
CANADIAN GERMAN FUEL CELL RESEARCH COOPERATION

PEM-Ca-D, GECKO, DEKADE



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Hydrogen & Fuel Cells
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www.h2-ise.com

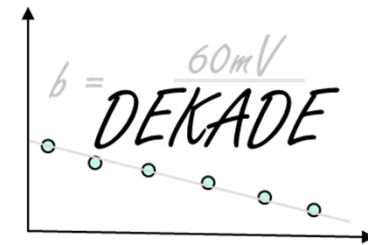
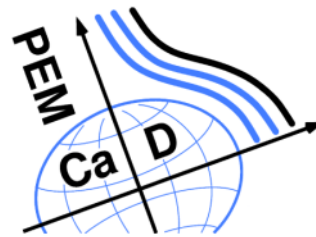
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To bring down costs, we have to understand the phenomena.



AGENDA

- Success story of Canadian-German fuel cell research co-operation
- Scientific findings and developments:
 - Spatially resolved fuel cell characterization
 - Estimation of gas velocity in channels
 - Water management in porous media
 - Direct membrane deposition
- Outlook

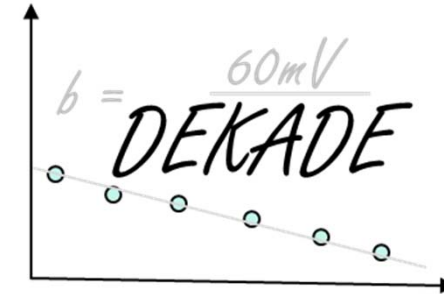
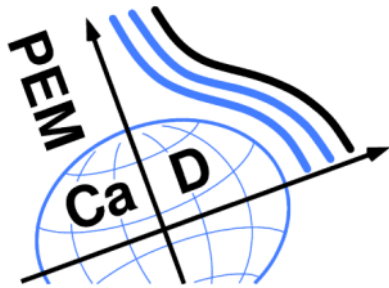


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10 years of German-Canadian Cooperation → Dekade



2009 - 2012	2013 - 2016	2017 - 2020
micro water management ■ DLR ■ Fraunhofer ISE ■ Fraunhofer ITWM ■ Uni Freiburg - IMTEK ■ ZSW	novel characterization methods ■ Fraunhofer ICT ■ Fraunhofer ISE ■ MPI-DktS ■ Uni Freiburg - IMTEK ■ ZSW	component development for improved performance, stability and costs ■ Fraunhofer ISE ■ Greenerity ■ Uni Freiburg - IAAC ■ Uni Freiburg – IMTEK ■ Volkswagen

Scientific Success Story I:

publications



- 44 Talks and Poster presentations
- 26 papers in peer-reviewed journals



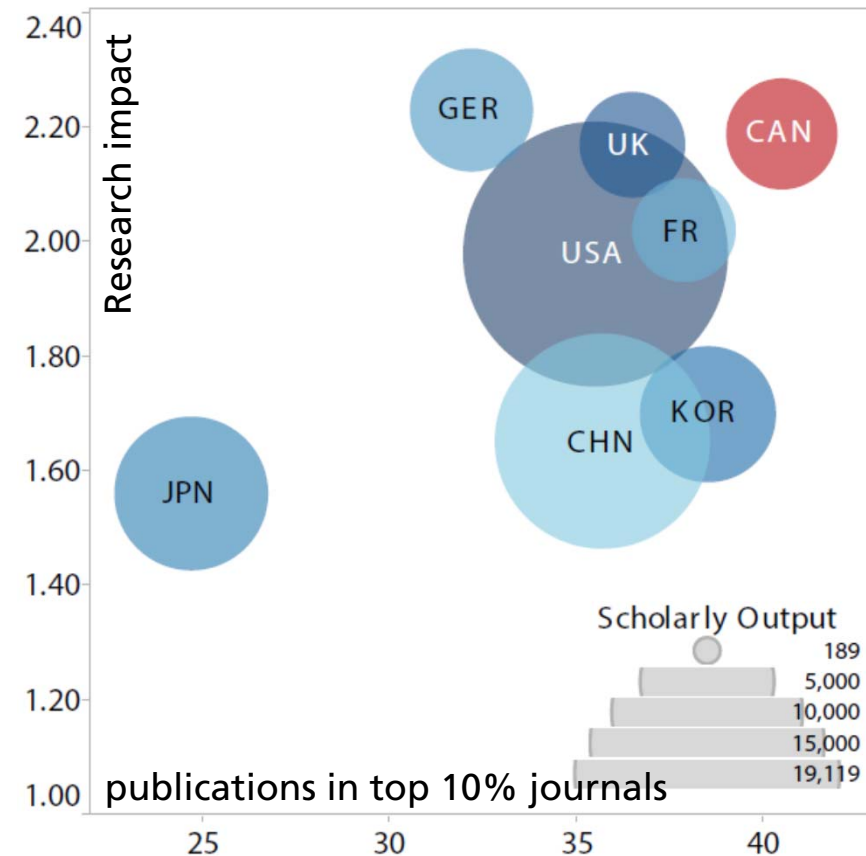
- 46 Talks and Poster presentations
- 18 papers in peer-reviewed journals

List of publications attached

Scientific Success Story II: publications

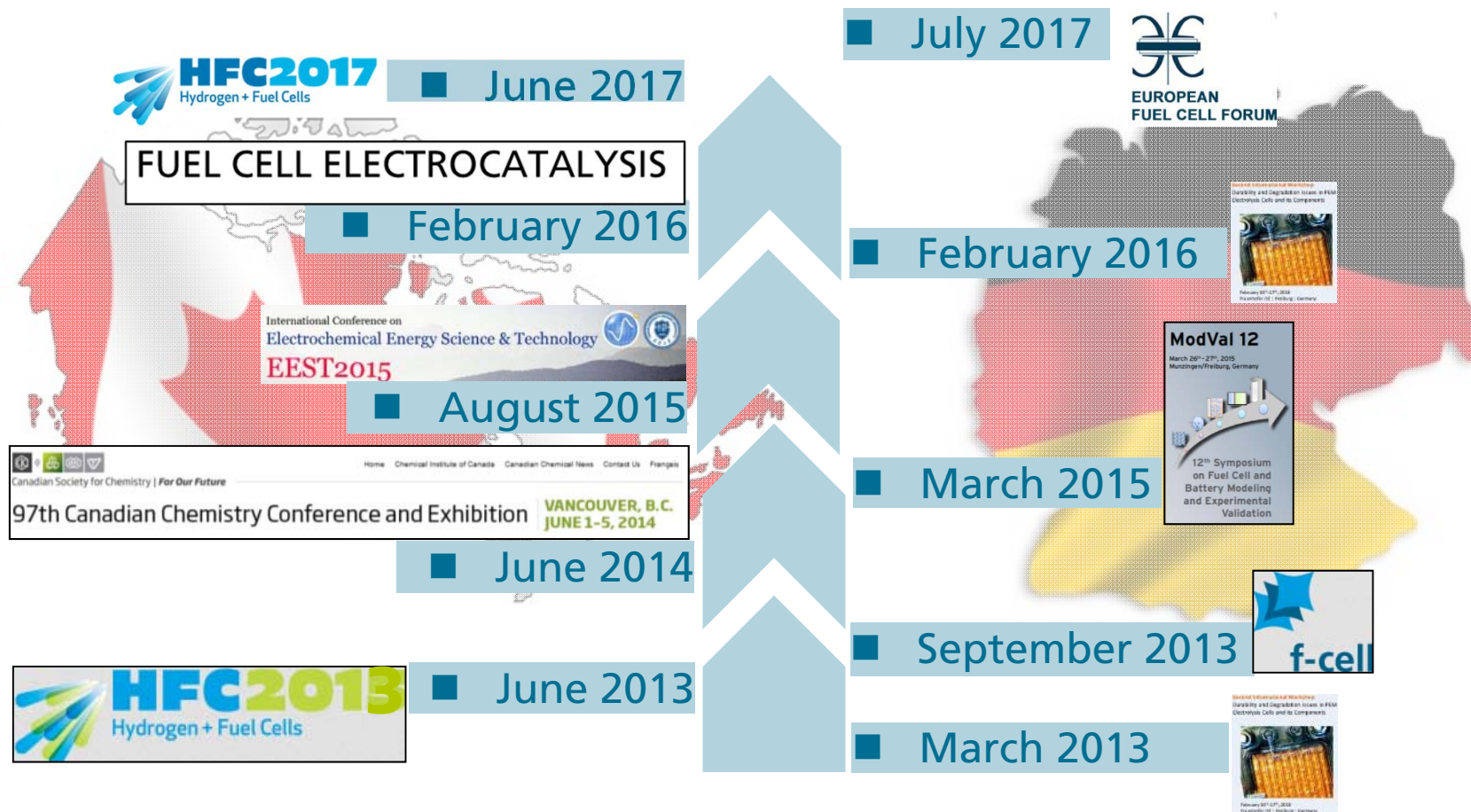


F-cell award 2015 for development in BMBF
project GECKO



Research impact in fuel cell chemistry by country
(2005-2015): SciVal. (graph provided by M.
Eikerling, SFU)

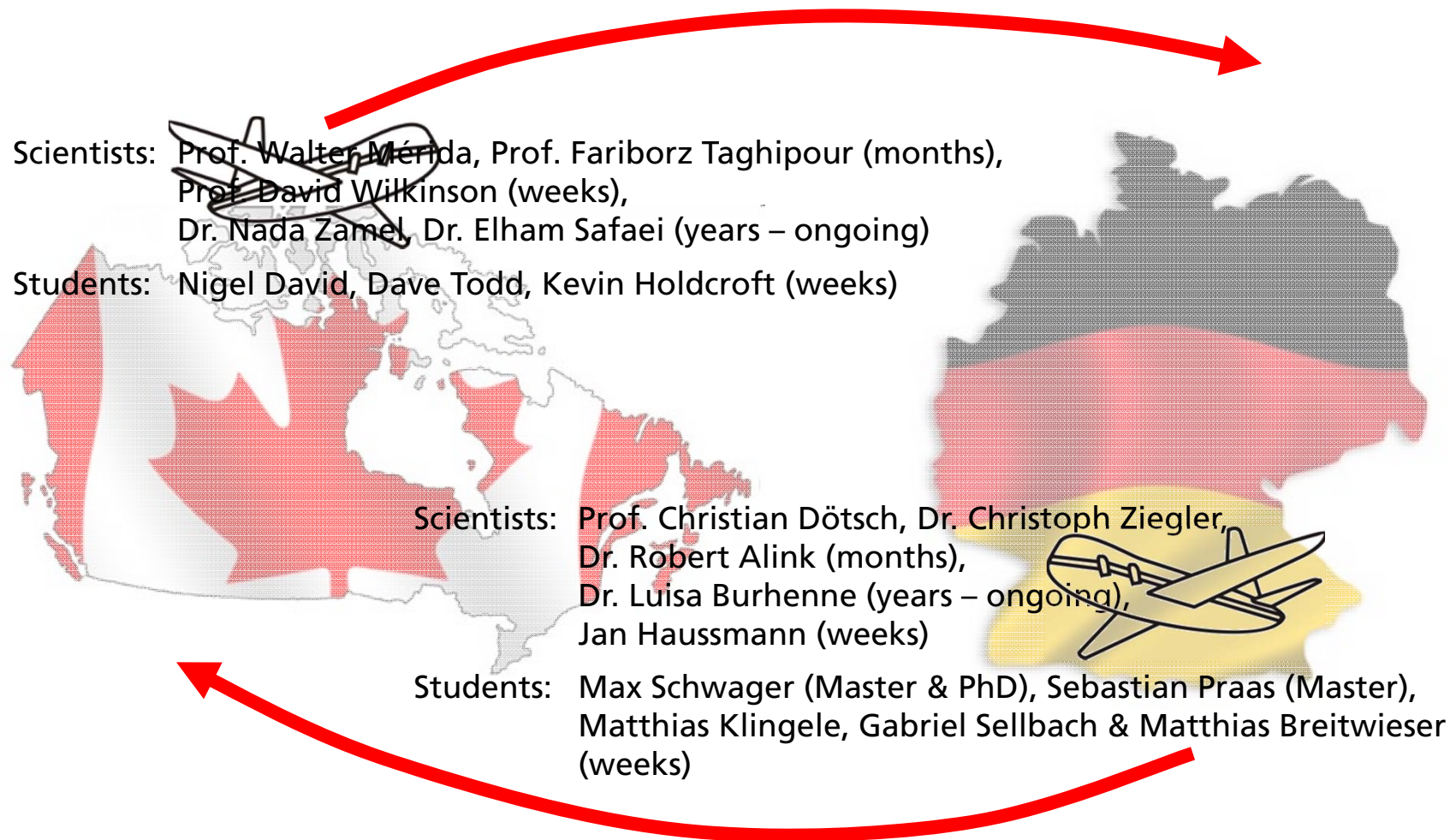
Scientific Success Story III: joint conferences



Scientific Success Story IV: great scientific network

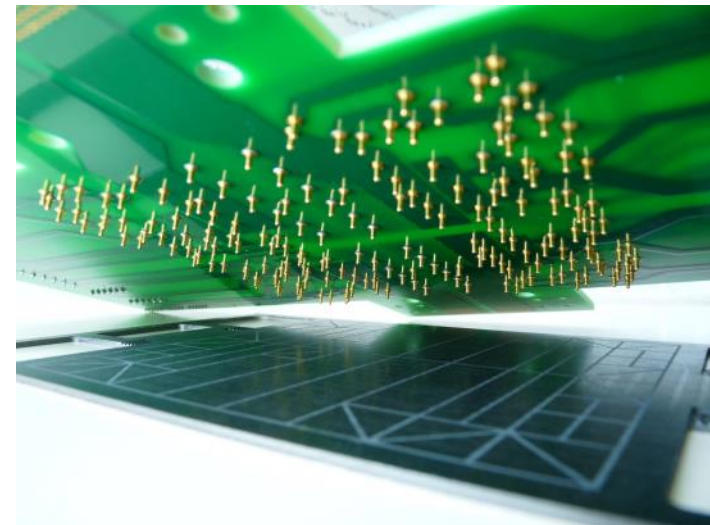


Scientific Success Story V: personal exchange

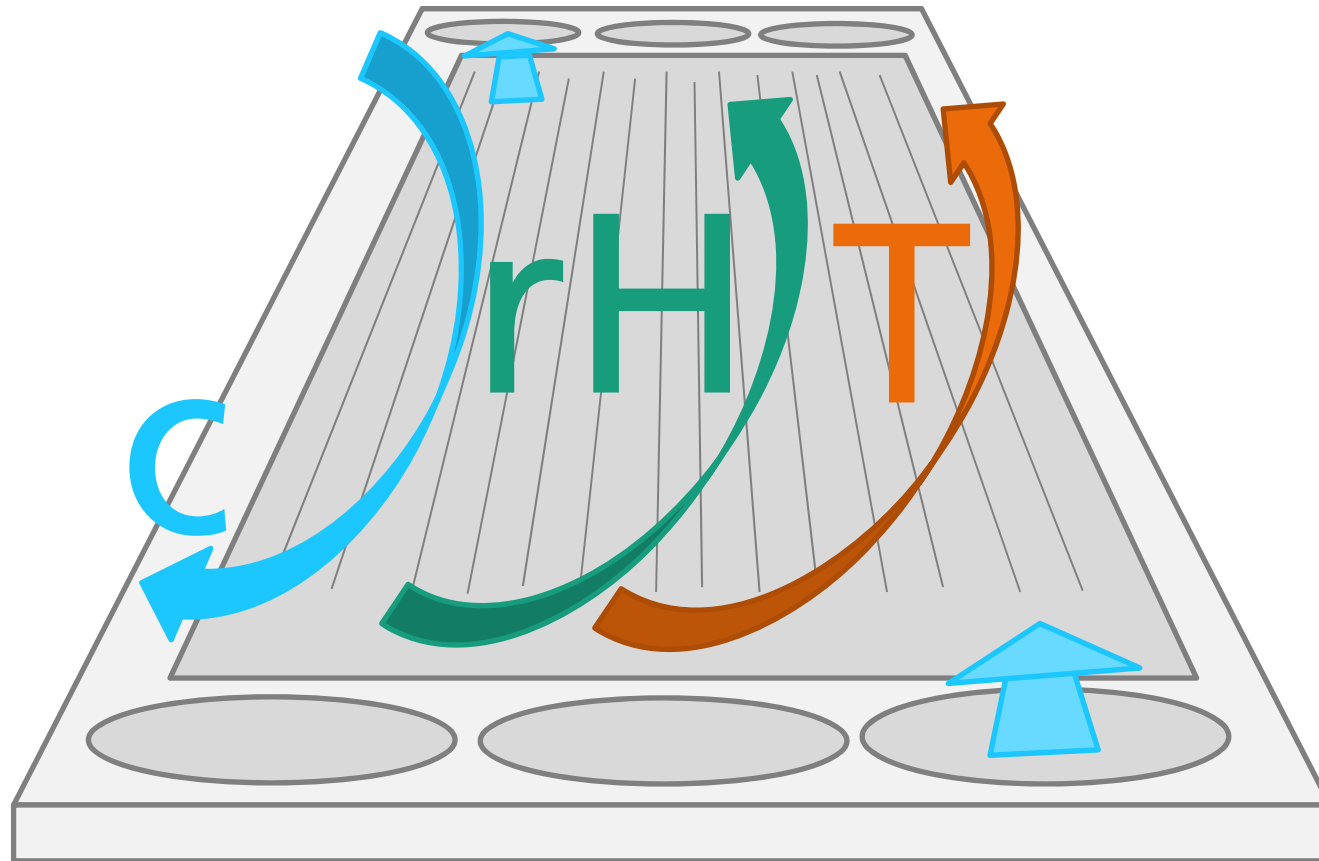


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Understanding local effects.



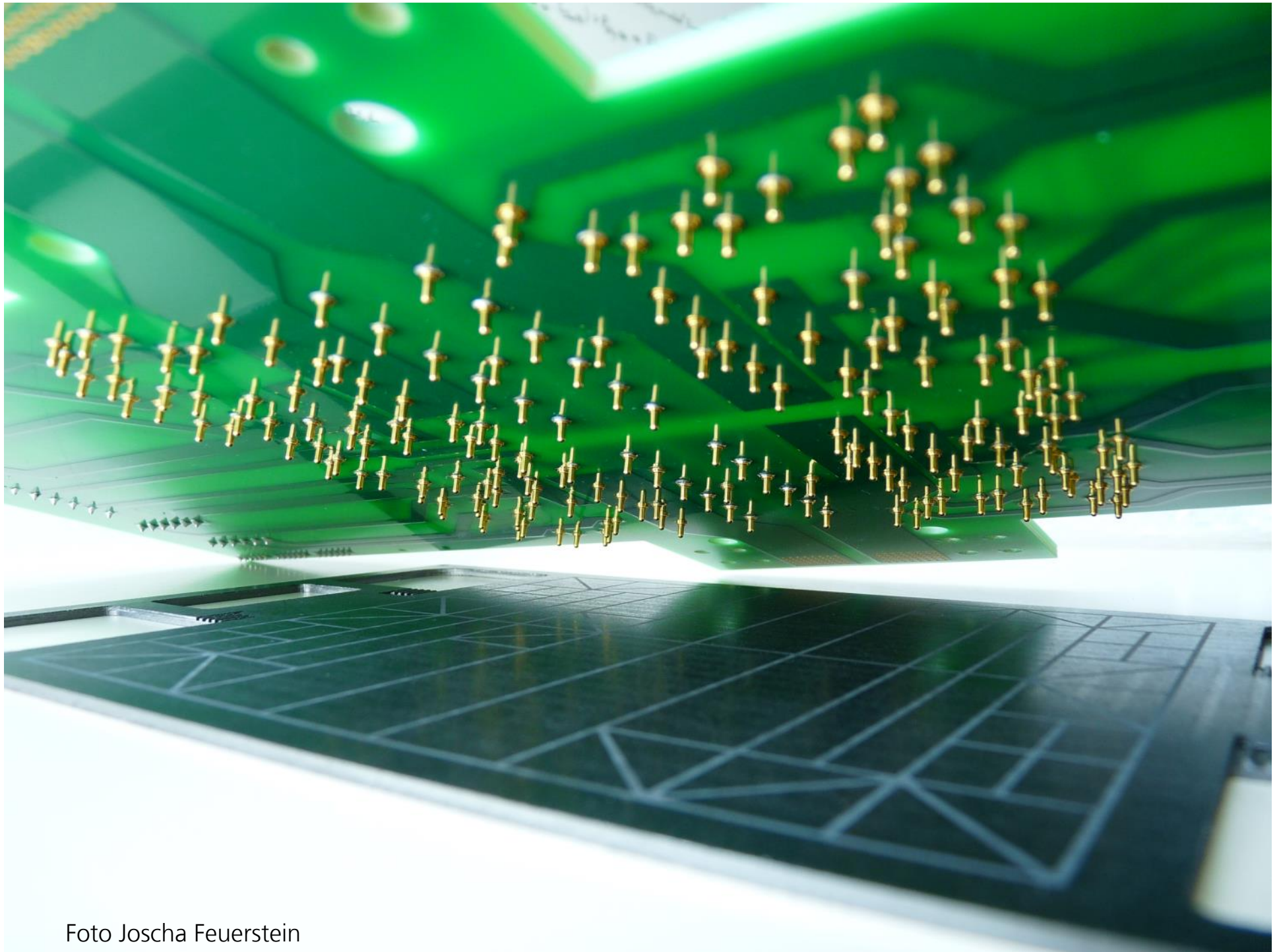
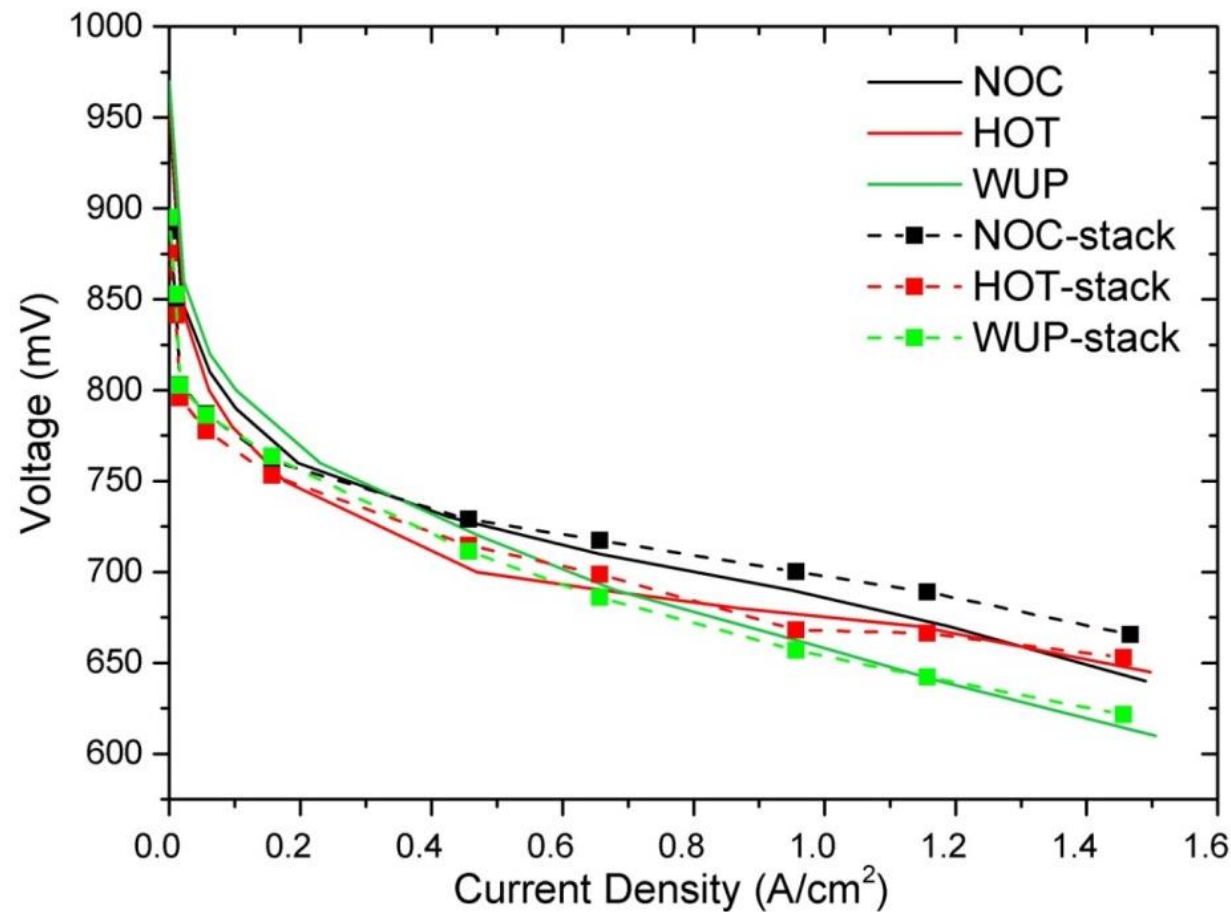


Foto Joscha Feuerstein

Foto
Joscha Feuerstein



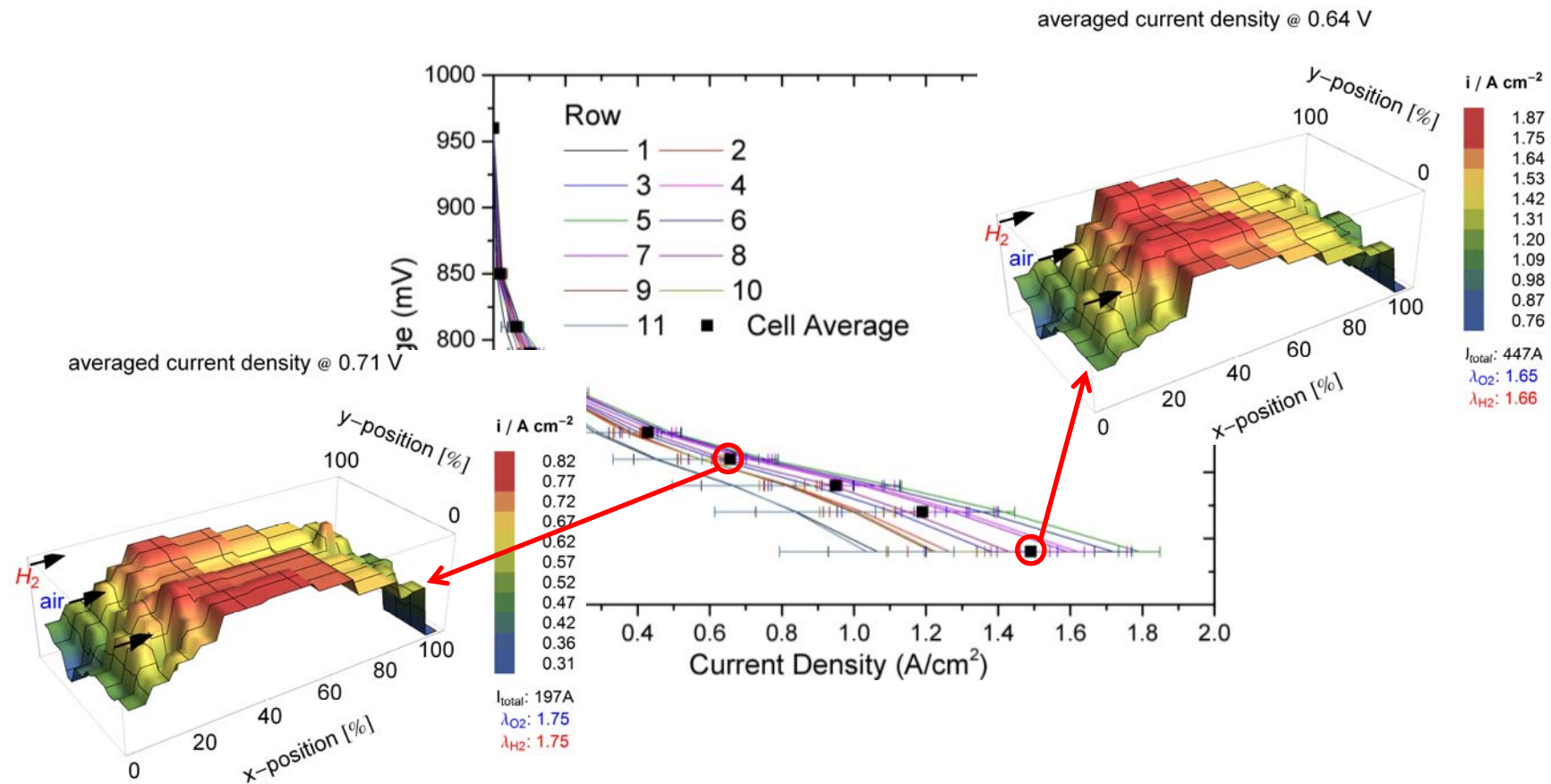
Spatially resolved characterization of automotive cells



Characterization of an automotive segmented single cell (lines) shows good agreement with average single cell performance in a stack.

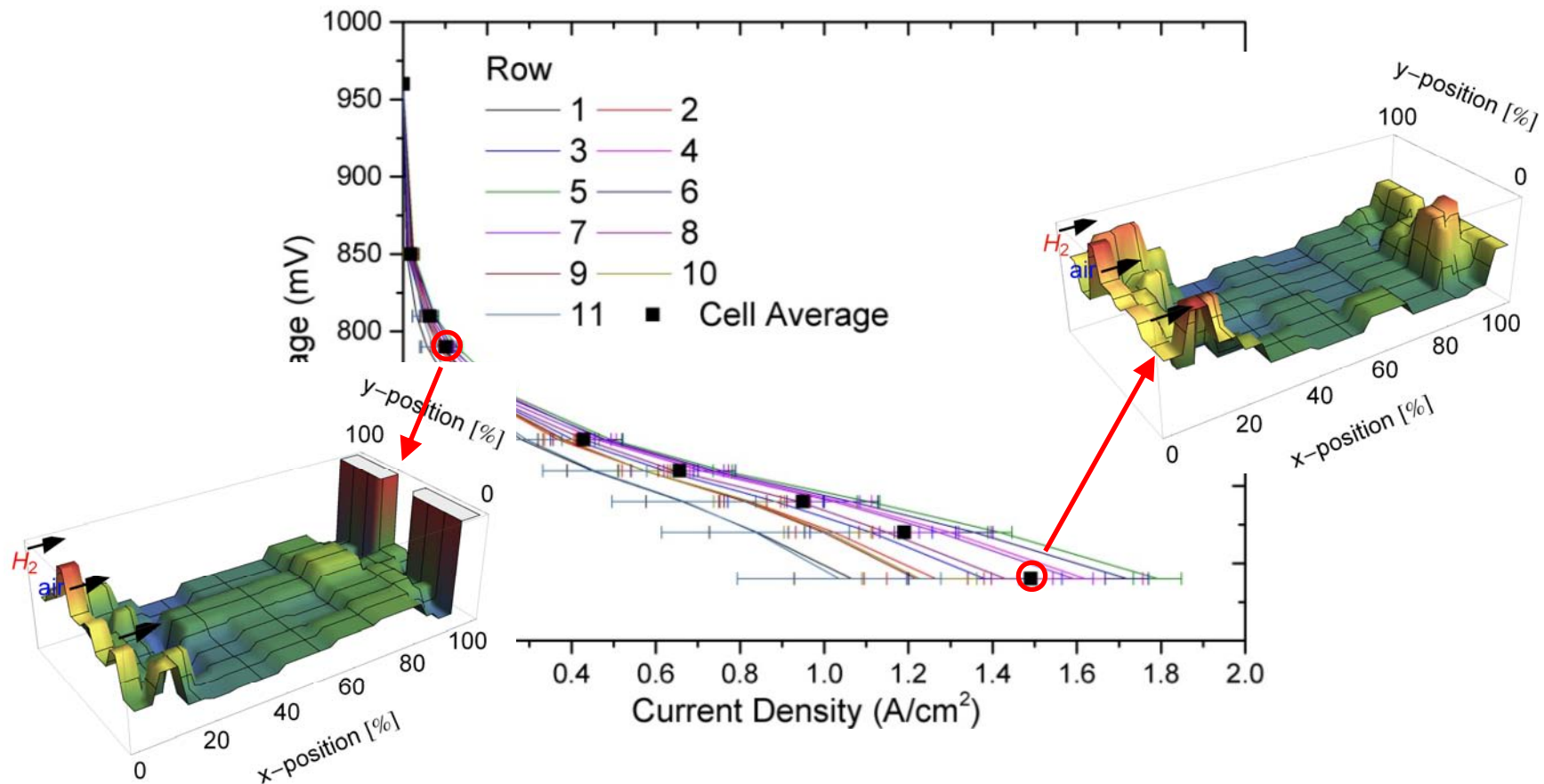
Spatially resolved characterization of automotive cells

Improving design and operation strategy



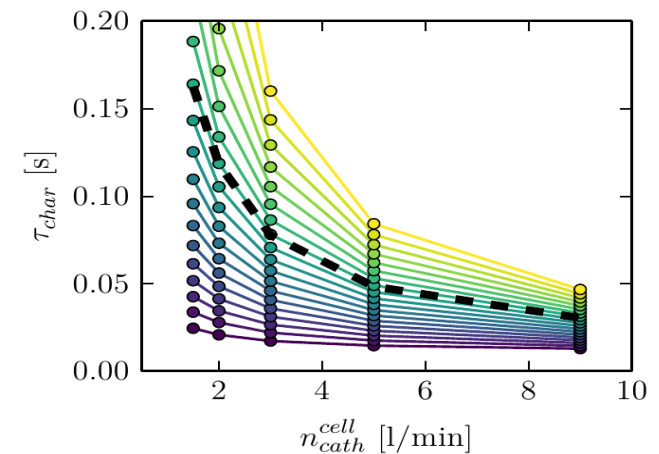
Spatially resolved characterization of automotive cells

Understanding water management and mass transport



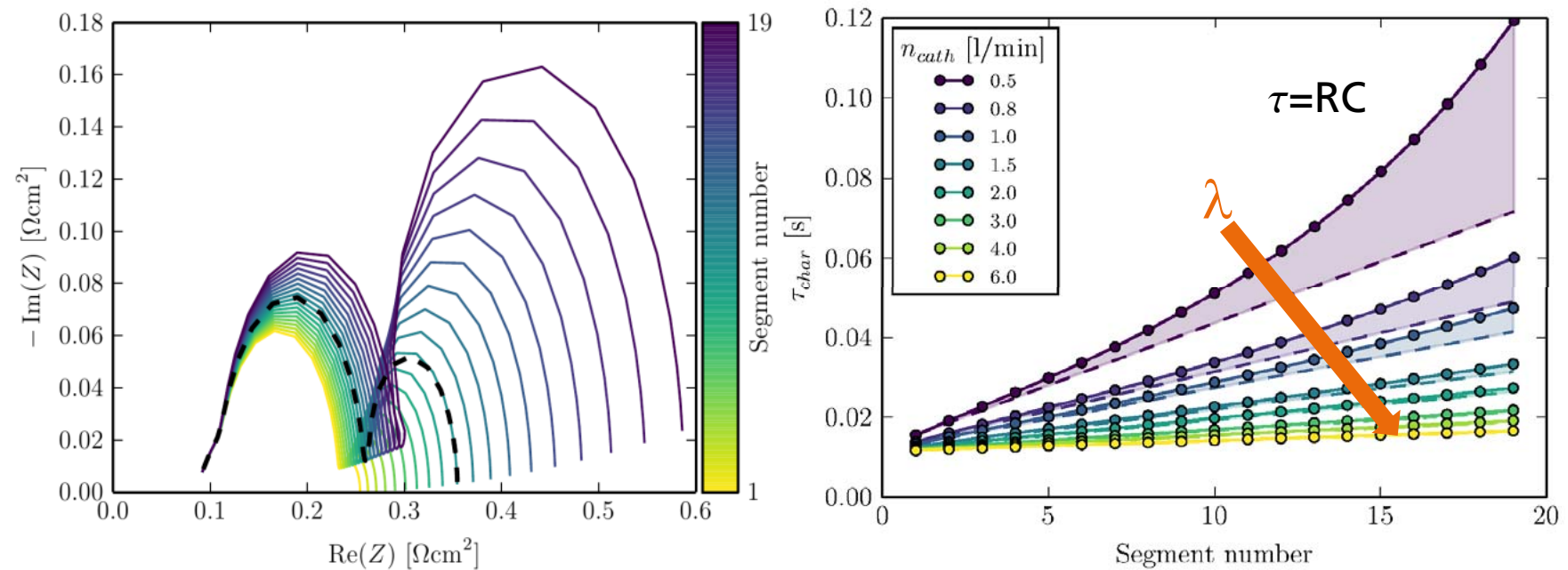
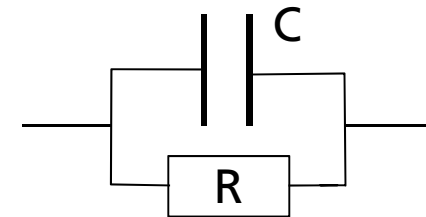
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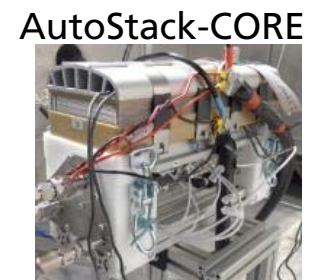
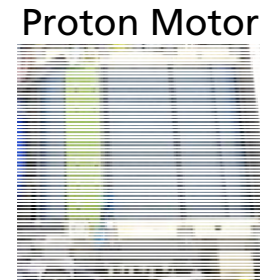
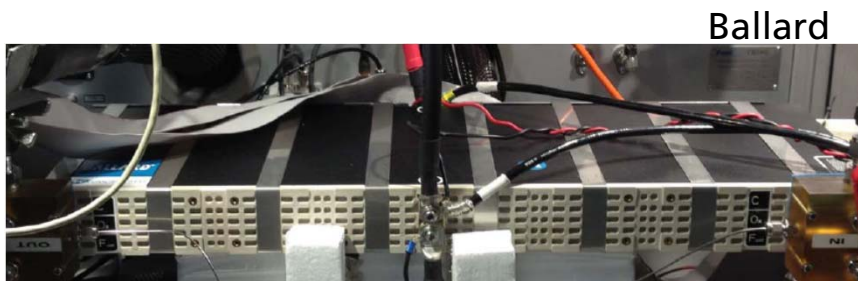
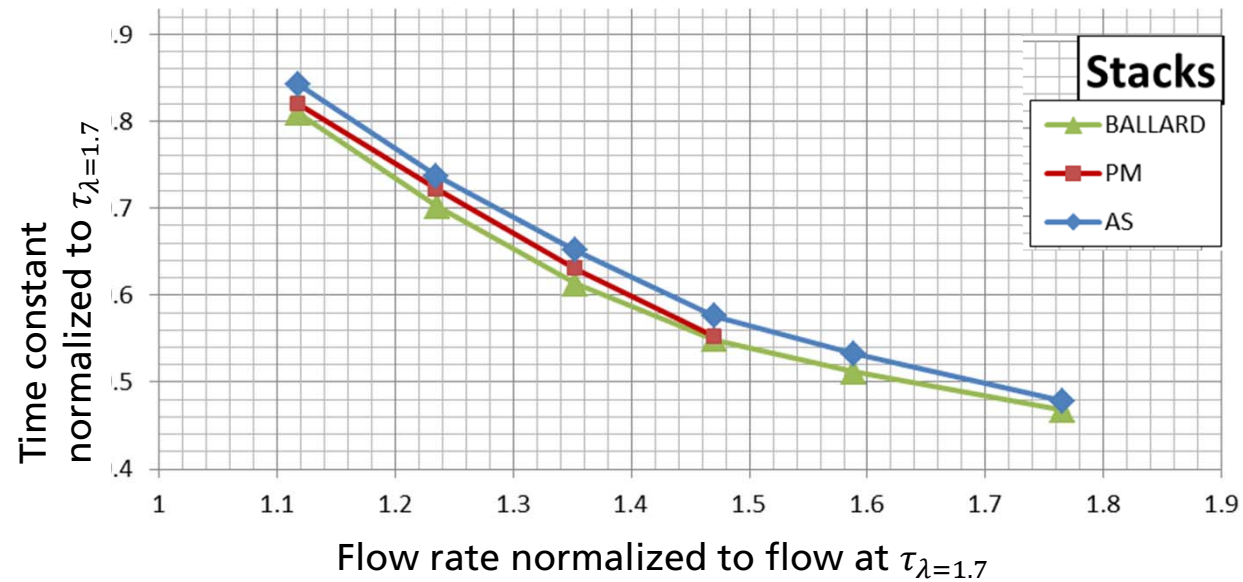


Development of novel characterization methods

Estimation of air residence time in feed channel by EIS

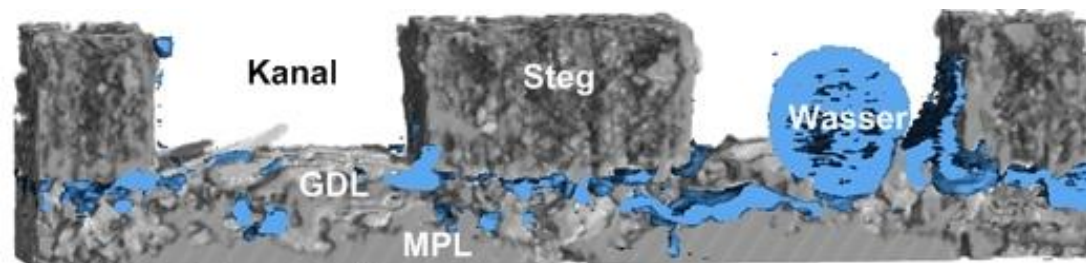


Effect experimentally proven for different stacks



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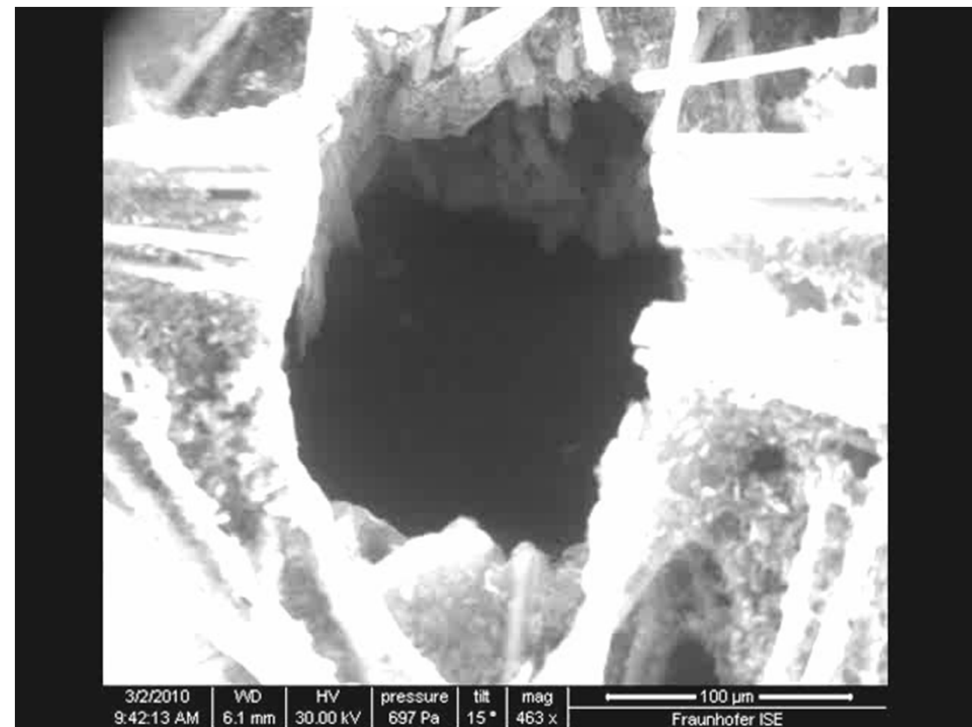
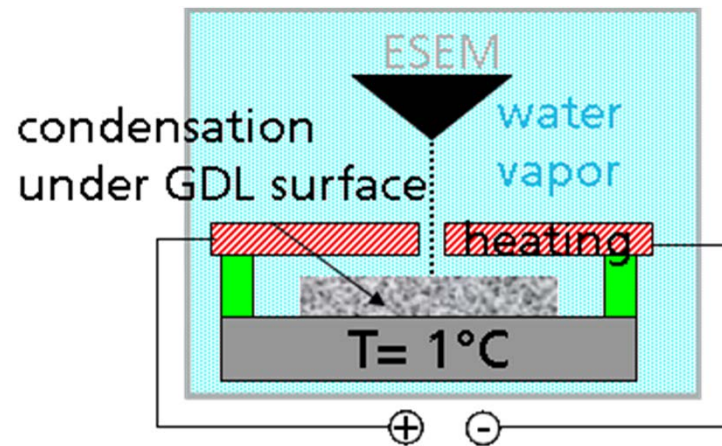
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 - **Water management in porous media**
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Optimizing water transport in GDLs

Investigation of

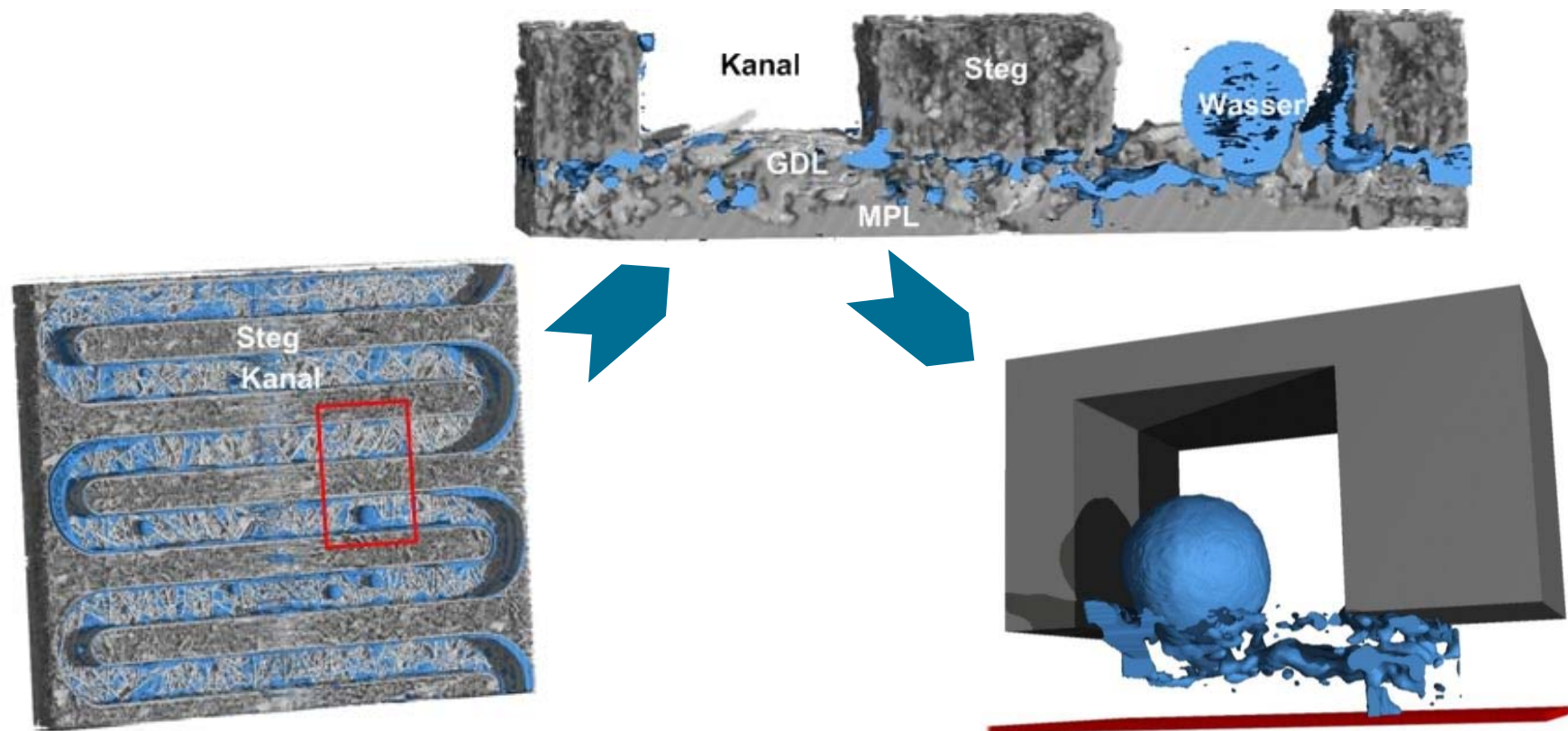
- the wetting properties of the GDL fibres
- the water transport in perforated GDLs



Visualizing water transport in laser perforated GDLs.
Fraunhofer ISE

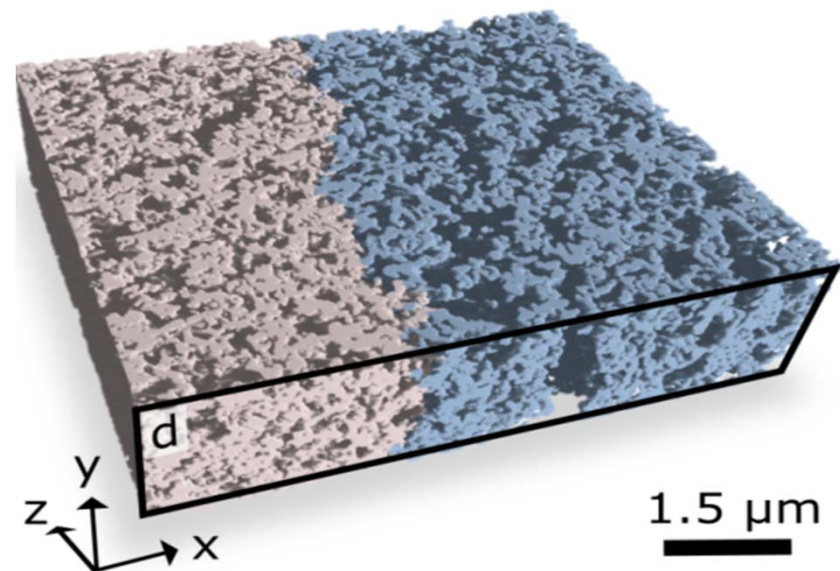
High resolution synchrotron tomography to investigate channel/land effects

- High precision resolution of water distribution: 5 $\mu\text{m}/\text{pixel}$



Tomographical investigations of CCL/MPL/GDL compositions

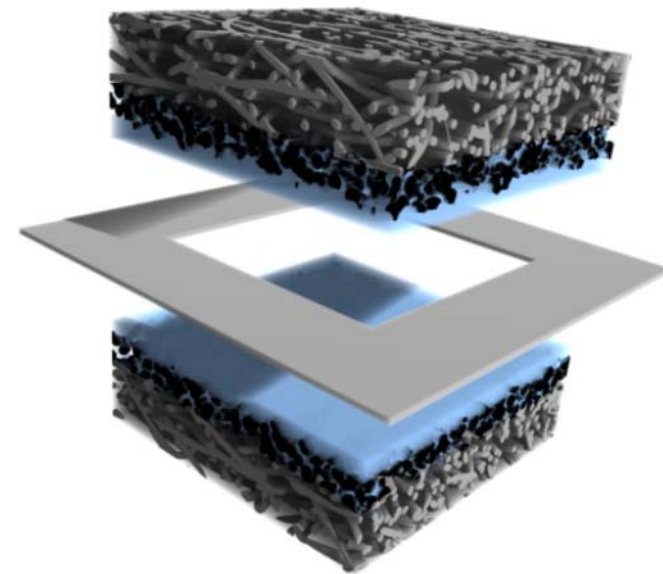
- Improved 3D reconstruction of porous media by Atomic Layer Deposition (ALD)
 - Improved contrast for segmentation
- Investigation of MPL/GDL interfaces



CCL (red), MPL (blue)

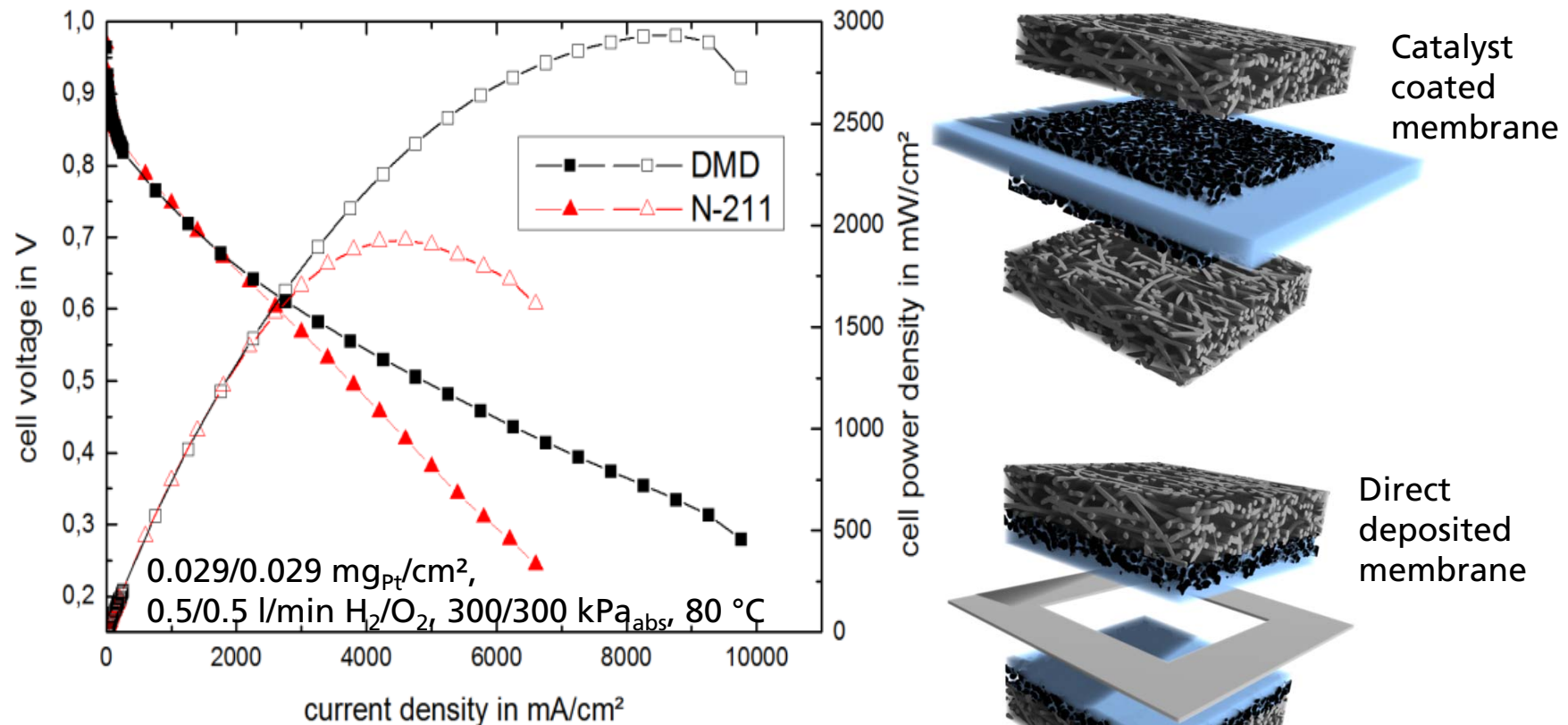
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Process and component development

Direct membrane deposition improves performance

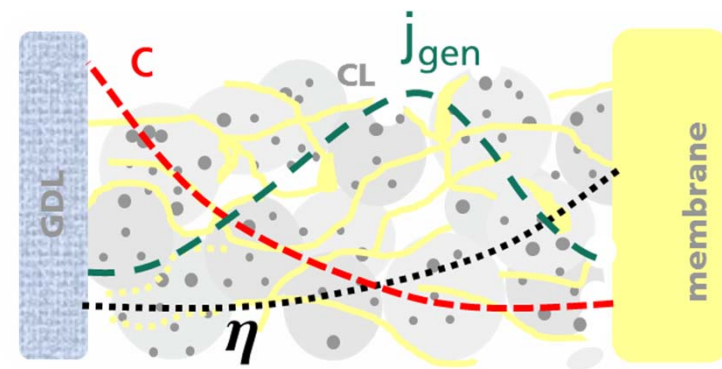


Breitwieser, M. et al., Improved Pt-utilization efficiency of low Pt-loading PEM fuel cell electrodes using direct membrane deposition. *Electrochemistry Communications*, 60, 168-171 (2015)

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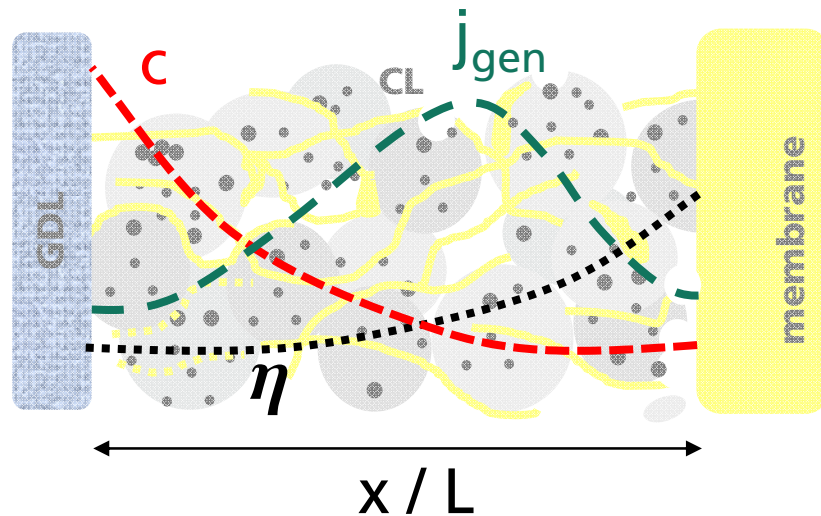
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Outlook: project DEKADE

Understanding through-plane effects



- Catalyst anchoring on stable carbon supports
- Reinforcement of direct deposition membranes
- multilayered electrode structures e.g. with Pt and/or ionomer gradient
- Investigation of production opportunities

Thank You Very Much for Your Attention!



Acknowledgement:

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Grant No. 03SF0544A

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Let us join our forces.

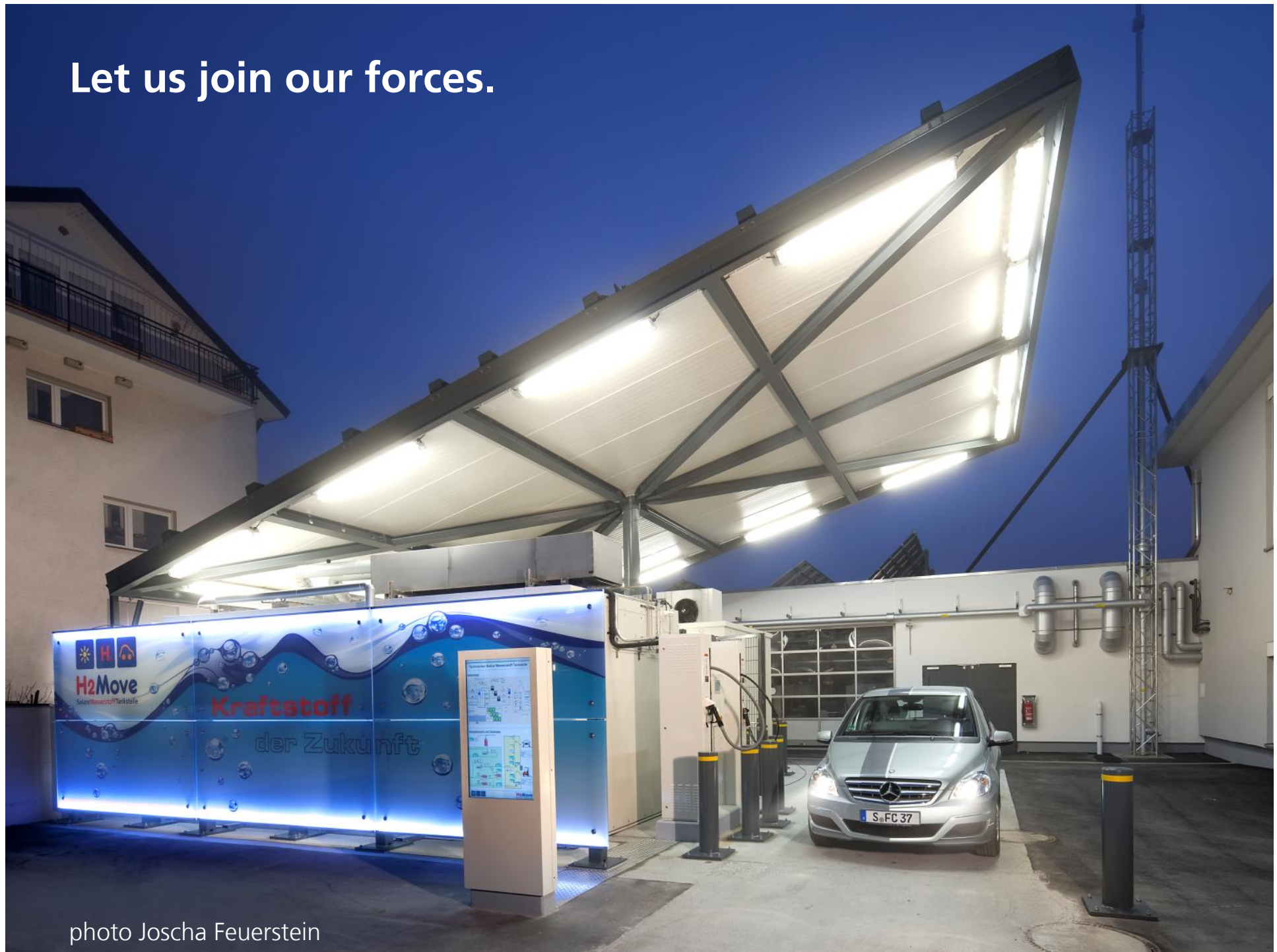


photo Joscha Feuerstein

PEM-Ca-D: scientific publications I

■ IMTEK

- T. Hutzenlaub, N. Paust, R. Zengerle, "The effect of wetting properties on bubble dynamics and fuel distribution in the flow field of direct methanol fuel cells", C. Ziegler, Journal of Power Sources 196 (2011) 8048– 8056.
- S. Thiele, T. Fürstenhaupt, D. Banham, T. Hutzenlaub, V. Birss, C. Ziegler, R. Zengerle, "Multiscale tomography of nanoporous carbon-supported noble metal catalyst layers", Journal of Power Sources, 228 (2013) 185-192.
- T. Hutzenlaub, J. Becker, R. Zengerle, S. Thiele, "Modelling the water distribution within a hydrophilic and hydrophobic 3D reconstructed cathode catalyst layer of a PEMFC", Journal of Power Sources 227 (2013) 260-266
- T. Hutzenlaub, J. Becker, R. Zengerle, S. Thiele, "How coarsening of a 3D reconstruction influences diffusivity and conductivity values of a PEMFC CCL, Electrochemistry Letters 2(2) (2012).

■ DLR

- E. Gülzow, M. Schulze, K.A. Friedrich, P. Fischer, H. Bettermann, Local in-situ analysis of PEM Fuel Cells by Impedance Spectroscopy and Raman Measurements, ECS Transactions, 30 (2011) 65
- R. Hiesgen, I. Wehl, K.A. Friedrich, M. Schulze, A. Haug, A. Bauder, A. Carrera, X.-Z. Yuan, H. Wang, Atomic Force Microscopy Investigation of Polymer Fuel Cell Gas Diffusion Layers Before and After Operation. ECS Transactions, 28 (2010) 79
- A. Haug, R. Hiesgen, M. Schulze, G. Schiller, K.A. Friedrich, Fourier Transform Infrared Spectroscopy. In: PEM Fuel Cell Diagnostic Tools PEM Fuel Cell Durability Handbook, 2. CRC Press (2011). p 369-379
- M. Schulze, A. Haug, X-Ray Photoelectron Spectroscopy. In: PEM Fuel Cell Diagnostic Tools PEM Fuel Cell Durability Handbook, 2. CRC Press (2011). p 381-394

PEM-Ca-D: scientific publications II

■ ZSW

- H. Markötter, I. Manke, P. Krüger, T. Arlt, J. Haußmann, M. Klages, H. Riesemeier, C. Hartnig, J. Scholta, J. Banhart, *Electrochemistry Communications*, 13 (2011) 1001-1004.
- H. Markötter, I. Manke, J. Haußmann, T. Arlt, M. Klages, P. Krüger, C. Hartnig, J. Scholta, B.R. Muller, H. Riesemeier, J. Banhart, *Micro & Nano Letters*, 7 (2012) 689-692.
- H. Markötter, R. Alink, J. Haußmann, K. Dittmann, T. Arlt, F. Wieder, C. Tötzke, M. Klages, C. Reiter, H. Riesemeier, J. Scholta, D. Gerteisen, J. Banhart, I. Manke, *International Journal of Hydrogen Energy* 37 (2012) 7757-7761.
- J. Haußmann, H. Markötter, R. Alink, A. Bauder, K. Dittmann, I. Manke, J. Scholta, *Journal of Power Sources* 239 (2013) 611-622
- K. Seidenberger, F. Wilhelm, J. Haußmann, H. Markötter, I. Manke, J. Scholta, *Journal of Power Sources* 239 (2013) 628-641
- H. Markötter, T. Arlt, C. Tötzke, K. Dittmann, P. Krüger, J. Haußmann, M. Klages, J. Scholta, R. Alink, D. Gerteisen, K. Wippermann, H. Riesemeier, I. Manke, J. Banhart, *ECS Transactions* 45(29) (2013) 195-202.

PEM-Ca-D: scientific publications III

■ Fraunhofer ISE

- R. Alink, W. Merida, D. Gerteisen; "Investigating the Water Transport in Porous Media for PEMFCs by Liquid Water Visualization in ESEM" FUEL CELLS 11, 2011, No. 4, 481–488
- D. Gerteisen, W. Mérida, T. Kurz, P. Lupotto, M. Schwager, C. Hebling; "Spatially resolved voltage, current and electrochemical impedance spectroscopy measurements" FUEL CELLS 11, 2011, No. 2, 339–349
- Dietmar Gerteisen, Nada Zamel, Christian Sadeler, Florian Geiger, Victor Ludwig, Christopher Hebling; "Effect of Operating Conditions on Current Density Distribution and High Frequency Resistance in a Segmented PEM Fuel Cell" International Journal of Hydrogen Energy, Volume 37, issue 9, 2011, p. 7736–7744
- Robert Alink, Jan Haußmann, Maximilian Schwager, Ingo Manke, Dietmar Gerteisen, "The Influence of Porous Transport Layer Modifications on the Water Management in PEM Fuel Cells" Journal of Power Sources 233 (2013) 358–368
- Nada Zamel, Arjun Bhattarai, Dietmar Gerteisen, "Effect of Perturbation on Electrochemical Impedance Spectroscopy of PEM Fuel Cells – Understanding the Characteristics" Fuel Cells, 13 (2013), 910–916
- Robert Alink, Dietmar Gerteisen, "Modeling the liquid water transport in the porous layers in PEM fuel cells using a water path network based percolation model" Energies 6(9) 2013

GECKO – publications I

■ IMTEK

- M. Breitwieser, M. Klingele, B. Britton, S. Holdcroft, R. Zengerle, S. Thiele. Improved Pt-utilization efficiency of low Pt-loading PEM fuel cell electrodes using direct membrane deposition, *Electrochemistry Communications* 60 (2015) 168–171.
- M. Klingele, M. Breitwieser, R. Zengerle, S. Thiele. Direct deposition of proton exchange membranes enabling high performance hydrogen fuel cells, *J. Mater. Chem. A* 3 (2015) 11239–11245.
- M. Klingele, R. Zengerle, S. Thiele. Quantification of artifacts in scanning electron microscopy tomography: Improving the reliability of calculated transport parameters in energy applications such as fuel cell and battery electrodes, *J. Power Sources* 275 (2015) 852–859.
- S. Vierrath, F. Güder, A. Menzel, M. Hagner, R. Zengerle, M. Zacharias, S. Thiele. Enhancing the quality of the tomography of nanoporous materials for better understanding of polymer electrolyte fuel cell materials, *J. Power Sources* 285 (2015) 413–417.
- N. Wehkamp, M. Breitwieser, A. Büchler, M. Klingele, R. Zengerle, S. Thiele. Directly deposited Nafion/TiO₂ composite membranes for high power medium temperature fuel cells. *RSC Adv* 6 (29), 2016, S. 24261–24266.
- L. Zielke, S. Vierrath, R. Moroni, A. Mondon, R. Zengerle, S. Thiele, “Three-dimensional morphology of the interface between micro porous layer and catalyst layer in a polymer electrolyte membrane fuel cell” (in Review bei RSC Advances)
- Vierrath, S, Breitwieser, M., Klingele, M., Britton, B., Holdcroft, S., Zengerle, R., & Thiele, S. Reasons for the high power density of fuel cells with directly deposited membranes. *J. Power Sources* 326 (2016) 170-175
- Klingele, M., Britton, B., Breitwieser, M., Vierrath, S, Zengerle, R., Holdcroft, S. & Thiele, S. A Completely Spray-Coated Membrane Electrode Assembly, *Electrochemistry Communications* 70 (2016) 65-68

GECKO – publications II

■ ISE

- Nada Zamel, Richard Hanke-Rauschenbach, Sebastian Kirsch, Arjun Bhattarai, Dietmar Gerteisen „ Relating the N-shaped polarization curve of a PEM fuel cell to local oxygen starvation and hydrogen evolution “ International Journal of Hydrogen Energy, Vol 38, (22), p.15318-15327, 2013
- Dietmar Gerteisen „ Impact of inhomogeneous catalyst layer properties on impedance spectra of polymer electrolyte membrane fuel cells “ J. Electrochem. Soc., 2015, volume 162, issue 14, F1431-F1438
- Nada Zamel „ The catalyst layer and its dimensionality – A look into its ingredients and how to characterize their effects “ Journal of Power Sources, Volume 309, 31 March 2016, Pages 141-159
- Stefan Keller, Tansu Özel, Anne-Christine Scherzer, Ulf Groos, Christopher Hebling, Yiannos Manoli „ Characteristic Time Constants Derived from the Low Frequency Arc of Impedance Spectra of Fuel Cell Stacks“ Journal of Electrochemical Energy Conversion and Storage, submitted
- Anne-Christine Scherzer, Stefan Keller, Nada Zamel, Dietmar Gerteisen „ A Numerical Model to Analyze the Characteristic Time Constant of the Low Frequency Arc in Impedance Spectra of Segmented Fuel Cells “ submitted

GECKO – publications III

■ MPI

- T. Vidaković-Koch, R. Hanke-Rauschenbach, I. González Martínez, K. Sundmacher (2016). Catalyst Layer Modeling for Gas-Diffusion-Electrodes. Springer Handbook of Electrochemistry (ed. C. Breitkopf, K. Swider-Lyons). Springer.
- I. Pena Arias, P. Trinke, R. Hanke-Rauschenbach, K. Sundmacher (2016). Understanding PEM fuel cell dynamics: The reversal curve. International Journal of Hydrogen Energy, submitted.
- A. Sorrentino, T. Vidakovic-Koch, R. Hanke-Rauschenbach, K. Sundmacher Concentration-induced Electrochemical Impedance Spectroscopy (cEIS) for the Analysis of PEM Fuel Cells, Electrochimica Acta 243 (2016) 53-64