





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)





WP1 – Stack Architecture and Development



□ Objectives of WP1 for Dolphin project:

- 1. Increase Power Density (W/cm²)
- 2. Reduce Mass (kg)
- 3. Reduce Volume (m³)



Drivers for the Dolphin stack:

1. Cost projection of the Dolphin stack



2. Industrialisation of product





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□ 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.

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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/cm ²) 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)

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□ 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%)
Volumetric power density (kW/l) at nominal power	4.1	≥ 5.0 (≥ +25%)
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Stack max operating temperature (°C)	95	105 (+10°C)



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□ 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



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□ Technical specifications defined for the 100 kW Dolphin stack

• Operating conditions for the Dolphin stack

	stæchiometric ratio Anode	1,5	std for recirculation H ₂
Anodic (%) stæchio Relative	Anodic Max dry N ₂ mole fraction (%)	30	
	stæchiometric ratio Cathode	1,6	
	Relative Humidity Anode	50	
	Relative Humidity Cathode	50	
Working conditions	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

	Current density @0,66V (A/cm²) @Pmax		Autostack Core @ 1,9A/cm ² @0,6V	
erformance	Power Density @0,66V (W/cm ²)		Dolphin Target	
	Charge Pt (mg/cm²) Anode		Dolphin Target	
	Charge Pt (mg/cm²) Cathode		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

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□ 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
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□ 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

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Modelling activities within WP1

Final target: Dolphin 100 kW stack



Weight/performance

Stack sizing tool by CAD:

- Power
- **Operation conditions**
- Virtual MEA
- Number of cells
- Active area
- Channel design
- Pressure drops

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□ Stack sizing tool from CEA

Maximum power operating conditions: 3.0 A cm^{-2} Active area (A₀) 150 cm² and channel length 170 mm

5 - Dimensionnement Pile Avec design i	des canaux sans design	pile rapide des canaux	Ajuster le nombre de ce pour atteindre la puissance s	flule système	-	_
			Puissance pile dimensionnée	100,000 KW	HC Z	
Type de plaque : Milénéu dense			Densité de puissance			
a max C lber	Longueur parallèlement aux c	anaux (B)	Puissance spécifique	5,822 KW/L		1
		15,97 cm	3	120 kW/kg		
	Surface accessible aux gaz	-	Tension	alabar.		99
	Particular second second second	60 %	Toronton and the sta	219,4 V		
a min	Profondeur canaux de refroidi	ssement	Tension maximale		FIC Z	_
	Engisseur totale de clanue	0.2 mm	Courant	400,3 ¥	Nombre de canaix dans la co	100 7.7
Dimensions du motif	characen mane de bradde :	0.8 mm	Gouran	455 8 4	Baccost 71 - 19 caca is passes - 1	11 -
a max = 0.5 mm	Surface des canaux de retroid	tissement	Surface active		Modifier le tri Rapport ou N	canaux:
a min = 0.5 mm		60 %	Contract and the	151.9 cm2		
b anode = 0,2 mm	Densité du matériau dense		Dimensions surface active (A)	B)	Rechercher les designs ada	iptės au
b cathode = 0,3 mm		4 kg/l	8,95 cm	x 16,97 cm	critere de perte de cha	rge
c = 0,5 mm bcr = 0,03 mm	Epaisseur des plaques de ser	rage : 2 cm	Volume de l'ensemble de piles	17,175 L	Rabbort VIS - 80 canaux, basset - Rabbort VIS - 80 canaux, basset - Rabbort 4/25 - 80 canaux, basset -	B/2 5/2 7/2
Nombre de plies en série électriquement	Densité des plaques de serra	ge 1.6 kg/l	Masse de l'ensemble de piles	32,054 kg	Rapport 19 - 94 canaux, bases = Rapport 949 - 94 canaux, bases = Rapport 949 - 94 canaux, bases =	612 713 613 **
Nombre de piles en parallèle électriquement :	Nombre de goujons		Nombre de ceitules		Perte de charge anode	
1		6		330		92,45 mba!
Densité de puissance visée	Diamètre d'un goujon	-	Volume d'une pile		Perte de charge cathode	in the second se
1,5 kW/L	And the second sec	0,6 cm	And a state of the	17,175 L	1	09,60 mba:
Puissance spécifique visée	Densité des goujons :		Masse d'une plie		Nombre de canaux à l'anode	-
1 KW/Kg	The state of the s	8 Kg/I		32,054 Kg	Manifest de la serie à barrete	89
Tension minimale visee	Perie de charge minimale	Ed mbar	Surface totale d'une plaque bi	794 8 cml	Nombre de passes a randoe	
Tensino maximale visée	Perte de charne maximale	SO INDAT	Volume de cellule	334,8 CHI-	Nombre de canaix à la calhor	-
450 VC	r ene de chorge maximore	150 mbar	YVIDING OF FERDING	47.37 cm*	include or conomic and conies	89
		the product	Volume de la plaque de serrad	IC .	Nombre de passes à la cathor	le
Ajustements du design pile et du point de	e fonctionnement			0,771 L		1
			Masse de matériau dense par	cellule	Débit de réactif anode	
Aguster nombre de cellules et courant pour atteindre la densité de puissance	Ajuster surface active et nour atteindre la densité de	courant puissance		78,32 g		285,78 NL/H
prei anemere le dellate de paraveire	pour aucinare la denance de	Palabolice	Masse d'une cellule		Débit de réactif cathode	
Ajuster nombre de cellules et courant pour affeindre la puissance spécifique	Ajuster surface active et pour atteindre la puissance	courant spécifique	Dimensions totales de la plaqu	87,53 g e		725,80 NL/H
	Section Sector Contractor		10,60 cm	x 37,24 cm	Légende :	-
Ajuster nombre de cellules, pour atteindre simultanémen	surface active et courant t les tensions mini et maxi		Exporter vers Matiab pour Refroidissement	étude	Données d'antrée Résultat non	modifiable modifiable

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

Progress on Design and Modelling





□ Stack sizing tool from CEA

Maximum power operating conditions: 3.0 A cm^{-2} Active area (A₀) 150 cm² and channel length 170 mm

5 - Dimensionnement Pile 7 - Calcul pi avec design i	tes canaux 7a - Calcul pile rapide sans design des canaux	Ajuster le nombre de cellule pour atteindre la puissance système	
Type de plaque : MWénéu dense		Puissance pile dimensionnée 100,000 kW Densilé de puissance 6,822 kW/L	
a max c bcr	Longueur paratèlement aux canaux (B) 16,97 cm Surface accessible aux gaz	Puissance spécifique 3,120 kW/kg Tension	
amin	60 % Profondeur canaux de refroidissement 0.2 mm	Tension maximale 405,9 V	8 FI2 Z
	Epaisseur totale de plaque	Courant	Nombre de canaux dans la coupe Z-Z
Dimensions du motif	0.8 mm	455,8 A	Rapport 71 - 89 canaux, passes = 1/1
a max = 0,5 mm	Surface des canaux de refroidissement	Surface active	Modifier le tri Rapport ou N canaux
a min = 0,5 mm	60 N	151,9 cm²	
b anode = 0,2 mm	Densité du matériau dense	Dimensions surface active (A x B)	Rechercher les designs adaptés au
b cathode = 0.3 mm	4 kg/l	8.95 cm x 16.97 cm	critère de perte de charge
c = 0,5 mm bcr = 0,03 mm	Epaisseur des plaques de serrage : 2 cm	Volume de l'ensemble de piles 17,176 L	Report 76 - 78 - resort preserve 512 A Report 76 - 80 canaux, passes - 8/2 Report 4/20 - 80 canaux, passes - 5/2
Nombre de plies en série électriquement : 1	Densité des plaques de serrage . 1.6 kg/l	Masse de l'ensemble de plies 32,054 kg	Rapport 19 - 94 canaux, basses = 612 Rapport 549 - 84 canaux, basses = 612 Rapport 14 - 84 canaux, basses = 613
Nombre de piles en parallèle électriquement :	Nombre de goujons	Nombre de celules	Perte de charge anode 92,45 mbaí
Densité de puissance visée	Diamètre d'un goujon	Volume d'une pile	Perte de charge cathode
1.5 KW/L	0.6 cm	17,175 L	109,60 mbai
Puissance spécifique visée	Densité des poujons	Masse dune ple	Nombre de canaux à l'anode
F BIAILES	Dennie des goojons	12 054 kg	90
Tenning minimula links	Tinda da altarena minimata	Custom Intelle divers streams binetimes	Manuface die manuelle à francedie
Tension minimale visee	Pene de charge minimale	Surface totale d'une plaque ofpolaire.	nombre de passes a ranode
225 W	50 mbar	394,8 cm ²	1
Tension maximale visée	Perte de charge maximale	Volume de cellule	Nombre de canaux à la cathode
450 V.	150 mbar	47,37 cm*	89
		Volume de la plaque de serrage	Nombre de passes à la cathode
Ajustements du design pile et du point de	e fonctionnement	0,771 L	
the second second is the second se		Masse de matériau dense par cellule	Débit de réactif anode
Ajuster nombre de cellules et courant	Ajuster surface active et courant	78.32 g	285.78 NL/H
pour acteingre la gensite de puissance	pour atteindre la densite de puissance	Masse d'une cellule	Débit de réactif cathode
Ajuster nombre de cellules et courant pour atteindre la puissance spécifique	Ajuster surface active et courant pour atteindre la puissance spécifique	87,53 g Dimensions totales de la plaque	725,80 NL//
		10.60 cm x 37.24 cm	Légende :
Ajuster nombre de cellules, pour atteindre simultanêmen	surface active et courant t les tensions mini et maxi	Exporter vers Matiab pour étude Refroidissement	Données d'entrée modifiable Résultat non modifiable
		Promotion de la company	

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	

 \Box Provides better flexibility \rightarrow 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



European Commission

□ 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





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

• Calibration of the model with fuel cell measurements Reference MEA: Gore CCM

Т	Ρ	RH	O ₂	H_2	QAir	Q _{H2}	Q _{N2_cat}	Q _{N2_cat}		
(°C)	(bar)	(%)	Fraction	Fraction	(NI/h)	(NI/h)	(Nl/h)	(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

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

• Sensitivity analysis: rib-channel pitch, rib-channel dimensions





2-D model from CEA



liten

reatech

No real optimum is identified

Trends are observed: the smaller the better (Pressure drop is not included on the 2D model)







• Effect of GDL thickness







Pitch of 200+200µm Constant 30µm thick MPL





□ Performances *increase* when thinning GDL *down to 10% of nominal value*

□ Below 5% performance start to drop (indicates current collection limitation)

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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

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- Design of Electrical&Fluidics Core (EFC) and Electrochemical Core (EC)
 - Sensitivity to ionomer distribution through thickness of the catalyst layer



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Oxygen concentration at the platinum surface through CL thickness





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





2-D model from CEA

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Current density distribution in the CL thickness

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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

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



	Refe	rence	Advanced		
	Anode	Cathode	Anode	Cathode	
repeating	eating 1 mm		0.4 mm		
ch area	0.08 mm ²	0.15 mm ²	0.03 mm ²	0.0625 mm ²	
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}	_b 135 μm		100 µm		
h _{mpl}	40 µm		25 µm		
h _{cat}	7.5 µm	10 µm	7.5 µm	10 µm	
h _{mem}	nem 15 μm		15 µm		

Reference \rightarrow Advanced

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





• Reactant distribution mid catalyst layer









Advanced channel





Contours of Mole fraction of h2

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

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

• Electric potential mid catalyst layer



Reference channel





Advanced channel

Advanced channel shows *more equal electric potential distribution*

Cell voltage *increased from 0.66 V to 0.73 V* (for the same current density)

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Temperature mid catalyst layer ٠



Reference channel







Anode 95.4 94.3 93.3 92.3 91.3 90.3 89.3 88.3 87.4 Contours of Static Temperature [C]

Advanced channel shows *more equal temperature distribution*

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European Commission

□ 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



Progress on Design and Modelling



Design of Stack Integrated Plates



Design of light and compact composite Integrated Terminal Plates

• Benchmark is an aluminium ITP from ZSW



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

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What's coming now...



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

Printed channels



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



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Cell compound

(see next slide

Piston

O-Ring

Endplate

Pressure

connector



Bipolarplat

cathode

Ending bipolarplate

cathode

Endplate

Inlay flowfield

Ending bipolarplate

Bipolarplate anode

Inlay flowfield anode

anode

Thank you for your attention!



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





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The University of Manchester



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