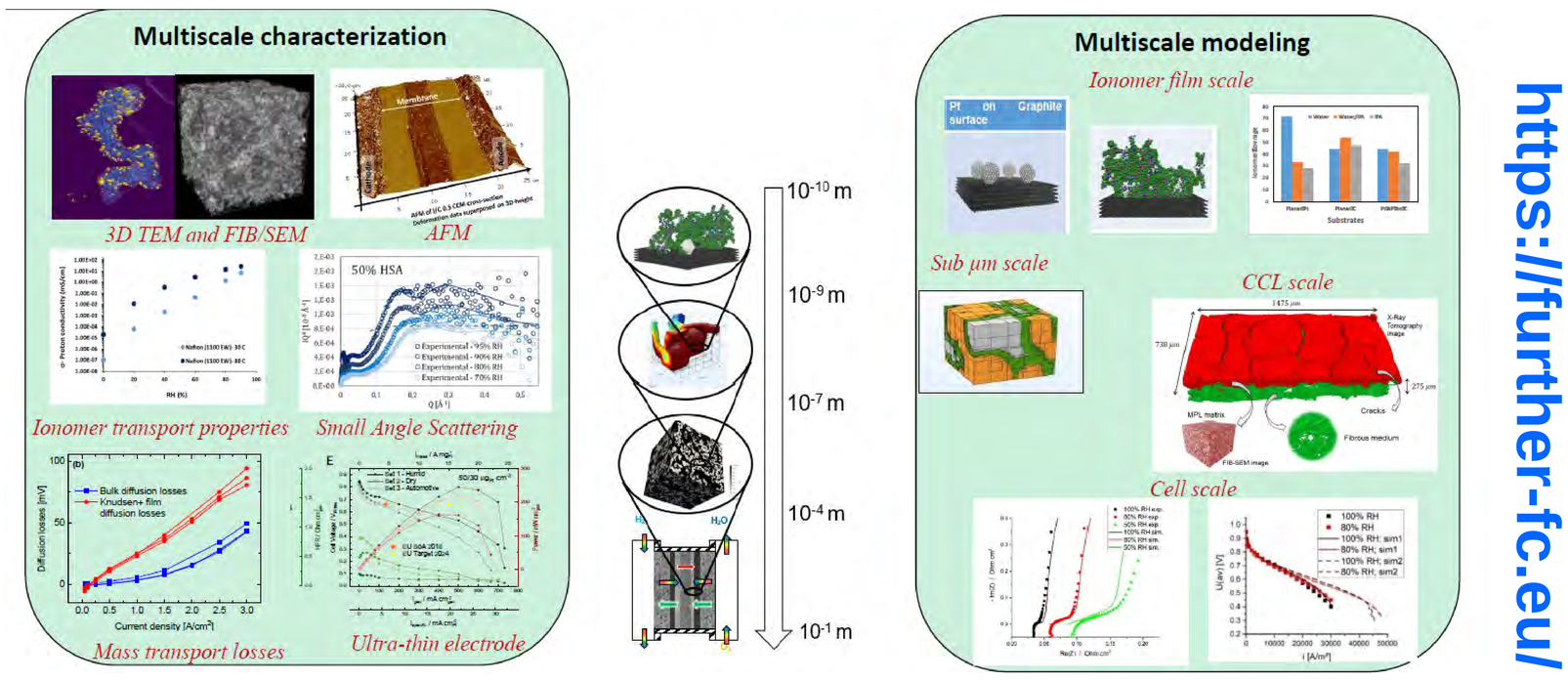
FURTHER-FC Newsletter #4
Further Understanding Related to Transport limitations at High current density towards future ElectRodes for Fuel Cells

News: Review of FURTHER-FC Workshop held at DLR, Stuttgart (Germany)

Main Progress FURTHER-FC - Research overview



https://further-fc.eu/

Agenda

FURTHER-FC Workshop Agenda			
08:45	Welcome Coffee		
General Talks			
09:15	Welcome and Introduction to the workshop	Jens Mitzel Pawel Gazdzicki Joël Pauchet	DLR DLR CEA
09:30	General challenges in PEMFC	Ludwig Jörissen	ZSW
09:50	Importance of strategic research challenges	Ludwig Jörissen Laurent Antoni	Hydrogen Europe Research
10:10	Overview of CAMELOT	Thor Aarhaug	SINTEF Industry
10:20	Overview of FURTHER-FC Introduction of project partners	Joël Pauchet	CEA
11:05	Coffee Break		
11:20	Main Progress	Arnaud Morin	CEA
11:40	Importance of the Project from Industry Point of View	Stephane Cotte	Toyota Motor Europe
12:00	Lunch break		
Scientific highlights from FURTHER-FC			
13:00	Ionomer Thin Films	Kunal Karan	University of Calgary
13:20	Characterization of the CCL structure – spatial distribution of the materials	Laure Guetaz Tobias Morawietz	CEA UES
13:40	Characterisation of CCL materials - local transport properties and transport-free electrocatalysis	Anthony Kucernak	ICL
14:00	Quantification of local conditions in MEA	Pierre Boillat	PSI
14:20	Electrochemical characterization	Jens Mitzel	DLR
14:40	Coffee Break		
15:00	Electrochemical modelling	Michael Eikerling	RWTH Aachen
15:30	Multiscale Modelling	Thomas Jahnke	DLR
16:00	High Oxygen Permeable Ionomers for Durable, High Power Density Cathodes	Andrew Park	Chemours US
16:20	Discussion with the audience	Joël Pauchet Arnaud Morin	CEA
16:40	Introduction of FURTHER-FC Project Officer	Luca FEOLA	Clean Hydrogen Partnership
16:50	Closing Remarks	Joël Pauchet	CEA
17:00	DLR Lab Tour	Jens Mitzel	DLR

Selected Presentation Summaries

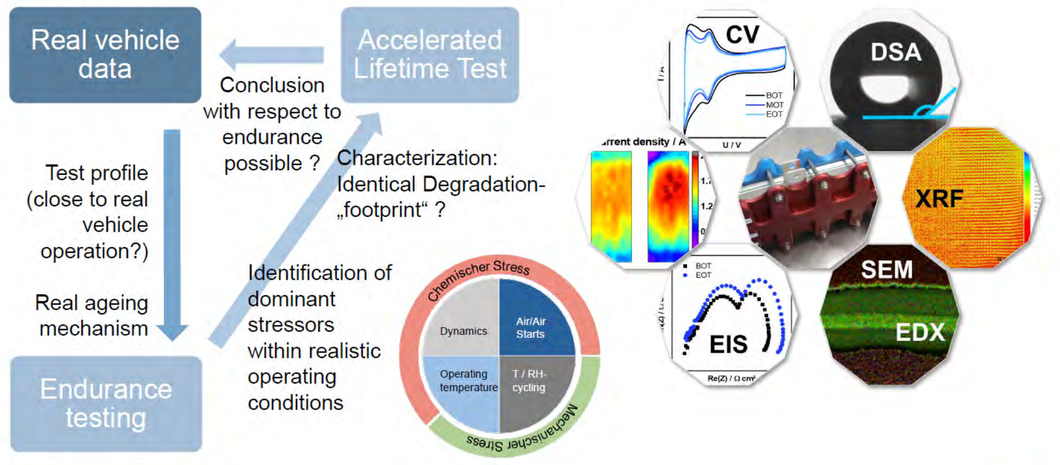
General Challenges in PEMFC – Ludwig Jörissen (ZSW)

General Challenges in PEMFC

Ludwig Jörissen

Stuttgart, 06.07.2022

FURTHER-FC Workshop



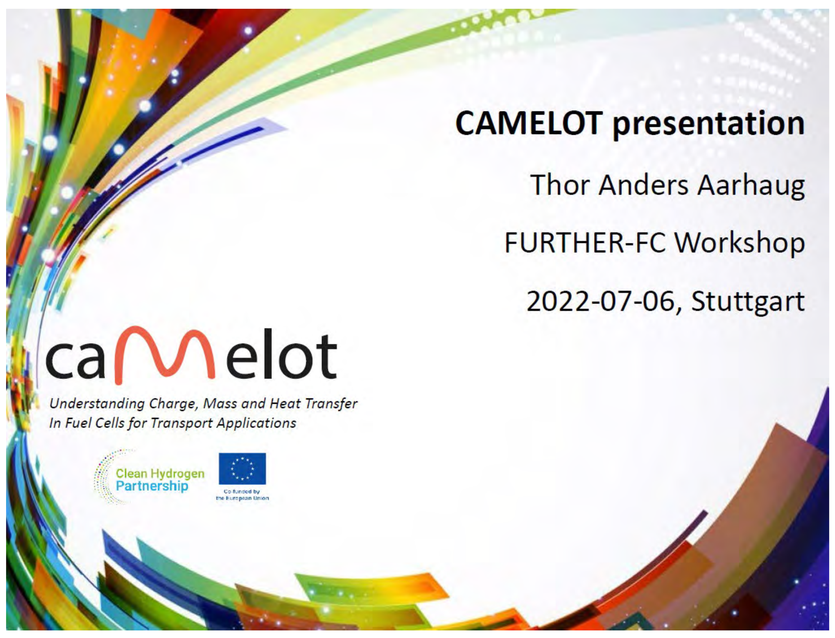
10 06.07.2022 I General Challenges in PEMFC I Ludwig Jörissen

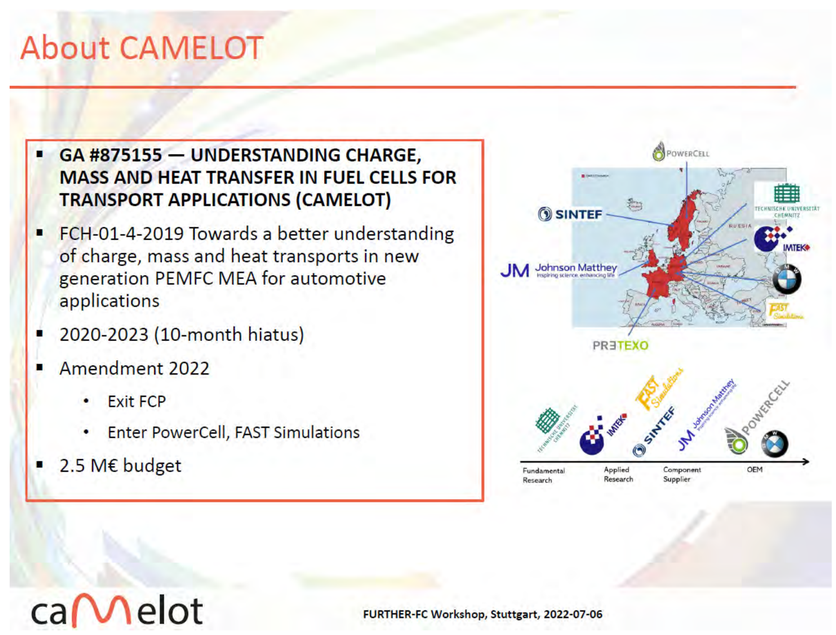
Summary

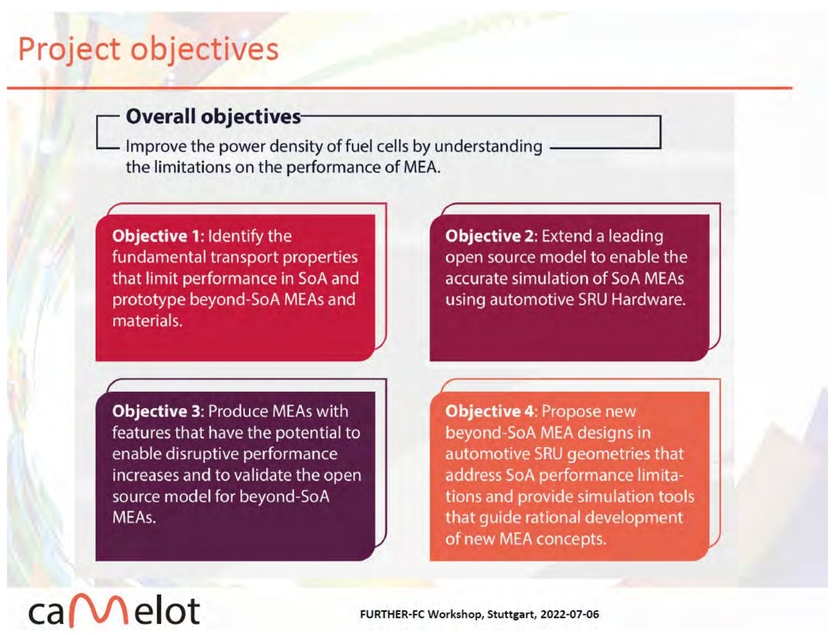
25k+ hours durability were show, but the exact „solution“ to long life is not fully understood*

- Fuel Cell specifications are moving targets!
  - Shift from maximizing power density at minimum noble metal loading to maximizing endurance.
  - Durability requirements in form of voltage loss over time shifts from, 12 µV·h^{-1} to ~ 2 µV·h^{-1}.
- Proposed measures:
  - Increased noble metal loading
  - Stabilize Pt-particle distribution and cataly<st supports
  - Use additives to reduce sensitivity to fuel contaminants, cell reversal and radical attack
  - Use thicker membranes
    - Good for uniform thickness los but how about pinhole formation
  - Decrease operating temperature
    - In contrast to heavy duty application providing lower heat rejection area
  - Operate between 0.85 V (catalyst stability) and 0.7 V (efficiency)
  - Oversize stack to compensate for activity losses
  - Adapt operating conditions over lifetime
  - Graphite vs. metallic bipolar plates?

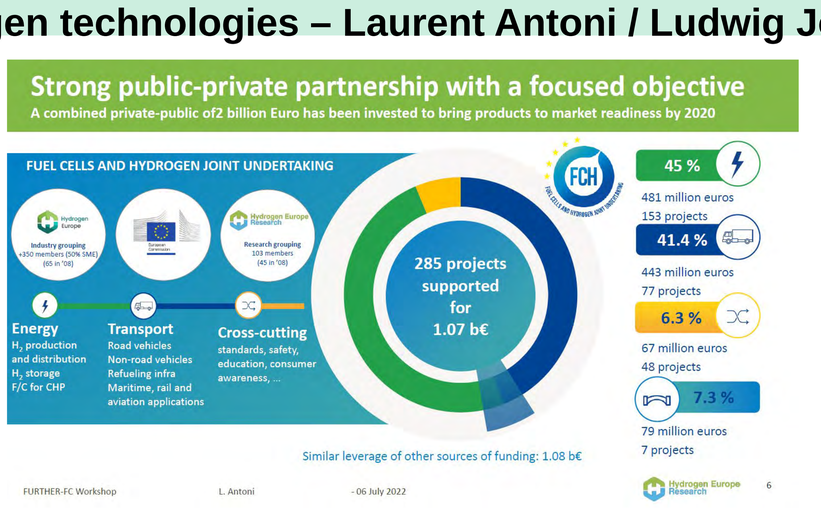
Overview of Camelot – Thor Anders Aarhaug (SINTEF)

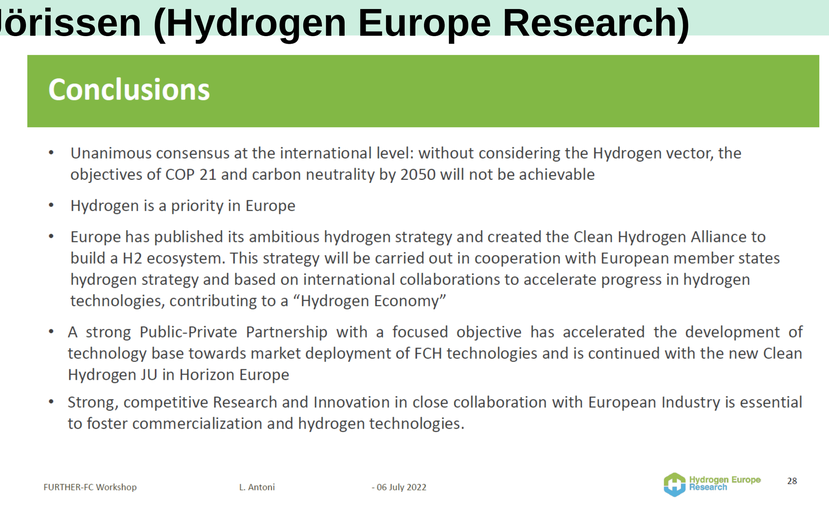






Hydrogen : a new player at the service of the environment and the economy
European research activities in hydrogen technologies – Laurent Antoni / Ludwig Jörissen (Hydrogen Europe Research)





FURTHER-FC Newsletter #4
Further Understanding Related to Transport limitations at High current density towards future ElectRodes for Fuel Cells

Characterization of the CCL structure – spatial distribution of the materials – Tobias Morawietz (UES), Laure Guetaz (CEA)

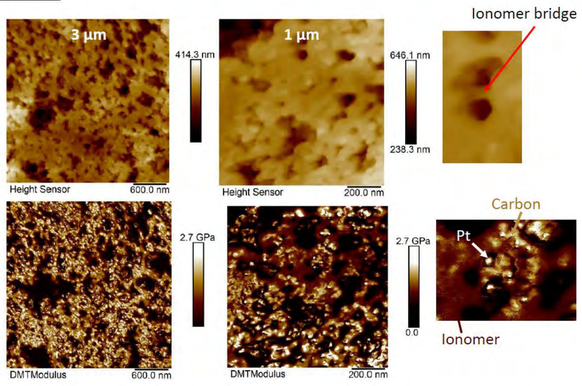
FURTHER-FC

Further **U**nderstanding **R**elated to **T**ransport limitations at **H**igh current density towards future **E**lect**R**odes for **F**uel **C**ells

Characterization of the CCL structure
Spatial distribution of the materials
((A. Morin (CEA), T. Morawietz (Esslingen Univ.), H. Kaess (Esslingen Univ.),
L. Guétaz (CEA), A. Ghorbel (CEA), T. David (CEA), Z. Saghi (CEA)

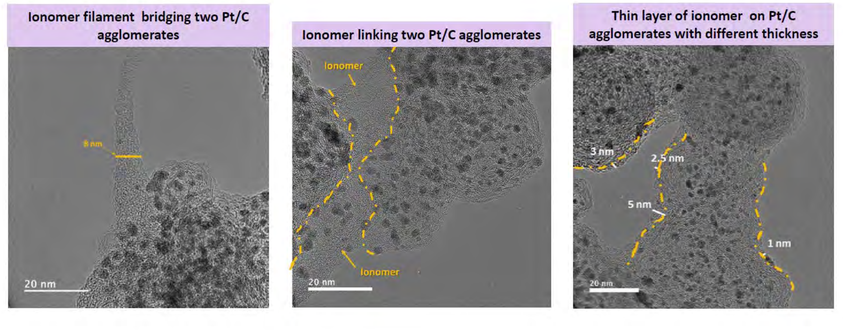
Public workshop, 06/07/2022, DLR/Stuttgart + visio — Characterization of the CCL structure

Analysis of the CCL surface

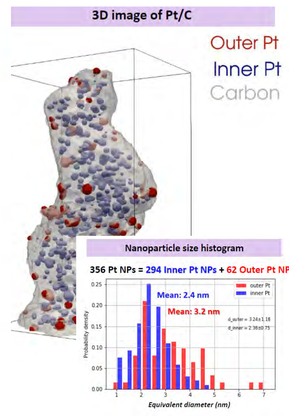


Public workshop, 06/07/2022, DLR/Stuttgart + visio — Characterization of the CCL structure

Distribution of the ionomer within a real electrodes



E-tomography: Pt nanoparticle distribution on the carbon support



Public workshop, 06/07/2022, DLR/Stuttgart + visio — Characterization of the CCL structure — **Public workshop, 06/07/2022, DLR/Stuttgart + visio** — FURTHER-FC: Characterization of the CCL structure - Spatial distribution of the materials

Characterisation of CCL materials – local transport properties and transport-free electrocatalysis - Anthony Kucernak (ICL)

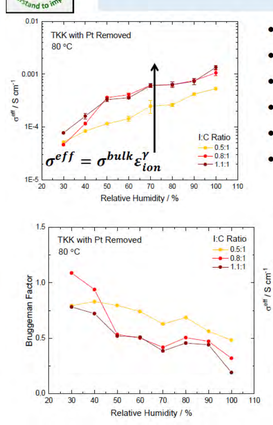
FURTHER-FC

Further **U**nderstanding **R**elated to **T**ransport limitations at **H**igh current density towards future **E**lect**R**odes for **F**uel **C**ells

Characterisation of CCL materials - local transport properties and transport-free electrocatalysis
Anthony Kucernak, Imperial College

Public workshop, 06/07/2022, DLR/Stuttgart + visio — FURTHER-FC: Characterisation of CCL materials - local transport properties and transport-free electrocatalysis — 1

Proton conductivity

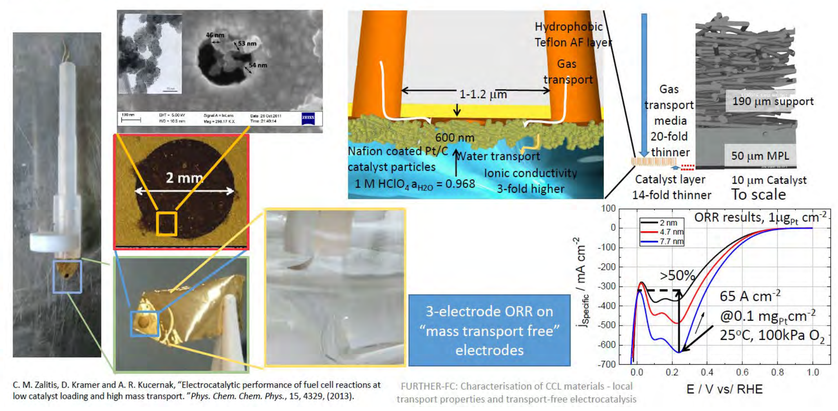


- Increase in proton conductivity as RH increases
- Increase in proton conductivity as I:C ratio increases
- Increase in proton conductivity when using HOPI ionomer
- Decrease in Bruggeman Factor as RH increases
- Little change in Bruggeman Factor with different I:C ratios
- As Bruggeman Factor <1, conductivity is less strongly affected by increases in ionomer

Proton conductivity in catalyst layer is liable to be a limiting factor in performance

FURTHER-FC: Characterisation of CCL materials - local transport properties and transport-free electrocatalysis — 8

Electrocatalysis
Ultra-low loading electrodes – Ex situ



3-electrode ORR on "mass transport free" electrodes

C. M. Zalitis, D. Kramer and A. R. Kucernak, "Electrocatalytic performance of fuel cell reactions at low catalyst loading and high mass transport." *Phys. Chem. Chem. Phys.*, 15, 4329, (2013).

FURTHER-FC: Characterisation of CCL materials - local transport properties and transport-free electrocatalysis

Electrochemical characterization - Jens Mitzel (DLR)

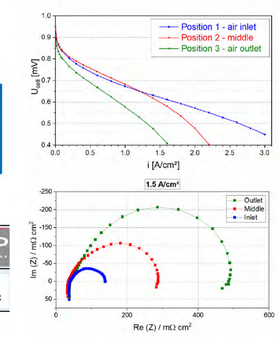
FURTHER-FC

Further **U**nderstanding **R**elated to **T**ransport limitations at **H**igh current density towards future **E**lect**R**odes for **F**uel **C**ells

Electrochemical Characterization
(Jens Mitzel, CEA, DLR, PSI, ICL)

Public workshop, 06/07/2022, DLR/Stuttgart + visio — FURTHER-FC: Electrochemical Characterization

Performance validation
Impact of stack position

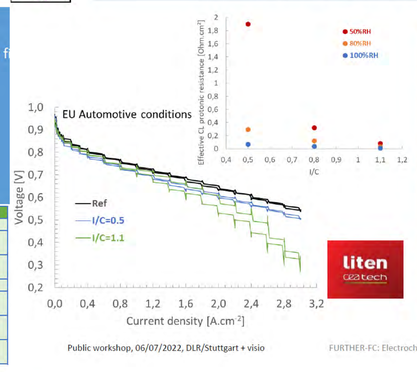


- Impact of transport properties depends on operating conditions
- Operating conditions in automotive stacks vary significantly along the flow f
- Differential cell conditions can mimic conditions in different positions
- Significant impact by:
  - **Oxygen concentration**
  - Cell temperature
  - Relative humidity

	Step1: Air inlet	Step 2: Middle	Step3: Air outlet
Cell temperature [°C]	68	77	80
H_2O content in dry gas at anode/cathode [%]	100/20.8	100/13.6	100/7.7
Total Pressure anode / cathode [bar_{abs}]	2.25/2.3	2.3/2.1	2.5/1.9
RH anode / cathode [%]	100/53	100/100	50/100
Gas inlet temperature anode/cathode [°C]	75/75	84/84	87/87
Min. H_2 / O_2 stoichiometry for 4 cm long channel [-]	8/8	8/5.25	8/3
Min. gas flow according to current density [A/cm²]	3	3	3

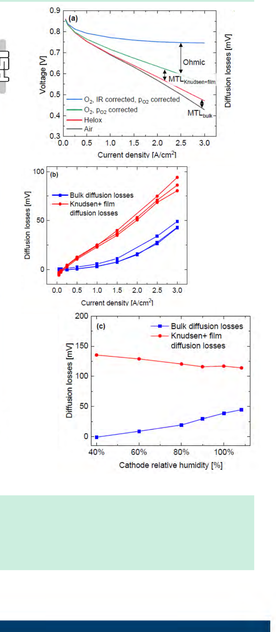
Public workshop, 06/07/2022, DLR/Stuttgart + visio — FURTHER-FC: Electrochemical Characterization — 7

Performance validation
Impact of ionomer content



- Reference CCM (I/C=0.8) shows highest performance
- Lower ionomer content (I/C=0.5) decreases performance and activity
- Higher ionomer content (I/C=1.1):
  - decreases performance and activity
  - increase transport resistance at high current density
- Effective proton transport resistance decreases
  - with increasing I/C ratio
  - with increasing relative humidity

Pulse Gas Analysis (PGA)
Impact of current density

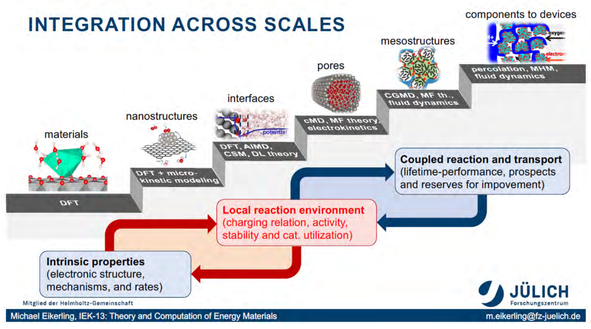


Electrochemical modelling - Michael Eikerling (RWTH Aachen)

CATALYST LAYER MODELING: THE NEXT GENERATION
Further FC Workshop, DLR Stuttgart, July 6, 2022
Michael Eikerling, Institute of Energy and Climate Research, IEK-13

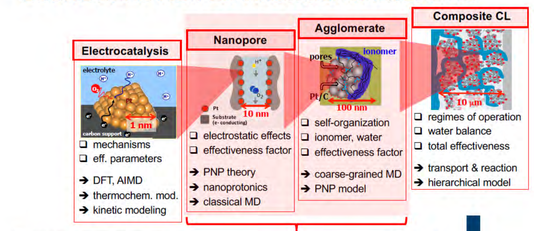
JÜLICH Forschungszentrum

INTEGRATION ACROSS SCALES



Mitglied der Helmholtz-Gemeinschaft
Michael Eikerling, IEK-13: Theory and Computation of Energy Materials — m.eikerling@fz-juelich.de

LOCAL REACTION ENVIRONMENT: COUPLING



Mitglied der Helmholtz-Gemeinschaft
Michael Eikerling, IEK-13: Theory and Computation of Energy Materials — m.eikerling@fz-juelich.de

SUMMARY

- Physical modeling as starting point for correlation analysis (*j*-V data)
- Making sense of extensive performance data for Pt loading reduction
- Role of ionomer: control local pH (and conductivity) and wettability
- Model of structure formation (ionomer assembly in catalyst layer)
- Learn how to keep secondary pore space hydrophobic
- Learn how to suppress water layer formation at CL|GDL boundary

Multiscale Modelling – Thomas Jahnke (DLR)

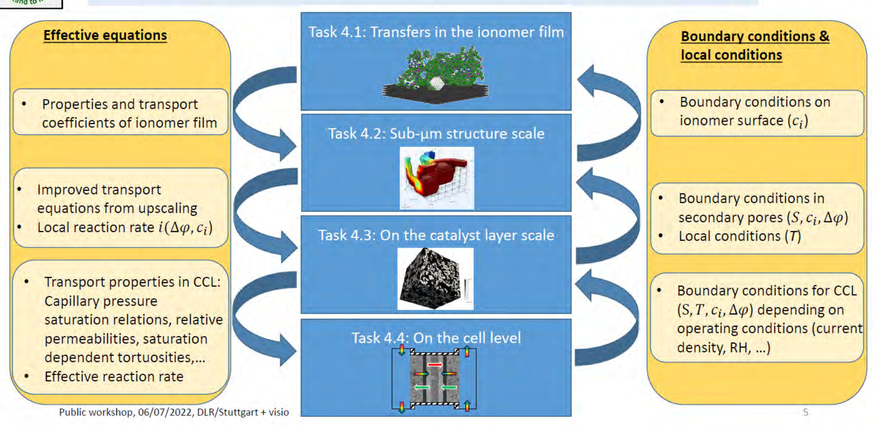
FURTHER-FC

Further **U**nderstanding **R**elated to **T**ransport limitations at **H**igh current density towards future **E**lect**R**odes for **F**uel **C**ells

Multiscale Modelling
T. Jahnke (DLR), K. Gülicher (DLR), K. Karan (UCA), M. Maloum (INPT), M. Prat (INPT), M. Quintard (INPT), P. Schott (CEA) , J. Pauchet (CEA)

Public workshop, 06/07/2022, DLR/Stuttgart + visio — FURTHER-FC: Multiscale Modelling

Coupling of models at different scales



Public workshop, 06/07/2022, DLR/Stuttgart + visio — 5

FURTHER-FC: WP 4

Multiscale-modeling: conclusions

- Molecular Dynamics simulation of ionomer film:
  - Simulation of ionomer self-assembly and solvent effects
  - Simulation of solvent evaporation
  - →Derivation of ionomer transport properties
- DNS and Lattice Boltzmann modeling of the CCL on sub-µm scale:
  - Development of models describing transport and electrochemistry on sub-µm scale
  - →Derivation of effective reaction kinetics depending on CCL microstructure
- DNS on MPL and CCL microstructures:
  - DNS in real MPL and CCL microstructures
  - →Derivation of effective transport properties of MPL and CCL
- Volume averaged differential cell model
  - Coupling of transport processes in all layers and electrochemistry in a 2D cell model
  - In-depth validation with dedicated electrochemical characterization
  - →Identification and quantification of performance losses

Public workshop, 06/07/2022, DLR/Stuttgart + visio — FURTHER-FC: Multiscale modeling — 23

FURTHER-FC Newsletter #4
Further Understanding Related to Transport limitations at High current density towards future ElectRodes for Fuel Cells

High Oxygen Permeable Ionomers for Durable, High Power Density Cathodes –Andrew Park (Chemours US)

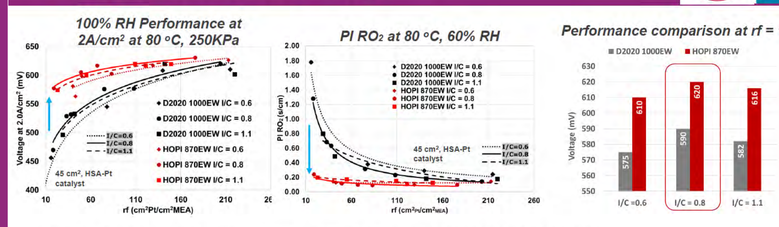
Nafion™

High Oxygen Permeable Ionomer (HOPI):

Applications in Next Gen Catalyst Layers

Andrew M. Park
July 6, 2022
FURTHER-FC Workshop

Electrode Performance: Catalyst & Ionomer Loadings



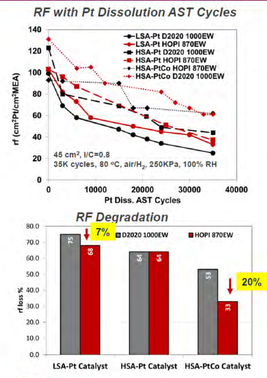
- Various catalyst loadings and three I/C ratios were investigated based on HSA-Pt catalyst
- **I/C = 0.8 was the optimum** for both D2020 and HOPI 870EW performance and PI RO_2

Compared to D2020 ionomer, HOPI 870EW showed:

- Performance gain at high current density and reduction of oxygen transport resistance with decreasing roughness factor
- 30 mV performance gain at rf=110 with optimum I/C ratio
- 60 mV performance gain at rf=30 with same optimum I/C ratio

Nafion™ 15

Electrode Durability



In comparison to D2020, HOPI 870EW showed:

- Minor change in rf loss for both LSA-Pt and HSA-Pt catalyst
- Major reduction of MEA performance degradation rate for each
- For HSA-PtCo catalyst, major reduction in rf loss and performance degradation at 0.1A/cm² but negative impact on degradation at high current density, possibly due to faster changes of CL morphology during AST cycling because of high crack density: 32% in HSA-PtCo/HOPI vs 4% in HSA-PtCo/D2020

Nafion™ Chemours™ 17

Importance of the Project from Industry Point of View – Stephane Cotte (TME)

FURTHER-FC

Further **U**nderstanding **R**elated to **T**ransport limitations at **H**igh current density towards future **E**lect**R**odes for **F**uel **C**ells

Importance of the Project from Industry Point of View

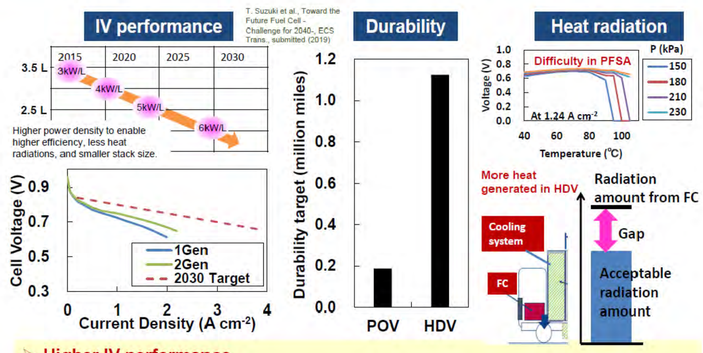
(Stéphane Cotte, Toyota Motor Europe)

Public workshop, 06/07/2022, DLR/Stuttgart + visio

FURTHER-FC: Importance of the Project from

PUBLIC 公開

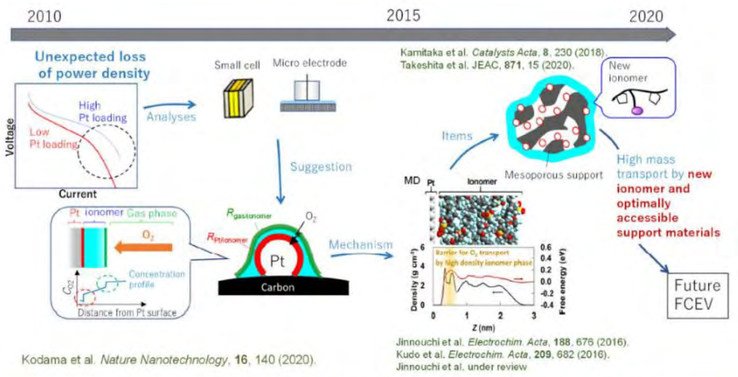
5. Importance of FURTHER-FC



- Higher IV performance.
- Higher durability.
- Compact heat radiation realized by efficient FC or high-temperature operation.

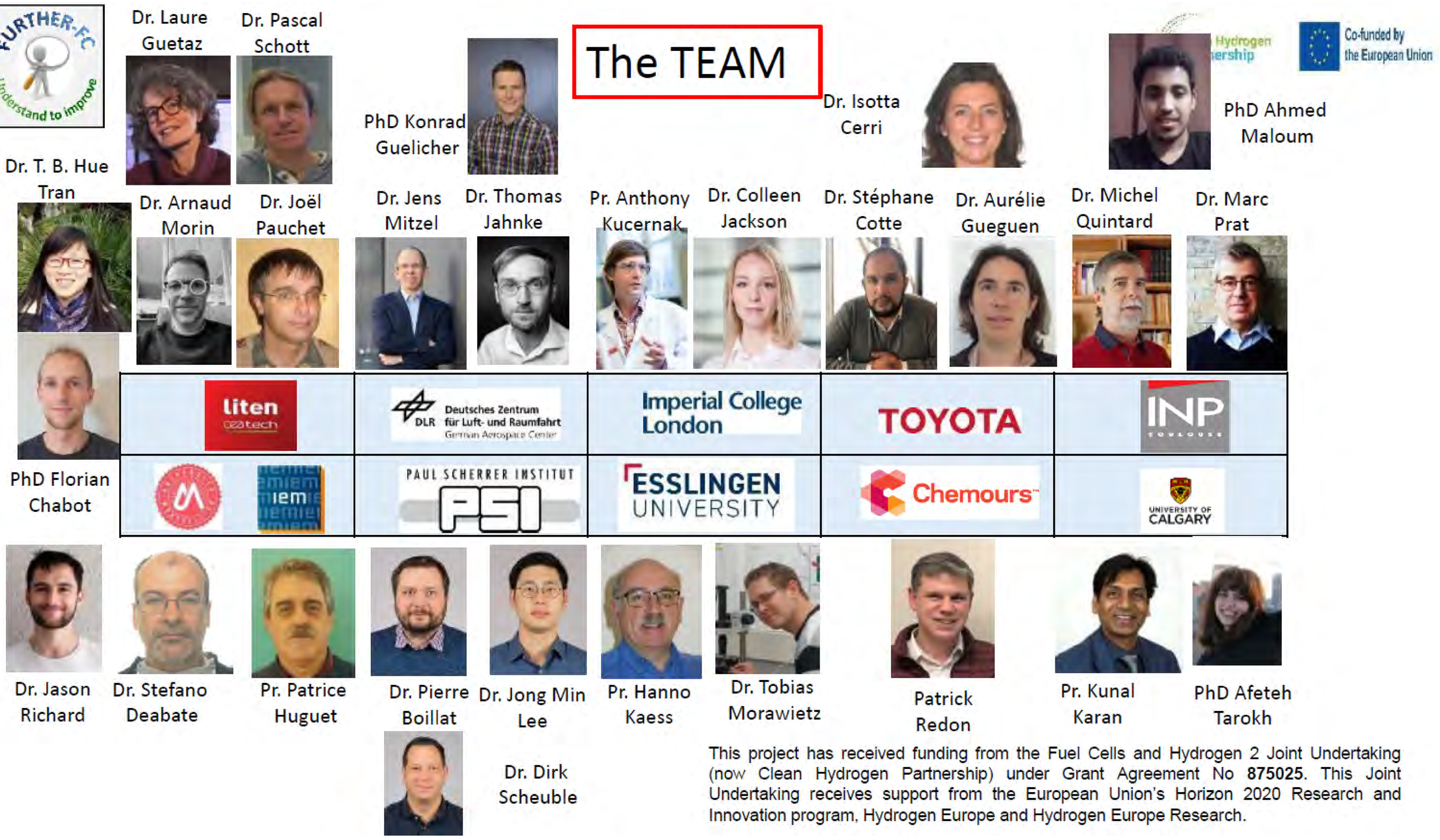
PUBLIC 公開

5. Importance of FURTHER-FC



- Enhancing local O_2 transport by new ionomer and meso-porous supports.
- Optimizing porous structure and ionomer distribution in catalyst layer.

FURTHER-FC Consortium



Acknowledgement

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under Grant Agreement No 875025. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation programme, Hydrogen Europe and Hydrogen Europe Research.

Contact:
joel.pauchet@cea.fr
tobias.morawietz@hs-esslingen.de