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

Overview of the project

(Joël PAUCHET, CEA, IEM, DLR, PSI, ICL, UES, TME, CHEM, INPT, UCA)

Funding

Call year: 2019

Call topic:
FCH-01-04 Towards a better understanding of charge, mass and heat transports in new generation PEMFC MEA for automotive applications

Project dates: 01/01/2020– 31/08/2024

FCH-JU max. contribution: 2 199 567 €
Partners contribution: 535 464 €

Consortium

Clean Hydrogen Partnership

Co-funded by the European Union

FURTHER-FC Understand to improve

2 industrial partners

8 RTO

Fundamental electrochemistry

Imperial College London

MEA manufacturing

TOYOTA

- Coordination
- Characterizations of microstructure, thin ionomer films, electrochemistry, operando local conditions
- Sub-µm modeling

cea

Improved membrane and ionomer

Chemours™

CCL, GDL modeling

INP Toulouse

In-operando Raman

iem

Université Montpellier

DLR Deutsches Zentrum für Luft- und Raumfahrt German Aerospace Center

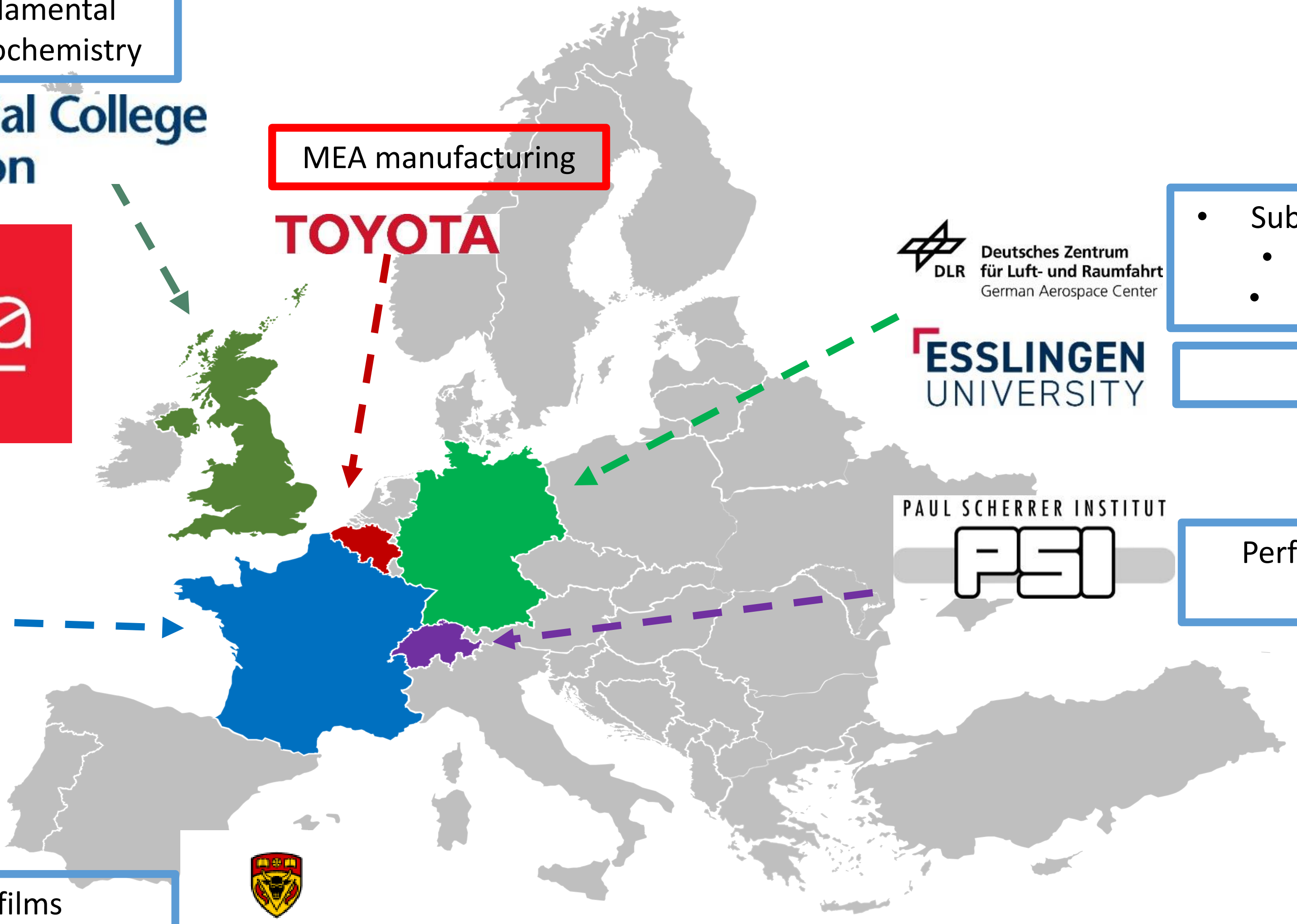
- Sub µm and cell modeling
- Characterization
- Performance tests

ESSLINGEN UNIVERSITY

AFM

PAUL SCHERRER INSTITUT PSI

Performance tests and limitations

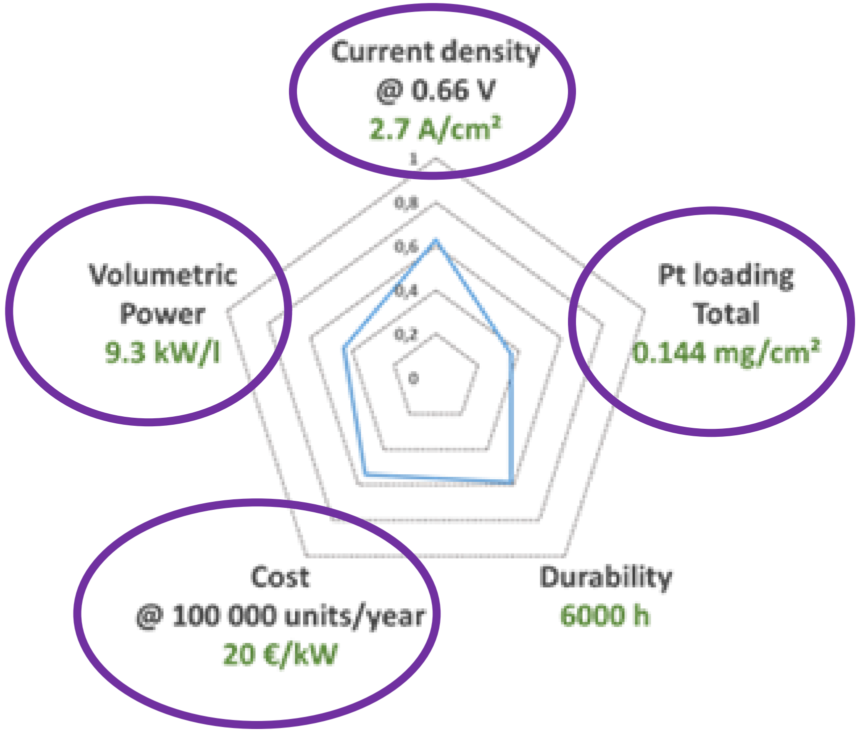


- Ionomer films
- Modeling/characterization

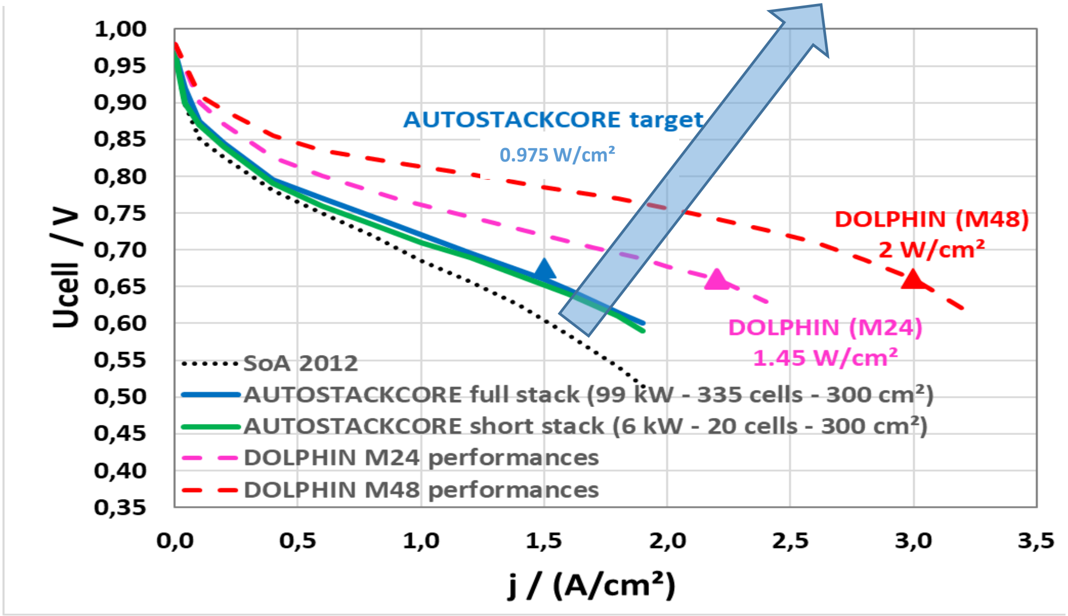
UNIVERSITY OF CALGARY

Context: PEMFC targets for light duty vehicles

Specifications for automotive stack: status and targets



Stack performance: status and targets



- Reduce cost
- Decrease Pt loading
- Increase performance

Increase current density

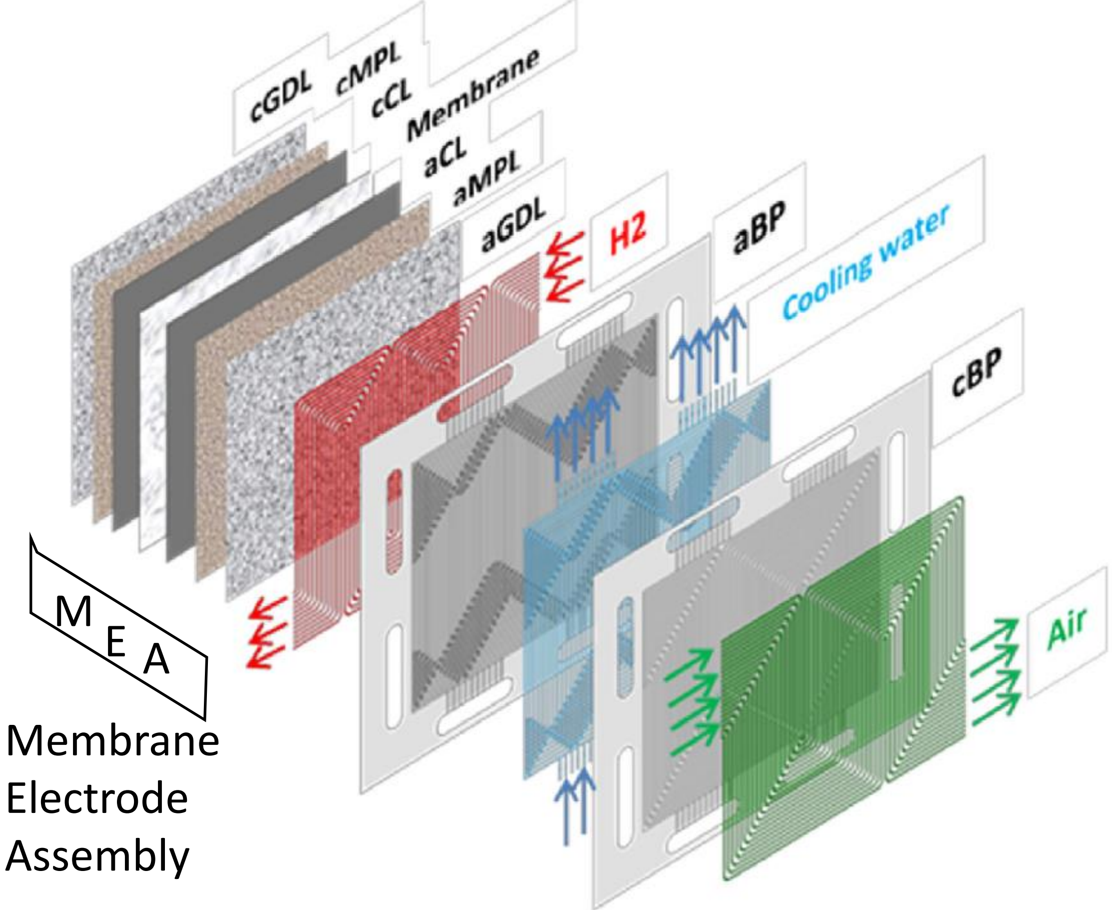
→ Larger flux

→ Larger transport limitations

PEMFC stack, cell and MEA

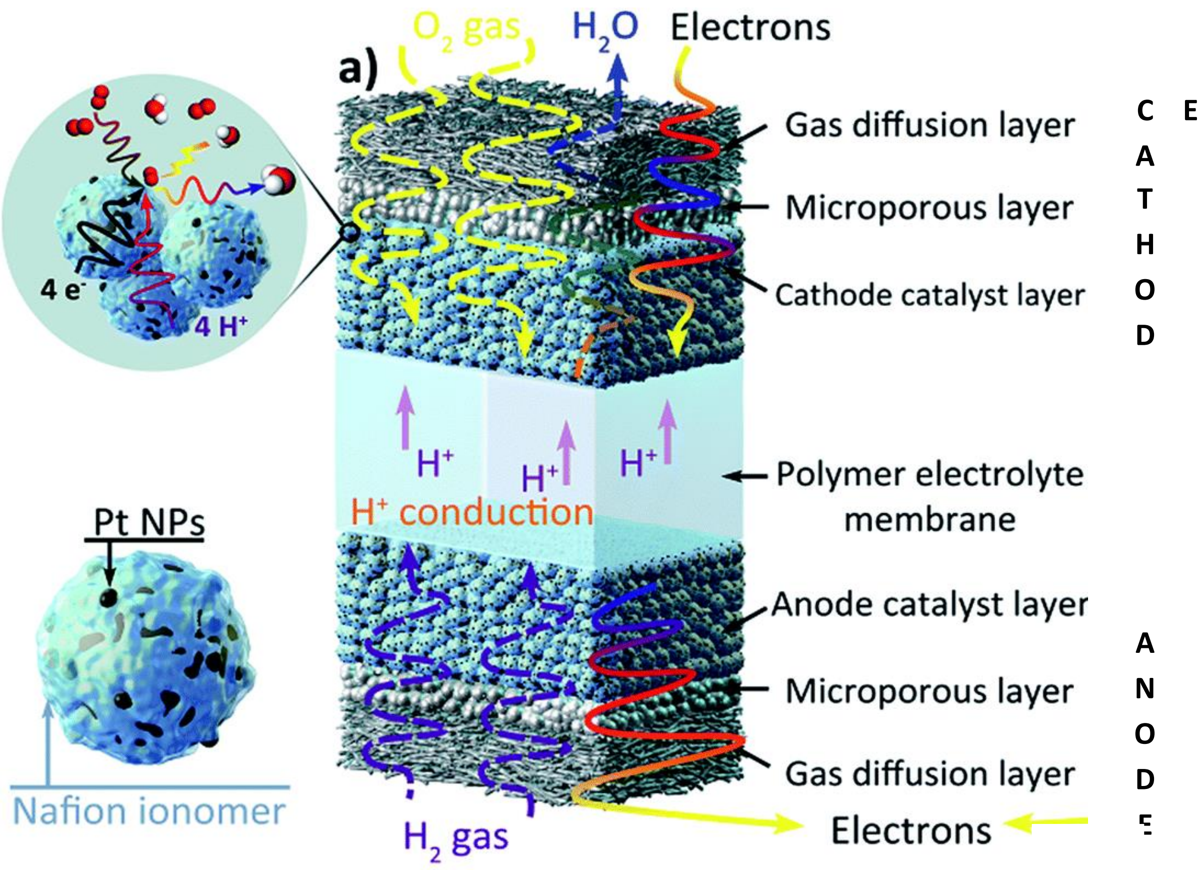
A multiscale and mutiphysics system

Scheme of a cell in a PEMFC stack



Nandjou et al., *Int. J. Hyd. Energy* **41**, 2016, 15573

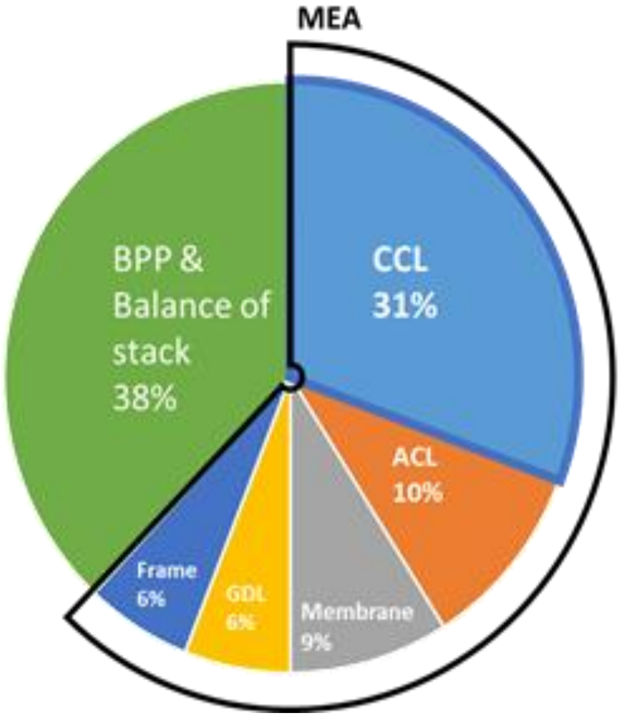
Scheme of a conventionnal MEA



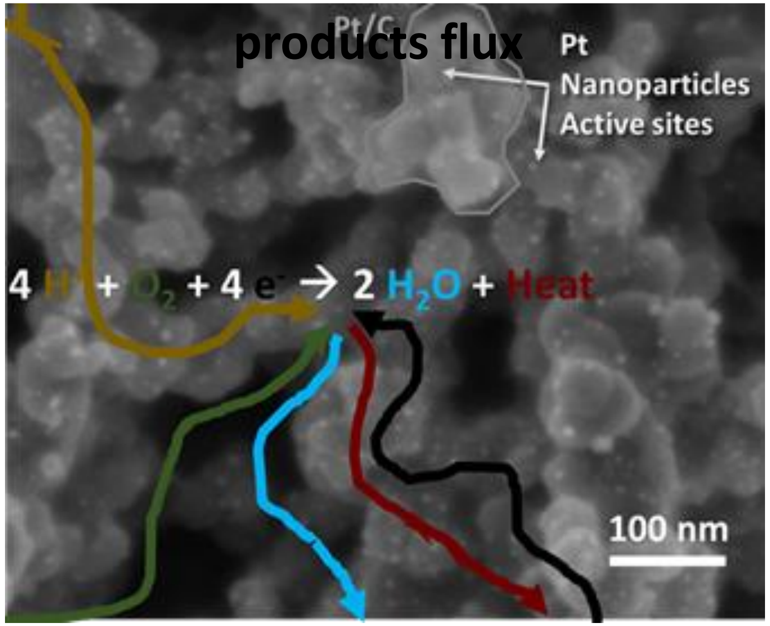
Zeng et al., J. Mater. Chem. A 6, 2018, 6521

Role of the CCL to decrease cost and improve performance

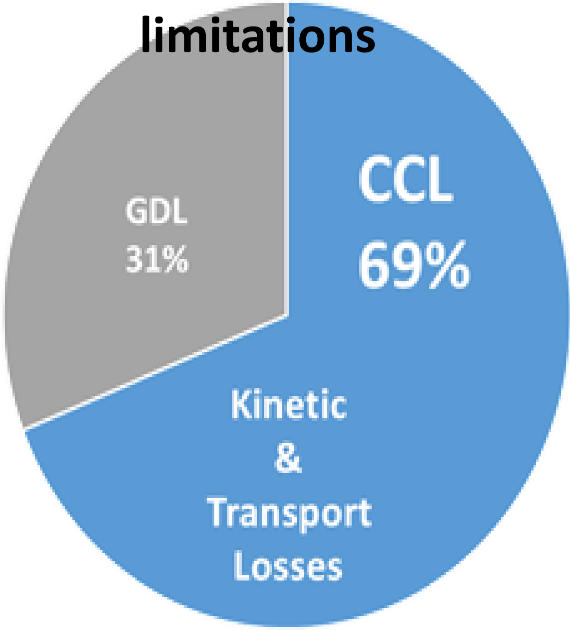
Breakdown of stack component costs



SEM image of Pt/C CCL with reactants and products flux



Breakdown of Membrane Electrode Assembly components limitations

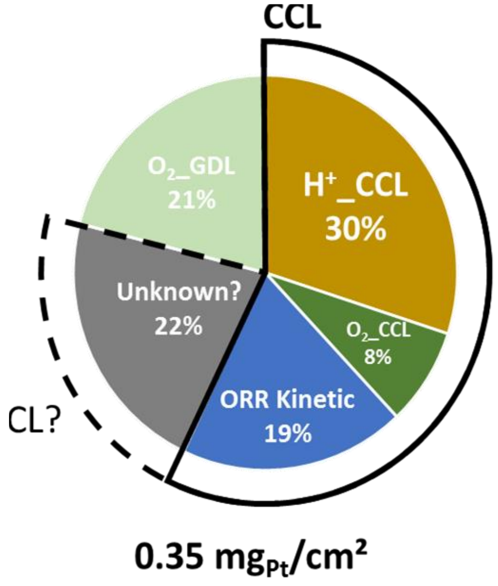


Complex tortuous structure in which

CCL most limiting component in terms of **cost, performance** and **durability** related to **ORR in coupling with transport limitations**

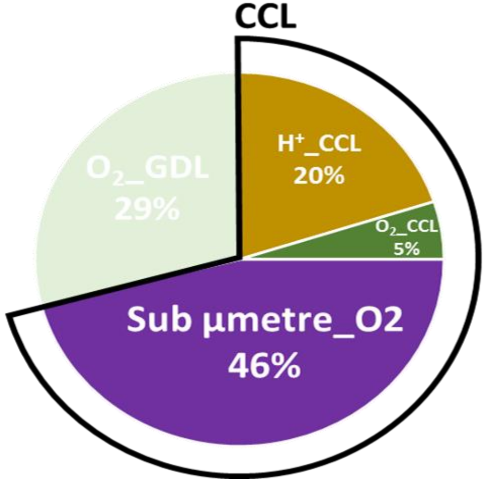
CCL performance limitations

Simulated performance limitations breakdown



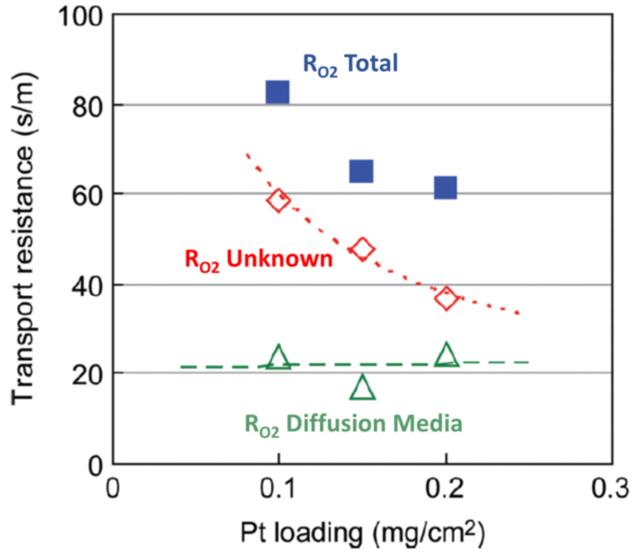
A lot of unknown transport limitations

Simulated mass-transport limitations breakdown



Large sub-micrometer O_2 transport limitations

Simulated O_2 transport resistance

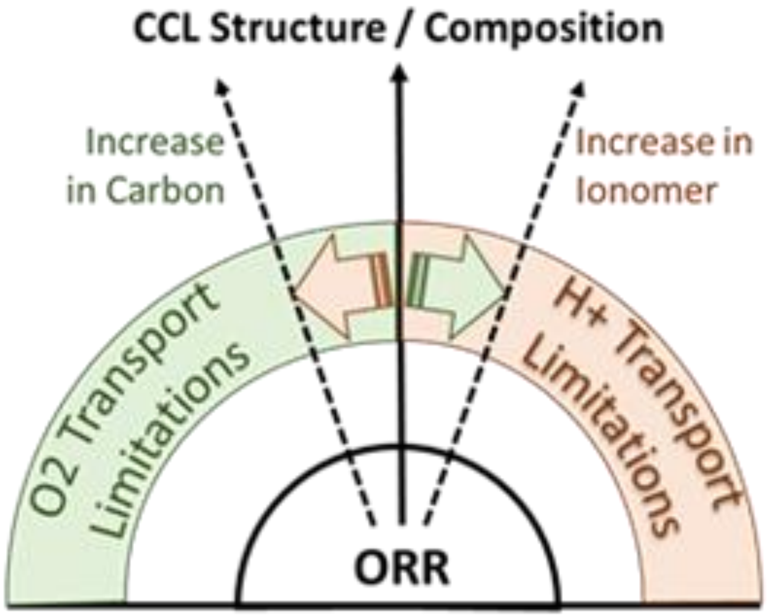


O_2 transport limitations increase as Pt loading decreases

Nonoyama, et al., Analysis of Oxygen

Low Pt loaded CCL shows unexplained high losses (ascribed mainly to O_2 transport losses) but kinetic and proton transport contributions on losses are often underestimated

Controling CCL transport limitations

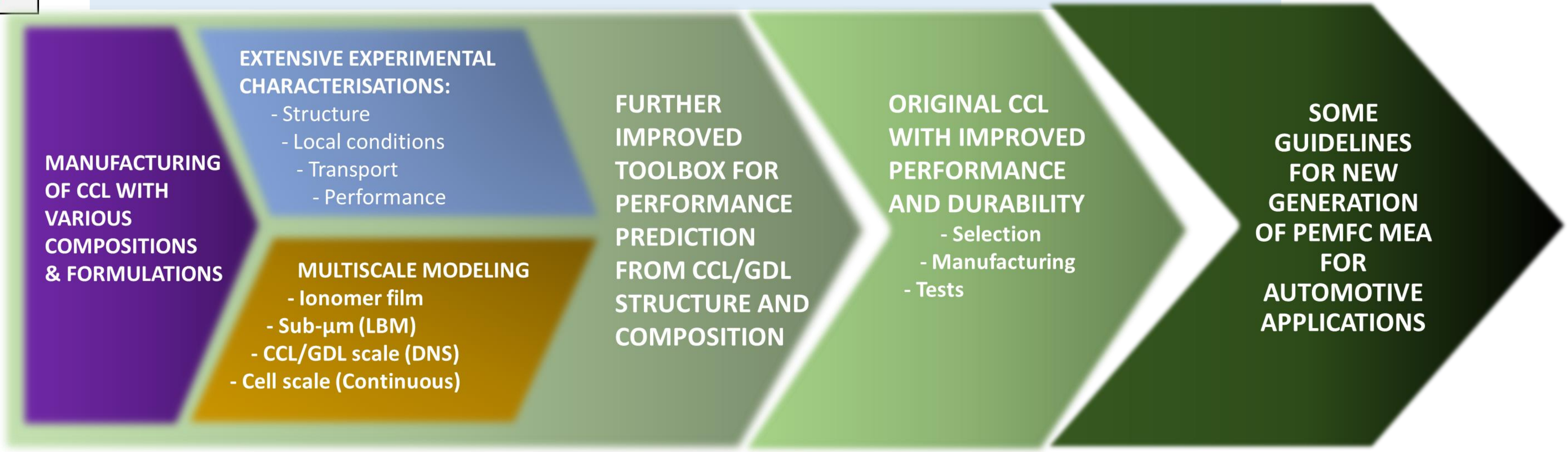


➔ **FURTHER-FC aims at better understanding these limitations**

Balance between O_2 and H^+ transport limitations related to ORR

BUT lack of knowledge on :
- CCL structure (Pt/C, ionomer, pore distributions…)
- H^+ and O_2 local and effective transport properties
- ORR kinetic depending on the local conditions
- Local operating conditions in CCL
- Influence of ink composition

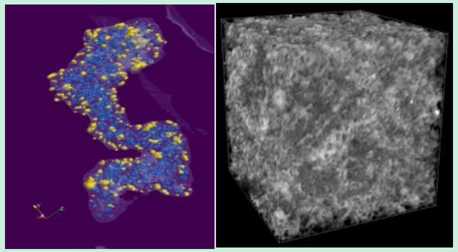
Global strategy and developments



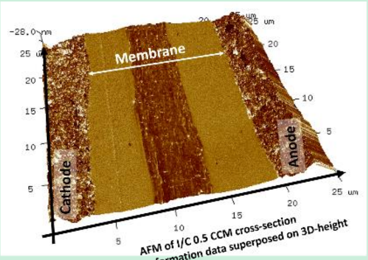
- **Strong link between models and characterizations to:**
  - Supply more relevant inputs to the models (gas diffusion, H^+ and O_2 transports, structure…)
  - Validate the models
  - Analyze the differences between CCL with different ink formulations
  - Analyze performance limitations due to the CCL
- **Design, manufacture and test a CCL with higher performance/durability**

‘Multi-scale approach’

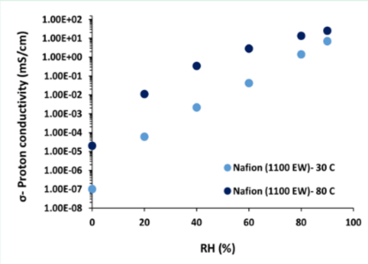
Multiscale characterization



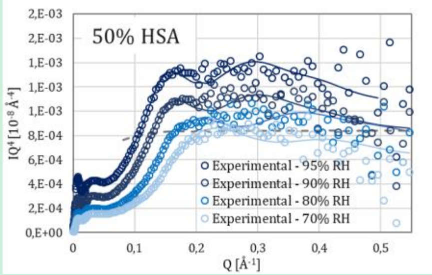
3D TEM and FIB/SEM



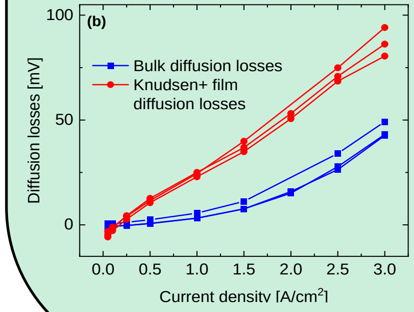
AFM



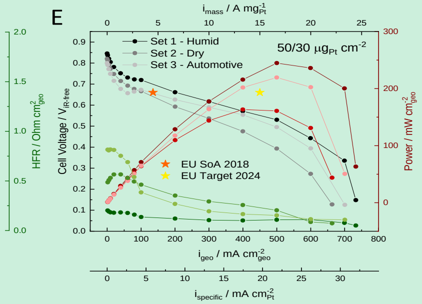
Ionomer transport properties



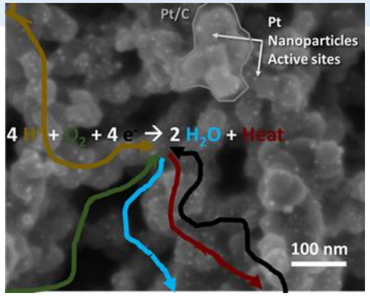
Small Angle Scattering

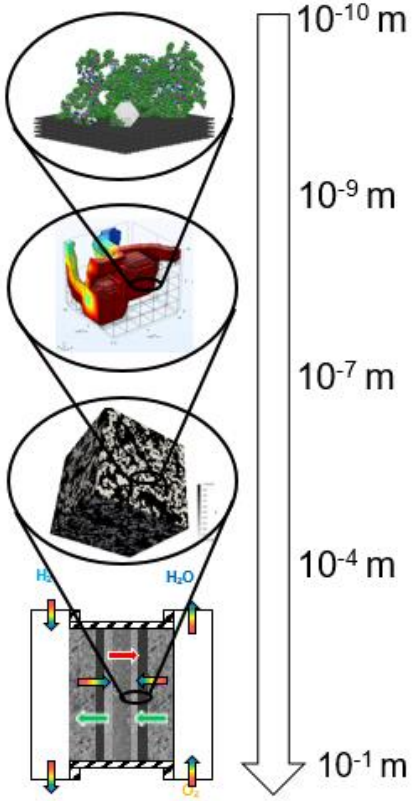


Mass transport losses



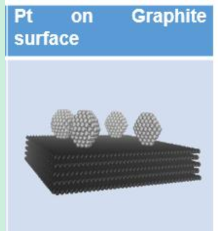
Ultra-thin electrode

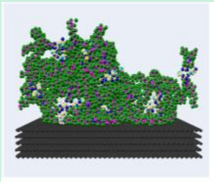


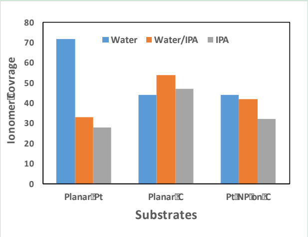


Multiscale modeling

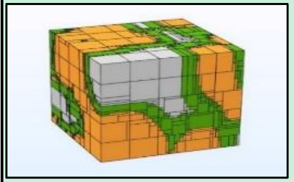
Ionomer film scale



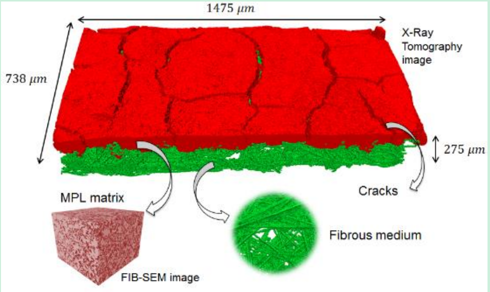




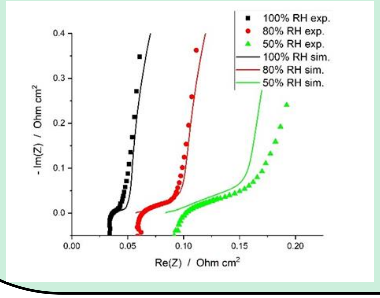
Sub µm scale

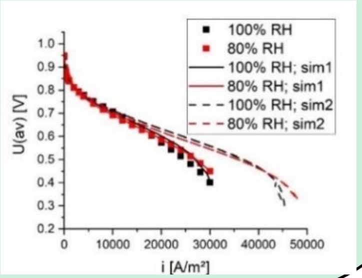


CCL scale



Cell scale





Customized CCL for characterizatio

To be updated as necessary

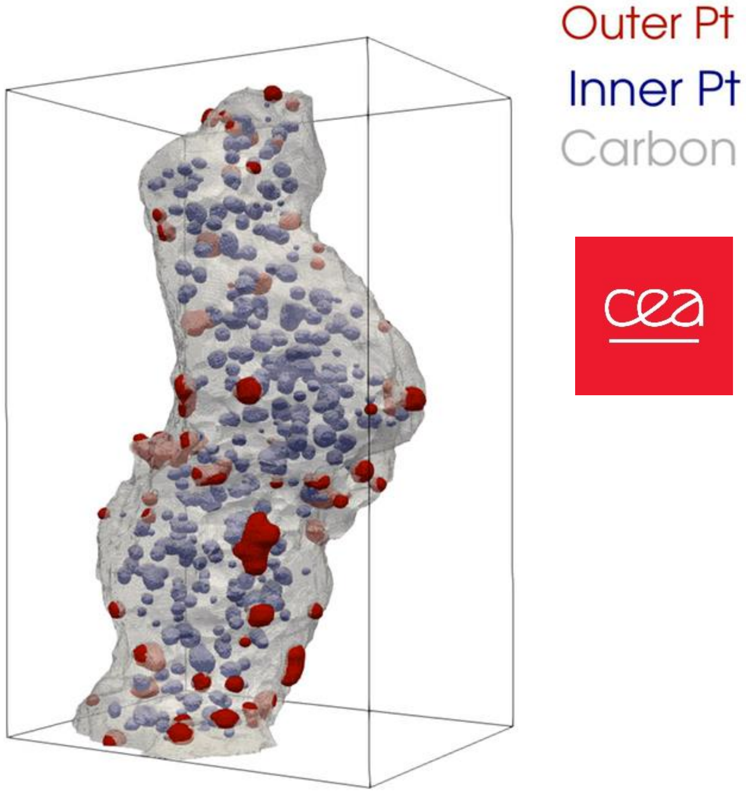
- Differential cell
- SGL 22BB
- Anode constant, 0,1 mgPt/cm²
- Ref cathode: TEC10E50E, D2020
- Ref OC: 80°C, H2/air, RH80, Stoe 1.5/2
- Focused on LDV but additional tests for HDV (Advisory Board recommendation)

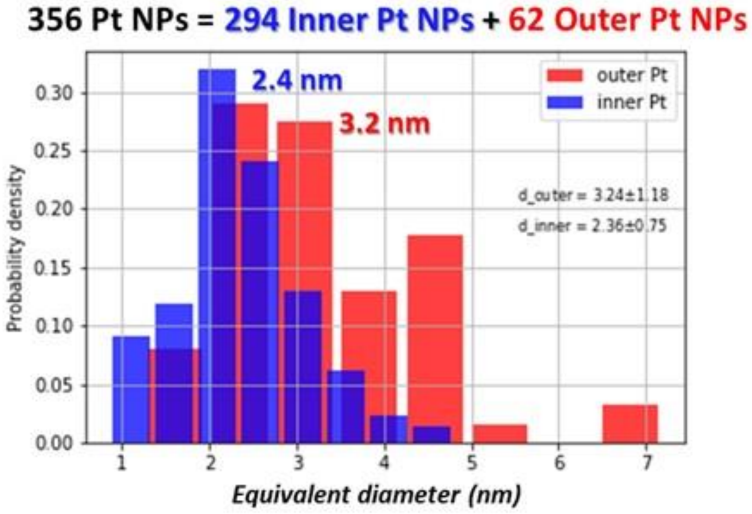
<table>
<tr><th>Type of study</th><th>Catalyst</th><th>Pt Loading [µg/cm²]</th><th>I/C</th><th>Ionomer</th></tr>
<tr><td><u>Reference</u></td><td>TKK HSAC 50%</td><td>200</td><td>0.8</td><td>D2020</td></tr>
<tr><td rowspan="2">Effect of <u>Pt loading</u> (x3) (changing thickness)</td><td>TKK HSAC 50%</td><td>100</td><td rowspan="2">0.8</td><td rowspan="2">D2020</td></tr>
<tr><td>TKK HSAC 50%</td><td>500</td></tr>
<tr><td rowspan="2">Effect of <u>thickness</u> by changing the Pt/C ratio
Checked on two Pt loading and on two types of support</td><td>TKK Graphitized 30%</td><td rowspan="2">200</td><td rowspan="2">0.8</td><td rowspan="2">D2020</td></tr>
<tr><td>TKK Graphitized 50%</td></tr>
<tr><td rowspan="2">Effect of <u>I/C</u> Ratio (x2)
Checked on two type of supports</td><td rowspan="2">TKK HSAC 50%</td><td rowspan="2">200</td><td>0.5</td><td rowspan="2">D2020</td></tr>
<tr><td>1.1</td></tr>
<tr><td rowspan="4">Effect of type of <u>ionomer</u> (x2)
Checked on two types of support, two thicknesses by changing Pt/C ratio and two I/C</td><td>TKK HSAC 50%</td><td rowspan="4">200</td><td>0.5</td><td></td></tr>
<tr><td>TKK HSAC 50%</td><td rowspan="2">0.8</td><td rowspan="3">HOPI</td></tr>
<tr><td>TKK Graphitized 30%</td></tr>
<tr><td>TKK HSAC 50%</td><td>1.1</td></tr>
</table>

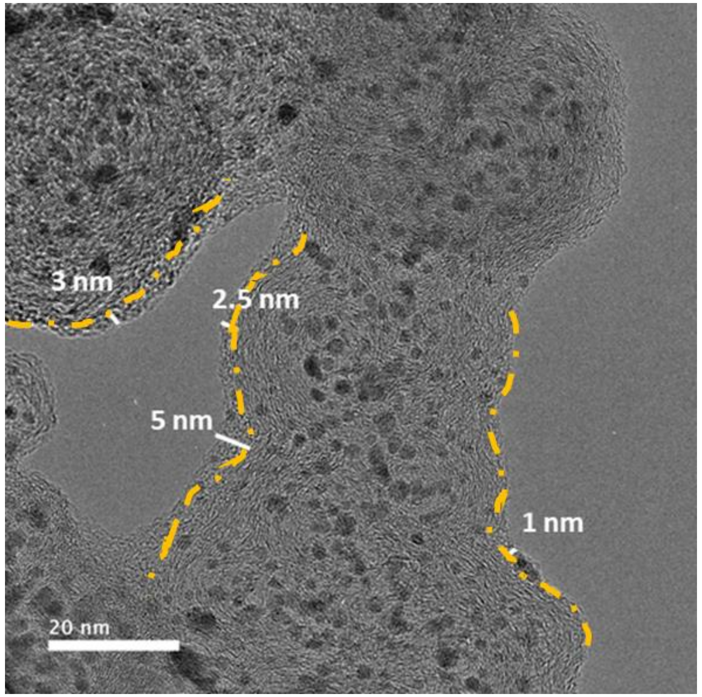
Characterization of CCL: struc

To be updated as necessary

As an example (HRTEM, AFM): distributions of ionomer, Pt, pores…



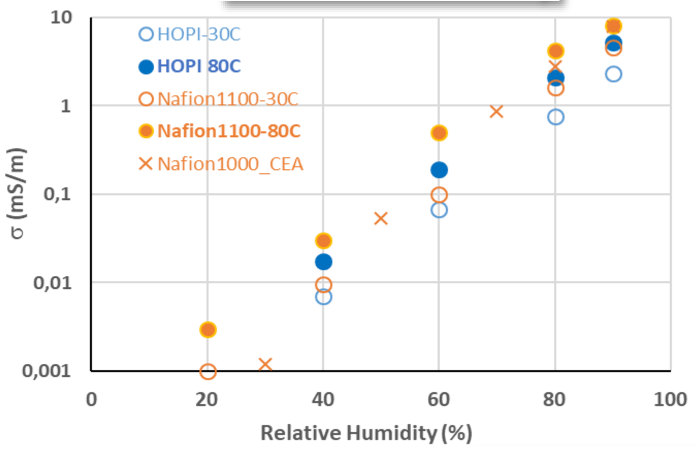




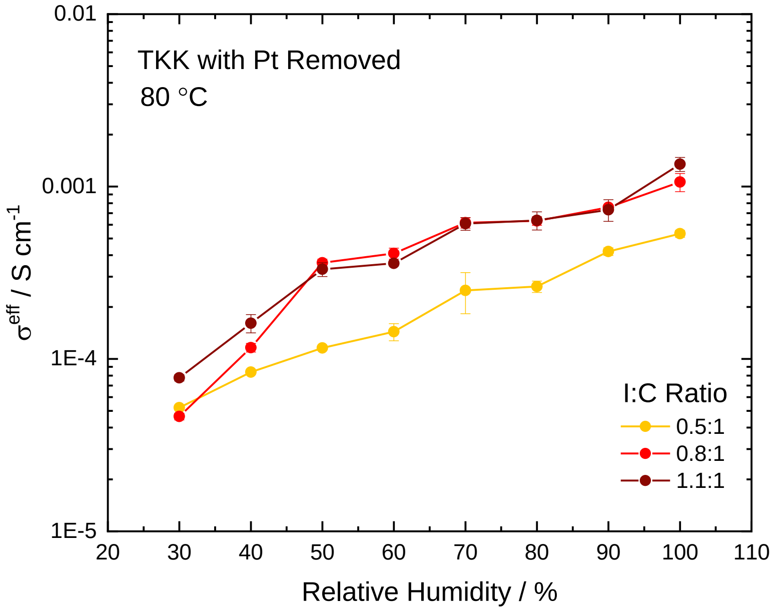
To be updated as necessary

As an example: transport in thin ionomer film, effective CCL properties

H^+ conductivity

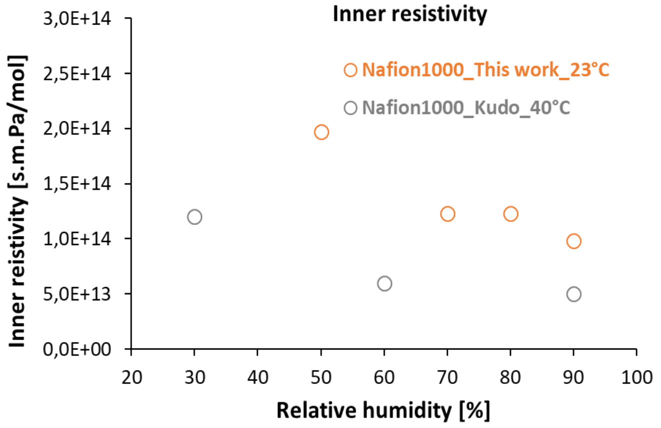


Effective through plane H^+ conductivity



Imperial College London

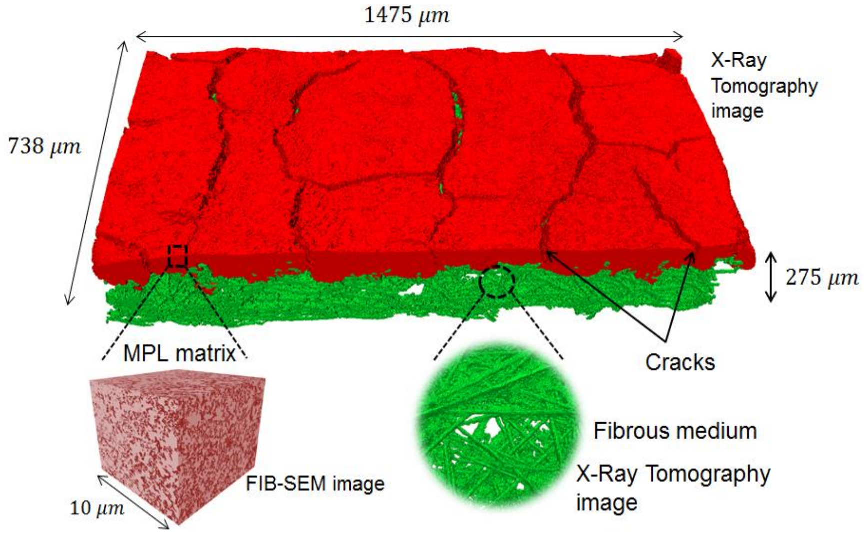
O_2 effective resistance

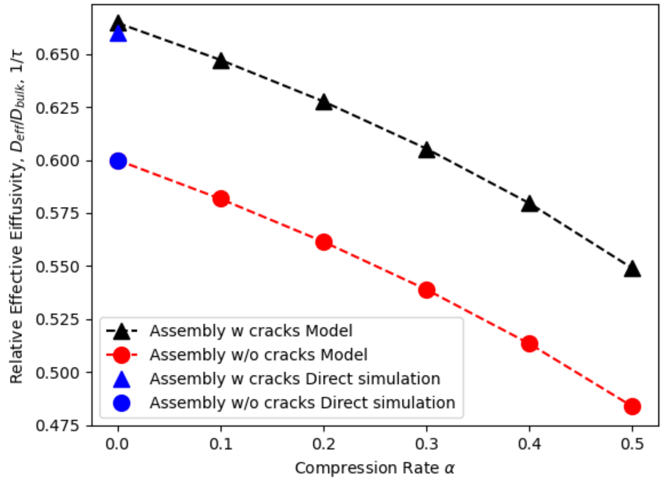


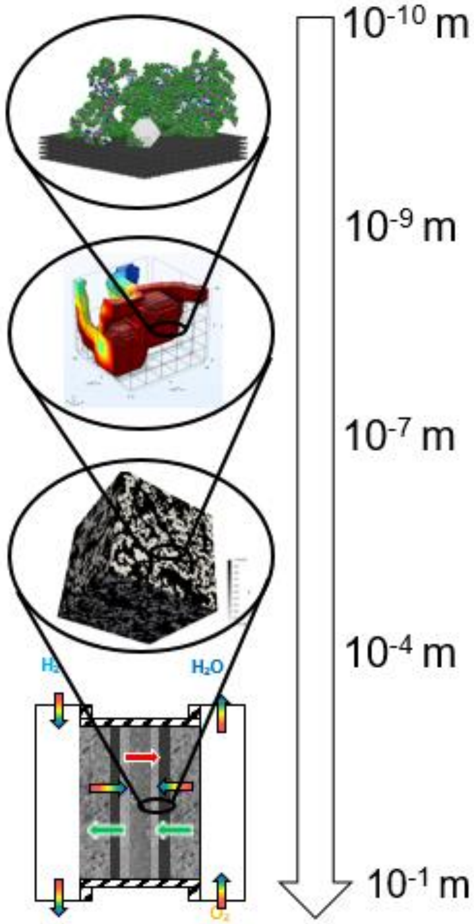
Multiscale modeling

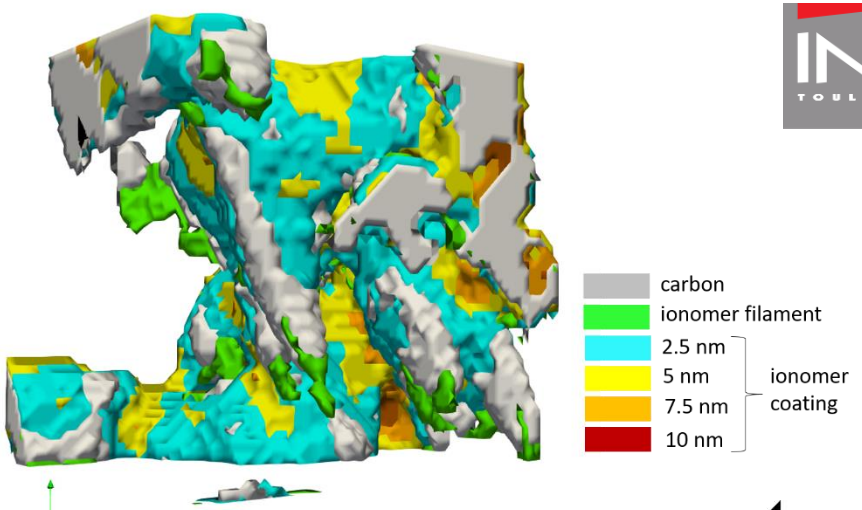
To be updated as necessary

As an example: 3D image-based computation of effective transport properties









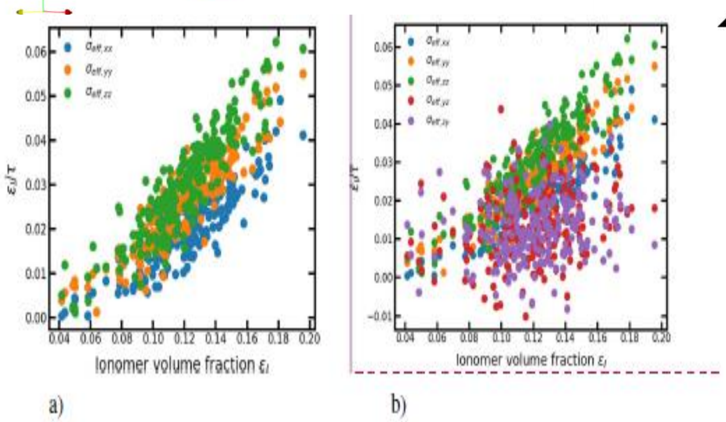
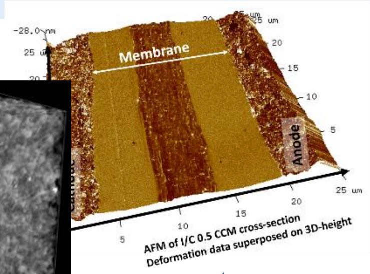
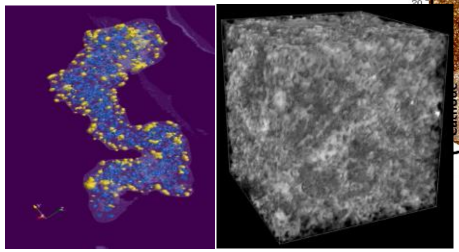


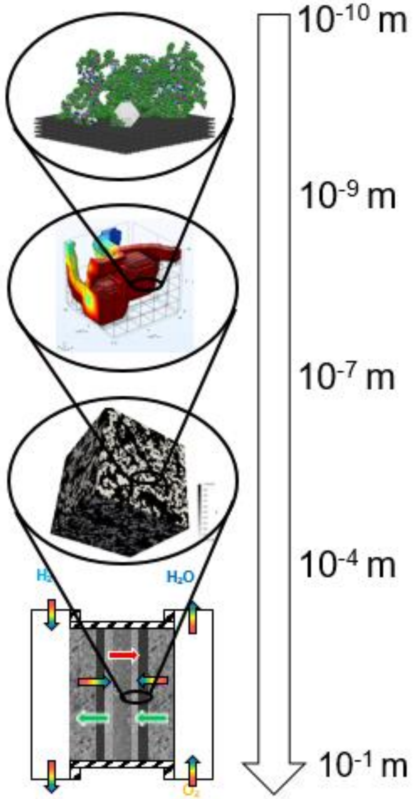
Fig.7. Distribution of the dimensionless components of CCL proton effective conductivity tensor σ^*_{eff} at scale L_I: a) diagonal components, b) diagonal components with off-diagonal components $\sigma^*_{eff,yz}$ and $\sigma^*_{eff,zy}$.

More information to come





3D TEM and FIB/SEM



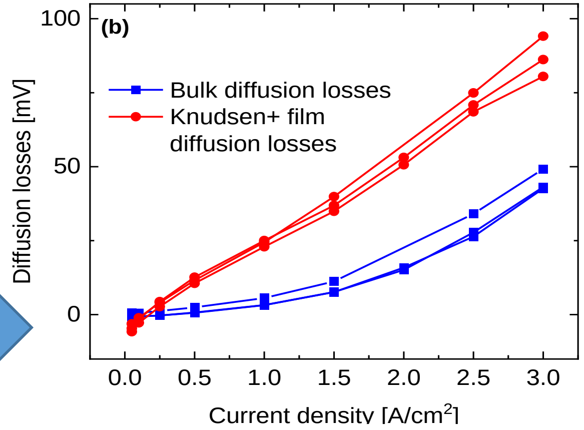
Characterization of the CCL structure by electron and AFM microscopy (T. Morawietz, Univ. Esslingen; L. Guetaz, CEA)

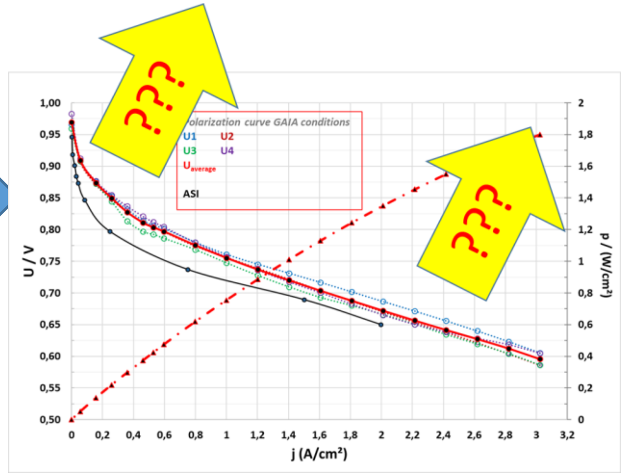
Characterization of transport properties (A. Kucernak, ICL; A. Morin, CEA)

Break

Discussion on MEA performance limitations (A. Morin, all)

Multiscale modeling performance from µm to cell scales (T. Jahnke, DLR)





Thank you for your attention!

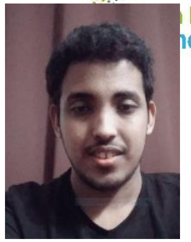
FURTHER-FC
Understand to improve

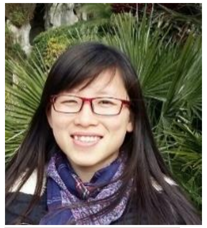
Hydrogen
nership
Co-funded by the European Union

Dr. Laure Guetaz


Dr. Pascal Schott


PhD Konrad Guelicher



PhD Ahmed Maloum

Dr. T. B. Hue Tran



PhD Florian Chabot

Dr. Arnaud Morin


Dr. Joël Pauchet


Dr. Jens Mitzel

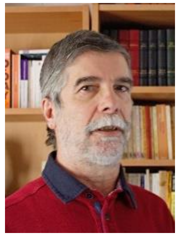

Dr. Thomas Jahnke


Pr. Anthony Kucernak


Dr. Colleen Jackson


Dr. Stéphane Cotte


Dr. Isotta Cerri


Dr. Michel Quintard


Dr. Marc Prat


liten ceatech	DLR Deutsches Zentrum für Luft- und Raumfahrt German Aerospace Center	Imperial College London	TOYOTA	INP TOULOUSE
Université de Montpellier / iem	PAUL SCHERRER INSTITUT PSI	ESSLINGEN UNIVERSITY	Chemours™	UNIVERSITY OF CALGARY


Dr. Jason Richard


Dr. Stefano Deabate


Pr. Patrice Huguet


Dr. Pierre Boillat


Dr. Jong Min Lee


Pr. Hanno Kaess


Dr. Tobias Morawietz


Patrick Redon


Pr. Kunal Karan


PhD Afeteh Tarokh