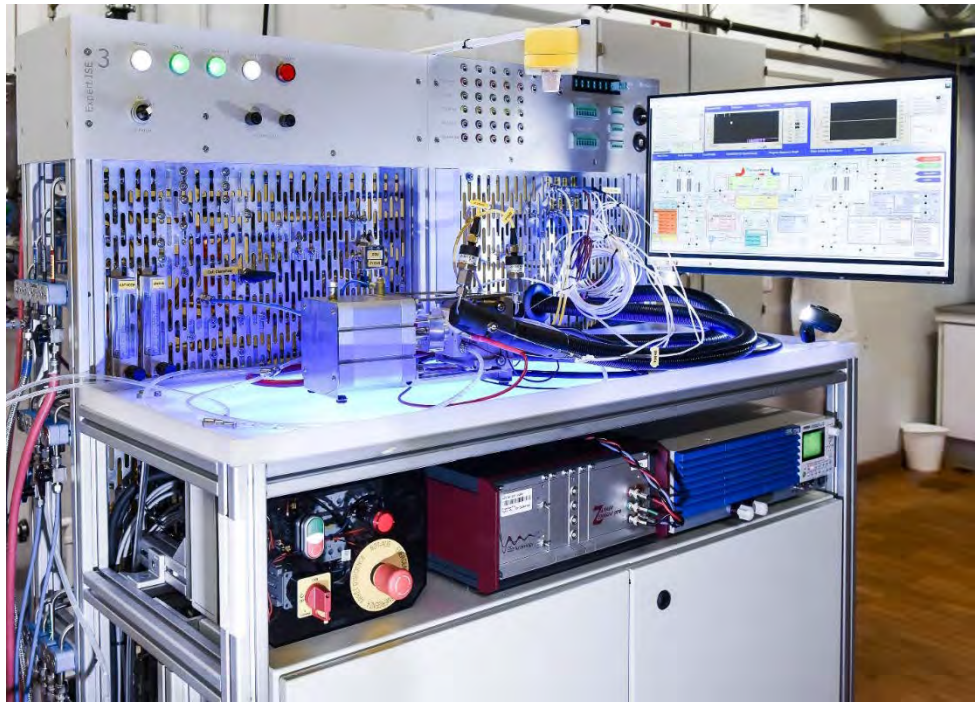
QUBK*: QUALIFIZIERUNG VON BRENNSTOFFZELLENKOMPONENTEN

***: spoken as „cubic“ to promote the validation of test protocols from DOE, EU, and NEDO**



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Fraunhofer Institute for Solar Energy Systems, ISE
Freiburg, Germany

Deutsche Wasserstoffversammlung

January 27, 2021

http://www.ise.fraunhofer.com
http://www.h2-ise.com

Gefördert durch: Bundesministerium für Verkehr und digitale Infrastruktur
Koordiniert durch: NOW GMBH
Projektträger: PTJ

Fraunhofer ISE

Fraunhofer Institute for Solar Energy Systems ISE

Research for the Energy Transformation

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Directors

Prof. Dr. Hans-Martin Henning

Prof. Dr. Andreas Bett

Staff

ca. 1300

Scientists, engineers, students

Budget 2019

Operation	93,5 Mio. EUR
Investment	10,6 Mio. EUR
Total	104,1 Mio. EUR

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Hydrogen Technologies @ the Fraunhofer Institute for Solar Energy Systems

Defossilization of Transport, Chemicals and Process Heat

Sustainable Mobility

Fuel cell car at the solar hydrogen filling station at Fraunhofer ISE

Synthetic Fuels and chemicals

Development of catalysts and processes incl. LCA analyses for Power-to-Liquid processes

Power-to-X Technologies

Water electrolysis as basic technology for renewable fuels; Power-to-Gas simulations

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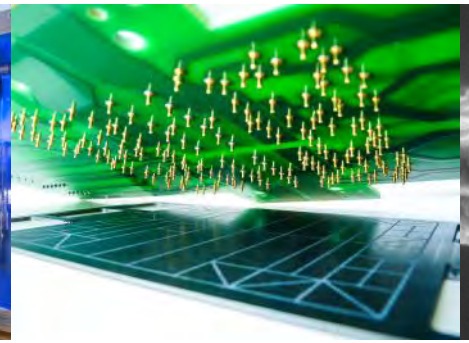
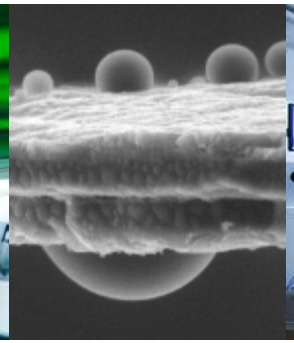
Fuel Cell Research at Fraunhofer ISE

Providing scientific sound services to our customers

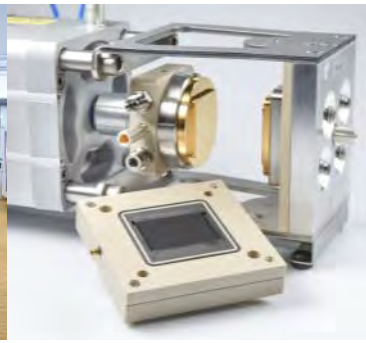
- > 25 years of fuel cell research
- 20 researchers plus students
- Ca. 3 Mio € annual budget (2020)
- 470 m² laboratory area
- Focus on transport application (LT PEMFC)
- Research from catalyst to system


stack testing


analysis of local effects


SEM analysis


MEA laboratory


test cell


environmental test of BoP

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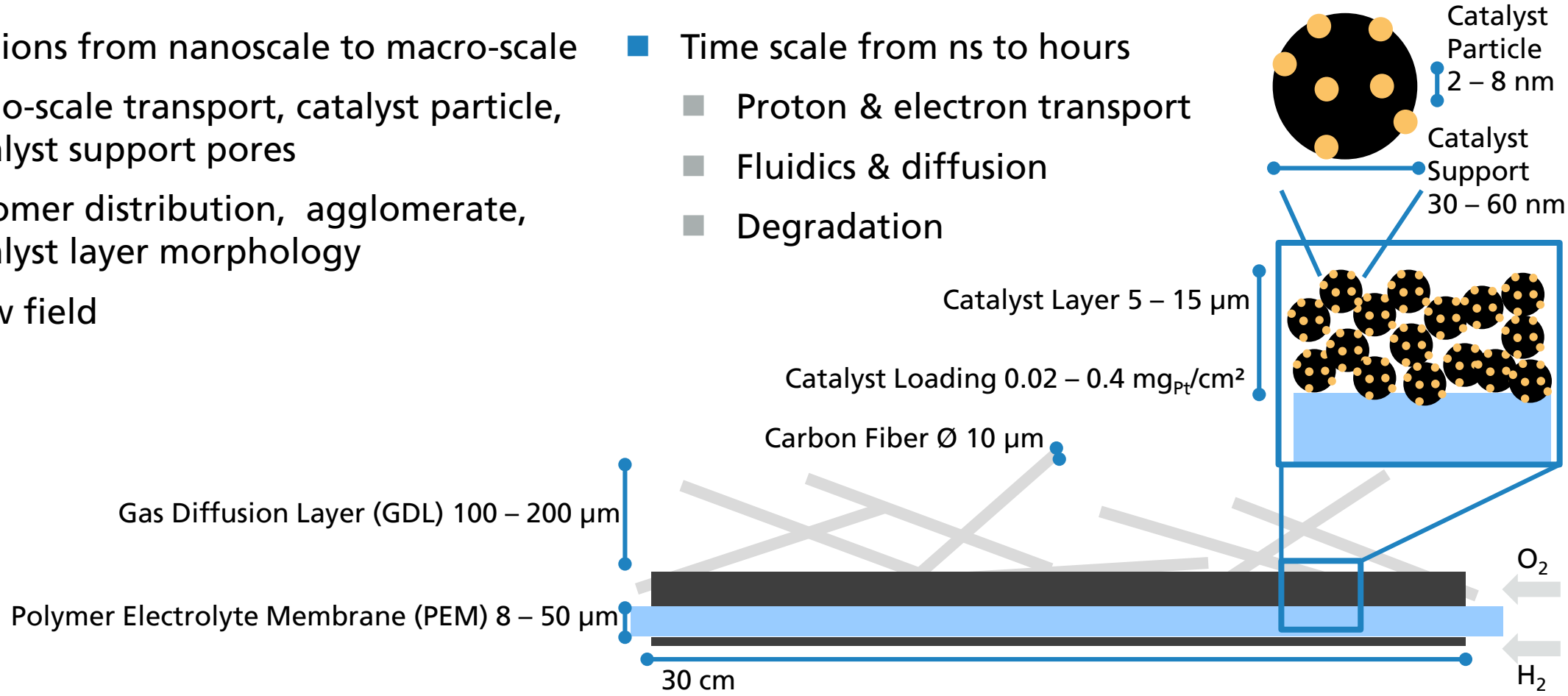
Motivation: The Membrane Electrode Assembly (MEA)

A multi-scale problem

- Dimensions from nanoscale to macro-scale
  - Nano-scale transport, catalyst particle, catalyst support pores
  - ionomer distribution, agglomerate, catalyst layer morphology
  - Flow field
- Time scale from ns to hours
  - Proton & electron transport
  - Fluidics & diffusion
  - Degradation



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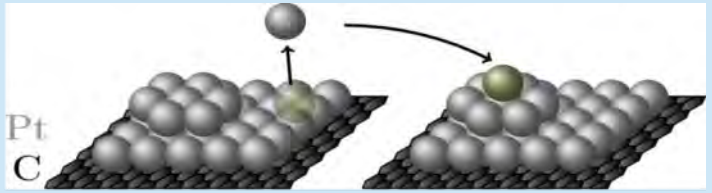
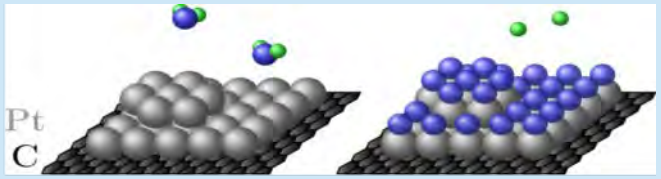
Degradation Mechanisms in Catalyst Coated Layers

Electrochemical dissolution and re-deposition (Ostwald ripening)

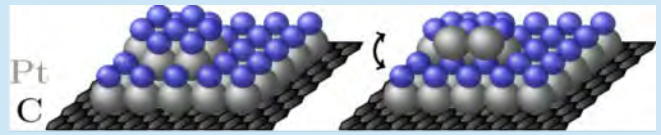


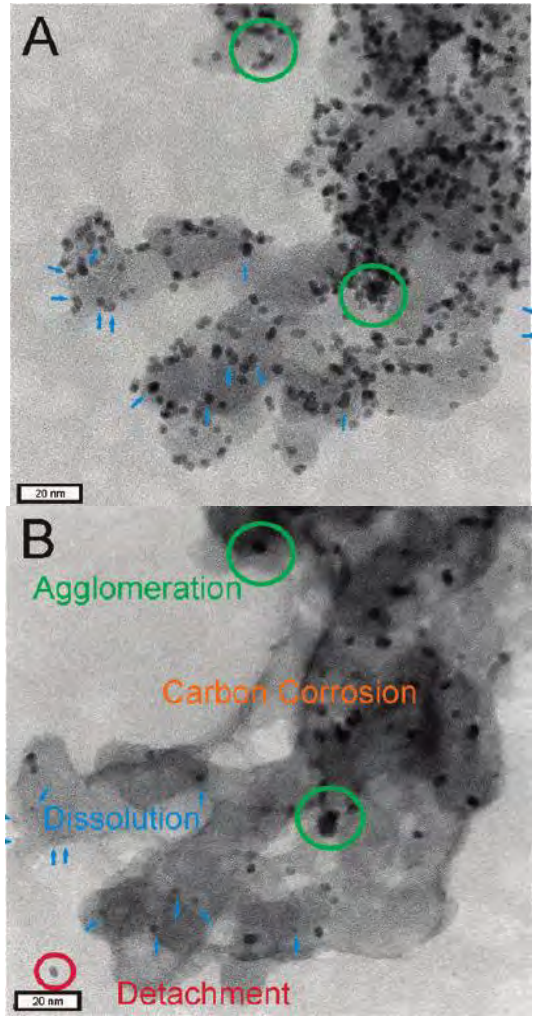
$$Pt = Pt^{2+} + 2e^-$$

Platinum oxidation, reduction and place exchange

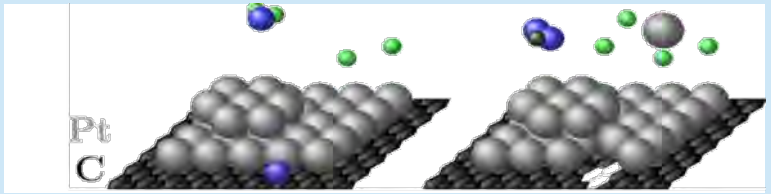


$$Pt + H_2O = PtO + 2H^+ + 2e^-$$





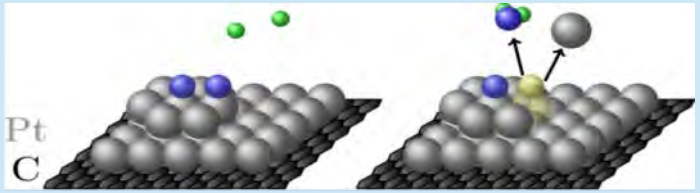
Carbon corrosion



$$C_{(s)} + H_2O \rightarrow C - O_{ad} + 2H^+ + 2e^-$$

$$C\text{-}O_{ad} + H_2O \rightarrow CO_{2(g)} + 2H^+ + 2e^-$$

Chemical dissolution of PtO



$$PtO + 2H^+ = Pt^{2+} + H_2O$$

Meier et al., ACS Catalysis 2012

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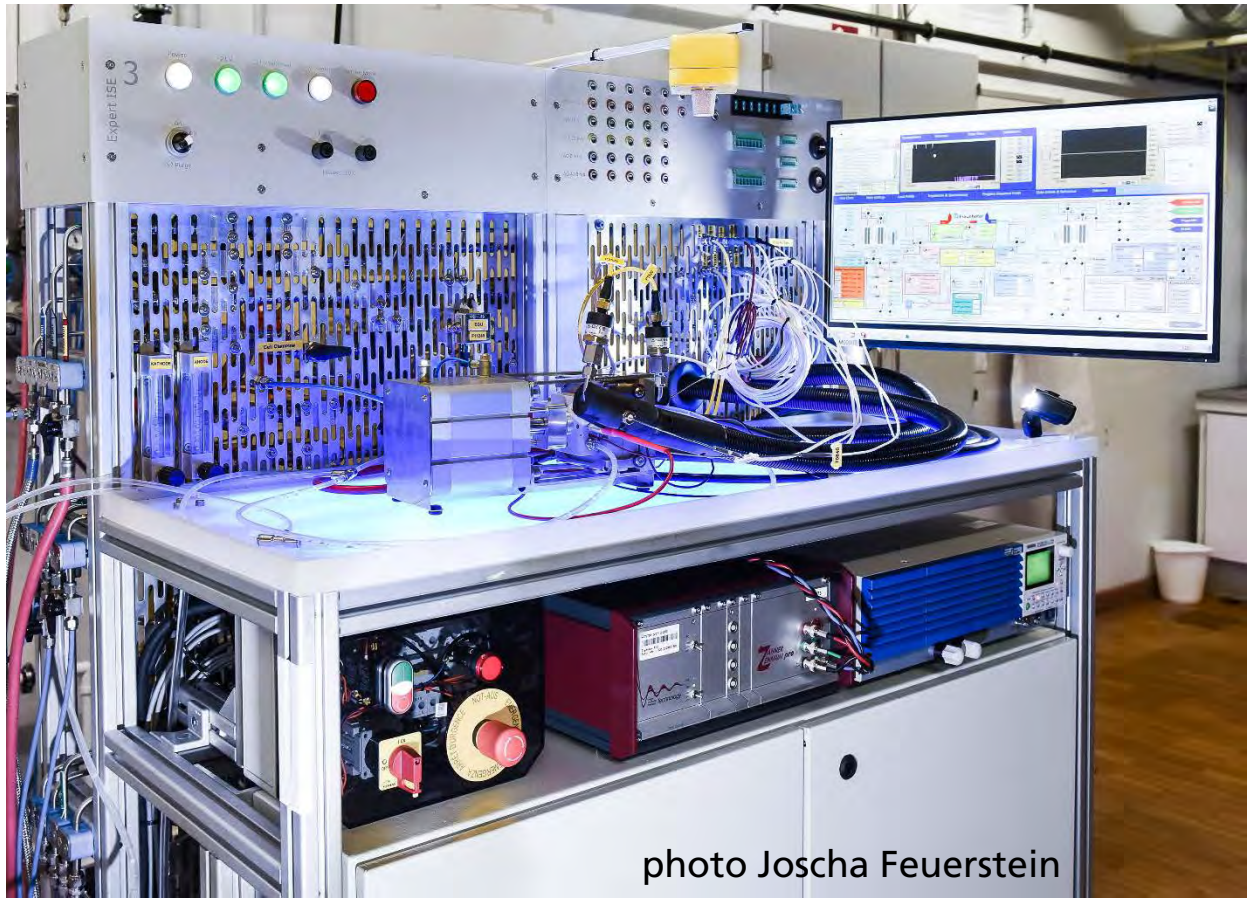
Fraunhofer ISE Test Stations

High quality material characterization



- 3rd generation of own developed test station
- Fully automated for 24/7 operation
- Operation with air, oxygen, hydrogen, nitrogen, or contaminants
- Dynamic humidification
- State-of-the-art electro-chemical in-situ characterization for polarization curve, electro-chemical impedance spectroscopy, cyclovoltammetry, linear sweep voltammetry, limited current measurement

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Fraunhofer-baltic PEM Fuel Differential Cell Test Cell

High quality material characterization

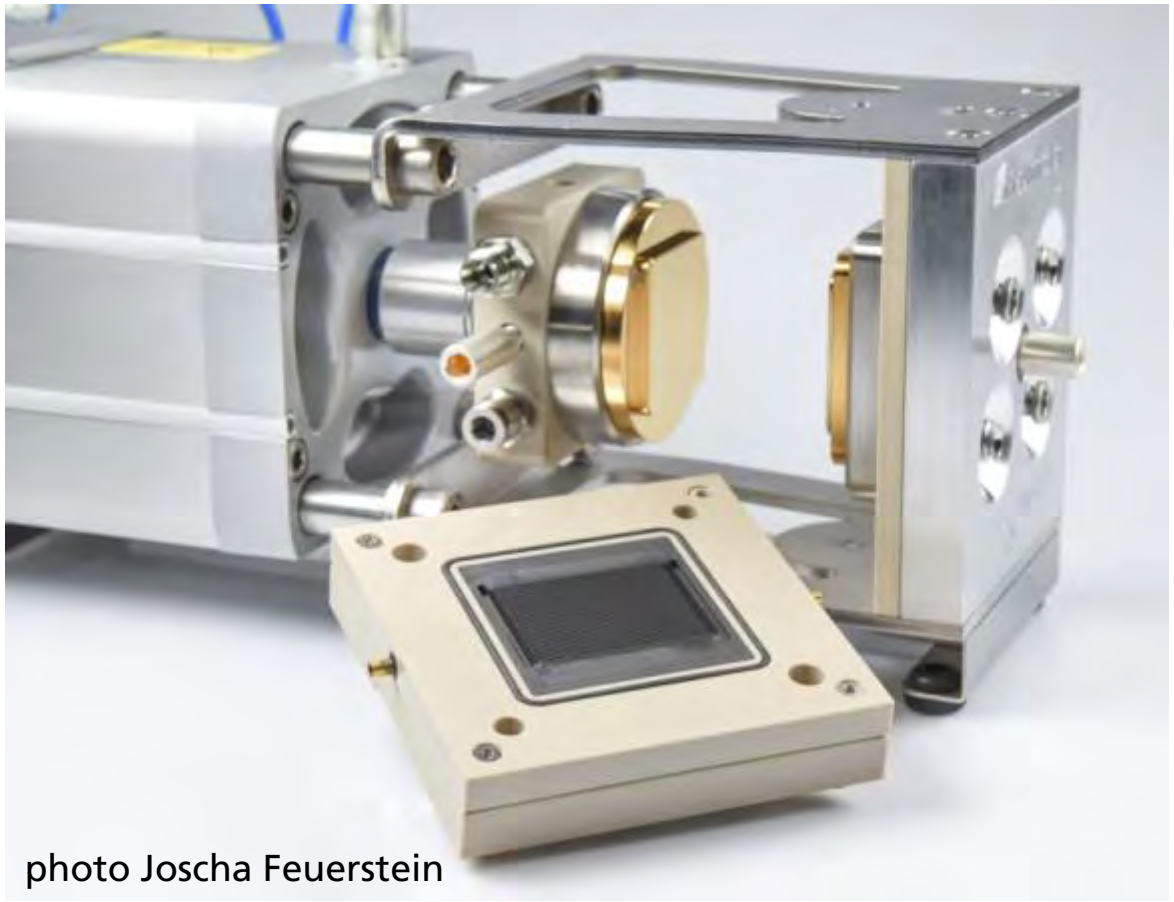
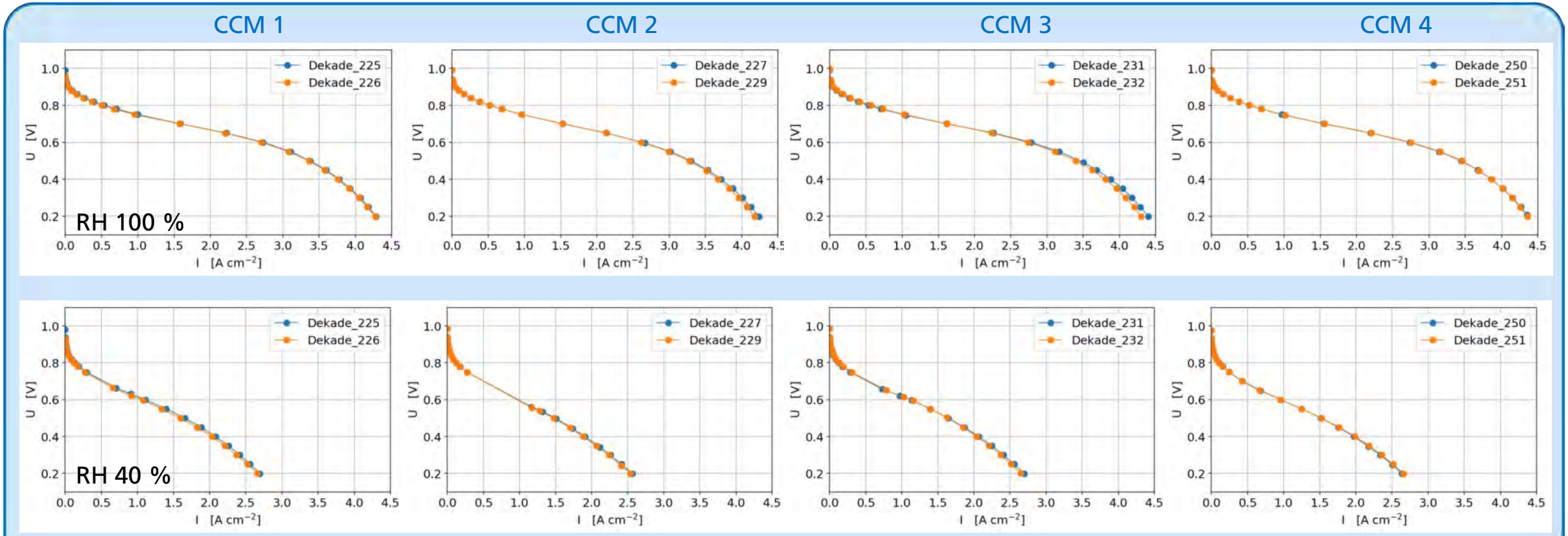


photo Joscha Feuerstein

- differential test cell (zero-gradient) even for high current densities up to 5 A/cm²
- liquid cooling
- controllable (pneumatic) clamping pressure directly on the active area (GDL thickness variable & no gasket compression set-off)
- easy handling for fast component exchange

High Reproducibility of 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), RH 100% A/C, 2 bar_a

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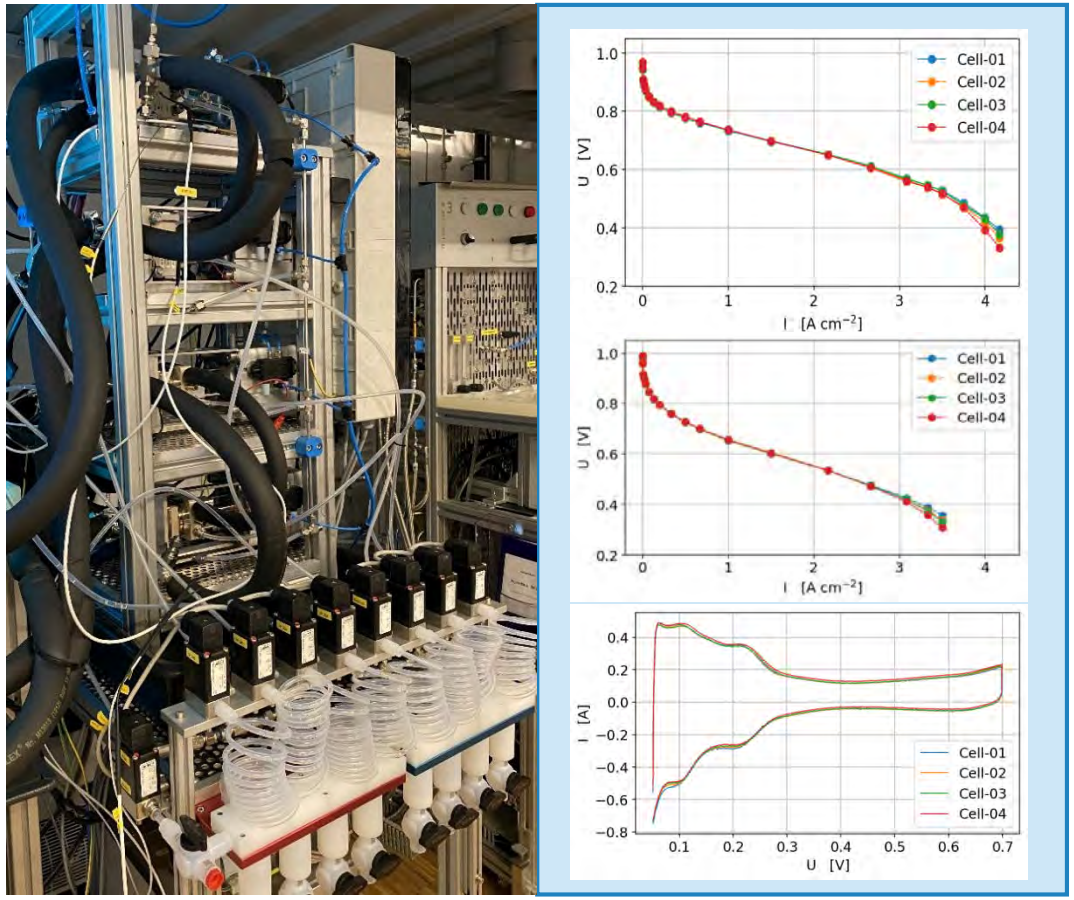
Fraunhofer ISE Multitcell-Characterization

High quality material characterization



- Simultaneous characterization of 4 zero-gradient test cells
- Product water collection separate for each cell and cathode and anode (e.g. for element analysis by ICP-MS)
- Best suited for long-term evaluation (e.g. membrane degradation, drive-cycle testing)

Polarization curve for same material in 4 test cells @ 100% r.H (above) and 40% r.H. (middle). ECSA for same material in 4 test cells.

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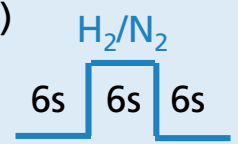
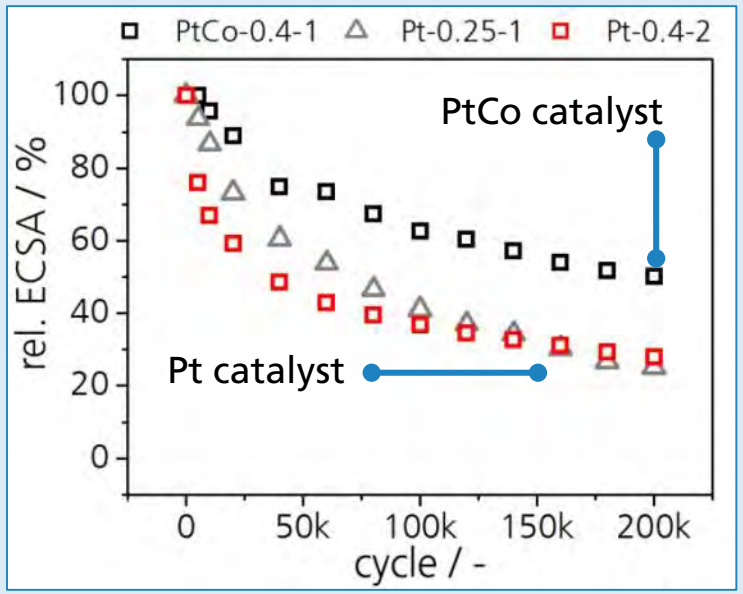
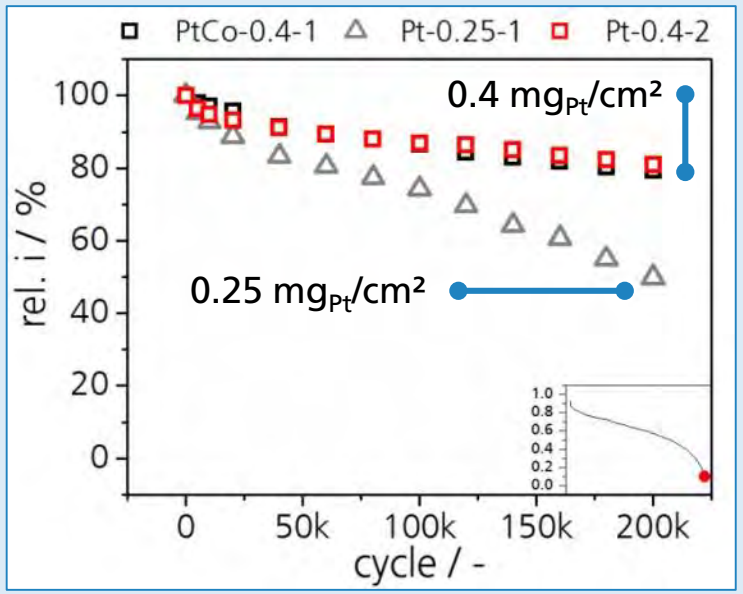
Degradation Mechanisms in Catalyst Coated Membranes

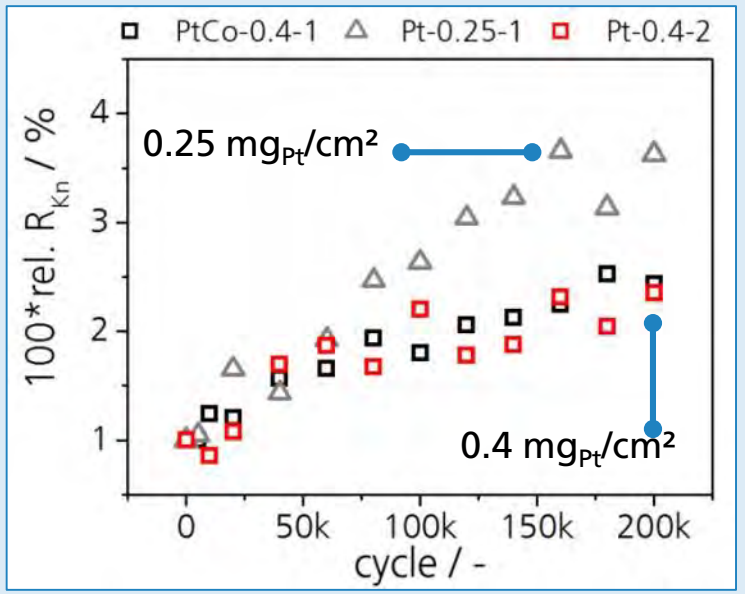
Accelerated Stress Tests for catalyst

(NEDO 1,00 V)
DOE 0,95 V
0,60 V









ECSA

- PtCo catalyst degradation slower than for Pt catalyst

Current density

- Low catalyst loading with stronger degradation

Morphology

- Low catalyst loading with stronger degradation

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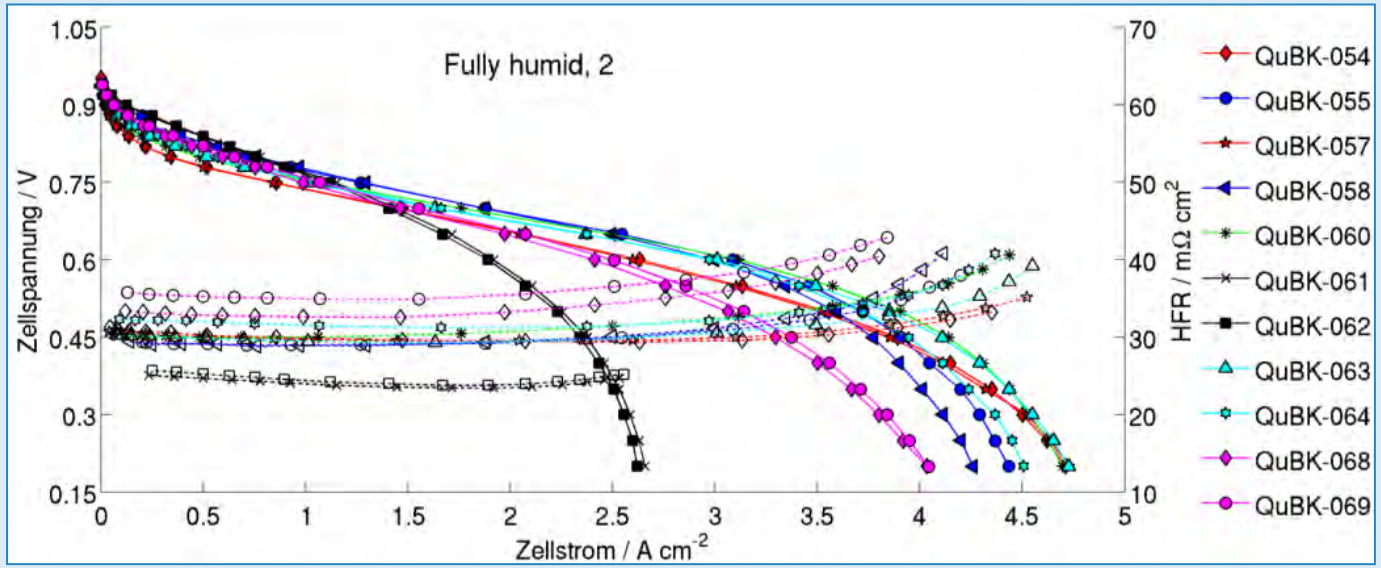
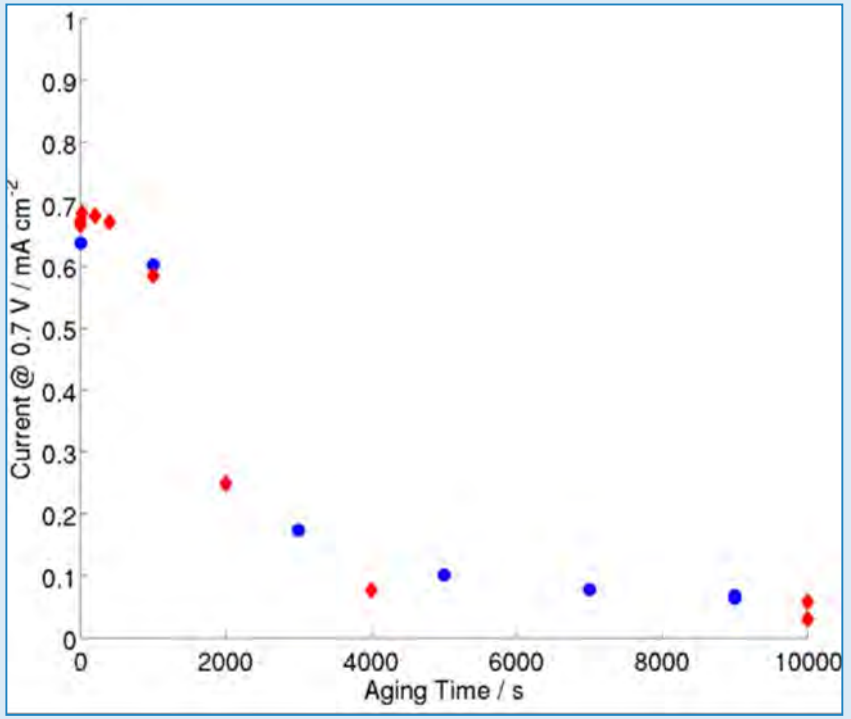
Degradation Mechanisms in Catalyst Coated Membranes

Accelerated Stress Tests for catalyst support

NEDO & DOE
1,5 V
1,0 V
H_2/N_2
2s 2s



Begin-of-Test polarization curves and high frequency resistance with 5 materiales for AST (catalyst support) according to DOE and NEDO



Current density @ 700 mV for one material according to ASTs from DOE (red) or NEDO (blue)

- Different characterization intervals do not affect the degradation behaviour

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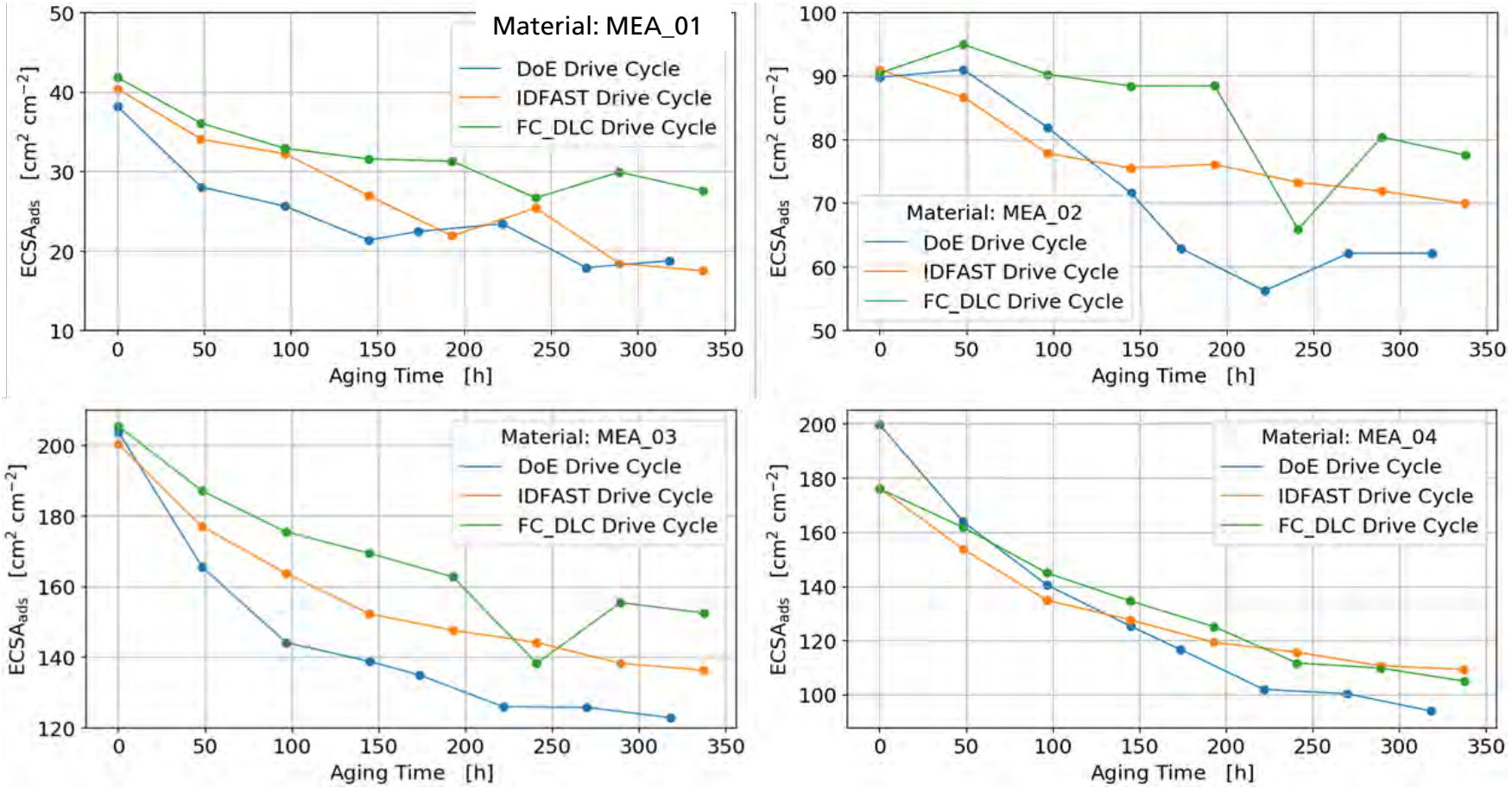
Degradation Mechanisms in Catalyst Coated Membranes

Drive Cycle Testing of MEAs

- 3 different drive cycles
- 4 different MEAs

➢ ECSA loss depends on cycle profile and catalyst loading



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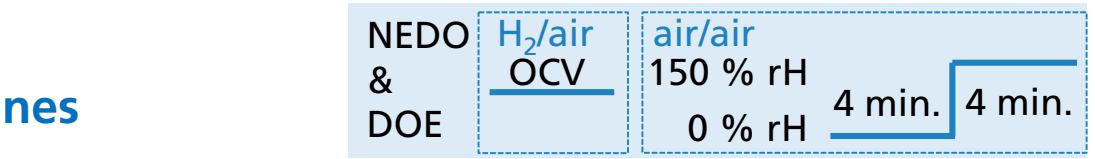
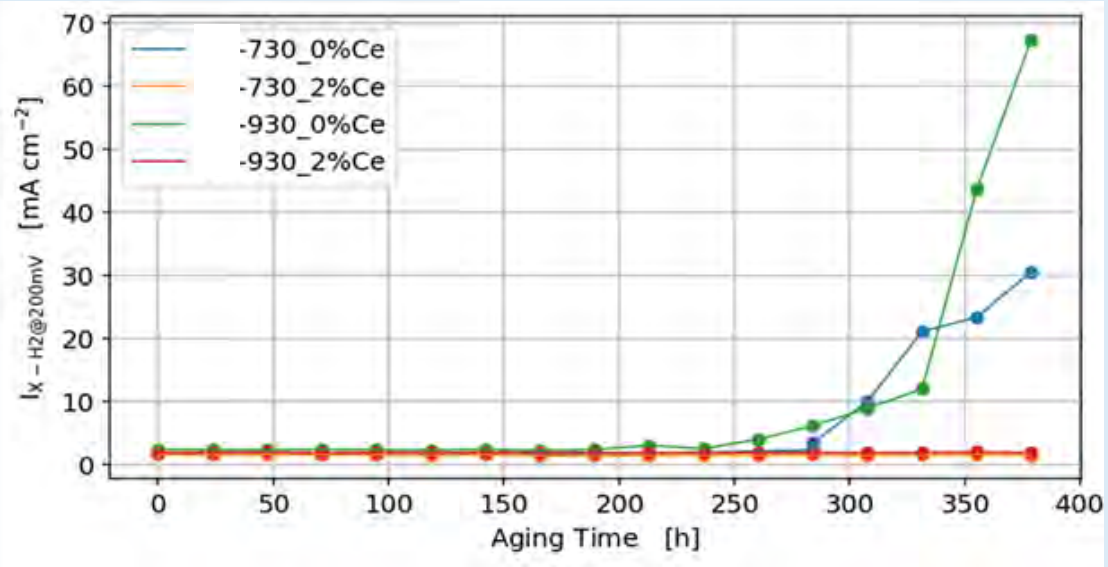
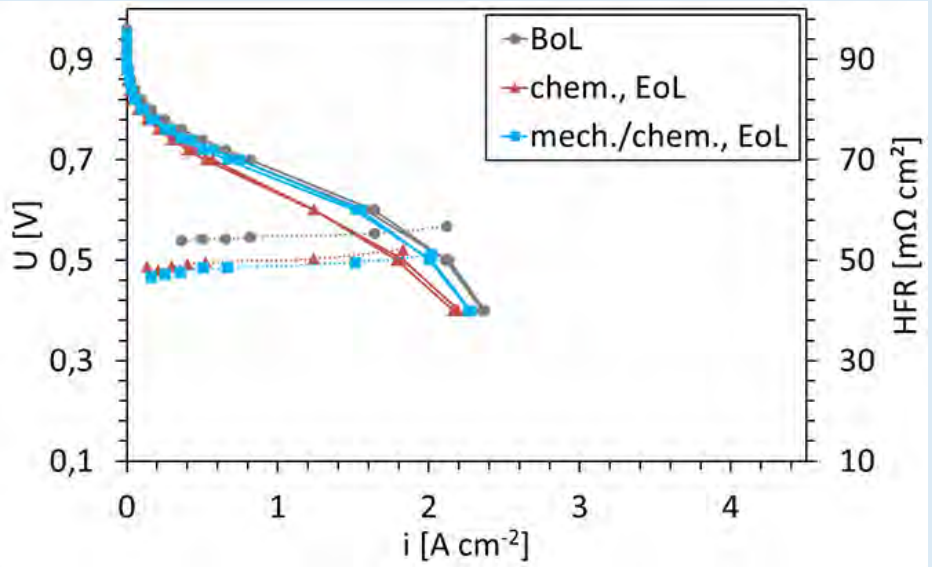
Degradation Mechanisms in Membranes

Accelerated Stress Tests for Polymer Electrolyte Membranes





Chemical aging of different membranes w & w/o Ce stabilization (OCV hold): the chemical stabilized membranes show no degradation over 350 h



Comparison of chemical and mechanical aging of a membrane

- Chemical aging dominates over mechanical aging

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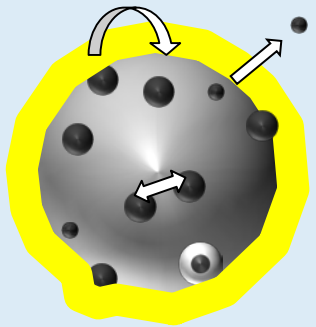
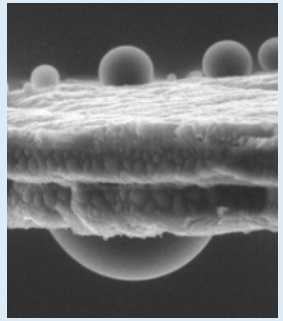
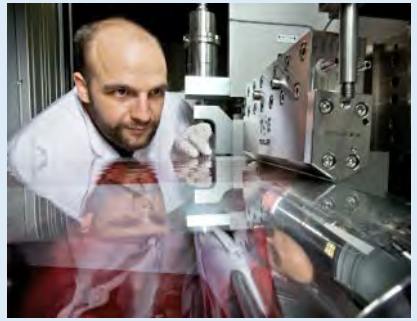
Take home messages

- Fully automated **test set-ups** are available
- Automated **test, characterization and break-in protocols** are validated
- A **variety of materials** was tested
- Process technology for **manufacturing of different catalyst layers** was established
- Effects of **different test protocols, characterization and materials** were investigated



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Thank You for Very Much for Your Attention!

Detailed information (in German) is given in the final project report:

https://www.ise.fraunhofer.de/en/research-projects/qubk.html

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