DOLPHIN

Disruptive pemfc stack with n**O**vel materia**L**s, **P**rocesses, arc**H**itecture and optimized **IN**terfaces

Progress on Design and Modelling

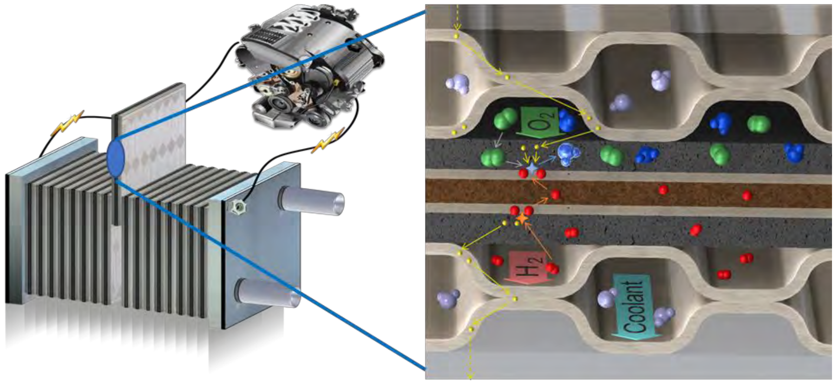
(Luis Castanheira, Symbio)

DOLPHIN Project: 1st public workshop (cell and manufacturing technologies) - virtual – 18/06/2021

WP1 – Stack Architecture and Development

❑ Objectives of WP1 for Dolphin project:

1. Increase Power Density (W/cm^2)
2. Reduce Mass (kg)
3. Reduce Volume (m^3)



Work-package leader:

SYMBIO
A FAURECIA MICHELIN HYDROGEN COMPANY

Drivers for the Dolphin stack:

1. *Cost projection of the Dolphin stack*

2. *Industrialisation of product*

Progress on Design and Modelling

WP1 – Stack Architecture and Development

- WP1 provides the industrial technical specifications:

Task 1.1 – Stack Specification and Design

Task 1.2 - Design of Electrical & Fluidics Core

Task 1.3 – Design of Electrochemical Core

Task 1.4 – Design of Integrated Terminal Plates

Task 1.5 – Stack Assembly Schemes

Task 1.6 – Characterisation Protocols and Quality Assessment

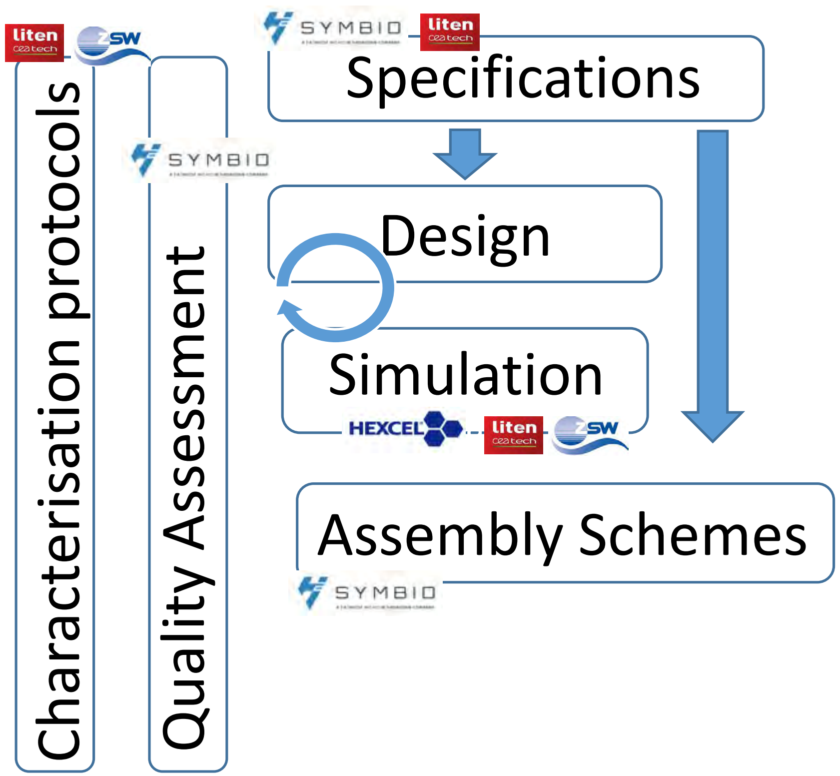
Strongly based on modelling activities and iterative steps to achieve optimisation and targets

Technical details are available online on RP1 Dolphin project.

Progress on Design and Modelling

WP1 – Stack Architecture and Development

The dynamics of WP1 lays on the internal input of WP1 and from numerous outputs from WP2, WP3, WP4 and WP5



- ❑ Challenging previous FCH-JU achievements in fuel cell stacks

INDICATORS	Int. SoA 2017 (AutoStack Core)	DOLPHIN (~ FCH-JU 2024 targets)
Weight-specific power density (kW/kg) at nominal power	3.4	≥ 4.0 (≥ +18%)
Volumetric power density (kW/l) at nominal power	4.1	≥ 5.0 (≥ +25%)
Area-specific power density (W/cm²) at 0.66 V	1.13	2.0 (+75%)
Cost (€/kW) at 100 000 units/year	36.8	< 20 (-45%)
Durability (hours)	3,500	6,000 (+70%)
Stack max operating temperature (°C)	95	105 (+10°C)

Stack Specification and Design

- Specification of an automotive 100 kW fuel cell stack for Dolphin

Challenging previous FCH-JU achievements in fuel cell stacks and industry standards

INDICATORS	Int. SoA 2017 (AutoStack Core)	DOLPHIN (~ FCH-JU 2024 targets)
Weight-specific power density (kW/kg) at nominal power	3.4	≥ 4.0 (≥ +18%)
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Durability (hours)	3,500	6,000 (+70%)
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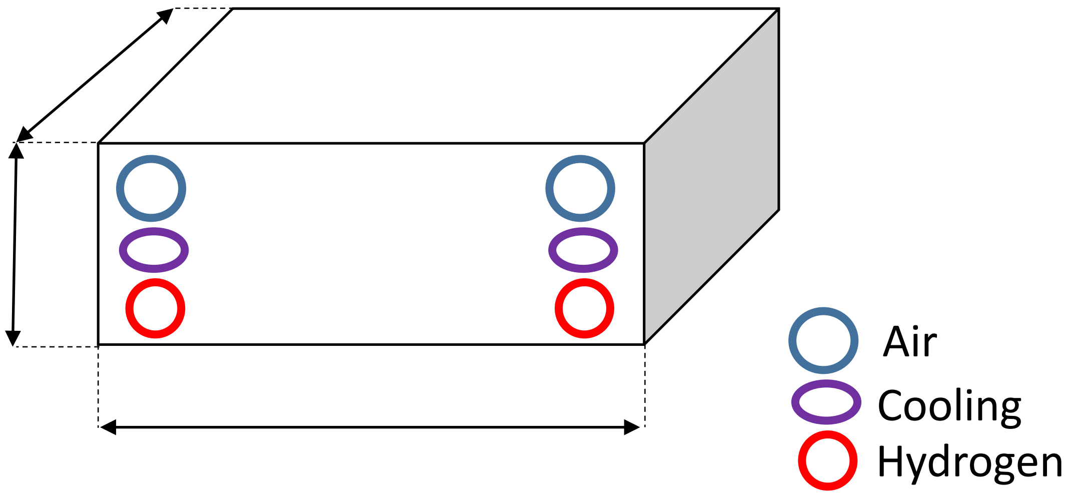
Stack Specification and Design

❑ Technical specifications defined for the 100 kW Dolphin stack

Dimensional limits for the Dolphin stack

Dimensional constraints	
Height BPP Max (h in mm)	<300
Width BPP Max (w in mm)	<150
Length Stack Max (L in mm)	<420
Stack Orientation	All type except BPP parallel to ground



Explored solutions to achieve dimensional constraints

WP2 presentation on new solutions, materials and processes

Stack Specification and Design

❑ Technical specifications defined for the 100 kW Dolphin stack

- Operating conditions for the Dolphin stack

Working conditions	stœchiometric ratio Anode	1,5	std for recirculation H_2
	Anodic Max dry N_2 mole fraction (%)	30	
	stœchiometric ratio Cathode	1,6	
	Relative Humidity Anode	50	
	Relative Humidity Cathode	50	
	Max N_2 at anode (%)	30	H_2 recirculation
	Stack temperature (defined in outlet stack) (°C)	95	Dolphin Target - - Permanent operation
	Delta temperature inlet vs outlet (°C Max)	12	
	Ambient temperature min in usage (°C)	-20	std auto - Pre-heating before start in extreme conditions
	Stack temperature peak in usage (°C)	105	Dolphin Target – Peak operation

- Performance targets for the Dolphin stack

Performance	Current density @0,66V (A/cm²) @Pmax	3,03	Autostack Core @ 1,9A/cm² @0,6V
	Power Density @0,66V (W/cm²)	2,00	Dolphin Target
	Charge Pt (mg/cm²) Anode	0,1	Dolphin Target
	Charge Pt (mg/cm²) Cathode	0,4	Dolphin Target
	Stack Power Density (KW/L) - At new	5	Dolphin Target - (Cells + End Plate + Compressions syst volume / Gross Power)
	Stack Specific Power Density (KW/Kg)	4	Dolphin Target - (Cells + End Plate + Compressions syst weight / Gross Power)

Blue values are targets which will be pursued through the project

Stack Specification and Design

❑ Technical specifications defined for the 100 kW Dolphin stack

- Durability targets for the Dolphin stack

Start / Stop Cycles (short stop)	150 000 cycles	1 Cycle OCV
Start up / Shut Down cycles (Long Stop)	35000 cycles	1 Cycle; Fluids circulation stop and start
Use Cycle	Harmonized FC DLC	
Durability	6000h	Harmonized FC DLC Or ID Fast Output will be used
Max Power degradation after ageing	10%	After 6000h ageing

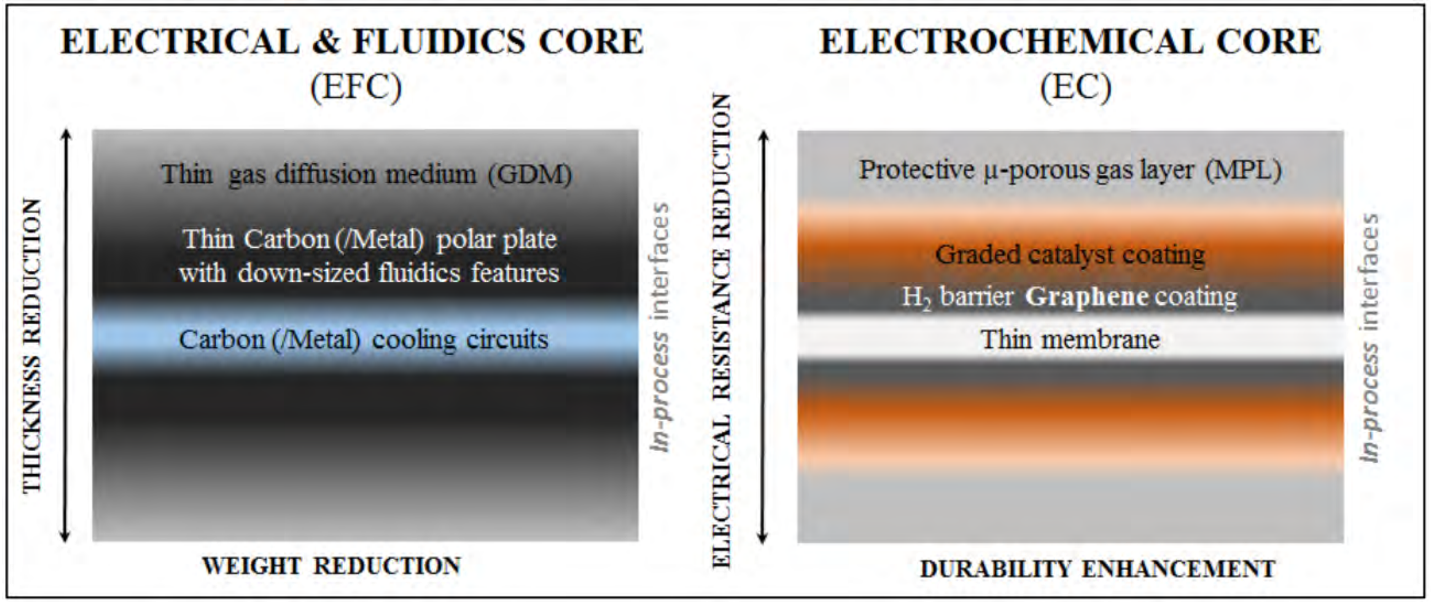
- Cost ambitions for the Dolphin stack

Stack Cost	<20 €/KW	100 000 stack/year

Stack Specification and Design

- ❑ Technical strategy to achieve the ambitions of the Dolphin stack

Dual Core architecture integrating fluidic and electronic conduction functions (EFC) + electrochemical functions (EC)



***Process integration** and **process simplification** for a multi-components approach*

Stack Specification and Design

- Modelling activities within WP1

Final target: *Dolphin 100 kW stack*

Demonstration: *Intermediate 5 kW stack (WP5)*

Stack sizing tool by CAD:
- Power
- Operation conditions
- Virtual MEA
- Number of cells
- Active area
- Channel design
- Pressure drops

Design of EFC:
- CFD analysis
- 2D model: rib/channel
- Multi-physics model
- 3D model: Fluent®

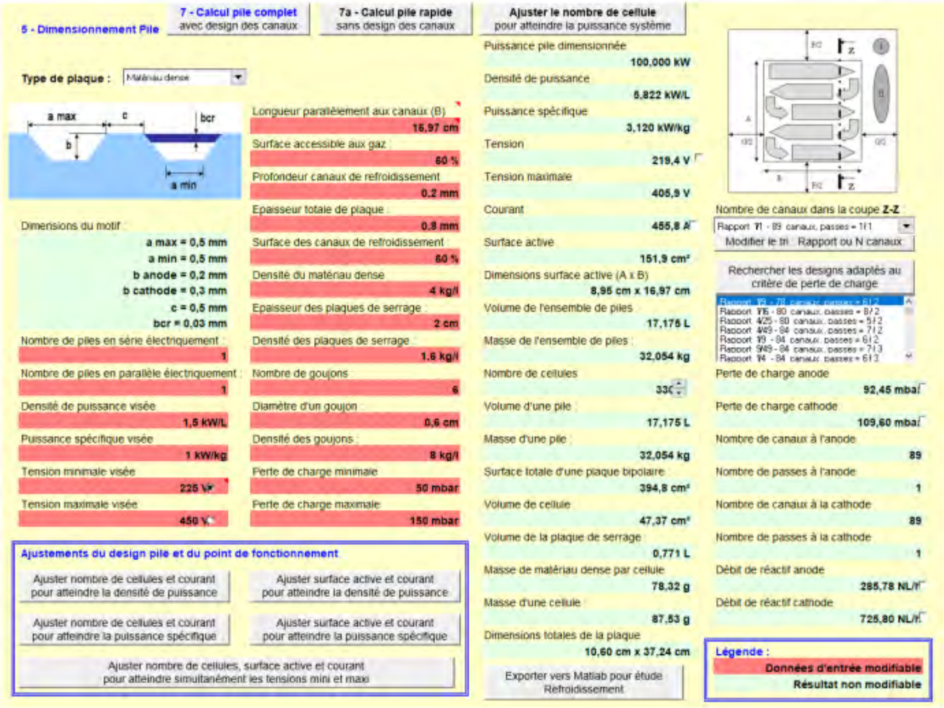
Design of EC:
- Evaluate ionomer/catalyst
- 1D model
- Diffusion of reactants

Design of ITP:
- FEA analysis
- Geometry
- Mechanical
- Fluidics
- Weight/performance

Stack Specification and Design

- ❑ Stack sizing tool from CEA

Maximum power operating conditions: 3.0 A cm^{-2}
Active area (A_0) 150 cm^2 and channel length 170 mm



Feasibility of 0,1 mm depth channels

Table 4: Pressure drop calculated at the cathode for several designs

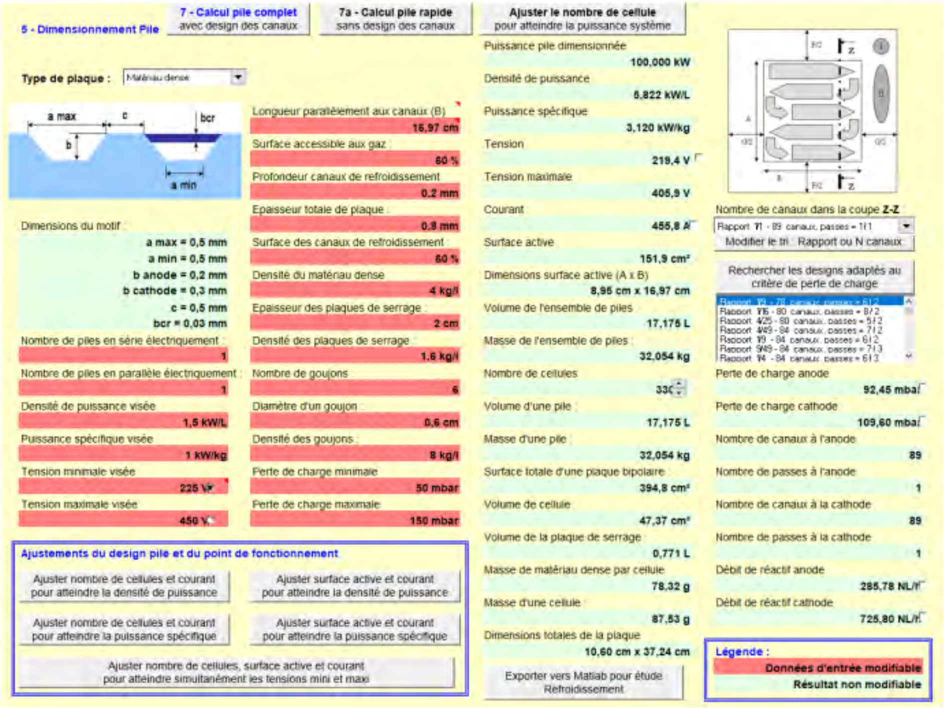
Channel width	Rib width	Channel depth	N# of channels	Delta P
0,5 mm	0,5 mm	0,3 mm	89	110 mbar
0,6 mm	0,6 mm	0,3 mm	74	102 mbar
0,4 mm	0,4 mm	0,3 mm	111	125 mbar
0,4 mm	0,4 mm	0,2 mm	111	400 mbar
0,3 mm	0,3 mm	0,2 mm	148	450 mbar
0,2 mm	0,2 mm	0,2 mm	222	600 mbar
0,1 mm	0,1 mm	0,1 mm	443	7370 mbar

- ❑ Pressure drop increases whilst the channel width decreases
- ❑ Decrease of the channel depth down to 0,1 mm creates unrealistic pressure drop
- ❑ Need to adapt the surface of the active area to correct pressure drops

Stack Specification and Design

- ❑ Stack sizing tool from CEA

Maximum power operating conditions: 3.0 A cm^{-2}
Active area (A_0) 150 cm² and channel length 170 mm



Feasibility of 0,1 mm depth channels

Increase of A_0 width from 90 mm to 160 mm

Table 5: Pressure drops calculated with a larger width of the active area

Channel width	Land width	Channel depth	N# of channels	Delta P anode	Delta P cathode
0,4 mm	0,4 mm	0,2 mm	200	23 mbar	123 mbar
0,3 mm	0,3 mm	0,2 mm	267	26 mbar	139 mbar
0,2 mm	0,2 mm	0,2 mm	400	34 mbar	185 mbar
0,1 mm	0,1 mm	0,1 mm	800	420 mbar	2300 mbar
0,1 mm	0,1 mm	0,2 mm	800	42 mbar	230 mbar

- ❑ Provides better flexibility → identifies restriction:

  Confirms that depth of 0,1 mm provides too much of pressure drop at the cathode

- ❑ Further iterations will explore channels depths between 0,1 mm and 0,2 mm to find an optimum operational compromise

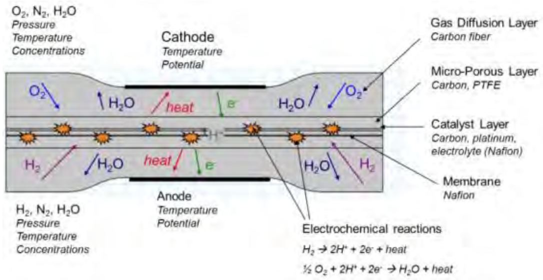
Progress on Design and Modelling

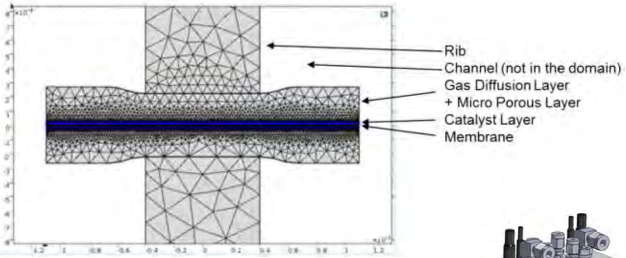
Modelling of EFC and EC

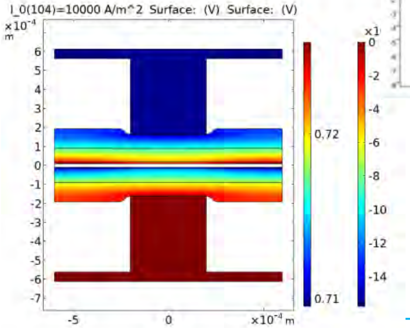
- Design of Electrical&Fluidics Core (EFC) and Electrochemical Core (EC)

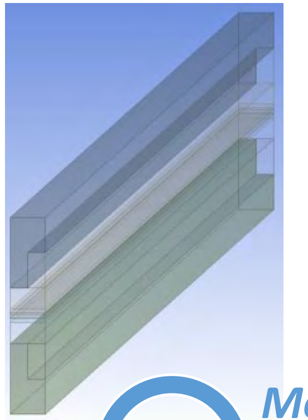
Modelling of the catalytic activities of the MEA and of the fluidics/thermal exchanges within the plate geometry

2-D model from CEA



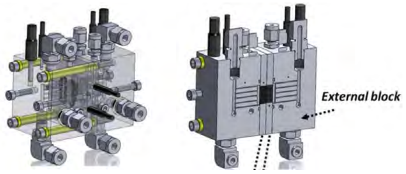






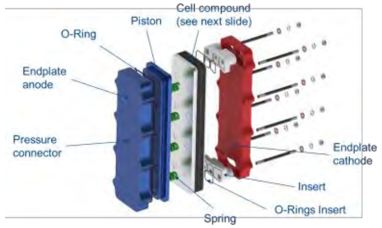
Modelling

Validation

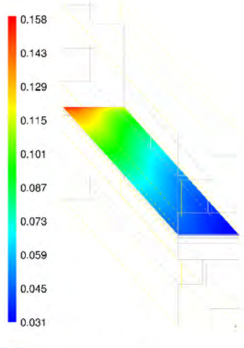


TP1

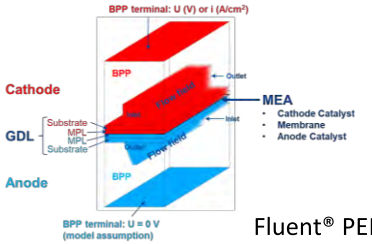
TP2



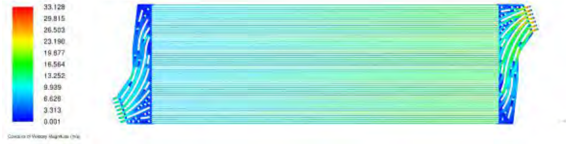
3-D model from ZSW



Contours of Mole fraction of o2



Fluent® PEMFC model



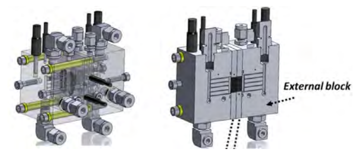
Modelling of EFC and EC

- Design of Electrical&Fluidics Core (EFC) and Electrochemical Core (EC)
  - Calibration of the model with fuel cell measurements

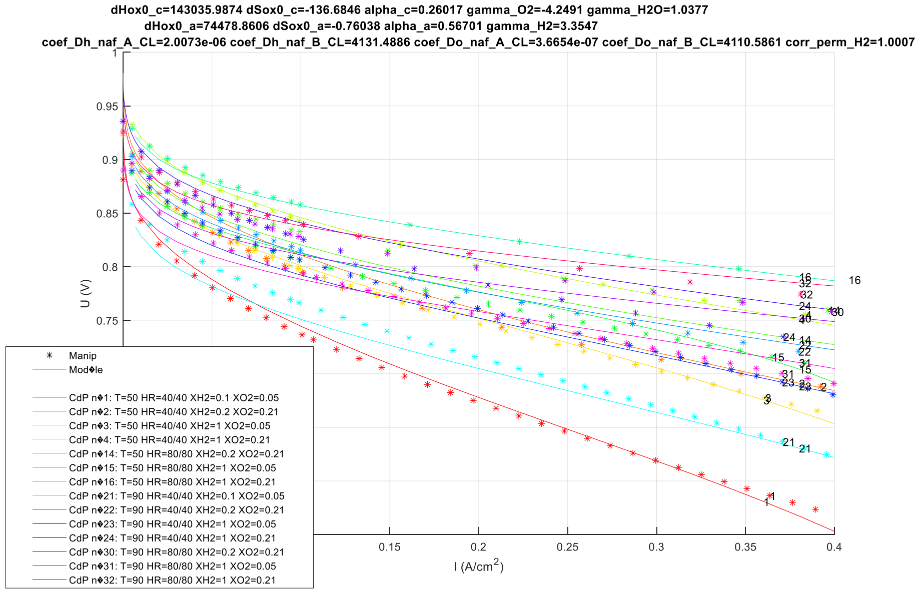
    Reference MEA: Gore CCM

2-D model from CEA

TP1



T (°C)	P (bar)	RH (%)	O_2 Fraction	H_2 Fraction	Q_{Air} (Nl/h)	Q_{H2} (Nl/h)	Q_{N2_cat} (Nl/h)	Q_{N2_cat} (Nl/h)	St_{O2min}	St_{H2min}
50	2	40	0,05	0,1	50	6	200	54	40	12
50	2	40	0,05	1	50	30	200	0	40	70
50	2	40	0,21	0,2	150	12	0	48	53	12
50	2	40	0,21	1	150	60	0	0	53	62
50	2	80	0,05	0,1	50	6	200	54	32	11
50	2	80	0,05	1	50	40	200	0	32	75
50	2	80	0,21	0,2	150	12	0	48	53	12
50	2	80	0,21	1	150	60	0	0	53	62
90	2	40	0,05	0,1	50	6	200	54	36	14
90	2	40	0,05	1	50	30	200	0	36	70
90	2	40	0,21	0,2	150	12	0	48	61	16
90	2	40	0,21	1	150	40	0	0	61	54
90	2	80	0,05	0,1	50	6	200	54	24	9
90	2	80	0,05	1	50	40	200	0	24	62
90	2	80	0,21	0,2	150	12	0	48	47	12
90	2	80	0,21	1	150	60	0	0	47	62



- Overall there is a an ***acceptable compromise*** between the 2-D model and experimental validation

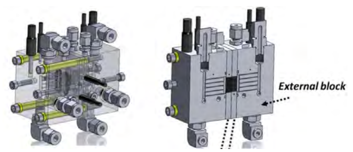
Progress on Design and Modelling

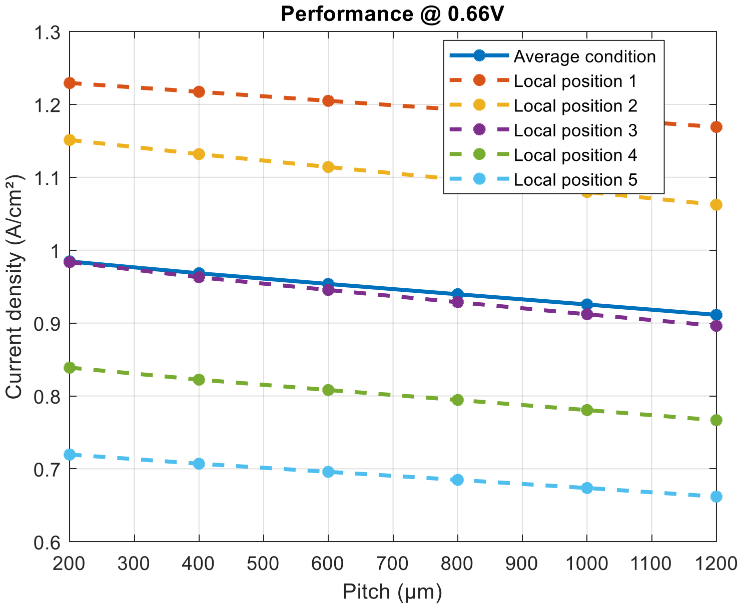
Modelling of EFC and EC

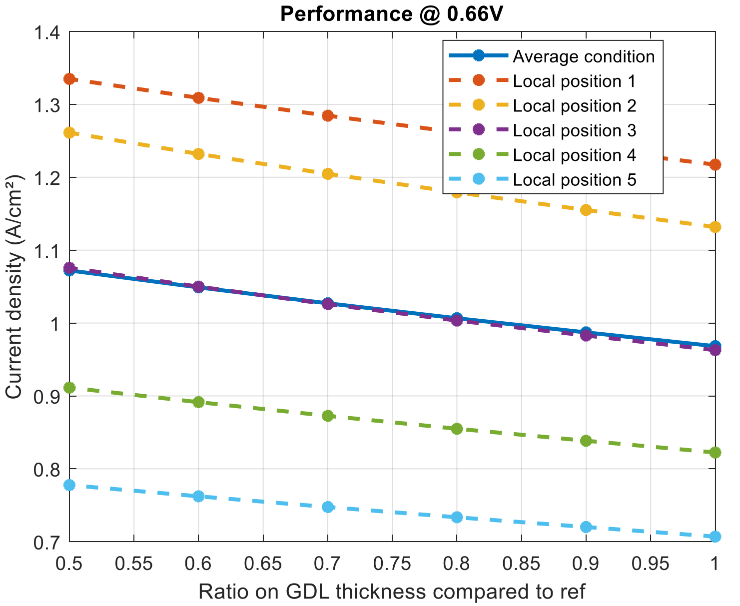
- Design of Electrical&Fluidics Core (EFC) and Electrochemical Core (EC)
  - Sensitivity analysis: rib-channel pitch, rib-channel dimensions

2-D model from CEA

TP1



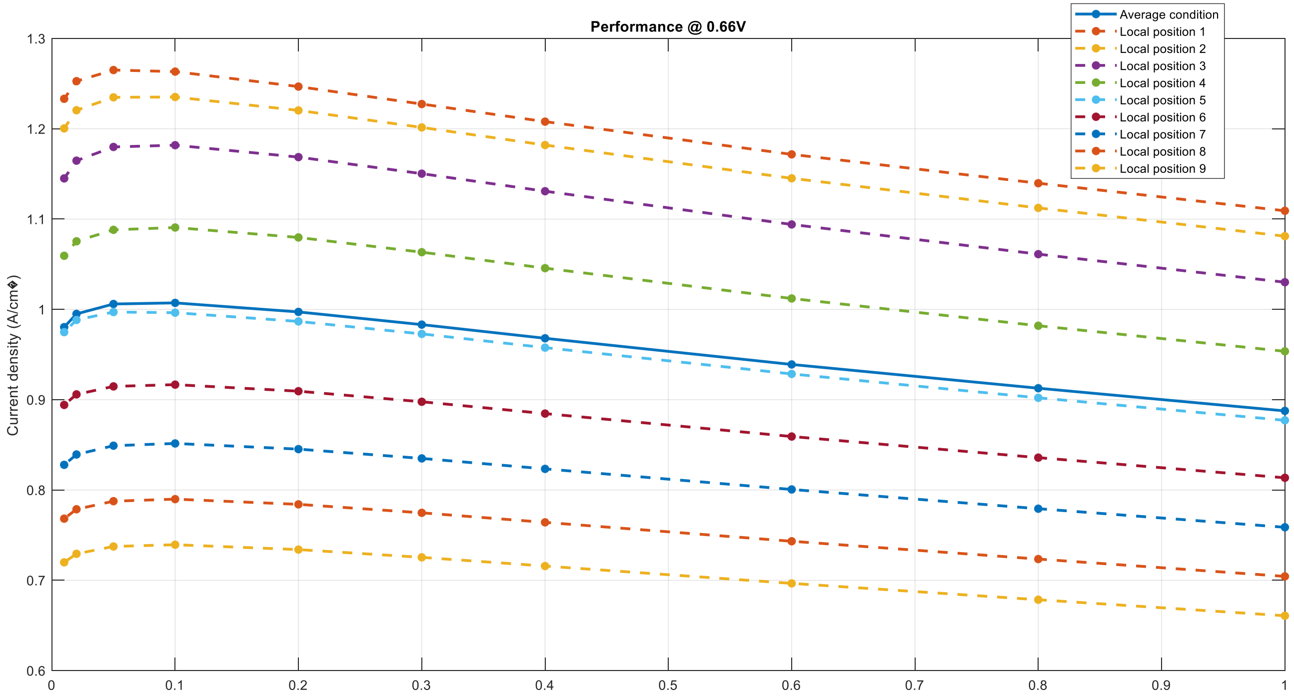




- No real optimum is identified
- Trends are observed: the smaller the better (Pressure drop is not included on the 2D model)

Modelling of EFC and EC

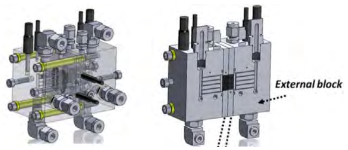
- Design of Electrical&Fluidics Core (EFC) and Electrochemical Core (EC)
  - Effect of GDL thickness



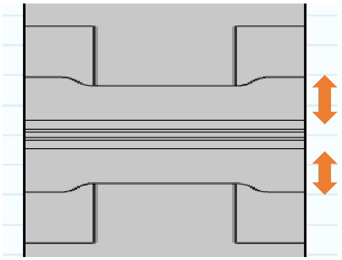
- Performances *increase* when thinning GDL *down to 10% of nominal value*
- Below 5% performance start to drop (indicates current collection limitation)

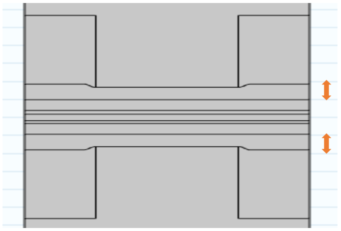
2-D model from CEA

TP1



Pitch of 200+200µm
Constant 30µm thick MPL





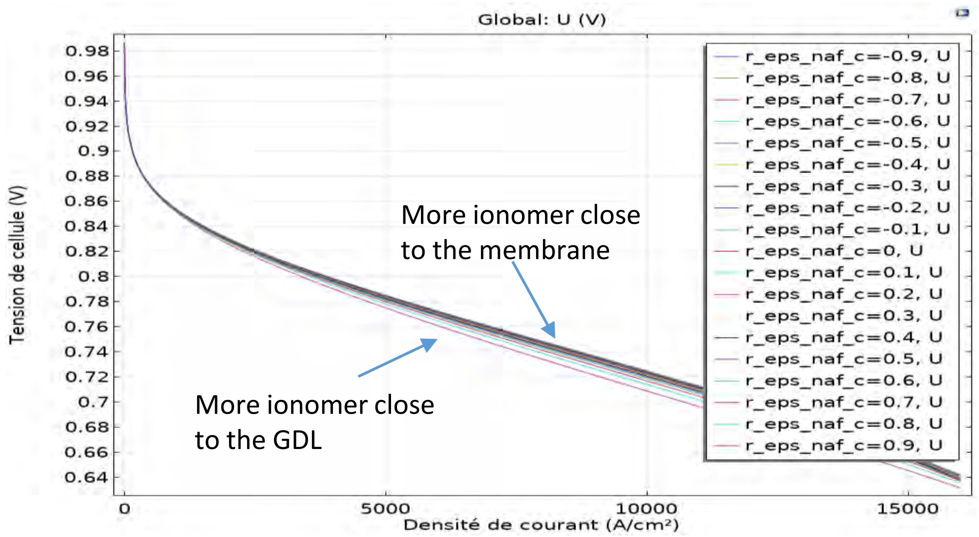
Progress on Design and Modelling

Modelling of EFC and EC

- Design of Electrical&Fluidics Core (EFC) and Electrochemical Core (EC)

2-D model from CEA

- Sensitivity to ionomer distribution through thickness of the catalyst layer



Many coupled effects. Increasing the local ionomer content:

- *increases* the ionic conductance
- decreases local porosity and *hinders* oxygen diffusion
- *increases* oxygen diffusion losses through the ionomer film
- affects the ionomer water content and its intrinsic conductivity

Progress on Design and Modelling

Modelling of EFC and EC

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2-D model from CEA

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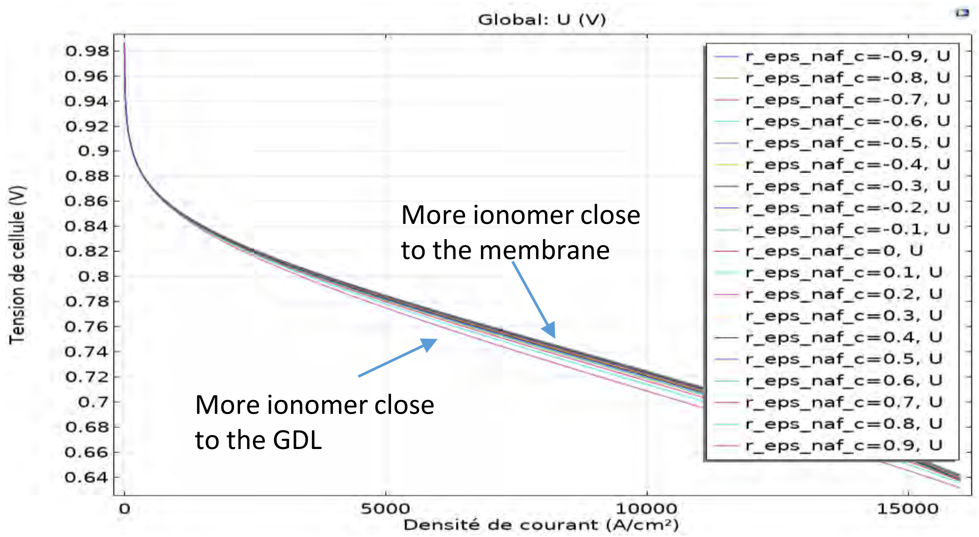
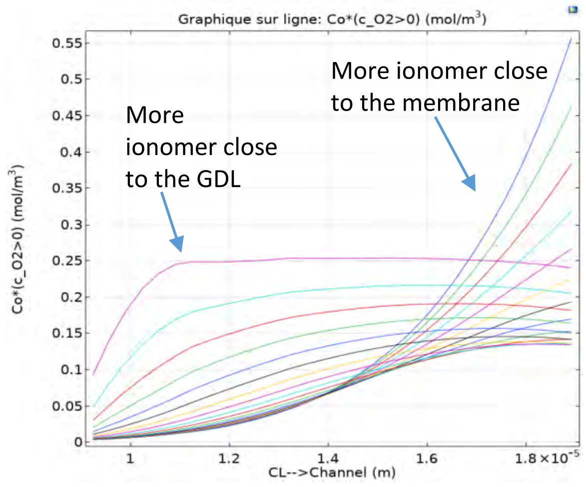




Oxygen concentration at the platinum surface through CL thickness

Many coupled effects. Increasing the local ionomer content:

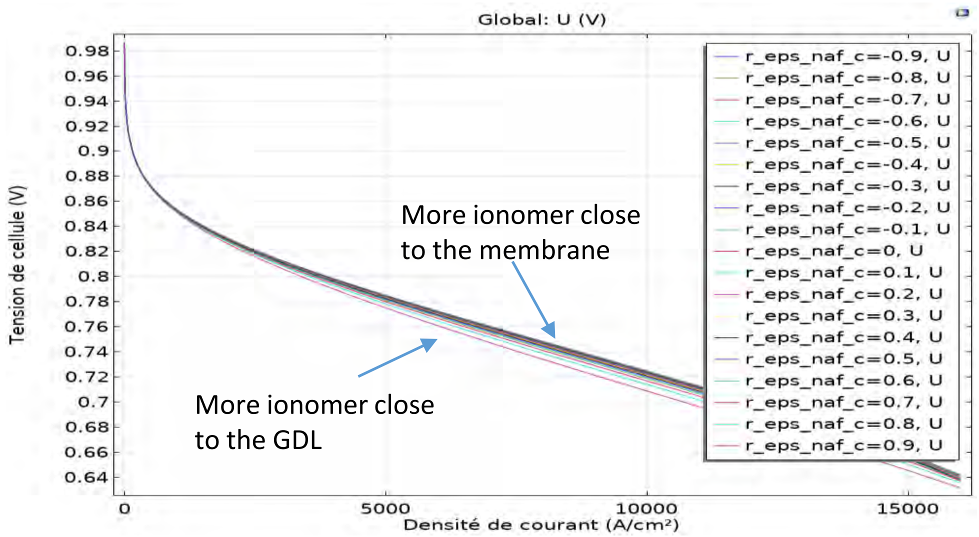
- ***increases*** the ionic conductance
- **decreases** local porosity and ***hinders*** oxygen diffusion
- ***increases*** oxygen diffusion losses through the ionomer film
- affects the ionomer water content and its intrinsic conductivity

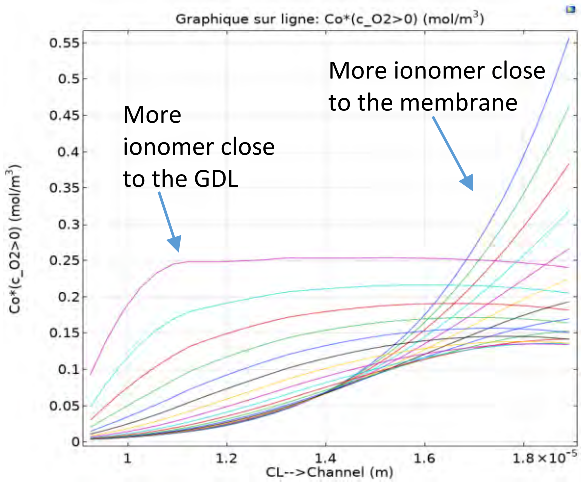
Modelling of EFC and EC

- Design of Electrical&Fluidics Core (EFC) and Electrochemical Core (EC)

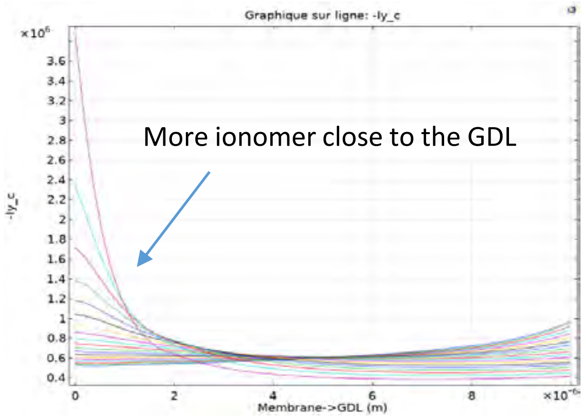
2-D model from CEA

  - Sensitivity to ionomer distribution through thickness of the catalyst layer





Oxygen concentration at the platinum surface through CL thickness



Current density distribution in the CL thickness

Many coupled effects. Increasing the local ionomer content:

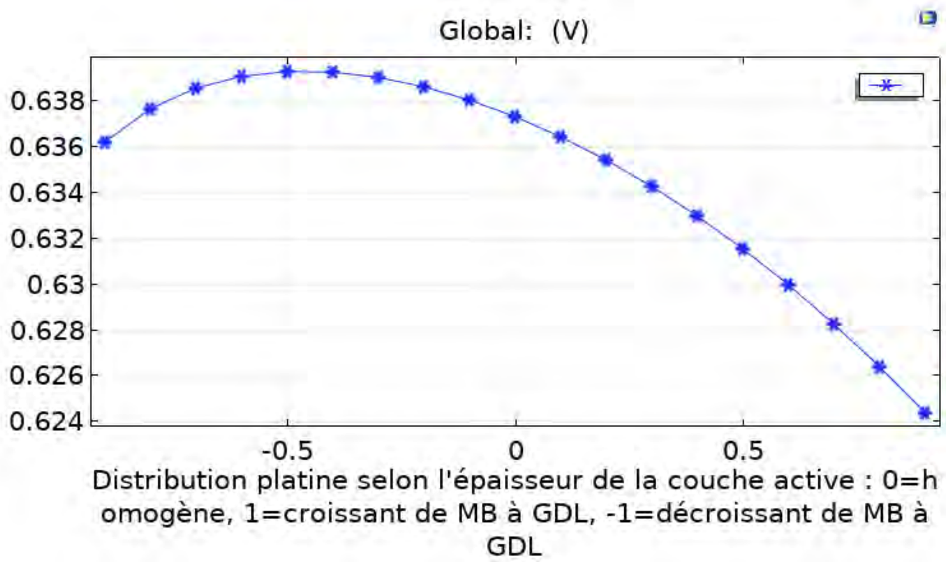
- ***increases*** the ionic conductance
- **decreases** local porosity and ***hinders*** oxygen diffusion
- ***increases*** oxygen diffusion losses through the ionomer film
- affects the ionomer water content and its intrinsic conductivity

Modelling of EFC and EC

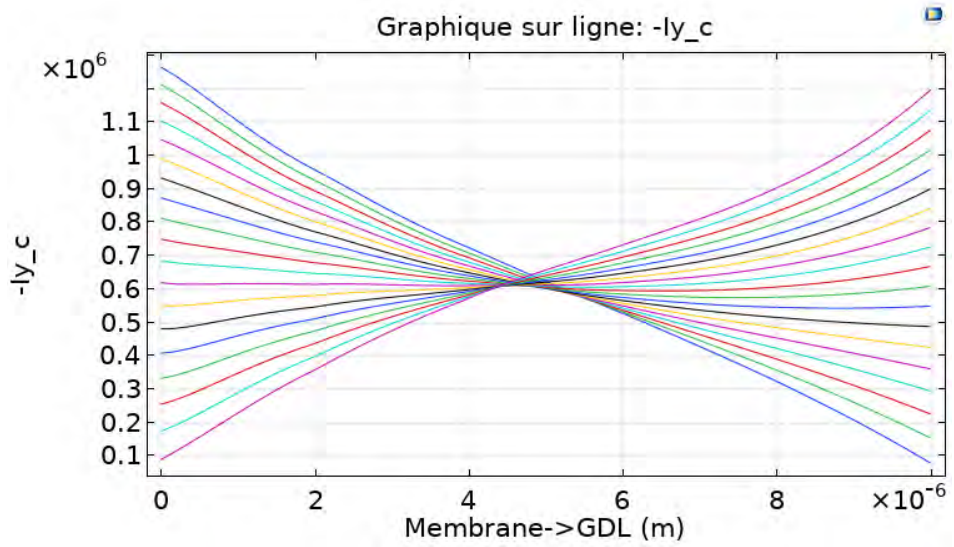
- Design of Electrical&Fluidics Core (EFC) and Electrochemical Core (EC)

2-D model from CEA

  - Sensitivity to platinum distribution through the thickness of the catalyst layer



MEA performance depending on platinum distribution



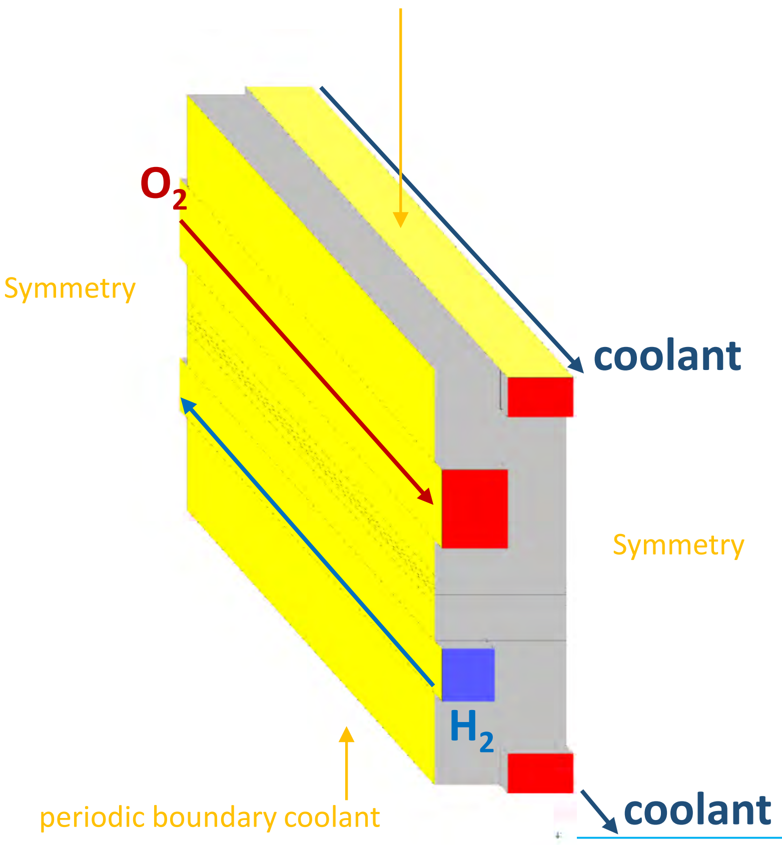
Current density distribution through the thickness of the CL

- Platinum distribution ***affects the strongly*** the current distribution in the CL, but not that much the overall performance

Modelling of EFC and EC

- Design of Electrical&Fluidics Core (EFC) and Electrochemical Core (EC)

3-D model from ZSW



	Reference		Advanced	
	Anode	Cathode	Anode	Cathode
repeating	1 mm		0.4 mm	
ch area	0.08 mm²	0.15 mm²	0.03 mm²	0.0625 mm²
rib width	0.6 mm	0.5 mm	0.25 mm	0.15 mm
ch width	0.4 mm	0.5 mm	0.15 mm	0.25 mm
ch depth	0.2 mm	0.3 mm	0.2 mm	0.25 mm
h_{sub}	135 µm		100 µm	
h_{mpl}	40 µm		25 µm	
h_{cat}	7.5 µm	10 µm	7.5 µm	10 µm
h_{mem}	15 µm		15 µm	

Reference → Advanced

- Repeating unit: -60% (active area)
- Anode channel area: -63%
- Cathode channel area: -58%
- Substrate thickness: -26%
- MPL thickness: -38%

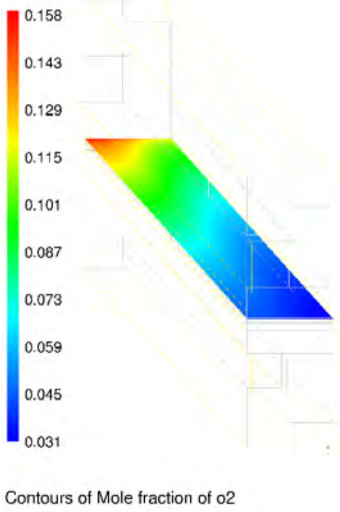
Modelling of EFC and EC

- Design of Electrical&Fluidics Core (EFC) and Electrochemical Core (EC)
  - Reactant distribution mid catalyst layer

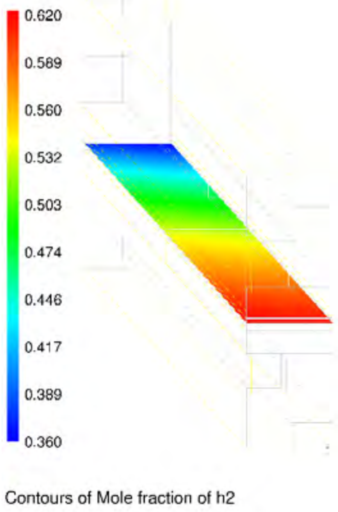
3-D model from ZSW

Reference channel

Cathode

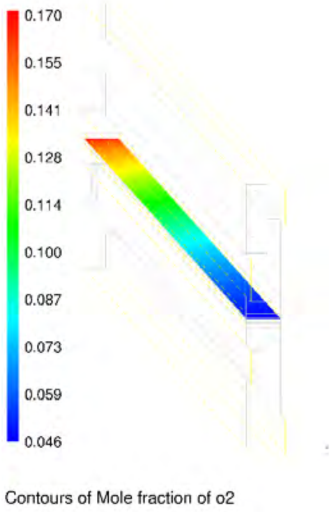


Anode

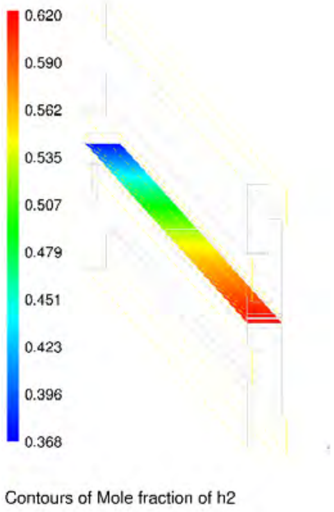


Advanced channel

Cathode



Anode



- Advanced channel shows ***more equal oxygen distribution*** (rip to channel)

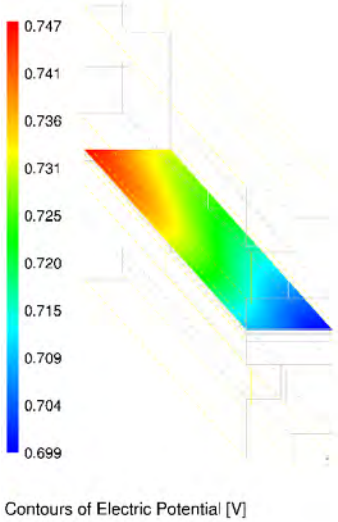
Modelling of EFC and EC

- Design of Electrical&Fluidics Core (EFC) and Electrochemical Core (EC)
  - Electric potential mid catalyst layer

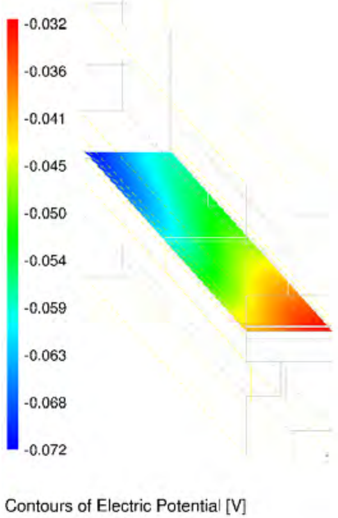
3-D model from ZSW

Reference channel

Cathode

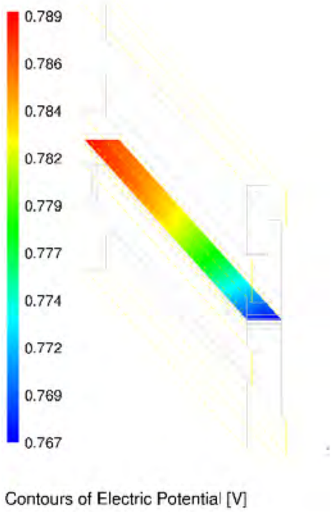


Anode

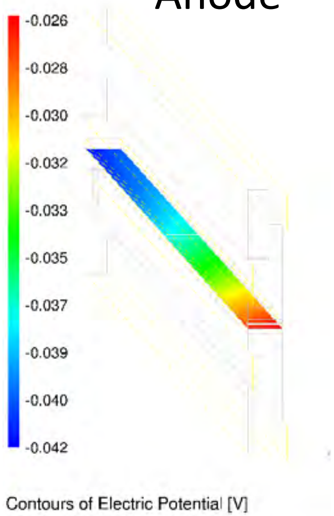


Advanced channel

Cathode



Anode



- Advanced channel shows ***more equal electric potential distribution***
- Cell voltage ***increased from 0.66 V to 0.73 V*** (for the same current density)

Progress on Design and Modelling

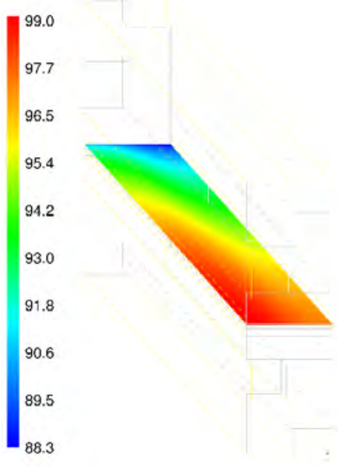
Modelling of EFC and EC

- Design of Electrical&Fluidics Core (EFC) and Electrochemical Core (EC)
    - Temperature mid catalyst layer

3-D model from ZSW

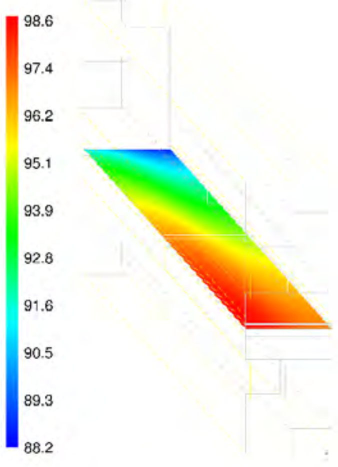
Reference channel

Cathode



Contours of Static Temperature [C]

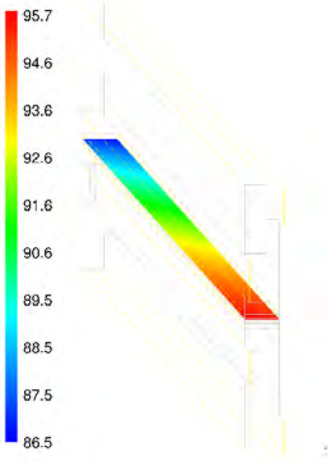
Anode



Contours of Static Temperature [C]

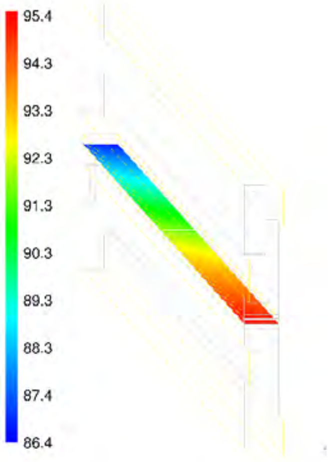
Advanced channel

Cathode



Contours of Static Temperature [C]

Anode



Contours of Static Temperature [C]

- Advanced channel shows ***more equal temperature distribution***

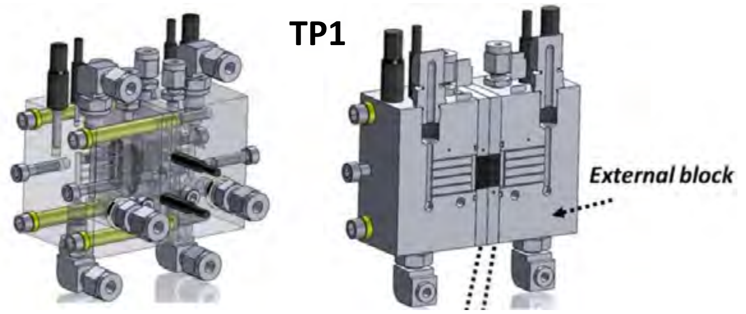
Progress on Design and Modelling

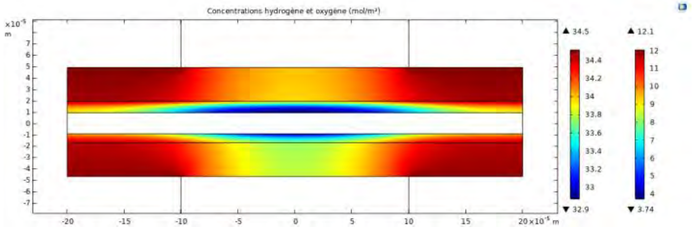
Modelling of EFC and EC

- Design of Electrical&Fluidics Core (EFC) and Electrochemical Core (EC)

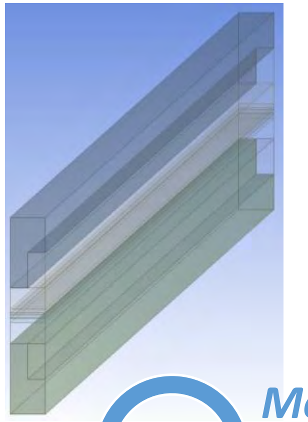
Modelling of the catalytic activities of the MEA and of the fluidics/thermal exchanges within the plate geometry

TP1





O2 (top) and H2 (bottom) concentrations in the MEA
Position 5; pitch 200/200

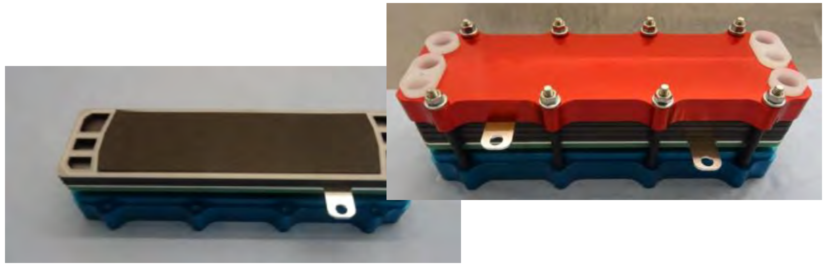


Modelling

Validation

3-D model from ZSW

TP2



Progress on Design and Modelling

Design of Stack Integrated Plates

DOLPHIN
Disruptive pemfc stack with nOvel materials, Processes, arcHitecture and optimized INterfaces

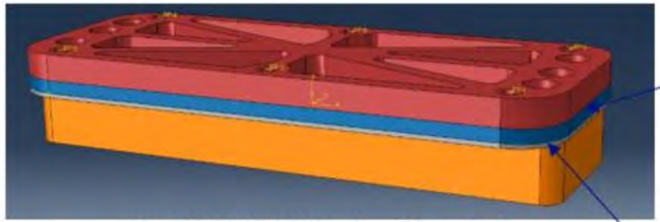
European Commission

FCH

❑ Design of light and compact composite Integrated Terminal Plates

- Benchmark is an aluminium ITP from ZSW

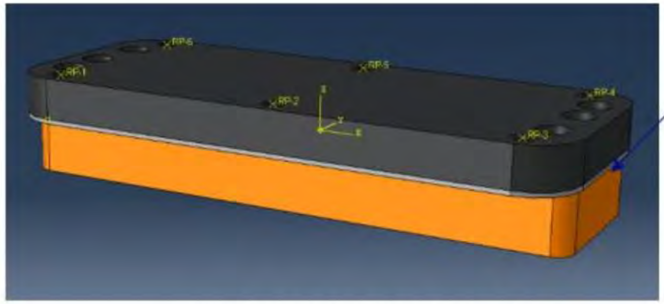
HEXCEL



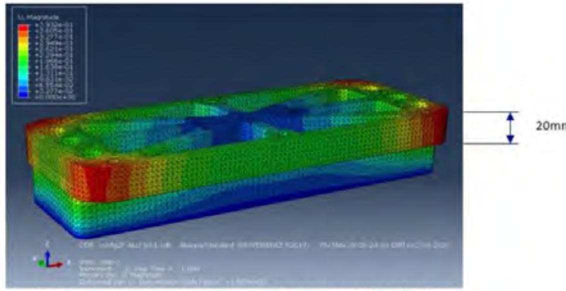
HexMC®-i M701 Carbon fiber design

Insulation layer

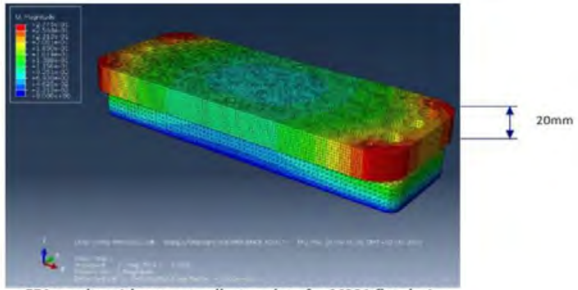
Collector plate



HexPly® M901 Glass fiber design



FEA results with current collector plate for HexMC®-i design



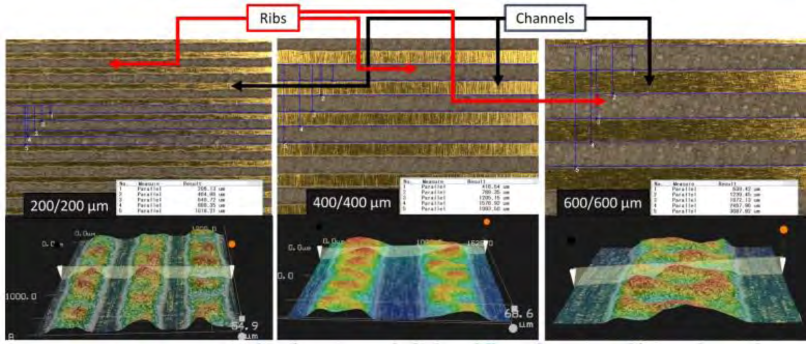
FEA results with current collector plate for M901 flat design

- Materials solution proposed:
  carbon fiber *vs.* glass fiber
- Both present advantages
- Possibility to explore attachment solutions: rods vs. straps

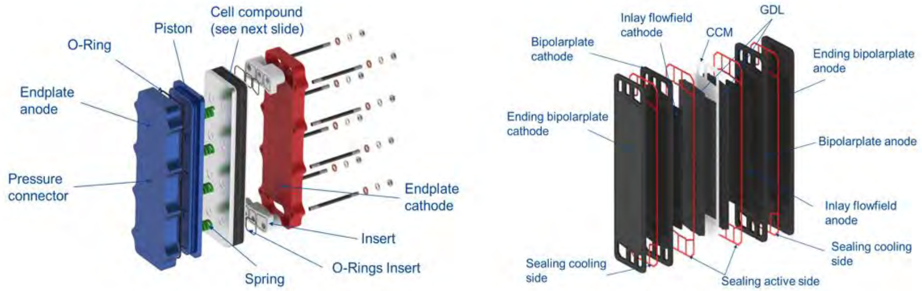
What's coming now…

- ❑ The real viability of the different strategies will be tested at short-stack scale

Printed channels



TP2 which will evolve for a short-stack



Rib-channel features

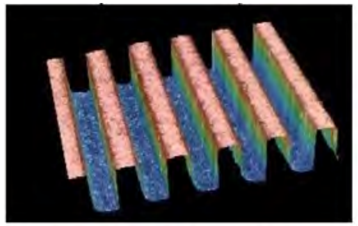
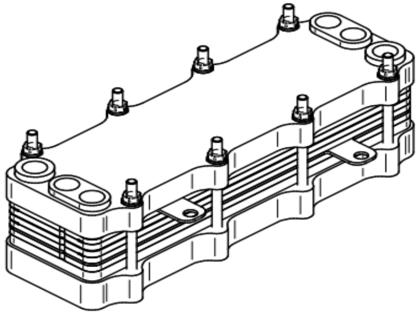
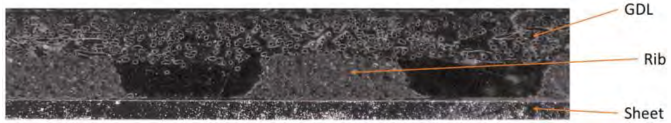


Figure 15: Shape of rib-channel (pitch < 400µm) structures manufactured by laser ablation from a graphitic baseplate (ZSW image).



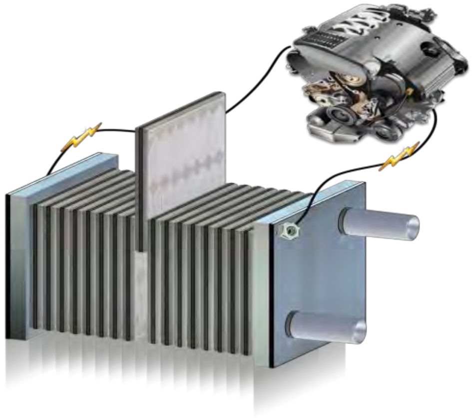
Molded thin sheets



Thank you for your attention!

DOLPHIN

Disruptive pemfc stack with nOvel materiaLs, Processes, arcHitecture and optimized INterfaces



The DOLPHIN project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No. 826204. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation programme, Hydrogen Europe and Hydrogen Europe Research.