FUEL CELL SYSTEMS @ FRAUNHOFER ISE

Assisting industry in fuel cell technology

photo: Joscha Feuerstein

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Fuel Cell Research at Fraunhofer ISE
Providing scientifically sound services to our customers

- > 25 years of fuel cell research
- > 20 researchers plus students
- 3.4 Mio € annual budget and 40% direct revenue by industry contract research (2020)
- >500 m² laboratory area with 10 single cell test stations, 4 short stack test stations, 1 system test site, 2 climate chambers (all fully automated for 24/7 operation)
- Focus on transport application (LT PEMFC)
Our Offers to our Customers: From Catalyst to System
Performance and degradation evaluation of fuel cells

- Modelling, developing and testing of membrane electrode assemblies (and its layers)
- Investigating and developing MEA process technologies
- Developing and analyzing bipolar plate coatings
- Characterizing fuel cell stacks
- Spatially resolved evaluation of cell and stack design, also at extreme climate conditions
- Fuel cell system technology: testing of balance of plant components, developing and testing of operating strategies (e.g. freeze start, hybridization, efficiency), monitoring of field tests
Value Proposition to our Customers
State of the art fuel cell expertise

- Optimizing materials and components
- Developing production technologies
- Understanding cell and stack designs
- Optimizing operating strategies from cell to system level (depending on environmental conditions and design rules)
- Validating models

Above: degradation modelling and (environmental) stack testing
Middle: CCM / MEA laboratory and test of contamination effects
Down: spatially resolved characterization of cell design and life-time testing of balance-of-plant components
We do performance and lifetime analysis.

photo Joscha Feuerstein
Fraunhofer ISE Single Cell Test Stations
High quality material characterization

- 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 in-situ characterization for polarization curve, electro-chemical impedance spectroscopy (air/H₂ and N₂/H₂), cyclovoltammetry, linear sweep voltammetry, limiting current measurement, CO stripping
Fraunhofer-baltic PEM Fuel Differential Cell Test Cell
High quality material characterization

- Differential test cell (zero-gradient) for homogeneous conditions
- Effective 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 and low down-time
Degradation Analysis
Evaluating components and materials of a Membrane Electrode Assembly

- Accelerated stress tests for catalyst, catalyst support, and membrane
- Characterization by polarization curves, impedance spectroscopy, linear sweep voltammetry, and limiting current density
We Use Our ex-situ Analytic Devices to Investigate BoL and EoL Microstructures.

Understanding material composition and structure

- SEM / EDX for element analysis of surfaces (e.g. catalyst layer, membrane, bipolar plates)
- XPS for catalyst analysis
- FIB-SEM and μCT for analysis of morphology (e.g. catalyst layer)
- ICP-MS for element analysis in liquids (e.g. product water, electrolytes)

Find out more regarding our ex-situ analytics equipment here:
Production Research for Catalyst Layers, GDLs, and MEAs
Identifying processes and quality control for scale-up

- Analyzing interdependencies of material composition, process technology and component morphology as well as performance and degradation
- Understanding defects and tolerances

Screen printing process at Fraunhofer ISE
Process Competences

DECAL-Process with Flatbed Screen Printing

- Ink formulation
- Ink dispersing
- Screen Printing
- Printed Catalyst Layers
- Drying
- Hot-Pressing
- In-situ characterization
High Reproducibility of Production Process and In-Situ Characterization
Polarization Curves, wet & dry conditions

<table>
<thead>
<tr>
<th>MEA 1</th>
<th>MEA 2</th>
<th>MEA 3</th>
<th>MEA 4</th>
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<td><img src="image3.png" alt="Graph" /></td>
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RH 100 %

RH 40 %

air/H₂, 0,25 mgPt/cm² (C), 0,05 mgPt/cm² (A), RH 100% A/C, 2 bar_a
Understanding Local Effects
Investigating local effects in single cells with customized segmented flowfield plates.

photo Joscha Feuerstein
Multi-channel characterization system for segmented single cells
Current Distribution Depending on Operation Conditions and Cell Design
Investigating local effects by segmented customer specific full scale cells

![Graph showing current distribution with voltage and current density axes.](image)

- **Row:** 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11
- **Cell average**
HFR Distribution Depending on Operation Conditions and Cell Design

Investigating local effects by segmented customer specific full scale cells

![Graph showing voltage vs. current density with rows labeled 1 to 11 and a cell average marker.](image)
Along-the-channel Test Cell
Investigating local effects from gas inlet to outlet

- Studying spatially resolved effects of customer designed channel-land geometries
- Component screening with (customer specific) stoichiometric operation and load profiles
- Minimized testing effort due to minimized active area of 250 x 20 mm² (25 segments á 10 x 20 mm²)
We investigate effects of contamination both on cathode and anode.
Characterization of Contamination Effects
Consulting regarding contamination tolerances and filtration needs

- Air pollution
- Hydrogen contamination
- Corrosion (cations)

Contamination with H$_2$S in H$_2$ gas flow on anode depending on anode catalyst loading

A: 50 µgPt/cm$^2$ | B: 25 µgPt/cm$^2$ | C: 15 µgPt/cm$^2$

Contamination effects by Fe$^{2+}$ cations: BOL and EOT ECSA with experimental simulation of start-up / shut-down condensation.
Performance and Degradation Modelling
Understanding life-time and optimizing operating strategies

- CCM through-plane performance model coupled with model for potential induced degradation

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 accelerated stress testing
Do You Know the Single Cell Behavior within a Fuel Cell Stack?
We test stacks or systems, also at extreme conditions.
Analyzing Single Cell Behavior Within a Stack
Understanding stack design and optimizing operation

- Average (bold), minimum, and maximum electrochemical 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.
Flow Distribution within an Automotive (Short) Stack
Understanding stack design and optimizing operation

![Graph showing flow distribution]

Variation of gas flows through single cells in a short stack

- stoich 1.65 @ 0.5 A/cm²
- stoich 2.00 @ 1.5 A/cm²

Characteristic time constant [s]

Cell no
We test balance-of-plant components.

Life-time testing of valves with Temperature cycling

photo Joscha Feuerstein
Testing of Balance-of-Plant Components
Validation of usability for fuel cell systems

- 2 climate chambers (e.g. with thermal imaging)
- Vacuum chamber for simulating high altitudes
  - Pressurized gases
  - Humidified gases
  - Leakage testing
  - Freeze-thaw cycles
  - Exposure tests
  - Aging tests
  - And much more…

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

Photo: Joscha Feuerstein

Life-time testing of a cooler at high temperature
Chemical Stability of System Components
Validation of usability for fuel cell systems

Wetted valve components after 8 weeks in deionized water

ICP-MS analysis of this water

SEM/EDX images

Fe

Cr

µg/l
Electro-Chemical Stability of Bipolar Plate Coatings
Understanding the details by applying different measurement technologies

Test set up for electro-chemical measurements
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
Electro-chemical Stability of Membranes
Benchmarking of components regarding life-time specifications

Accellerated stress testing of 3 different fuel cell membranes by open circuit voltage hold in combination with wet/dry cycling

Test of chemical membrane stability by Fenton-testing depending on temperature and time

Fenton mixture with 20 mg$_{Fe}$/l

Fluoride ion [F$^-$] concentration

tested membranes

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System Development
Designing, supply chain consulting, developing, testing

- **LiteFCBike**

  Fuel cell hybrid system with two air-cooled stacks and metal hydride storages (70 W)

  Fuel cell hybrid system integrated into luggage rack and connected to Conodrive™
System Modelling
Designing and operating systems

- Investigation of customer specific system configurations
- Analysis of system losses

System loss distribution

Drive cycle analysis of system efficiency
Scientific Publications
Proofing our results by the international scientific community

Download at our website
Let us join our forces.

photo Joscha Feuerstein