-technologies-and-electrical-energy-storage/fuel-cell-systems.html

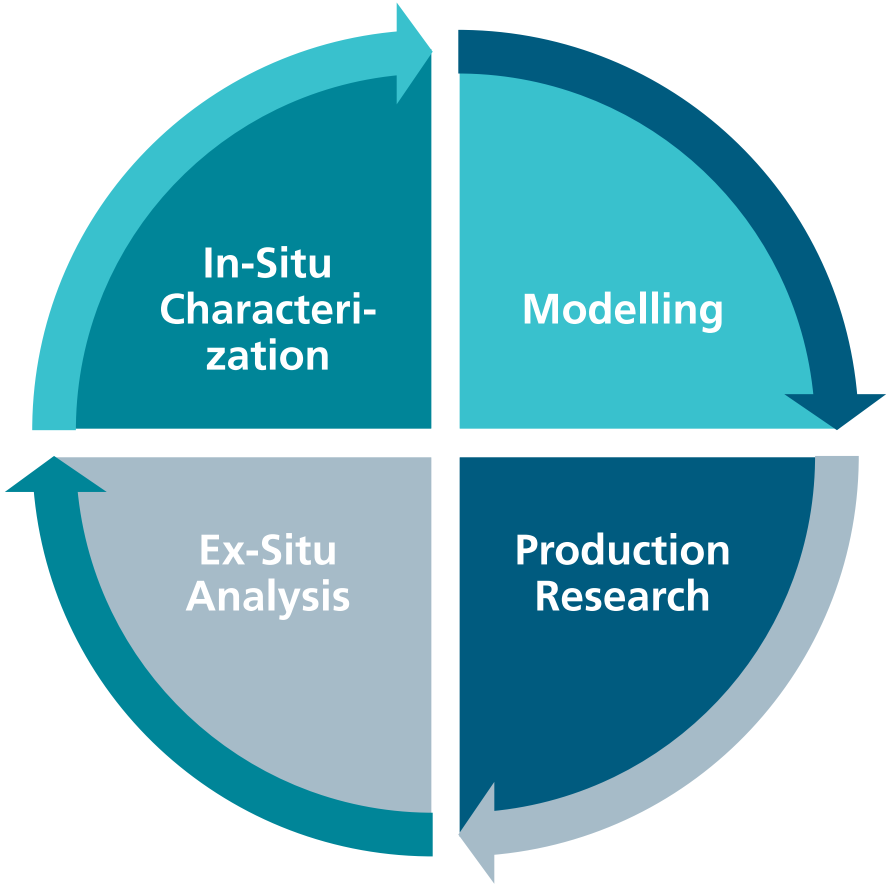
Fuel Cell Experience Since the 1990s



Value Proposition to Our Customers

Concentrating on Low Temperature PEM Fuel Cell Membrane Electrode Assemblies

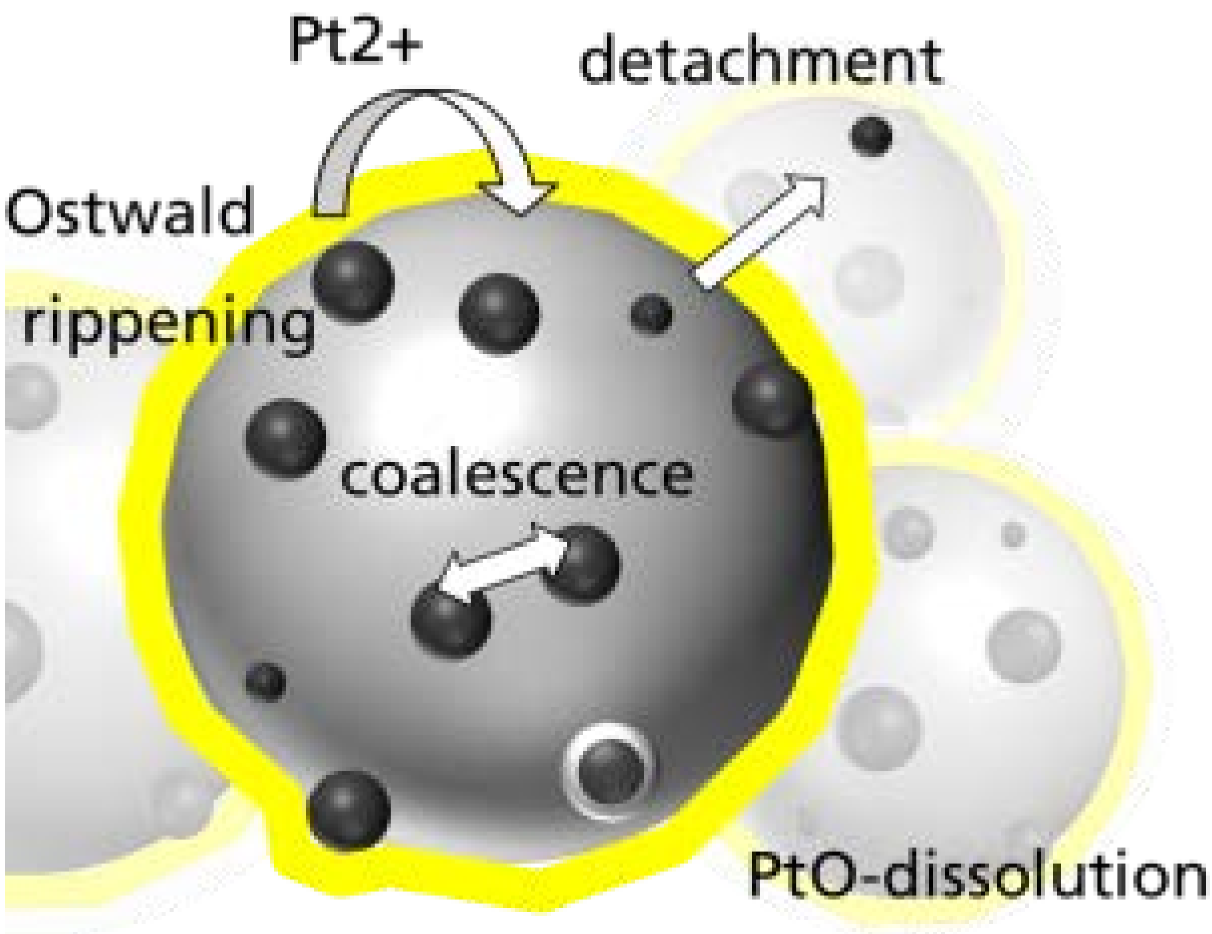
1. Understanding Cell & Stack Designs
2. Developing Production Technologies & Processes
3. Optimizing Materials & Components
4. Optimizing Operating Strategies from Cell to System Level



Proofing our results by the international scientific community

YEAR	TITLE/AUTHOR
2021	Activation mechanisms in the catalyst coated membrane of PEM fuel cells Christmann, K.; Friedrich, K.A.; Zamel, N.
2021	Application of Artificial Intelligence in the Context of Fuel Cells: Presentation held at Hydrogen Lunch Online Edition, 18.03.2021, Freiburg, Germany Scherzer, A.-C.; Schneider, P.; Zamel, N.
2021	Application of Artificial Intelligence in the Context of Fuel Cells. An overview of surveyed literature: Presentation held at f-cell, Stuttgart, Germany, Virtual, 14.09.-15.09.2021 Scherzer, A.-C.; Schneider, P.; Zamel, N.
2021	Catalyst Coated Membranes - their Structure, their Performance and their Durability: Presentation held at World Fuel Cell Conference (WFCC), Virtual, Canada, 16.08.2021-20.08.2021 Zamel, N.
2021	Characterizing Automotive PEMFC Membrane Electrode Assemblies: Presentation held at KOITA Fraunhofer Webinar, South Korea, June 7th, 2021 Groos, U.; Georg, A.; Gerteisen, G.; Hebling, C.; Klingele, M.; Sadeler, C.; Scherzer, A.; Schneider, P.
2021	A Decade of German-Canadian Cooperation in Fuel Cells. Looking back at our story so far : Presentation h...ld at Digitale Informationsreise nach Deutschland für kanadische Akteure: "Elektromobilität: Batt... /Flexible Produktion", online, Germany, 28.09.2021-30.09.2021 Zamel, N.; Gerteisen, D.; Groos, U.; Hebling, C.
2021	From Catalyst Powder to Membrane Electrode Asse... Stuttgart, Germany, September 15th, 202... Clement, F.; Keding, R.; Kling...
2021	Hydrog... ...chweizer H2-Forum, Konstanz,
20...	...errepresentation of Women in STEM: AI-enabled Solutions and More ...el, N.; Al-Othman, A.
2021	Modeling the Flow Behavior of Catalyst Inks for PEM Fuel Cells by an Evolutionary Algorithm Ney, L.; Singh, R.; Göttlicher, N.; Le, H.-P.; Tepner, S.; Klingele, M.; Keding, R.; Clement, F.

Download our publication from our website::
https://www.ise.fraunhofer.de/en/business-areas/hydrogen-technologies-and-electrical-energy-storage/fuel-cell-systems.html

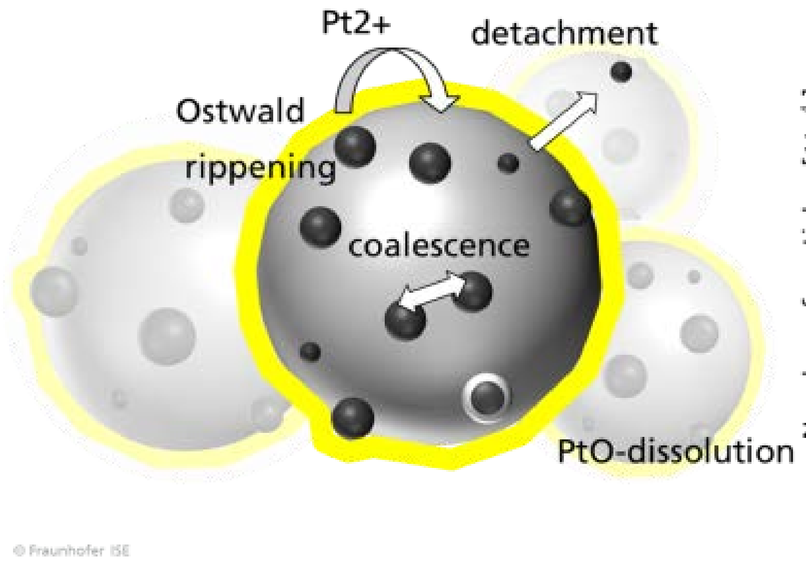

Pt2+
detachment
Ostwald
rippening
coalescence
PtO-dissolution

02

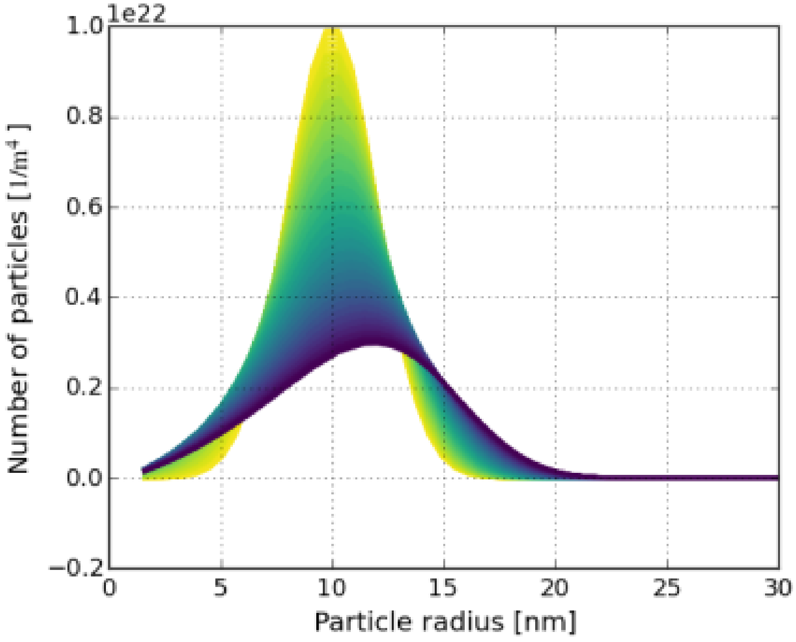
Modeling

Performance and State-of-Health Modeling

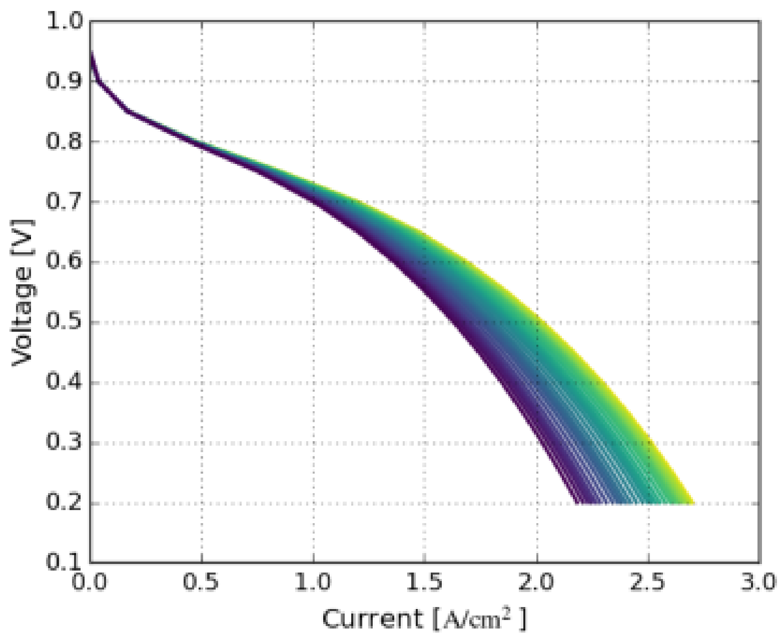
Optimizing electrodes and operating strategies



Phenomena of potential induced degradation of electro-chemical surface area (ECSA)



Simulation of ECSA degradation due to potential cycling of CCM



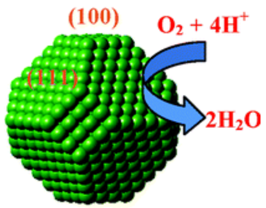
Simulation of performance degradation due to accellerated stress testing

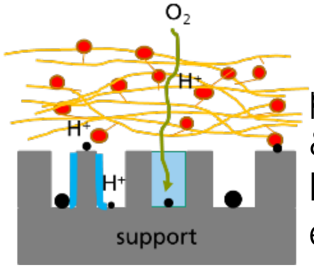
Federal Ministry of Education and Research
Federal Ministry for Economic Affairs and Energy
Fraunhofer ISE

Modeling the Microstructure of Catalysts

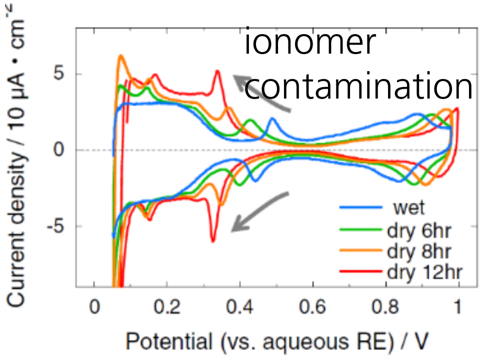
Optimizing electrodes

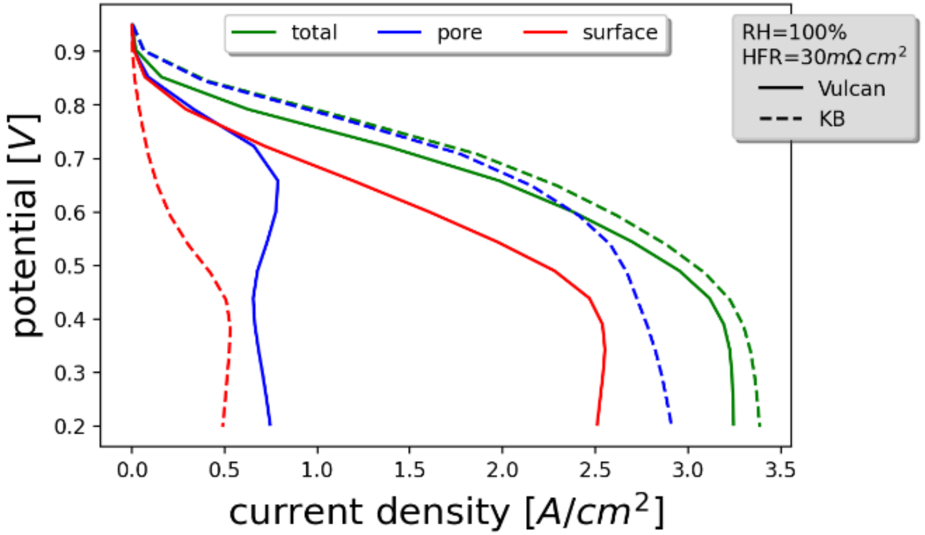
particle size dependent kinetics



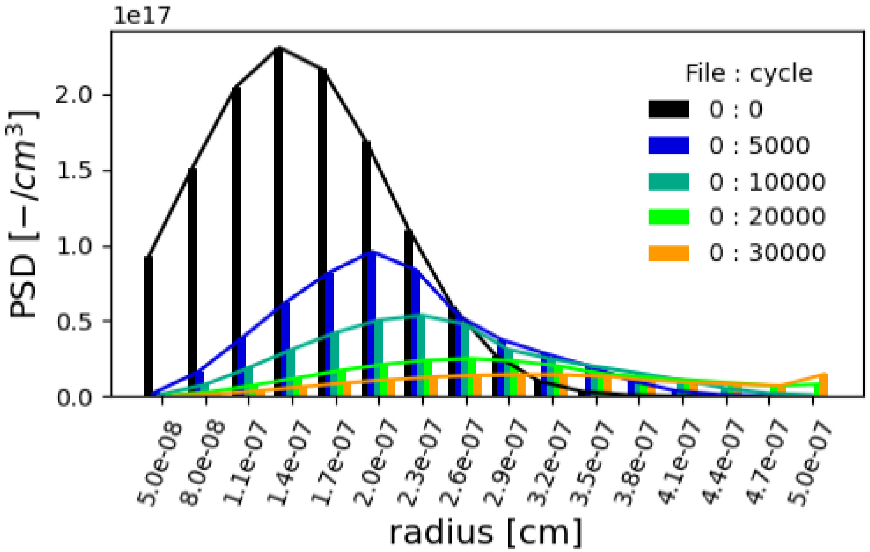


pore size & humidity effects

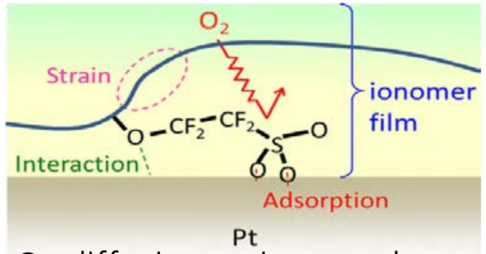




Influence of Pt distribution inside & outside support particle pores on polarization curve



Pt particle size distribution dependent on the cylce number with an accellerated stress test



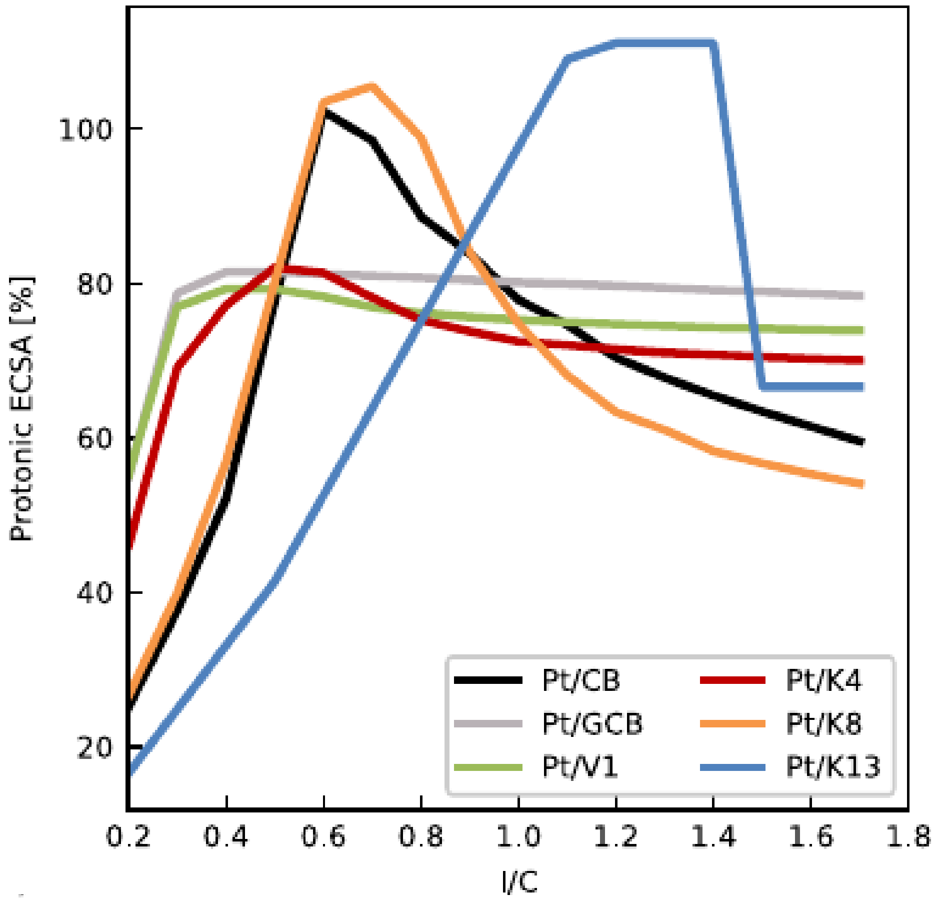
O_2 diffusion resistance due to ionomer thin film

FC-CAT FC-RAT Federal Ministry of Education and Research Fraunhofer ISE

Modeling the Microstructure of Catalysts

Optimizing electrodes

- Morphological properties are unique to each Pt/C/ionomer system
- Modeled processes depend on local particle, pore sizes and local ionomer film thickness → different local combinations can have different effects
- Global properties of CCL can be calculated from local distributions as well



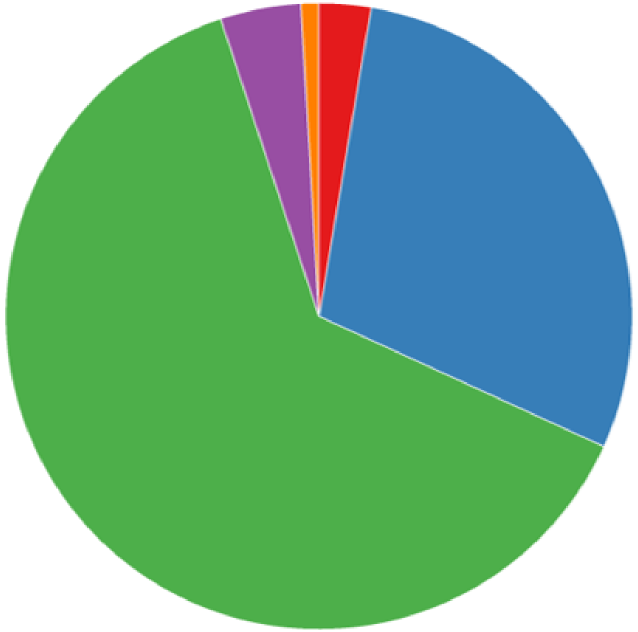
Above: catalyst morphology with different pore sizes in support, different Pt particle diameters and Pt particles inside & outside porse, different ionomer coverage
Below: Electrochemical Surface Area (ECSA) with respect to ionomer to carbon ratio and low or high surface area carbon

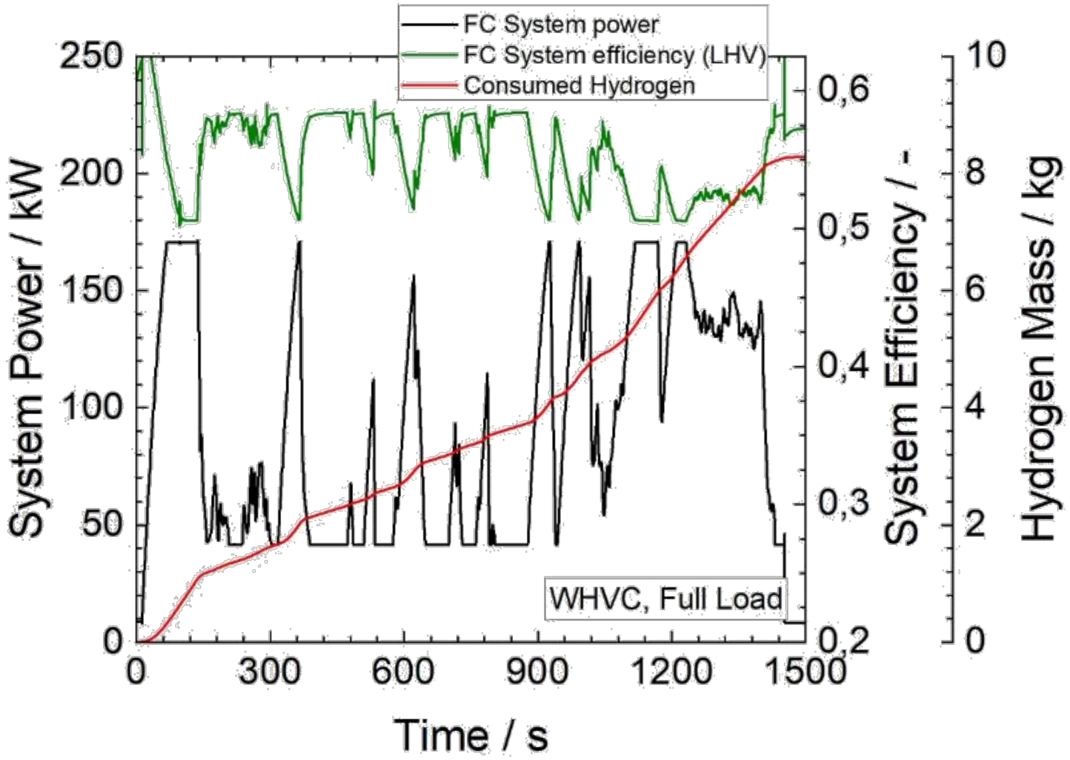
Scherzer, A. C., Schneider, P., Herring, P. K., Klingele, M., Zamel, N., Gerteisen, D. (2022). Modeling the Morphological Effects of Catalyst and Ionomer Loading on Porous Carbon Supports of PEMFC. Journal of The Electrochemical Society

System Modelling

Optimizing customer specific system designs and operating strategies

	kW
Air compressor	23,64
Anodic recircula-tion	1,56
Cooling Pump	0,34
Other electronics	1
Voltage converter (eta: 96%)	10,92

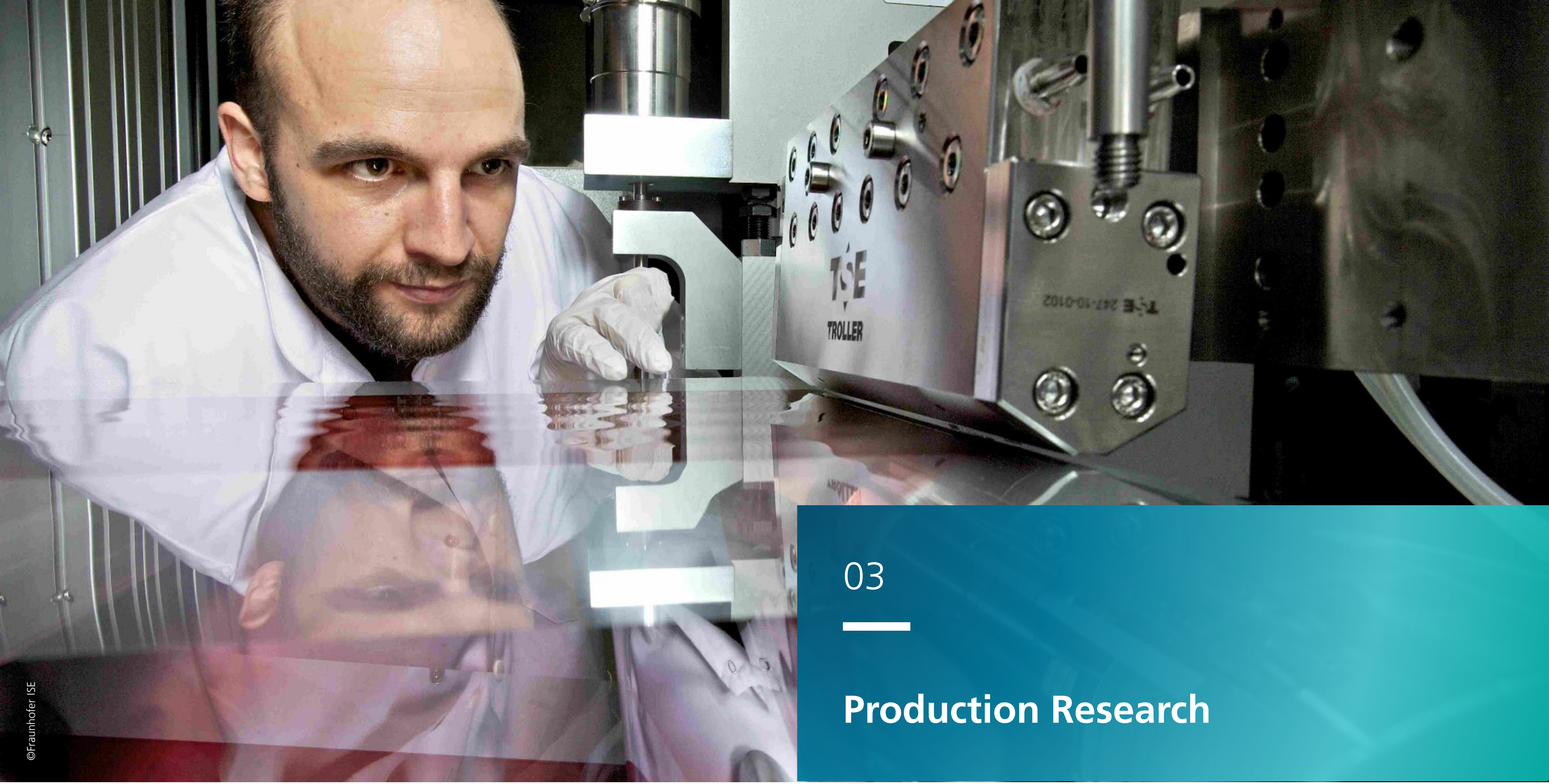




Investigating system losses in a customer system design and specific load profiles

System efficiency and hydrogen consumption according to a specific drive cycle

Fraunhofer ISE



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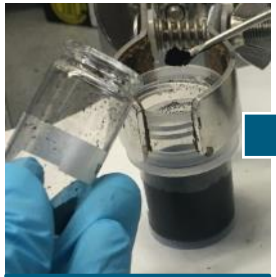
03

Production Research

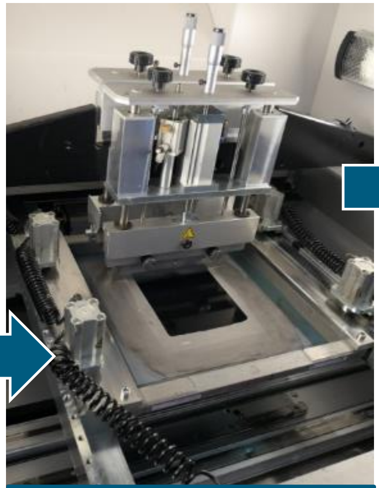
MEA Production Research

Finding best process technologies and parameters – from catalyst powder to complete MEAs

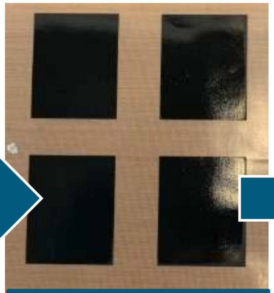


Ink formulation

Ink dispersing



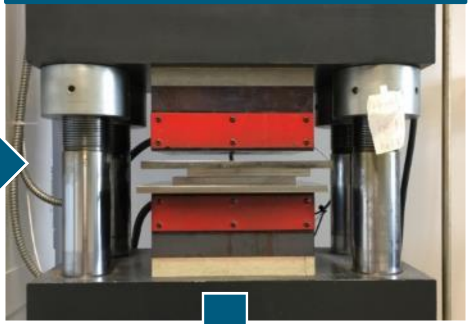
Screen Printing



Printed Catalyst Layers

Drying

Hot-Pressing

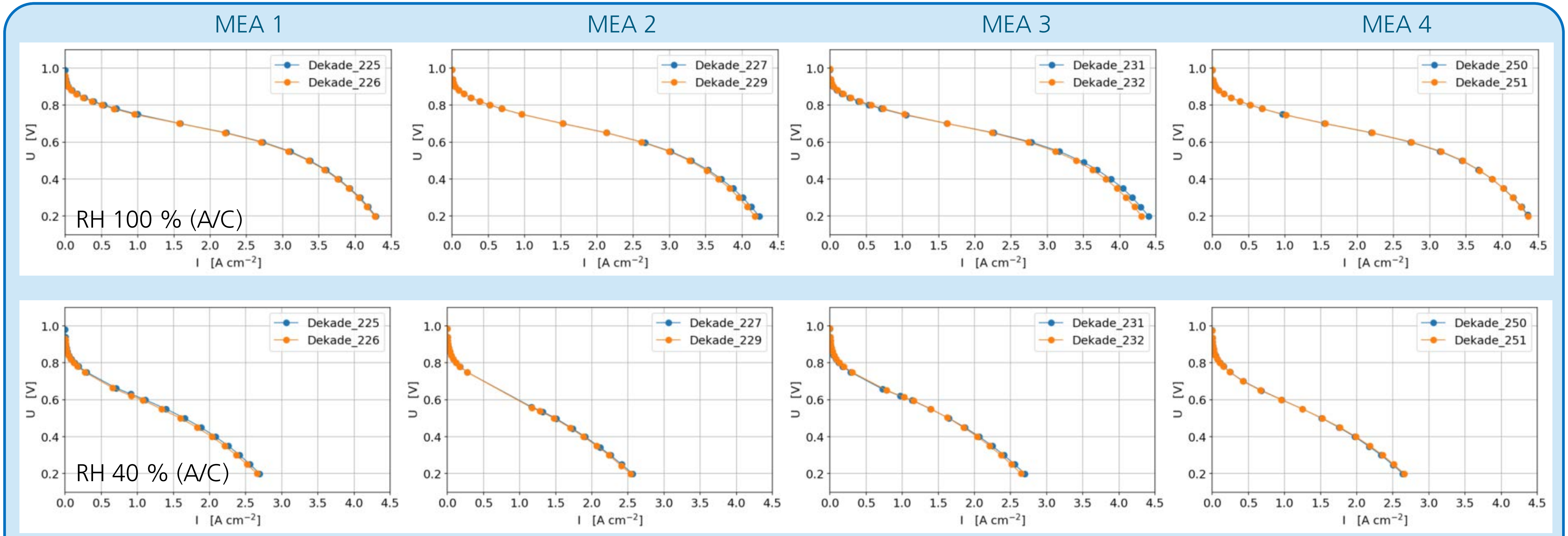


In-situ characterization

Our latest report (German): https://www.ise.fraunhofer.de/content/dam/ise/de/documents/projekte/Zwischenbericht_HyFab_2021.pdf

High Reproducibility of Production Process and In-Situ Characterization

Polarization Curves @ wet & dry conditions



air/H_2, 0,25 mg_{Pt}/cm^2 (C), 0,05 mg_{Pt}/cm^2 (A), 2 bar_a

Federal Ministry of Education and Research

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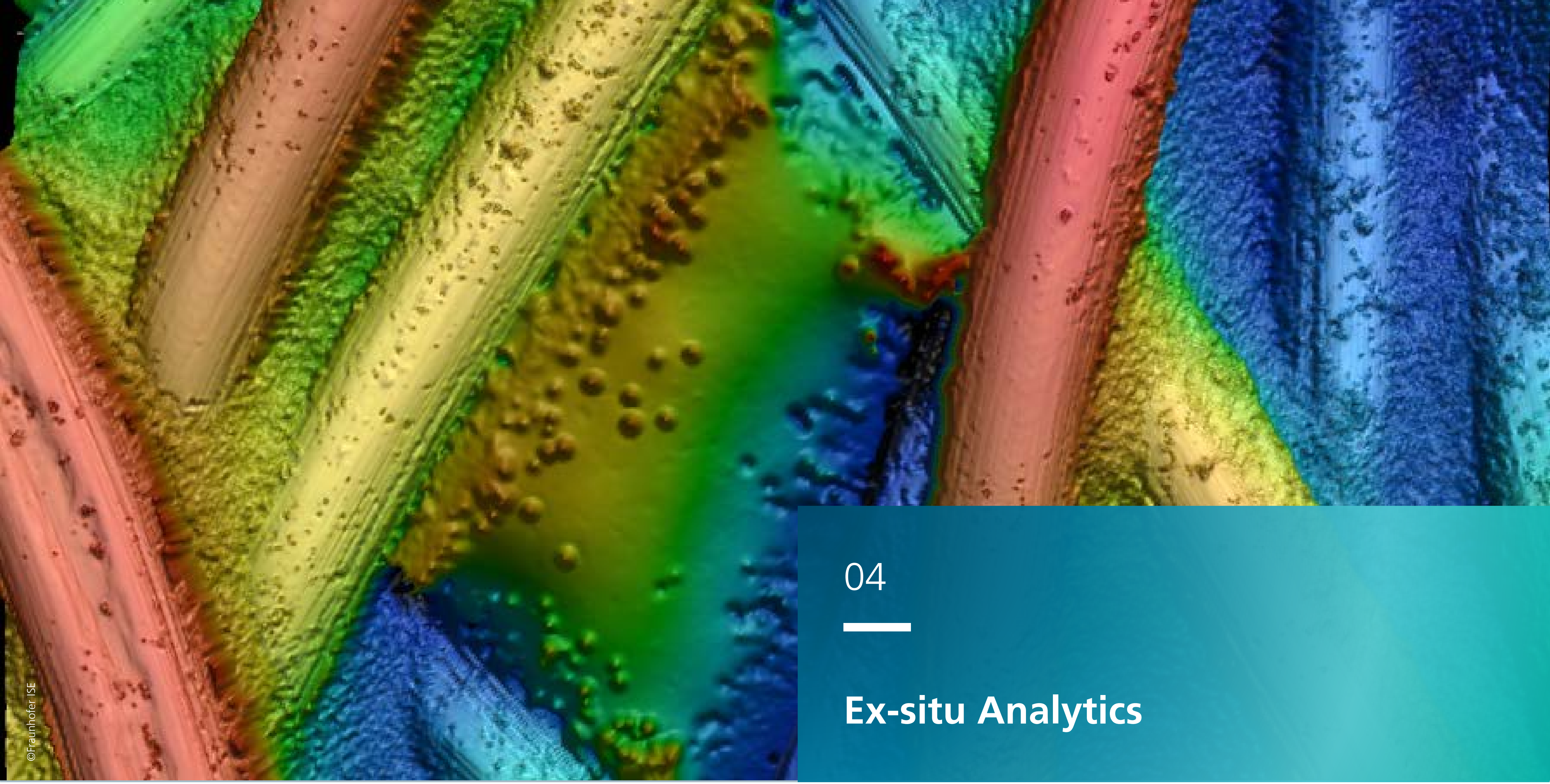


04

Ex-situ Analytics

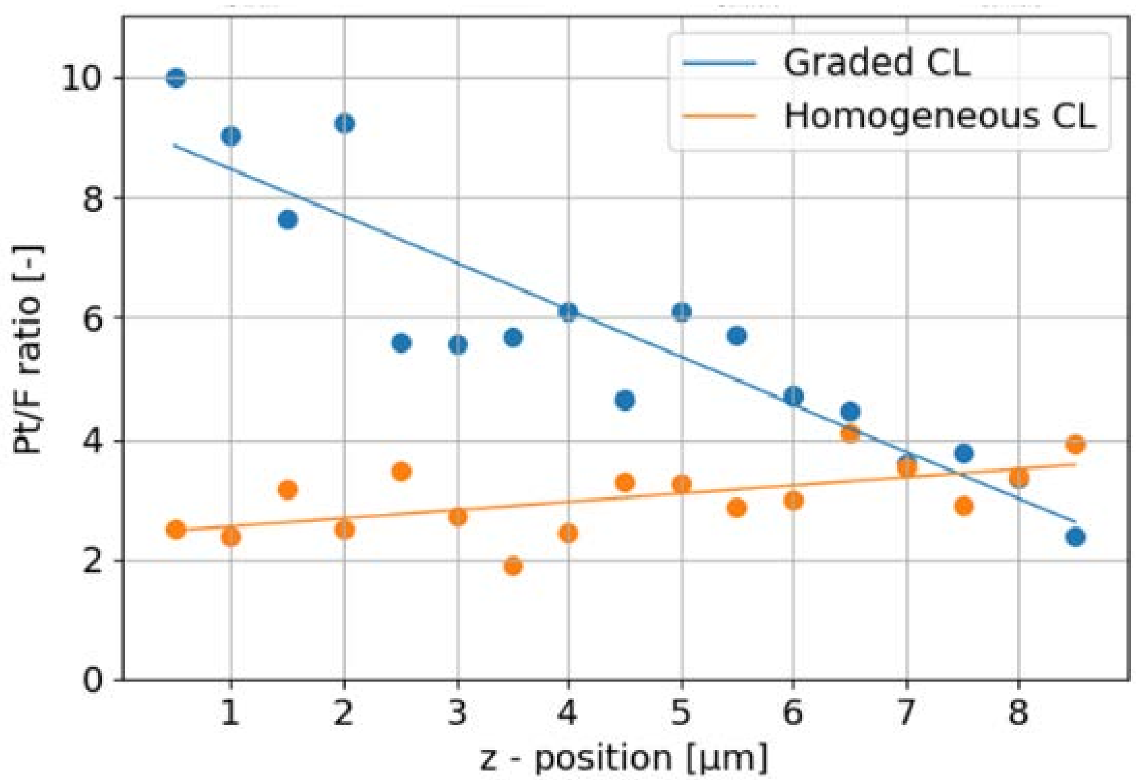
Investigating BoL and EoL Microstructures of Fuel Cell Components

Understanding material composition and structure

Our Analytical Equipment

1. Laserscanning microscope and profilometer for surface microscopy
2. SEM / EDX for element analysis of surfaces
3. XRF for catalyst distribution on surfaces
4. XPS for catalyst analysis
5. FIB-SEM and µCT for analysis of morphology
6. ICP-MS for element analysis in liquids

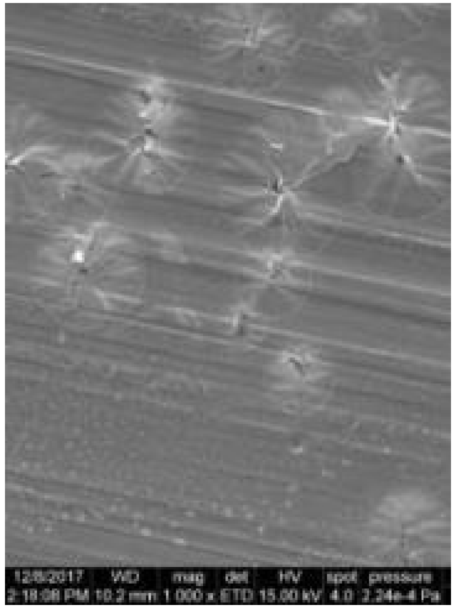
Find out more regarding our ex-situ analytics equipment: https://www.ise.fraunhofer.de/content/dam/ise/de/downloads/pdf/H2T-Ex-Situ-Analytics.pdf



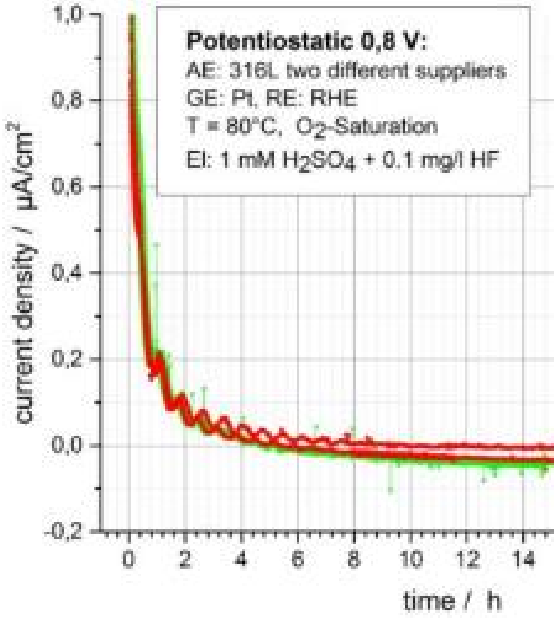
SEM microscopy of a Fraunhofer ISE CCM with ionomer-graded catalyst layer. EDX allows to analyze the spatial element distribution of Pt and F

Electro-Chemical Stability of Bipolar Plate Coatings

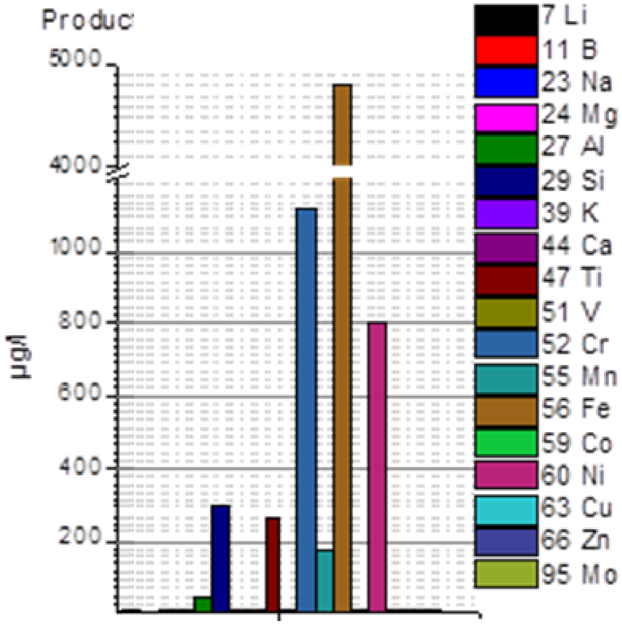
Understanding the details by applying different measurement technologies



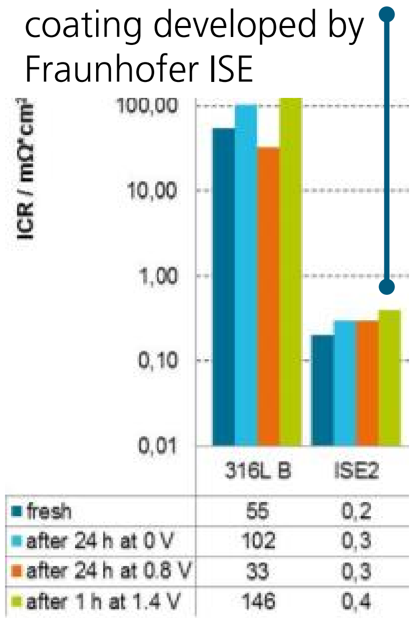
SEM (EDX) image of a bipolar plate coating



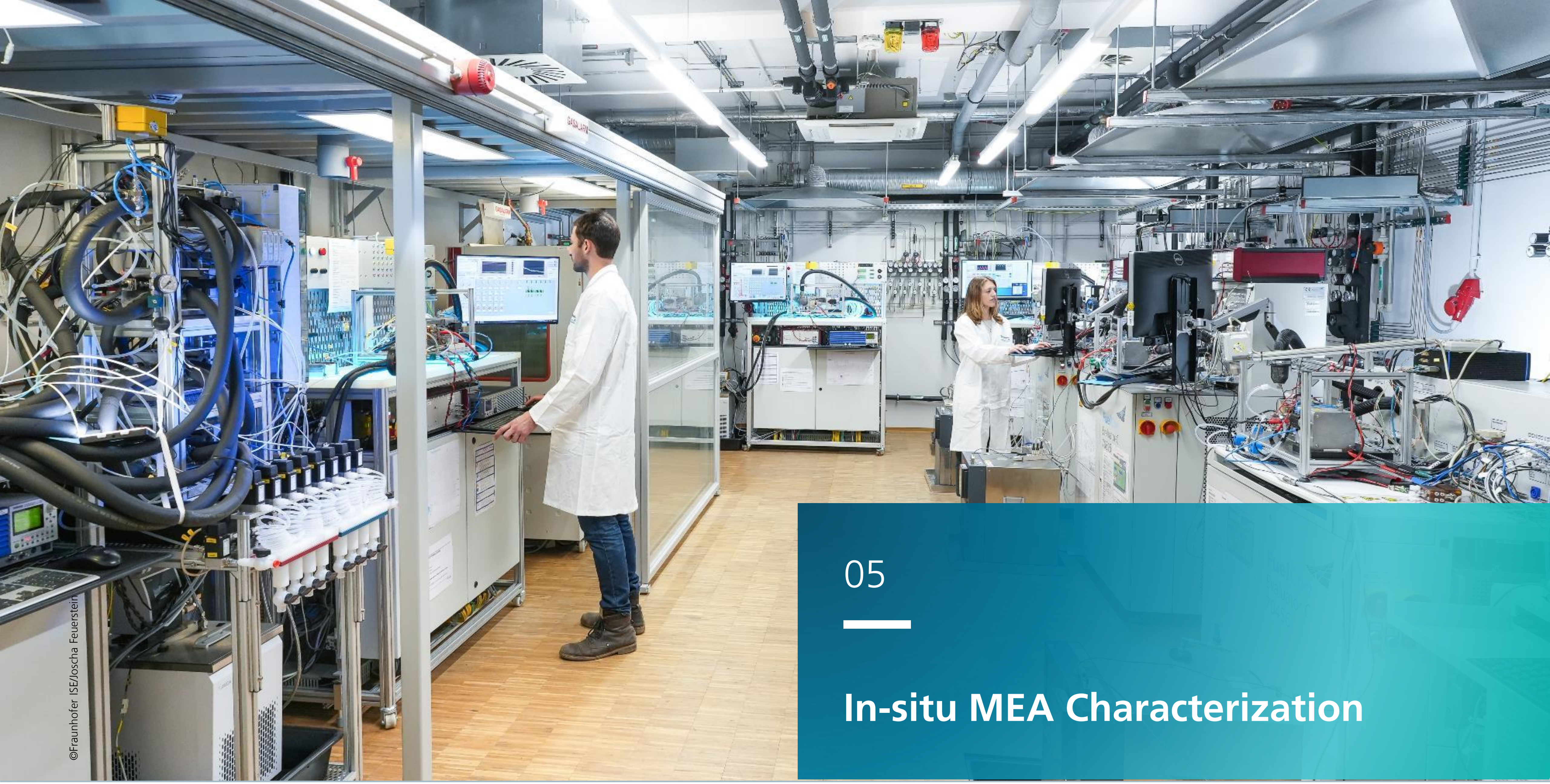
Corrosion current measurement with coated bipolar plates



Element analysis by ICP-MS of electrolyte from corrosion current testing



Interfacial contact resistance of aged bipolar plates with different coatings



05

In-situ MEA Characterization

Fraunhofer ISE Single Cell Test Stations

High quality material characterization

Technical Highlights

- 3rd generation of in-house developed test stations
- Fully automated for 24/7 operation
- Operation with air, oxygen, hydrogen, nitrogen, or contaminants
- Dynamic humidification
- State-of-the-art electro-chemical characterization:
  - polarization curve
  - electro-chemical impedance spectroscopy (air/H_2 and N_2/H_2)
  - Cyclovoltammetry & linear sweep voltammetry
  - limiting current measurement
  - CO stripping & CO displacement

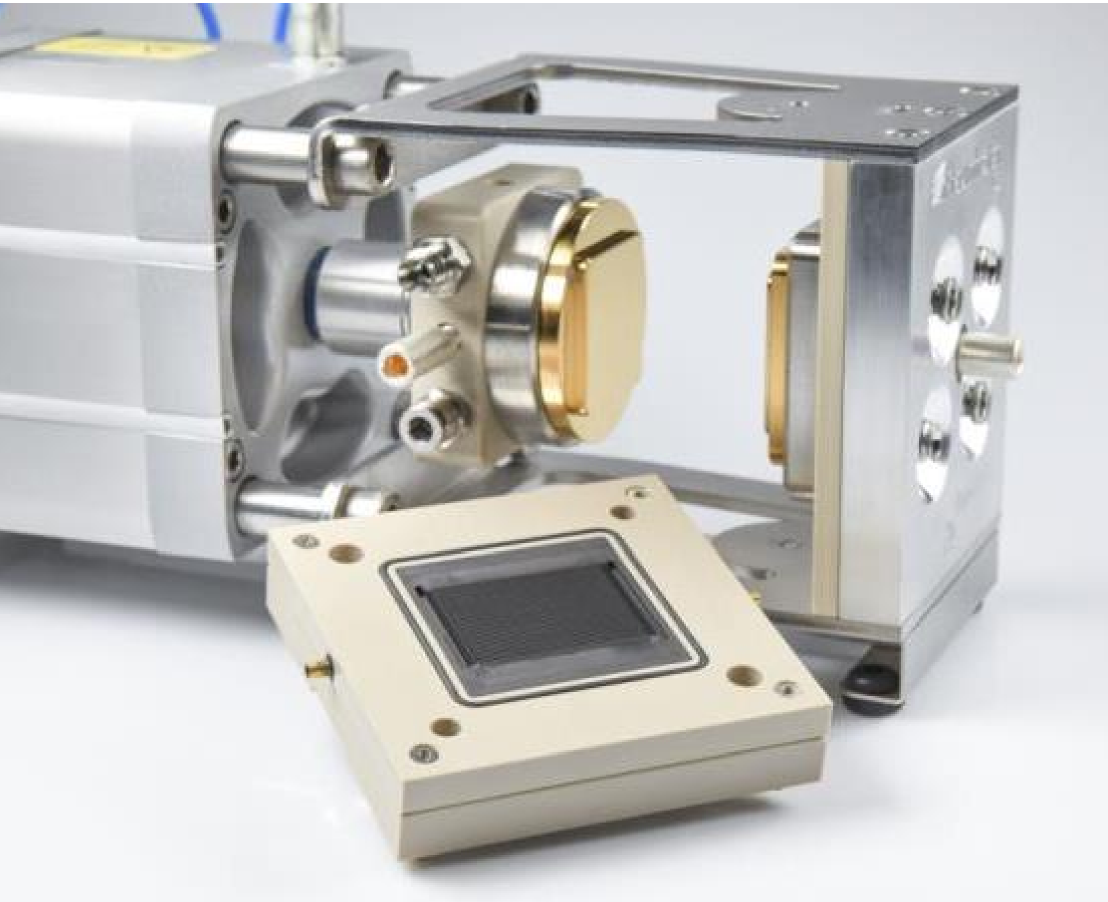
Gefördert durch: Bundesministerium für Verkehr und digitale Infrastruktur
Koordiniert durch: NOW
Projektträger: PtJ
Fraunhofer ISE

Fraunhofer ISE Baltic Differential Test Cell

High quality material characterization

Technical Highlights

- Differential test cell (zero-gradient) for very homogeneous operating conditions
- Effective liquid cooling
- Controllable (pneumatic) clamping pressure directly on the active area (GDL thickness variable & no gasket compression set-off)
- Graphitic plates guarantee corrosion free long-term operation & customer specific flowfield designs
- Easy handling for fast component exchange and low down-time
- NEWS: also available for metallic plates and in-operando testing of bipolar coatings



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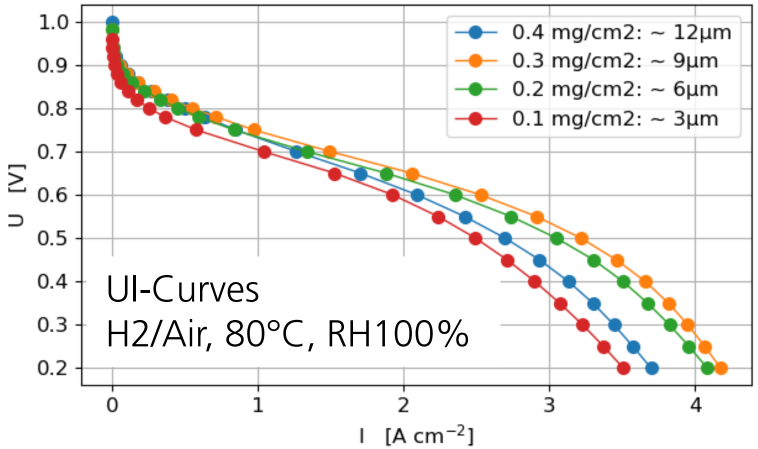
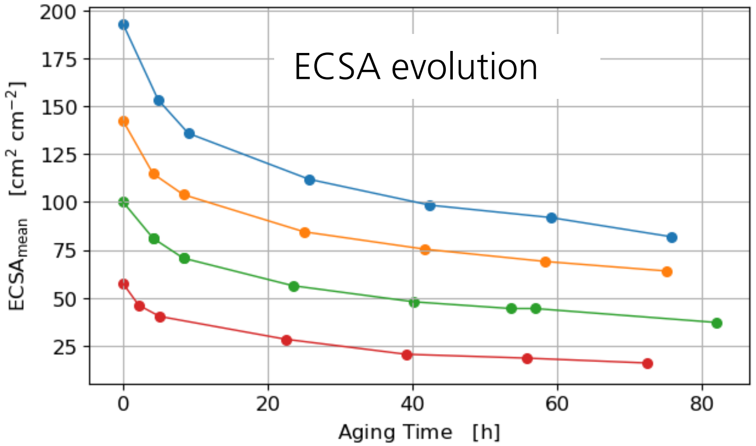
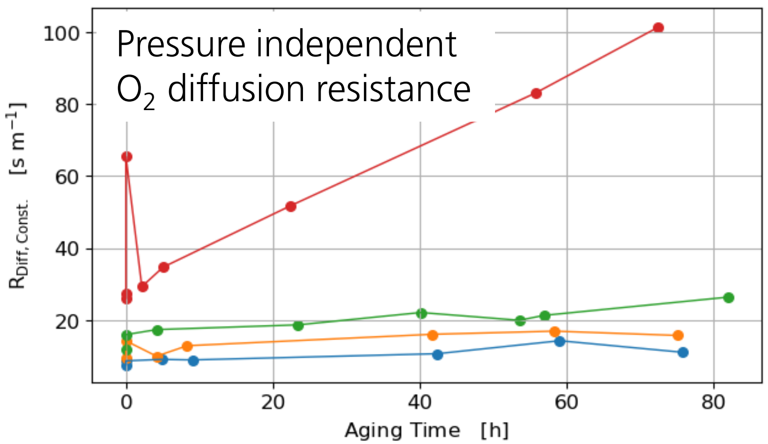
Koordiniert durch: NOW-GMBH.DE
Projektträger: PtJ

Degradation Analysis

Evaluating components and materials of a Membrane Electrode Assembly







Performance and degradation of 4 fuel cell catalyst coated membranes with different cathode Pt loadings. CCMs manufactured by Fraunhofer ISE.

- Accelerated stress tests for catalyst, catalyst support, and membrane
- Characterization by polarization curves, impedance spectroscopy (air/H2 or N2/H2), cyclo voltammetry, linear sweep voltammetry, limiting current density, CO stripping & CO displacement

Our latest report (German):
https://www.ise.fraunhofer.de/content/dam/ise/de/documents/projekte/Abschlussbericht_QuBK.pdf

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Koordiniert durch: NOW
Projektträger: PtJ

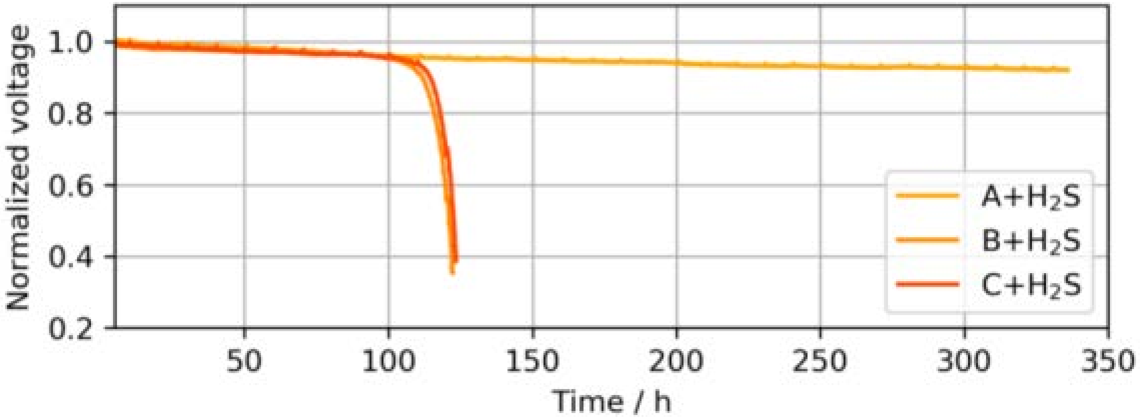
Contamination

Characterizing anode & cathode contamination

- Air pollution
- Hydrogen contamination
- Corrosion of bipolar plates or system components (cation contamination)

Contamination Effects

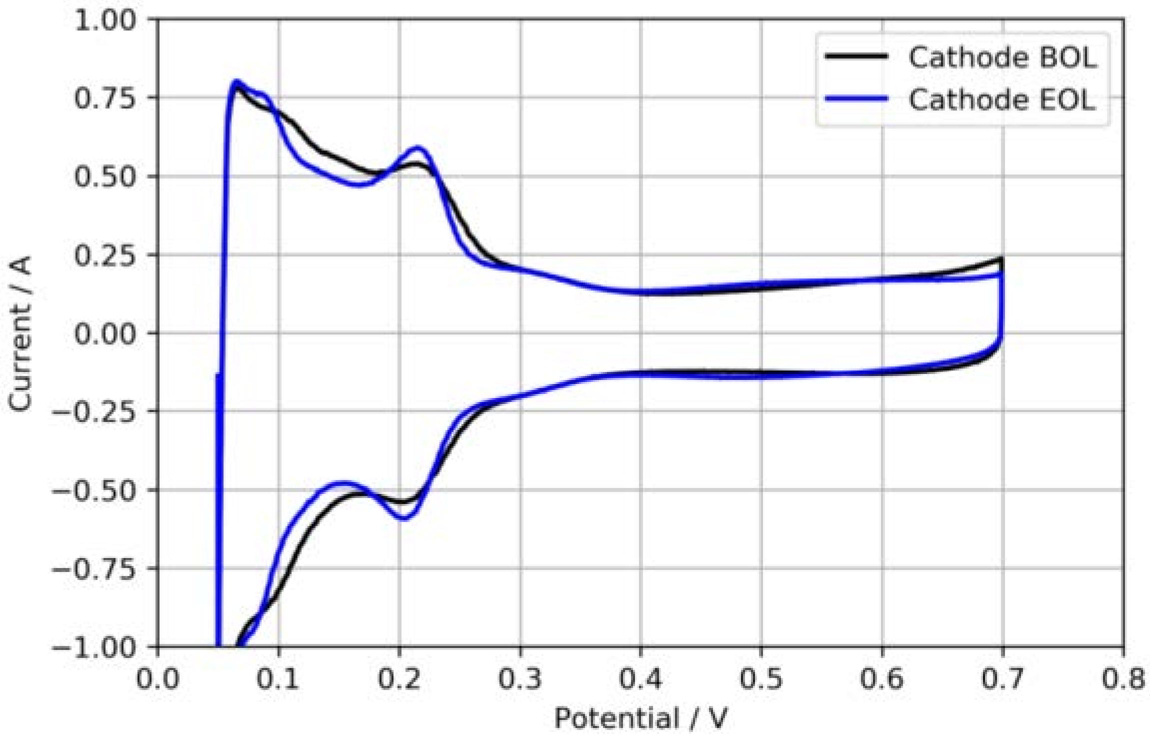
Consulting regarding contamination tolerances and filtration needs



A: 50 µgPt/cm² | B: 25 µgPt/cm² | C: 15 µgPt/cm²

Contamination with H_2S in H_2 gas flow on anode depending on anode catalyst loading

Our latest report (German):
https://publica.fraunhofer.de/eprints/urn_nbn_de_0011-n-6339942.pdf



Contamination effects by Fe^{2+} cations: BOL and EOT ECSA with experimental simulation of start-up / shut-down condensation

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Projektträger: PtJ

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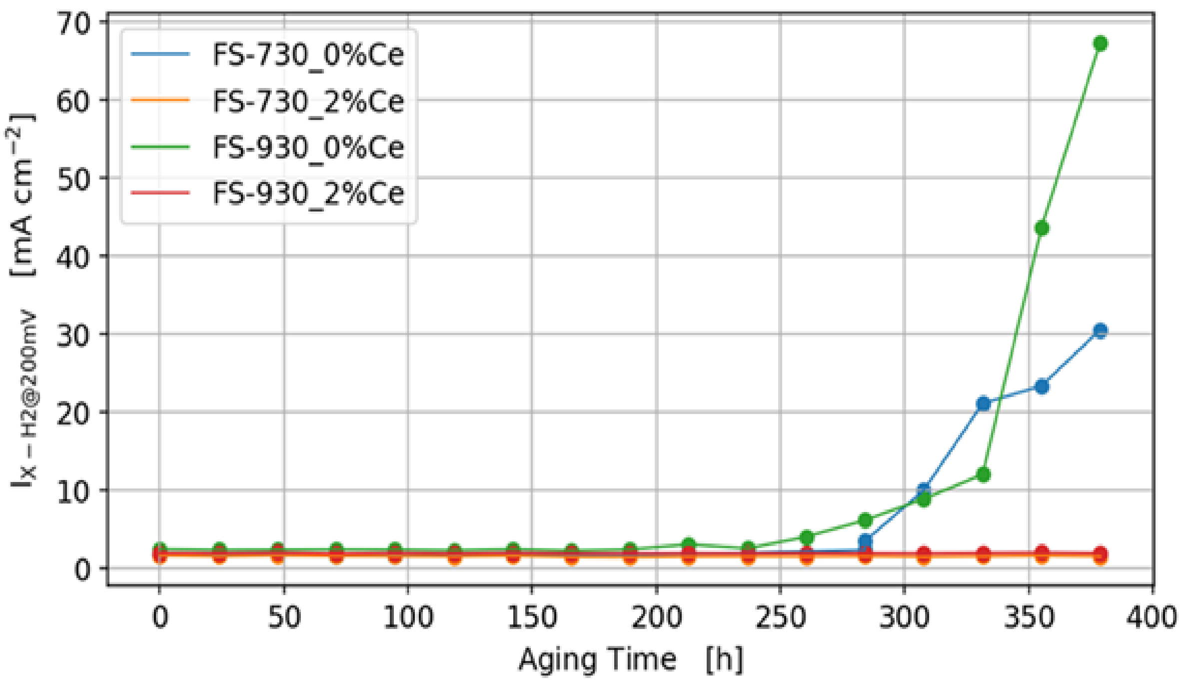
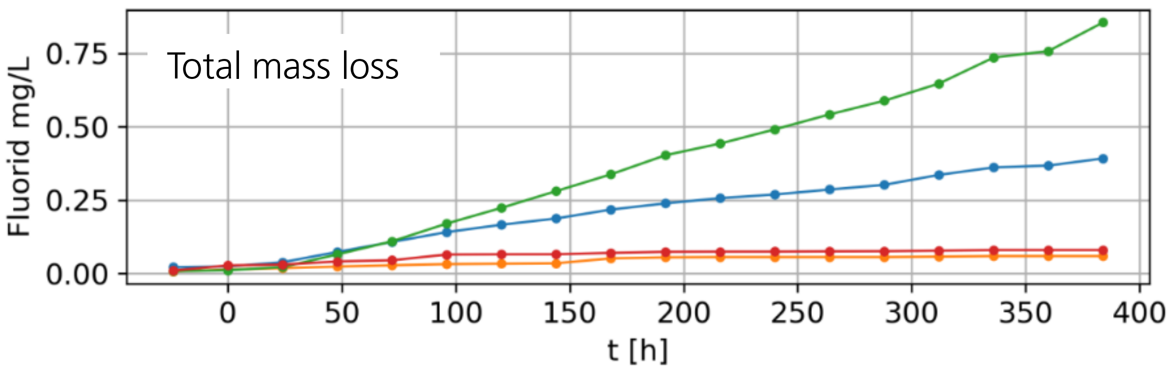
Electro-chemical Stability of Membranes

Benchmarking of components regarding life-time specifications



Cross over current during accelerated stress testing (OCV hold) of four fuel cell membranes with two different equivalent weights and with & w/o radical scavengers



Fluorine release rate in product water during OCV hold with four fuel cell membranes. Analysis by ICP-MS

Our latest report (German):
https://publica.fraunhofer.de/eprints/urn_nbn_de_0011-n-6339942.pdf

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Projektträger: PtJ
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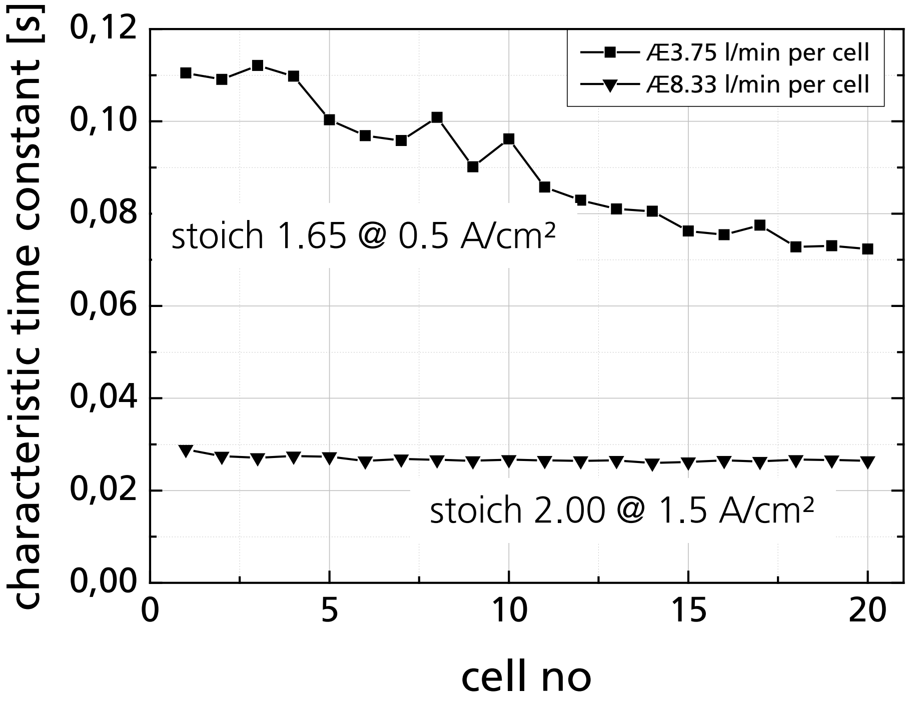
06

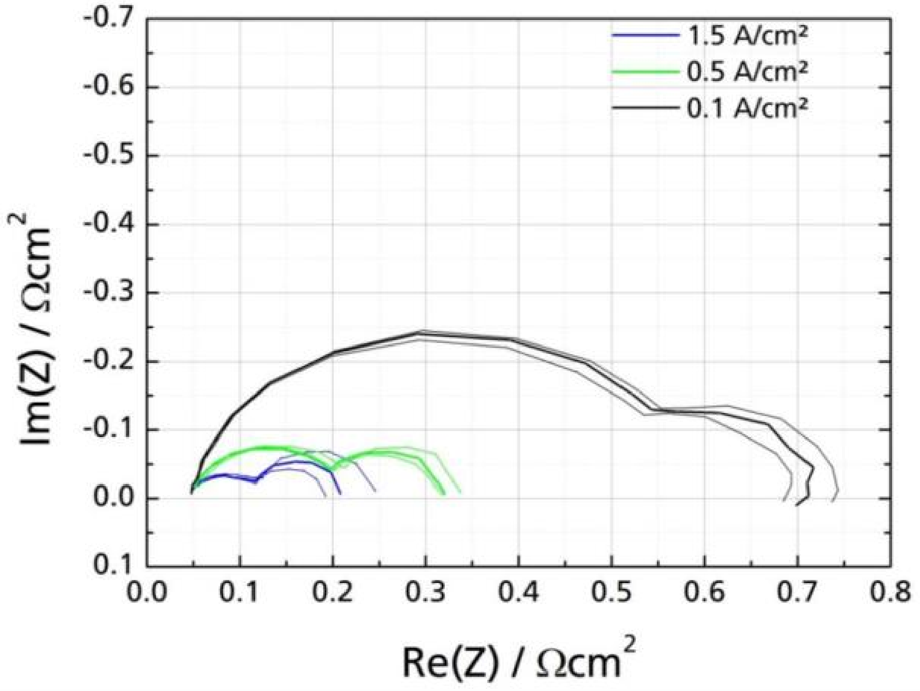
In-situ Stack Characterization

Single Cell Behavior Within a Stack

Analyzing stacks & operation strategies according to load profiles also at extreme climate conditions



Variation of gas stoichiometry in a short stack. Estimation of gas flows through single cells in a short stack by analyzing the low frequency impedance of the single cells

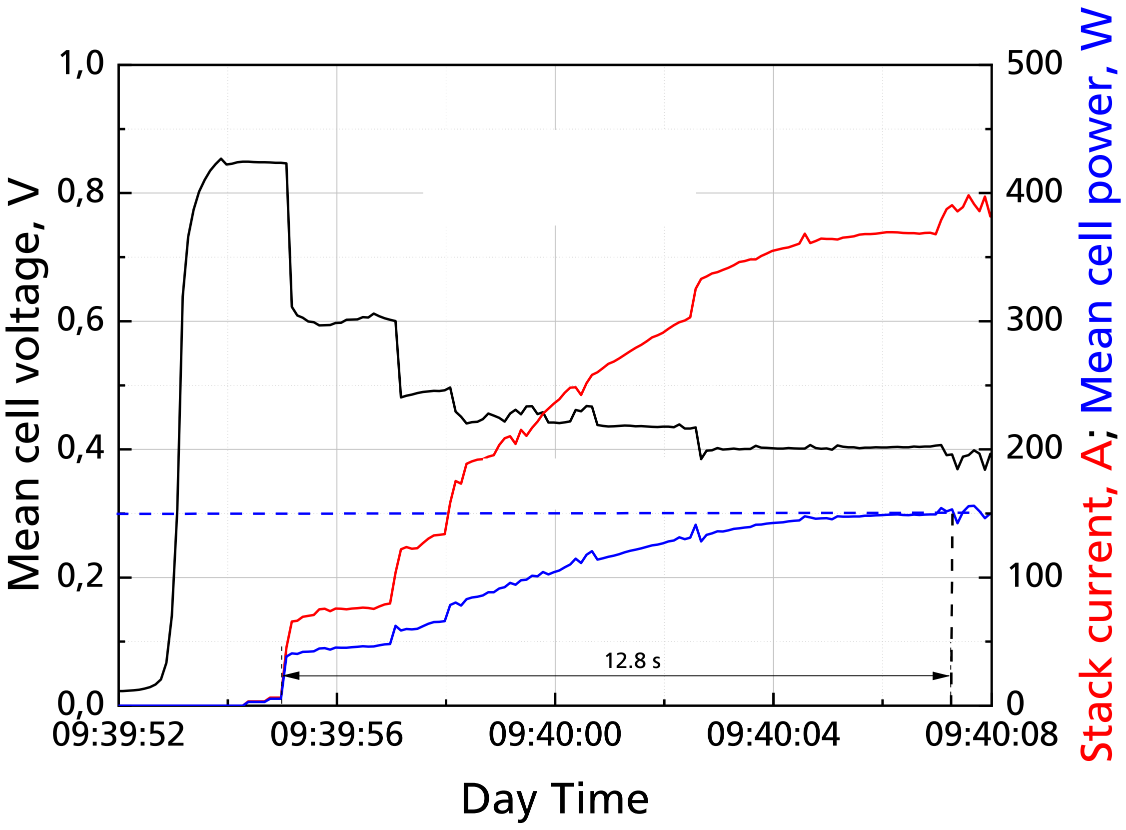


Average (bold), minimum, and maximum electro-chemical impedance spectra at different current densities of an automotive short stack

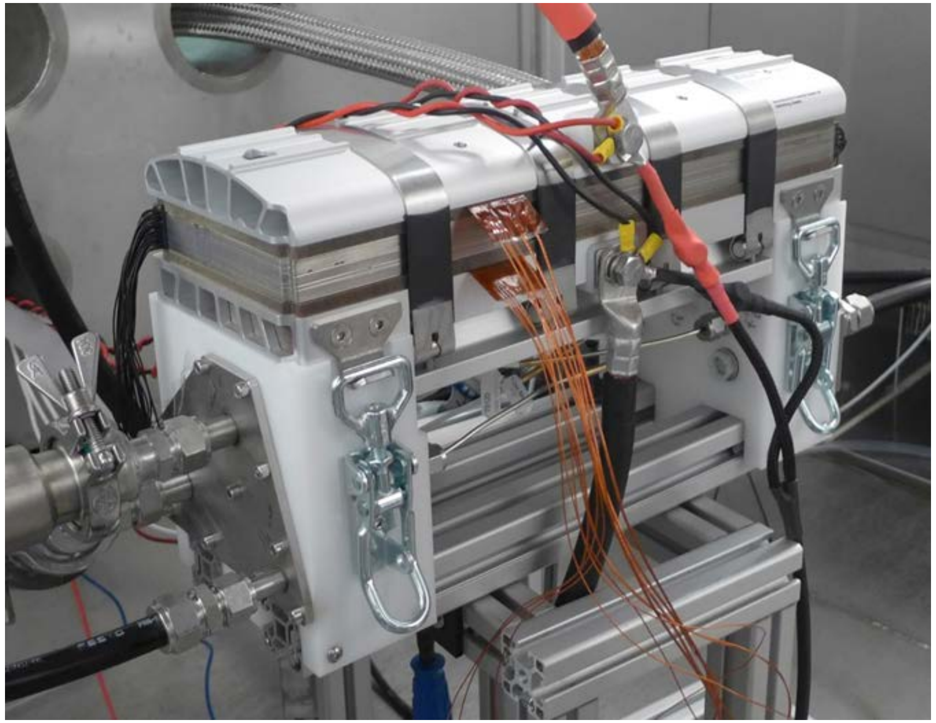
EIS measurement at frequencies from 1 kHz to 0.1 Hz with 5 points per decade in galvanostatic mode with an amplitude of 4 A AC

Freeze Start and Freeze-Thaw Cycling

Analyzing stacks & operation strategies according to load profiles also at extreme climate conditions



Less than 13 s to 50 % nominal power @ -20 °C



Autostack CORE Evolution 2 (short stack)

FHG-SK: ISE-PUBLIC

FUEL CELLS AND HYDROGEN JOINT UNDERTAKING GA: 325335

07

Testing Balance-of-Plant Components

Testing Balance-of-Plant Components

Validating BoP use in fuel cell systems

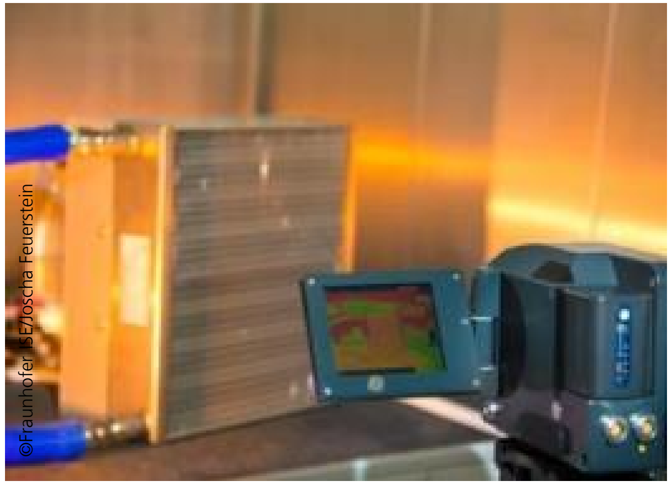
Equipment

- 2 climate chambers (e.g. with thermal imaging)
- Vacuum chamber for simulating high altitude

Opportunities

- Tests with pressurized und humidified gases
- Leakage testing
- Freeze-thaw cycling, freeze start
- Hydrogen or electrolyte exposure tests
- Aging tests
- and much more…

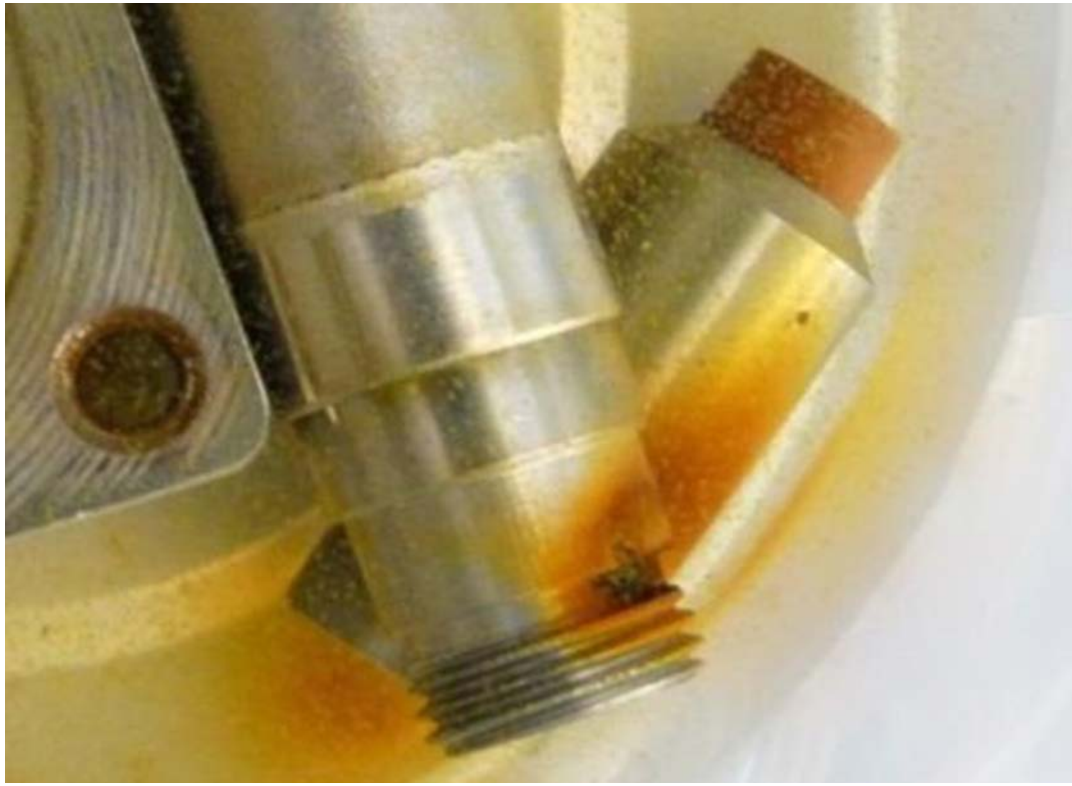
Case for integration of H_2 pressure sensors in order to perform pressure cycle tests with humidity variation



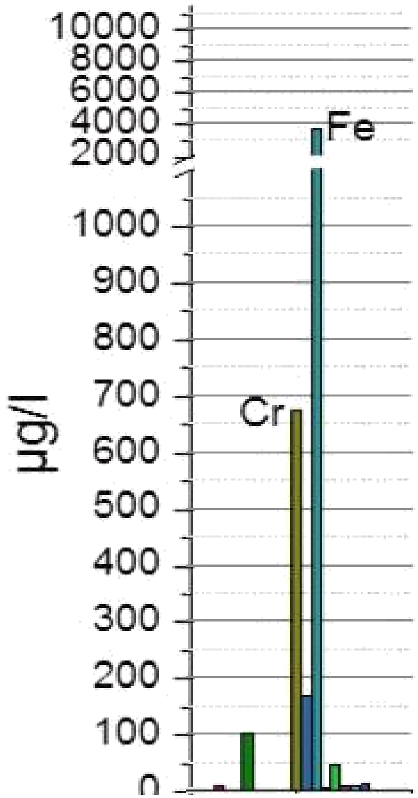
Life-time testing of a cooler at high temperature

Corrosion Testing of Balance-of-Plant Components

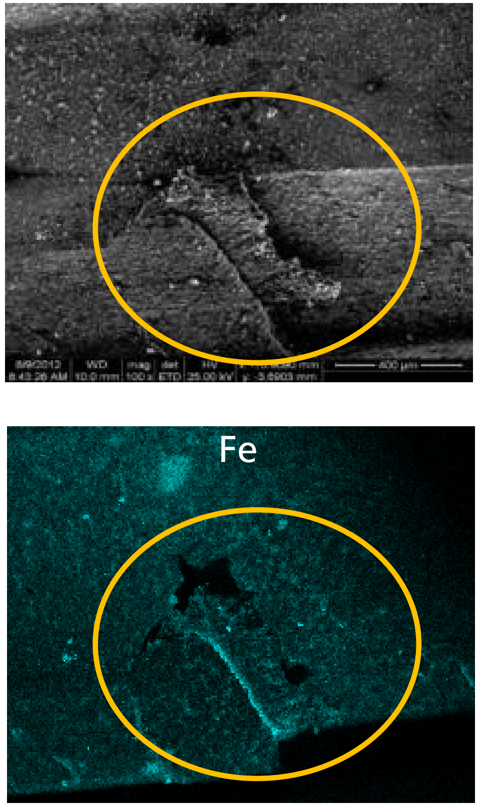
Validating BoP use in fuel cell systems



Valve components after 8 weeks in deionized water



ICP-MS analysis of this water



SEM/EDX images

Contact

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