DOLPHIN

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

DOLPHIN Workshop, Ulm June 16th 2023

Talk 1.2 : Progress on design and modelling

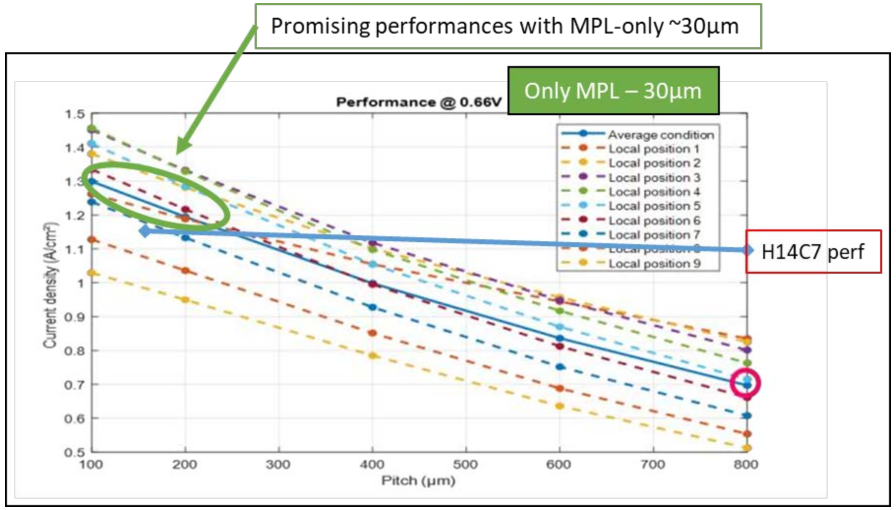
J. RAPIOR, all

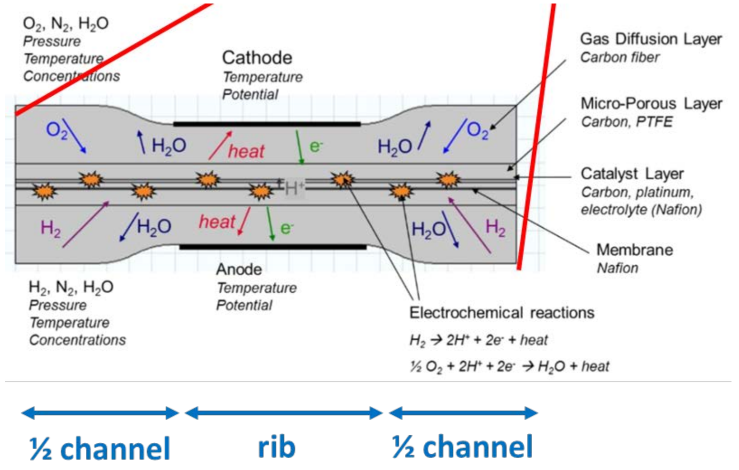
Clean Hydrogen Partnership
Co-funded by the European Union

Updates on modelling

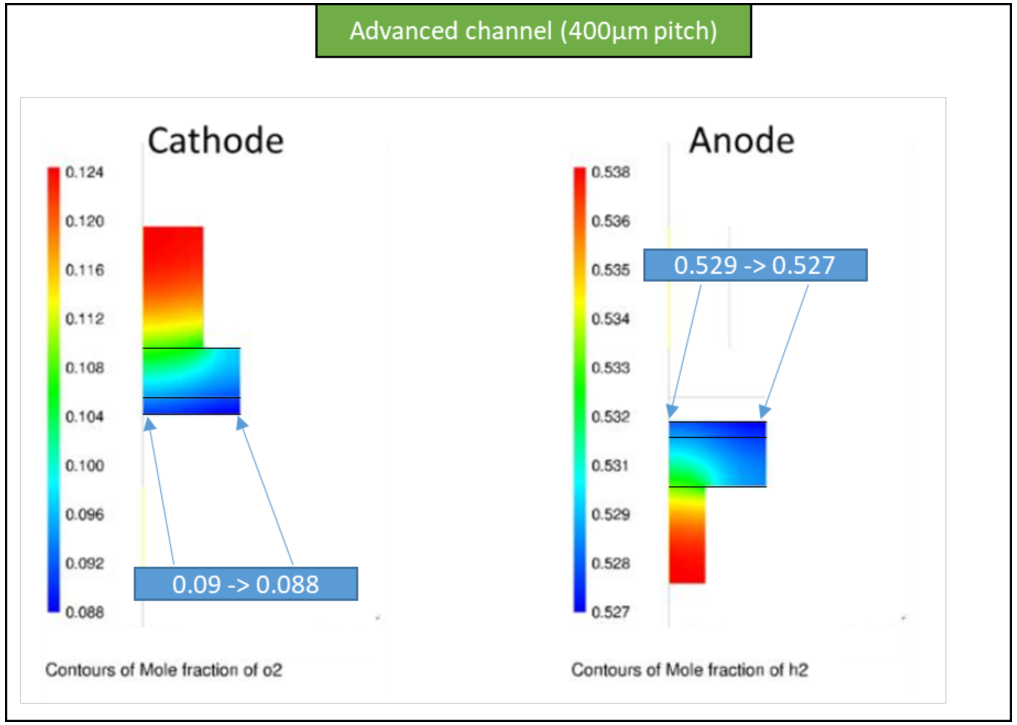
Informations shared during 1st workshop

- 2D model : influence of GDL thickness





- 3D model : influence of GDL teeth/channel pitch (gas diffusion)



Ionomer and catalyst distribution

<u>Ionomer and catalyst gradient simulation</u> : 2D model (COMSOL)

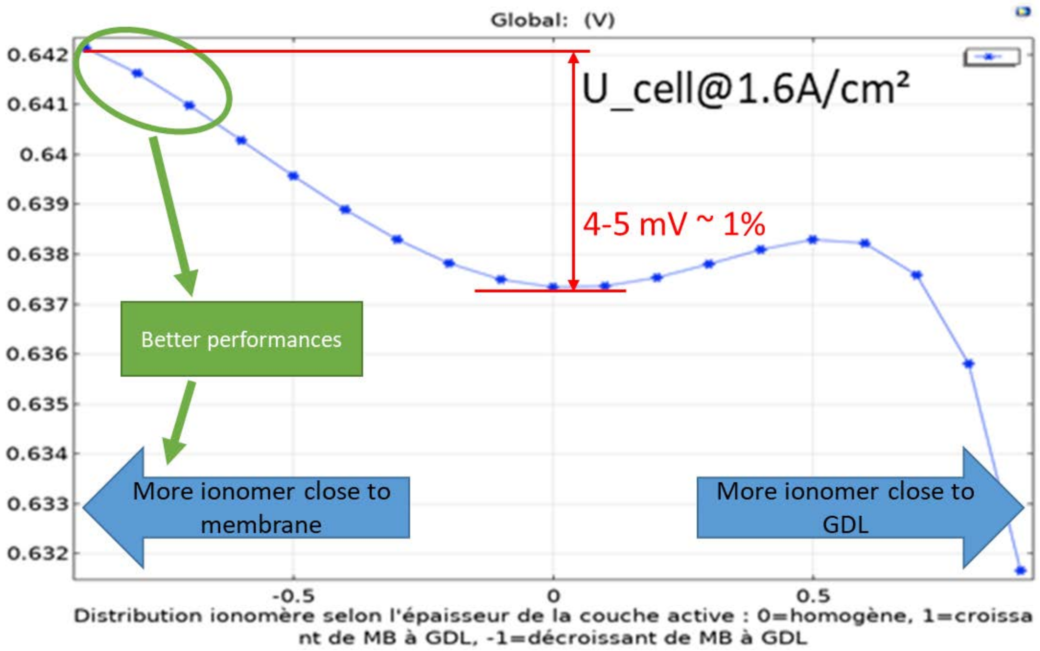
- Same catalyst layer thicknesses
- Same total Platinium and ionomer amount

More Platinium close to the CL/PEM interface

More Platinium close to the CL/GDL layer

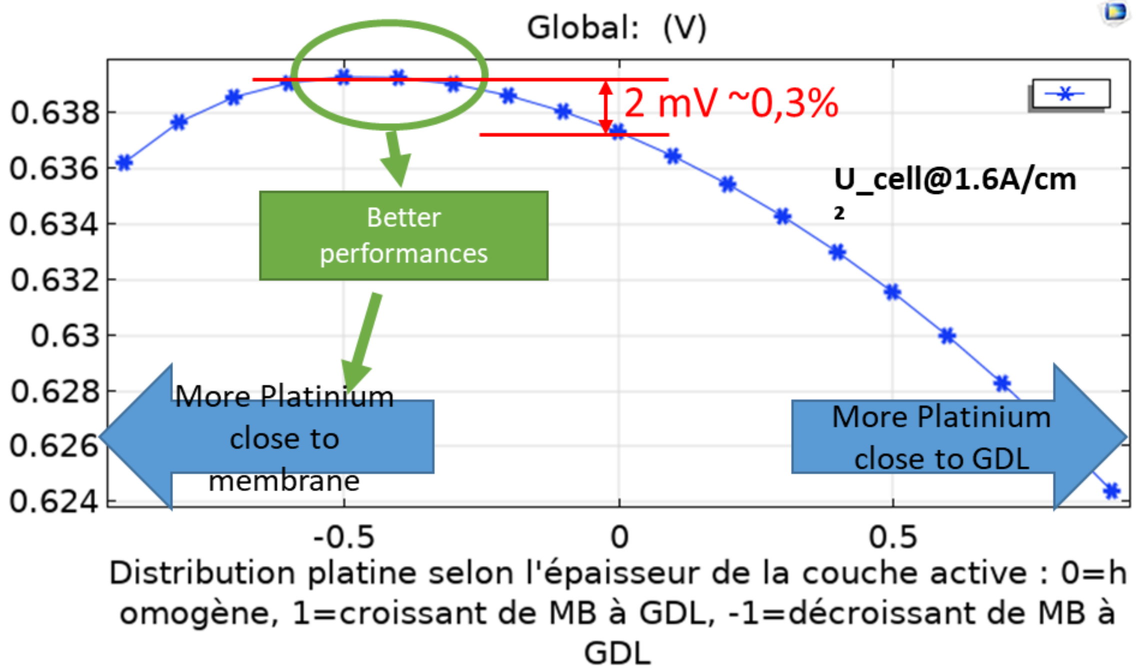
Ionomer and catalyst distribution

Ionomer gradient :



~ 1% performance increase putting more ionomer close to membrane

Platinium gradient :



~ 0,3 % performance increase putting more platinum close to membrane

Stack specification and design

1.1 - Stack specification

Specification for the 100kW have been frozen.

Key parameters :

- Max 400 cells (~400V @OCV)
- Active area : 175cm² (<300A @ target max current density 3A/cm²)
- Active_area / total_area ratio : 45% ➔ 384cm² total area

- Max pressure drop : (regarding automotive system constraints)
  - Cathode < 300mbar (for system components, and in/out pressure homogeneity)
  - Anode < 100mbar (for recirculating system efficiency)
  - Cooling < 350mbar (for system integration, and to keep pressure equivalent to gas side)

- End of life criteria : max power reached at 0,6V

General	Max stack voltage (OCV)	400	V	Passenger car architecture (400V boost-only DCDC)
	Max cell number	400	cells	1V/cell @OCV
	Active area	175	cm²	To reach 100kW at max power with 400 cells
	Total area	384	cm²	45% active_area / total_area ratio

Max power (Under system conditions)	Stack power	100	kW	
	Cell voltage	0.66	V	
	Min Power density	1.45	W/cm²	Go/no go criteria
	Max current density	3	A/cm²	DOLPHIN target
	Stack voltage	264	V	
	Stack current	379	A	Not over 400A, for safety contactors and DCDC disponibility
	Stack volumic power density (with end plates)	5	kW/l	KPI
	Stack massic power density (with end plates)	4	kW/kg	KPI
	Cooling outlet temperature	90	°C	For vehicle's front radiator easy dimensionning
	Max inlet/outlet temperature difference	12	°C	

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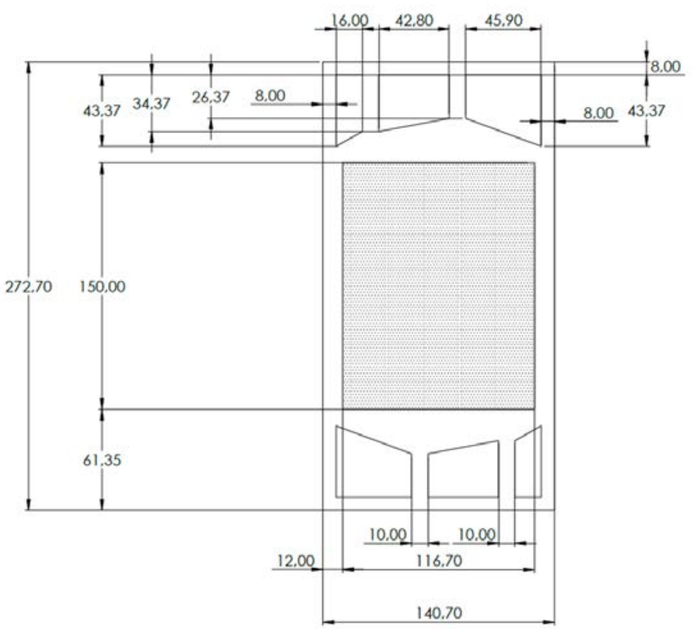
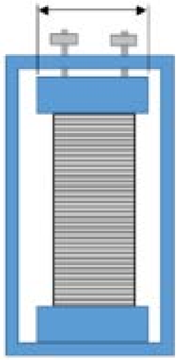
100kW Stack specification

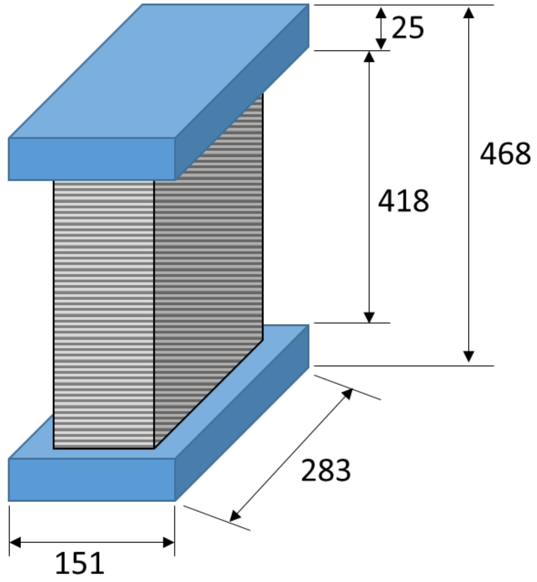


Key dimensions :

- Max cell pitch : 1,04mm
- Compression technology : straps, or carter (not tie rods, for volume optimization)
- Cells dimensions
  - Active area dimensions is a compromize to match pressure drops for the selected EFC technologies
- Stack dimensions ➔ Target to reach power density
- End plates dimensions and mechanical performances :
  - Max thickness = 25mm
  - Bending under load regarding electrical contact resistance homogeneity
  - Max overall flatness regarding sealing compression



Compression by straps or carter



Dimensionning chain :

- Stack Current
- Stack Voltage
- Reachable perfs (W/cm²)
- Pressure drops

➔ Active area dimensions ➔ Cells dimensions ➔ Terminal plates dimensions
- Vol power density
➔ Max cell pitch

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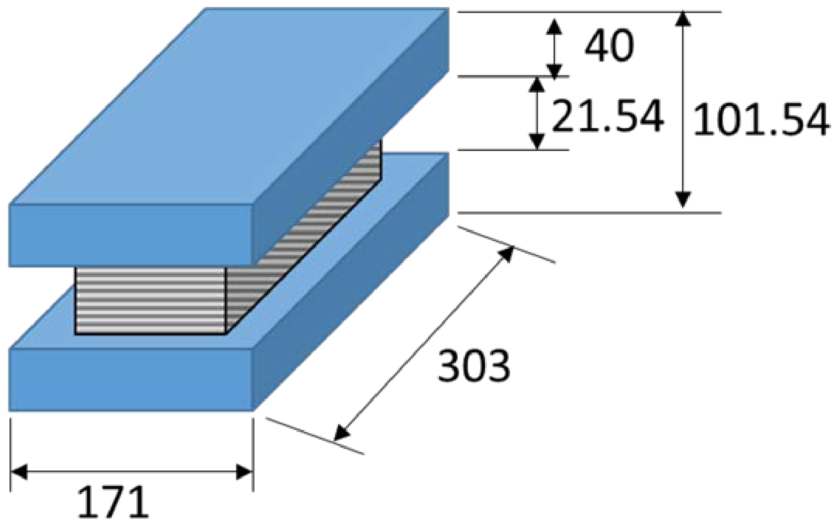
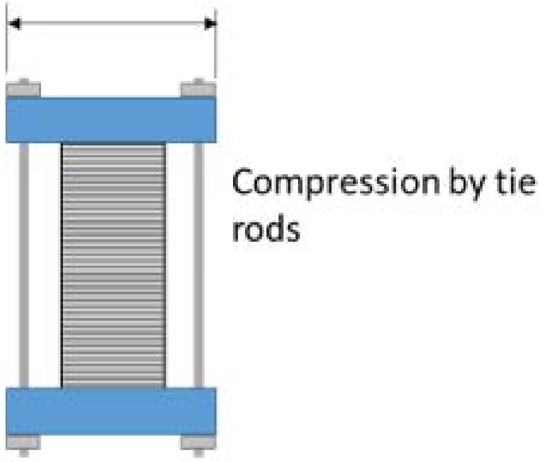
5kW stack specification (TP4)

Based on the 100kW stack specification, the 5kW stack requirements have also been edited :

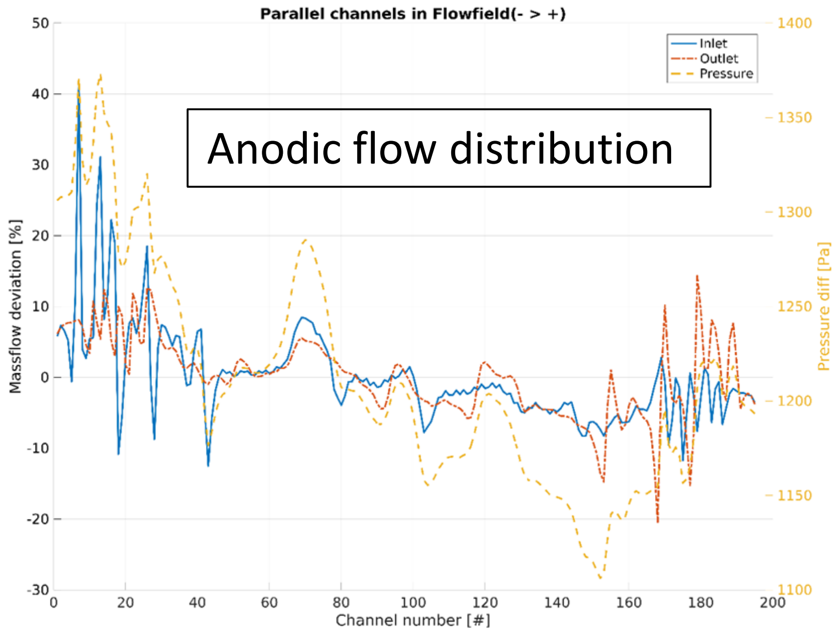
- Same cells than the 100kW stack
- Between 15 and 20 cells
- Compression technology : tie rods (most adapted to prototyping)
  - Thicker end plates allowed, to match the bending requirements
  - Larger to allow the space for the rods



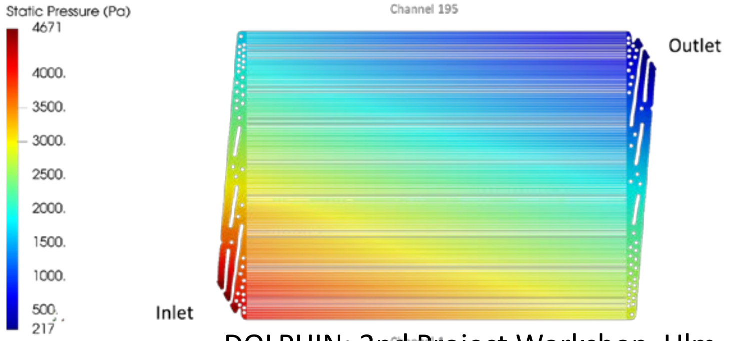


Electrical and fluidic core :

- A standard TP4 design have been proposed (manifolds, distribution area, cooling circuit). Modeling have been done to assess the fluids flow and concentration homogeneity :



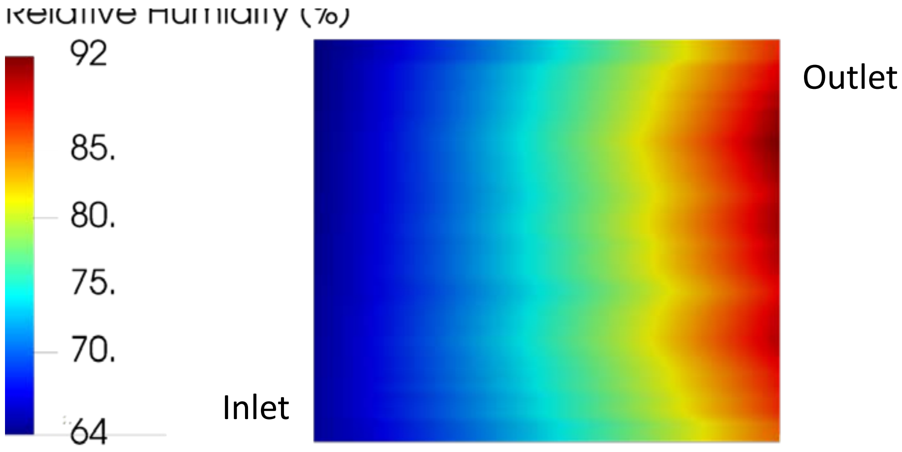
Anodic flow distribution



Δp = 50 mbar

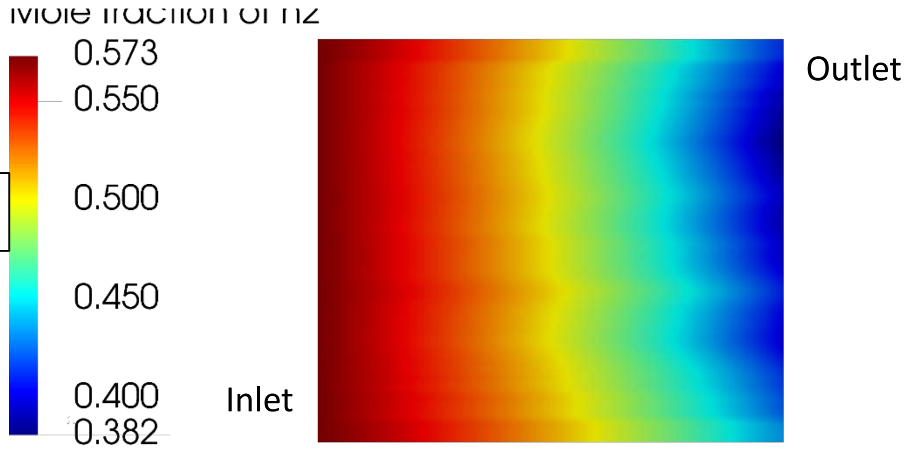
Anodic RH distribution

No condensation expected (without crossover, mean temperature)



Anodic reactant distribution

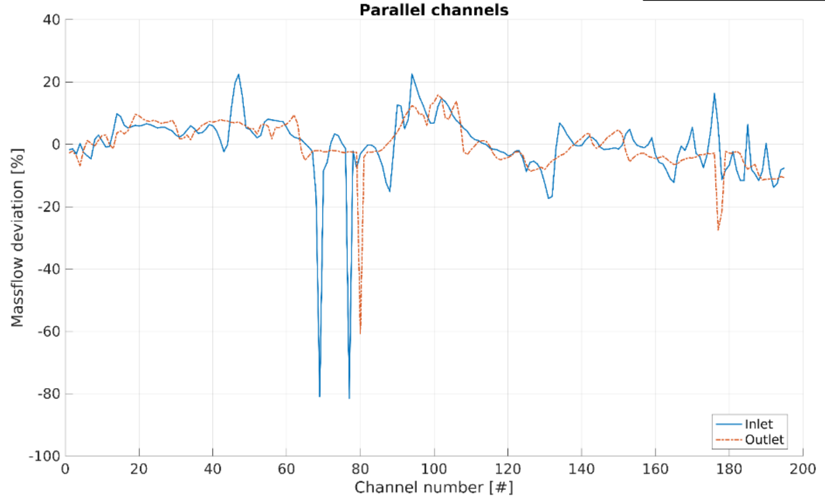
No starvation expected



Electrical and fluidic core

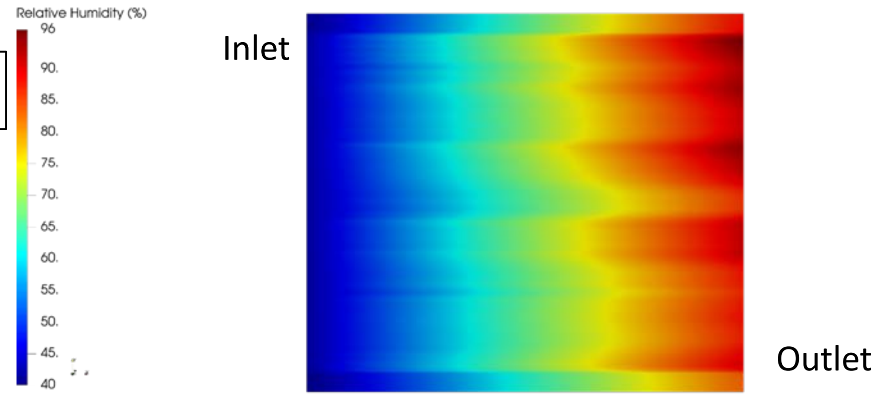
Cathodic flow distribution

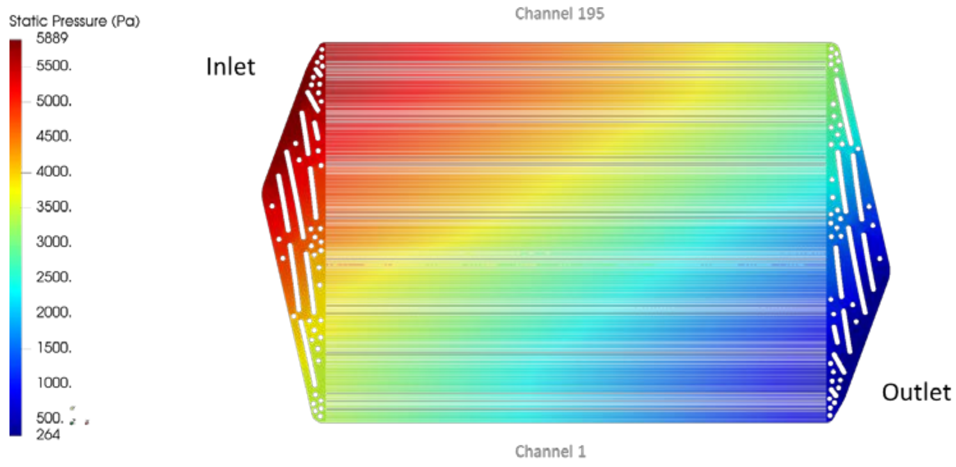
Δp = 59 mbar (63mbar incl. ports)



Cathodic RH distribution

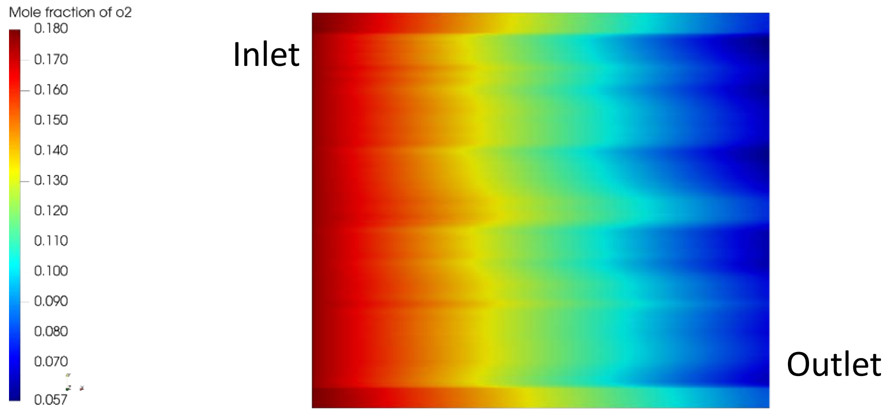
No condensation expected (without crossover, mean temperature)



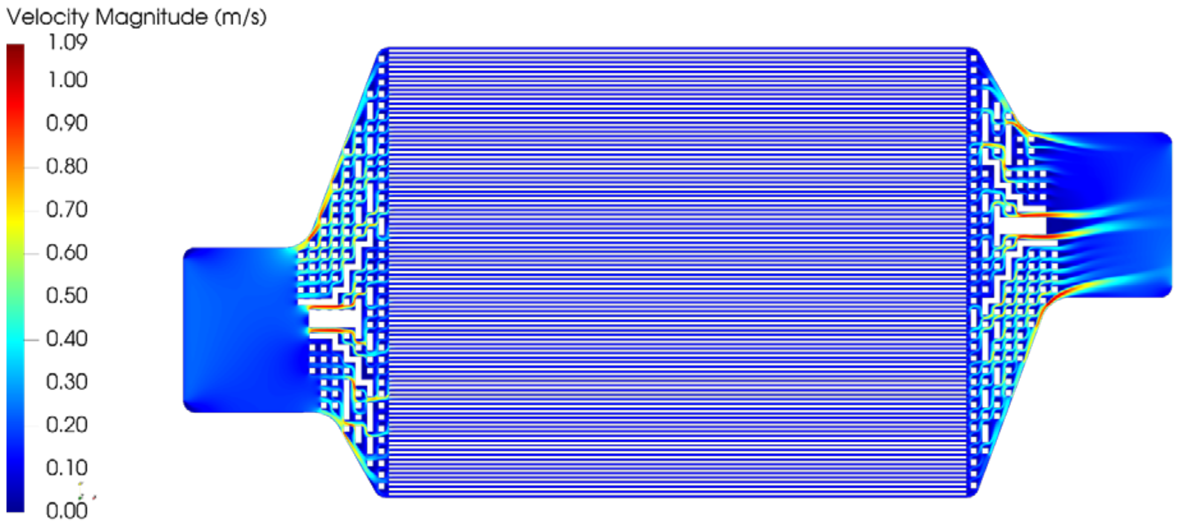


Cathodic reactant distribution

No starvation expected

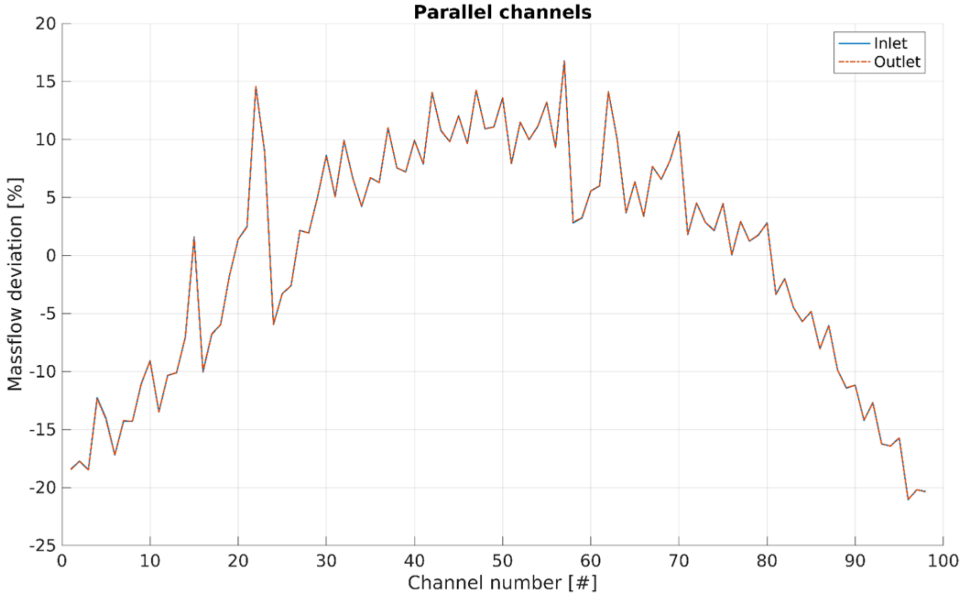


Electrical and fluidic core



Cooling flow distribution

Δp = 6 mbar



This generic design has been adapted for additive manufacturing (cf. Talk 3.2)

Characterization protocols and Quality assessment

Definition of system conditions

The project's operating conditions are not necessarely adapted to a system use, mainly regarding stoechiometry and operating pressure. The air compressor is the major power consumer of the system.

➔Stoechiometry and air pressure needs to be determined carefully to get the best system efficency.

Done for this task :

- Pressure sensivity tests
- System energetic assessment model

Pressure sensivity test protocol

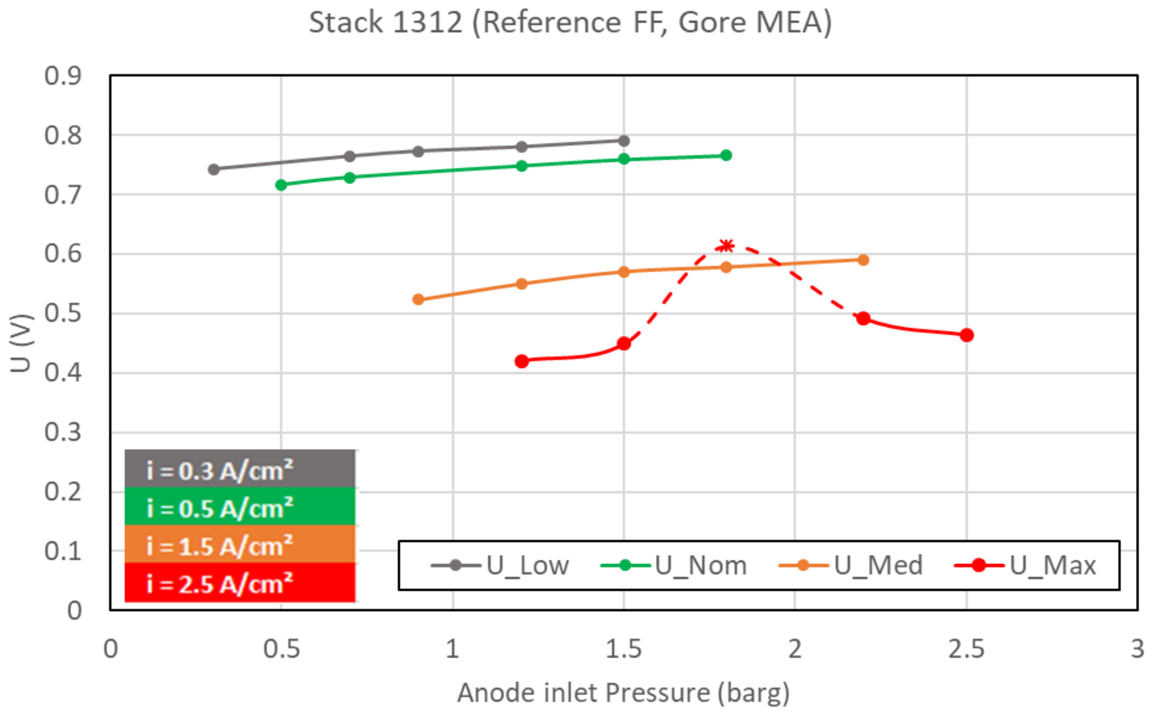
Pol Curve	*Low power conditions (10%)*	Nominal conditions (25%)	Medium power conditions (50%)	Max power conditions (100%)
Sto H2/Air	2.0 / 1.8	2.0 / 1.8	1.5 / 1.6	1.5/1.6
RH Anode/Cath *(dew point °C)*	50%/50% *(50.3°C/50.3°C)*	50%/50% *(57.5°C/57.5°C)*	50%/30% *(66.6°C/55.4°C)*	50%/30% *(66.6°C/55.4°C)*
PInlet Anode/Cath (bar abs)	1.3/Patm outlet 1.7/1.5 1.9/1.7 2.2/2.0 2.5/2.3	1.5/1.3 1.7/1.5 2.2/2.0 2.5/2.3 2.8/2.6	1.9/1.7 2.2/2.0 2.5/2.3 2.8/2.6 3.2/3.0	1.9/1.7 2.2/2.0 2.5/2.3 2.8/2.6 3.2/3.0 *3.5/3.7 (or bench max)*
Cell Temperature (Coolant Inlet)	65°C	73°C	83°C	83°C
Fixed Current density points	*0.3 A/cm² (minimum flowrate 0.3 A/cm²)*	0.5 A/cm²	1.5 A/cm²	2.5 A/cm² and 3 A/cm² (if possible with Ucell >0.5V)

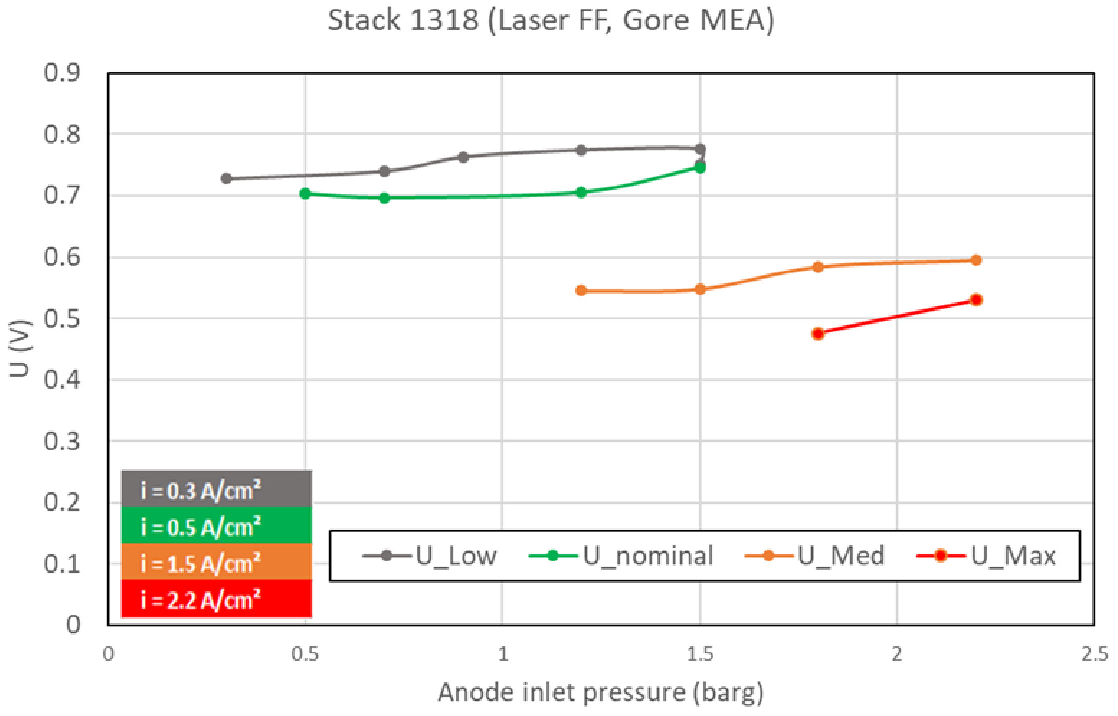
- Fixed current density values. 5 minutes for each pressure configuration (dwell time similiar to pol. curves)
- **Reference FF + ref MEA : possible at CEA**
- **Refined FF + ref MEA : to be done at ZSW (no refined pads available at CEA)**

Definition of system conditions

Pressure sensivity test results :

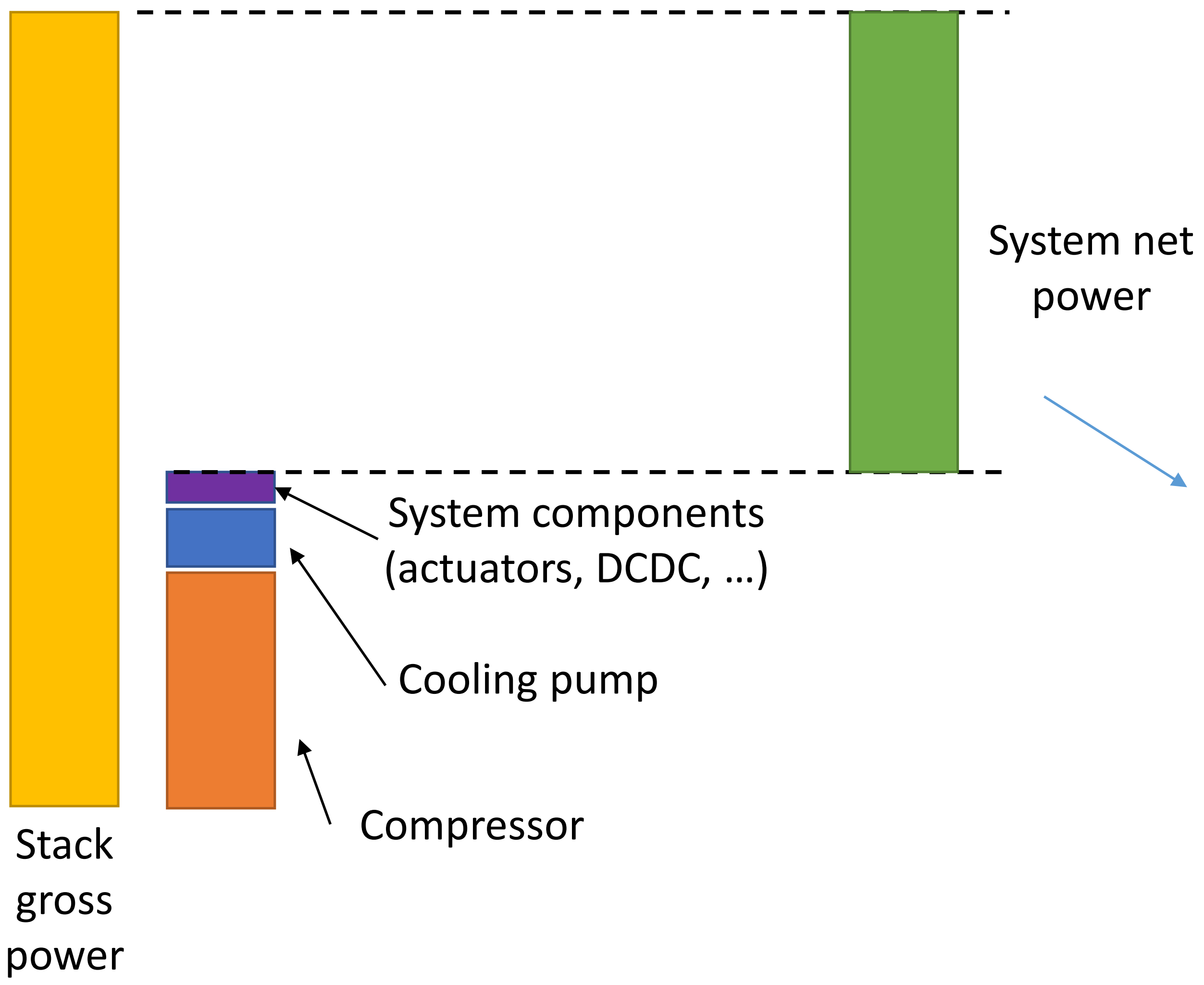
- 4 operating points, with different pressure levels



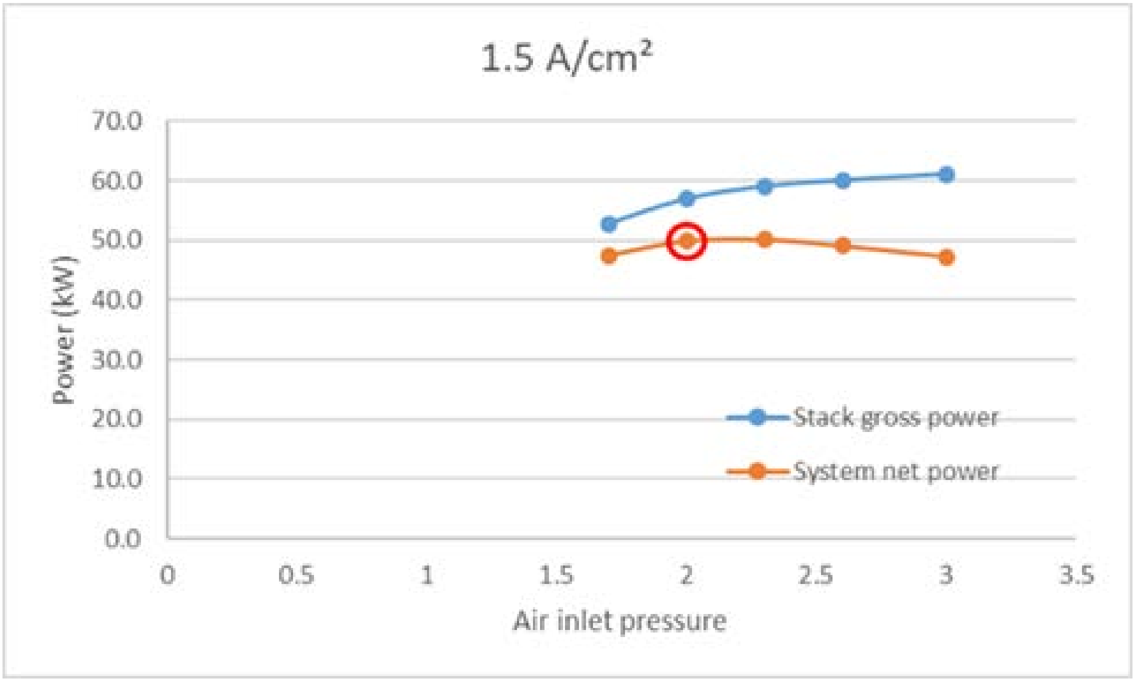


Definition of system conditions

System energetic assessment model :



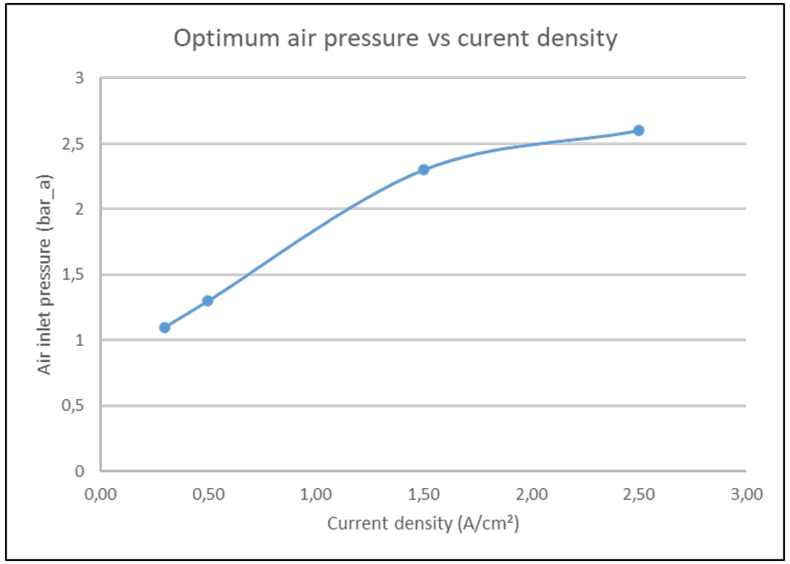
Optimum pressure found for each operating point



Definition of system conditions

System operating conditions defined regarding the study's results :

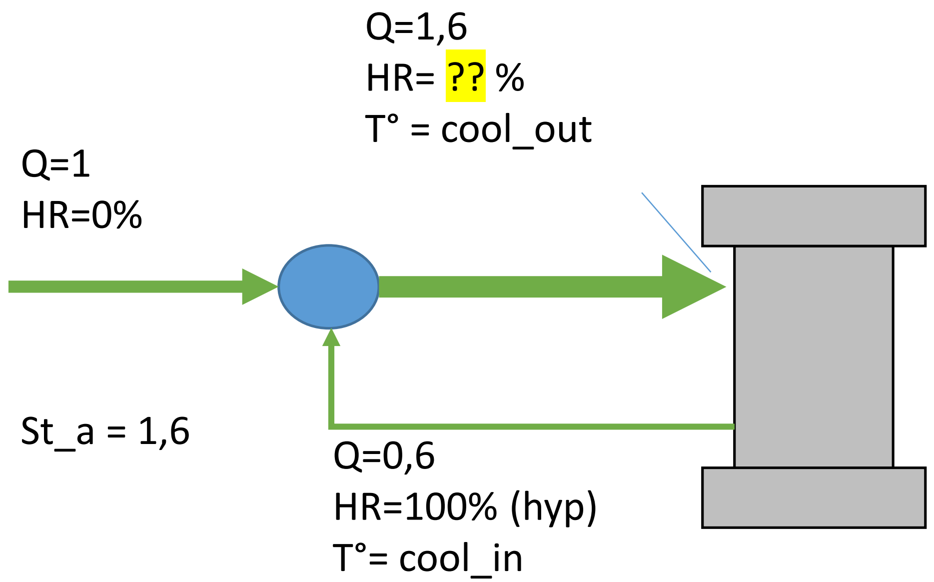
System conditions	Low power conditions (10%)	Nominal power conditions (25%)	Medium power conditions (50%)	Max power conditions (100%)
Current density	0,3 A/cm²	0,5 A/cm²	1,5 A/cm²	2,5 A/cm²
Stoech H2 / Air	2,0 / 1,8	2,0 / 1,8	1,6 / 1,8	1,6 / 1,8
RH Anode / Cathode (Dew Point °C)	40% / 50% (45,8°C / 50,3°C)	40% / 50% (52,8°C / 57,5°C)	30% / 50% (55,4°C / 66,5°C)	30% / 50% (55,4°C / 66,5°C)
P_inlet Anode / Cath (bar_abs)	1,3 / 1,1	1,5 / 1,3	2,2 / 2,0	2,8 / 2,6
Cell Temperature (coolant inlet)	65°C	73°C	83°C	83°C
Cell Temperature (coolant outlet)	77 °C	85°C	95°C	95°C



- **2,5 A/cm² :**
  - 2,6 bars is still the optimum (63,1 kW net power)
  - 3 bars gives a higher gross power (84,5kW vs 81kW), but a lower net power (60,3 kW)
- Less sensivity to flooding with lower pressure

Definition of system conditions

- Anodic stoechiometry adjusted to be representative of a system : high stoechiometry is not reachable with a recirculation system



New anodic HR calculated on the anodic stoichiometry and the temperature.

Cathodic HR based on state of the art, and DOLPHIN tests.

Test protocol

- We also work with different operating conditions as a benchmark :
  - We also test our materials with **GAIA conditions**, who are optimized for high stack performance (high humidity, high pressure)

Parameter	Unit	IDF	EUH	ASC	DOL
T Cl	°C	68	80	68	83
T A/C	°C	70	82	70	83
DPT A/C	°C	58.0/43	64.0/53.0	48.4/53.0	57.5/57.5
RH A/C	%	63.6/30.3	50.5/30.2	39.9/50.1	50.0/50.0
Stoic A/C	1	1.4/1.6	1.4/1.6	1.4/1.6	1.5/1.6
p A/C	barg	2.0/1.8	1.5/1.3	1.2/1.0	1.5/1.2
p in/out	-	out	out	out	out
Mingas A/C	A/cm²	0.3	0.3	0.3	0.3
N2 A	%	10	0	30	0

- We are also working in defining some conditions who can be the best compromize between high system efficiency (net power) and stack efficiency (W/cm²).

- Test protocol have beed defined :
  - Compression protocol
  - Break-in
  - Polarization curve
  - Start / stop
  - Durability (FCDLC)

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Thank you for your attention!

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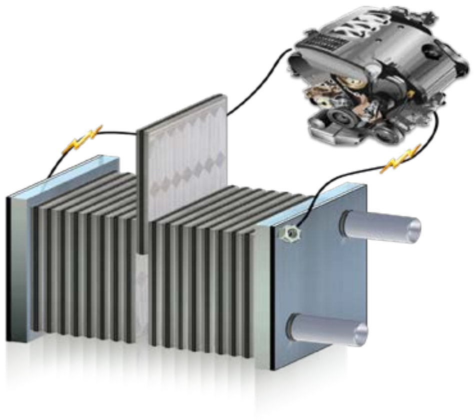

Clean Hydrogen Partnership

Co-funded by the European Union

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ADDITIVE

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