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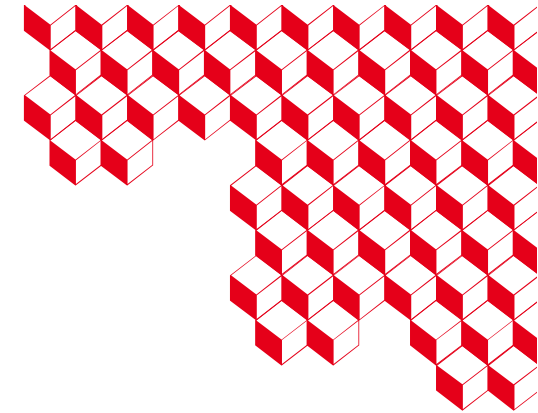
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Experimental study of the effects of operating conditions on the performance and stability of a PEM fuel cell supplied with dry air analysed with a segmented cell

Djabril MOHAMED^{a,b}, Jean-Philippe POIROT-CROUVEZIER^a, Sophie DIDIERJEAN^b

^a Univ. Grenoble Alpes, CEA, LITEN, DEHT, 38000 Grenoble, France

^b LEMTA, CNRS, Université de Lorraine, 54000 Nancy, France



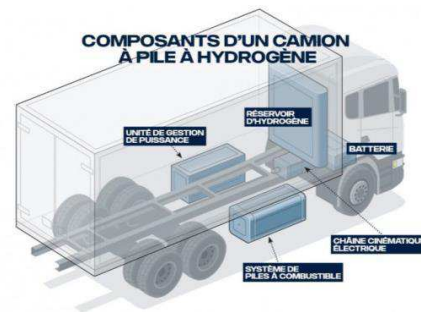
HYSYSPEM project : Simplify PEMFC systems



The European Union has set a target of reducing emissions from heavy duty vehicles by **45%** by **2030**.

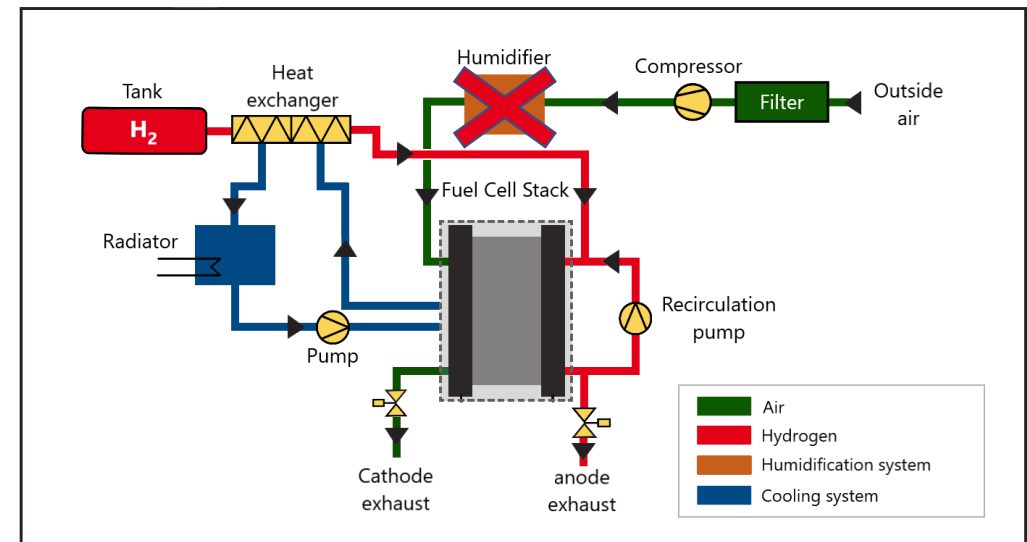
The **HYSYSPEM** project involves the design of a hybrid fuel cell system:

- Modular multi-stack
- High-power application
- Simplified architectures



Removal of the air humidifier

HYDROGEN FUEL CELL SYSTEM



Objective: Experimental study of the impact of dry air supply on a fuel cell.

SUMMARY



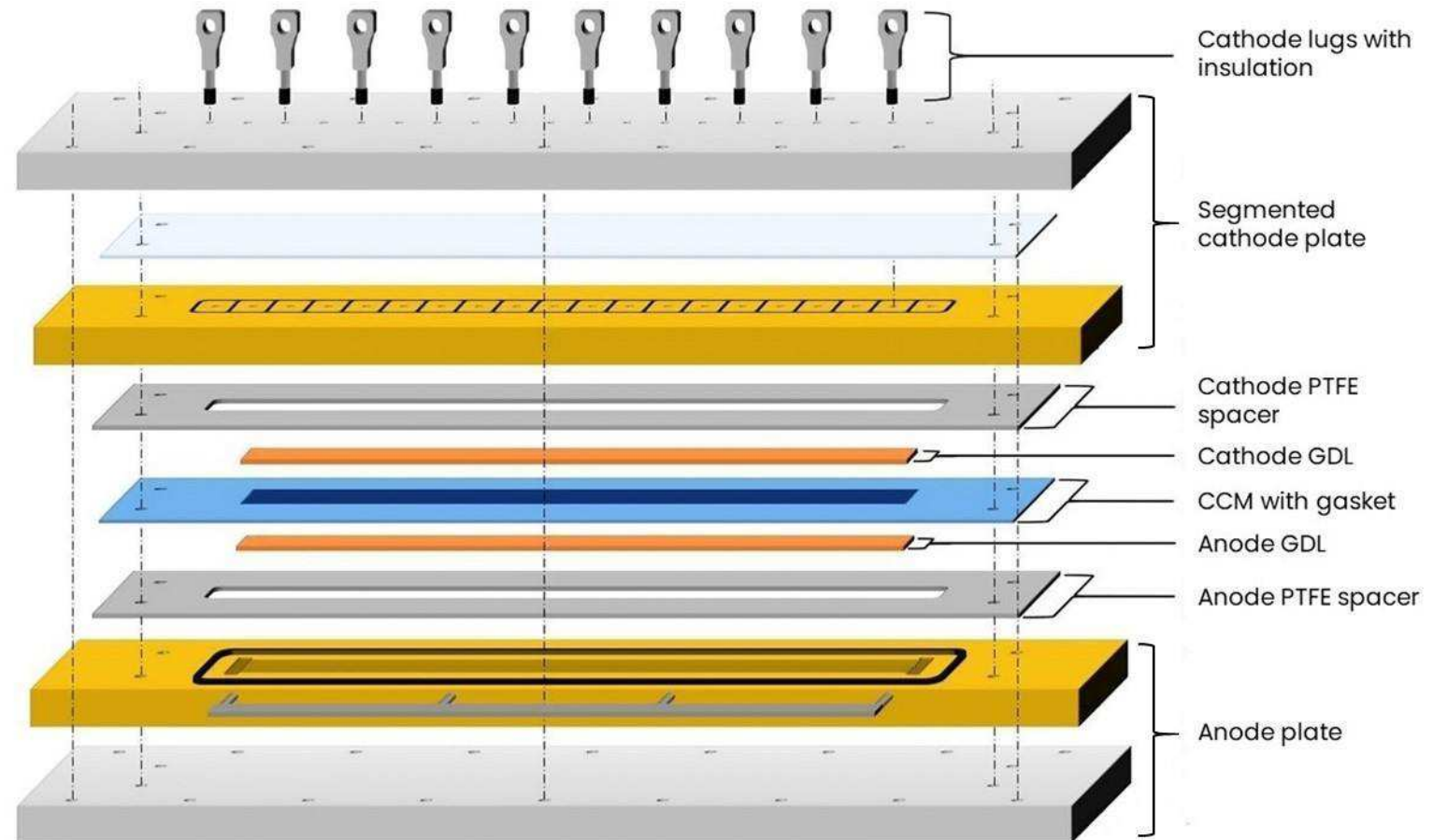
Instrumented single-cell study

1. Experimental bench & protocol
2. Experimental results
3. Specific features of dry air operation

Experimental tool: Segmented cell



Characteristics of the segmented cell	
Active surface area	30x1 cm ²
Segments	20
Membrane	Nafion XL
Electrode loading (mg/cm ²)	0,1 anode 0,3 cathode
Flow configuration	counter-current



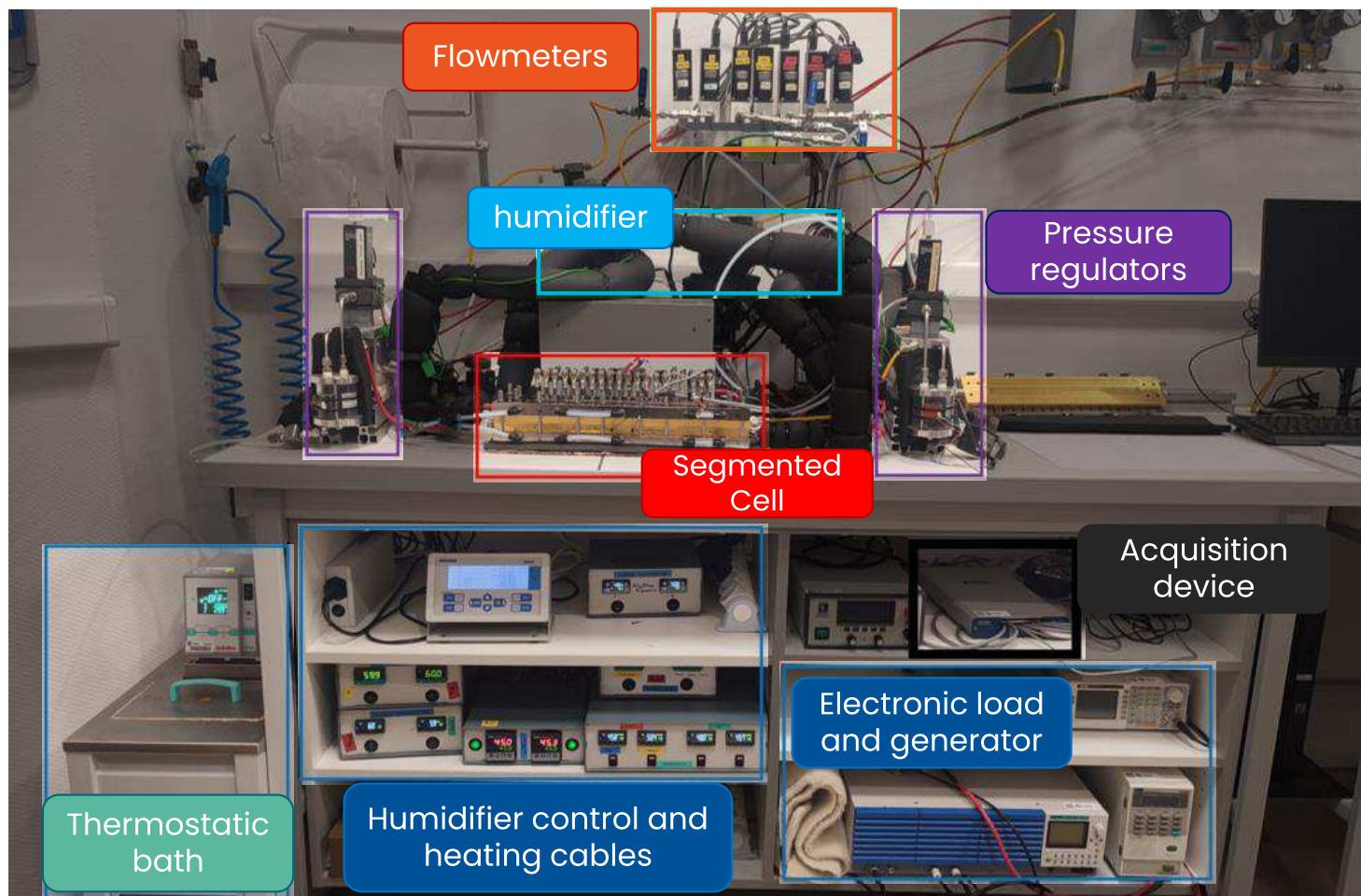
T. Schmitt, « Method development and experimental investigation of dynamic water distribution in a segmented PEMFC », Energy and Mechanics, Université de Lorraine, Vandoeuvre-lès-Nancy, 2023.

4th FRH2 Meeting - La Grande Motte, France - 7 to 11 October 2024





Presentation of the experimental bench



Operating parameters

Gas stoichiometry

Gas humidity

Pressure

Temperature



Parameters of the experimental campaign

Objective: compare operation with dry air supply and with wet air supply on 3 aspects

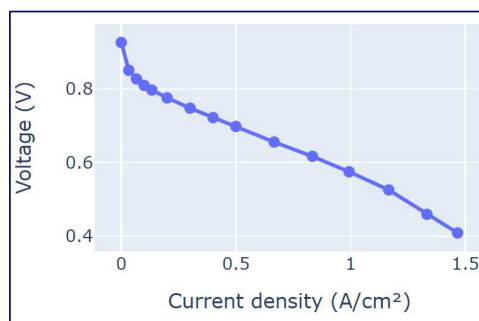
Stability

30 min steady-state tests

- Current profile study
- Determining the stability of the operating point

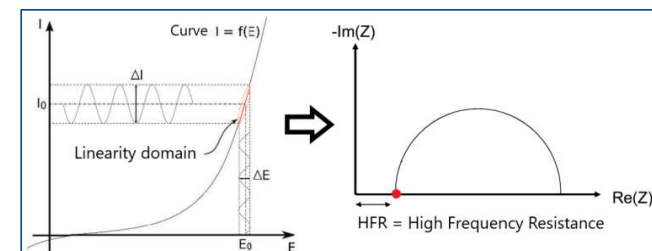
Performances

Polarisation curve



Humidification


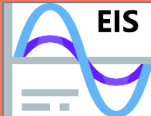

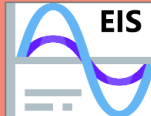

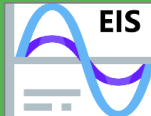


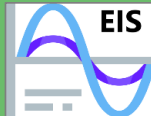

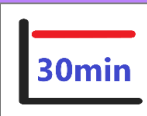
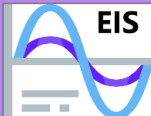
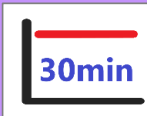
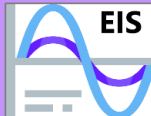
Electrochemical Impedance Spectroscopy (EIS)



Parameters	Temperature (°C)	Total pressure (Bars)	Air stoichiometry (-)	H ₂ stoichiometry (-)	Air humidity (%)	H ₂ humidity (%)
Reference parameters	70	1,5	2	1,2	50	50
Study range	60-80	1,5-3	1,5-3	1,2-2	0 or 50	30-60

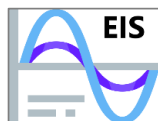


Experimental protocol

Step	Current set point	Humid 50% RH	Dry 0% RH
1	0,2 A/cm ²	 	 
2	0,5 A/cm ²	  	  
3	1,2 A/cm ²	 	 
4	Idem Step 2		
5	Idem Step 1		



30min steady-state



Electrochemical Impedance Spectroscopy

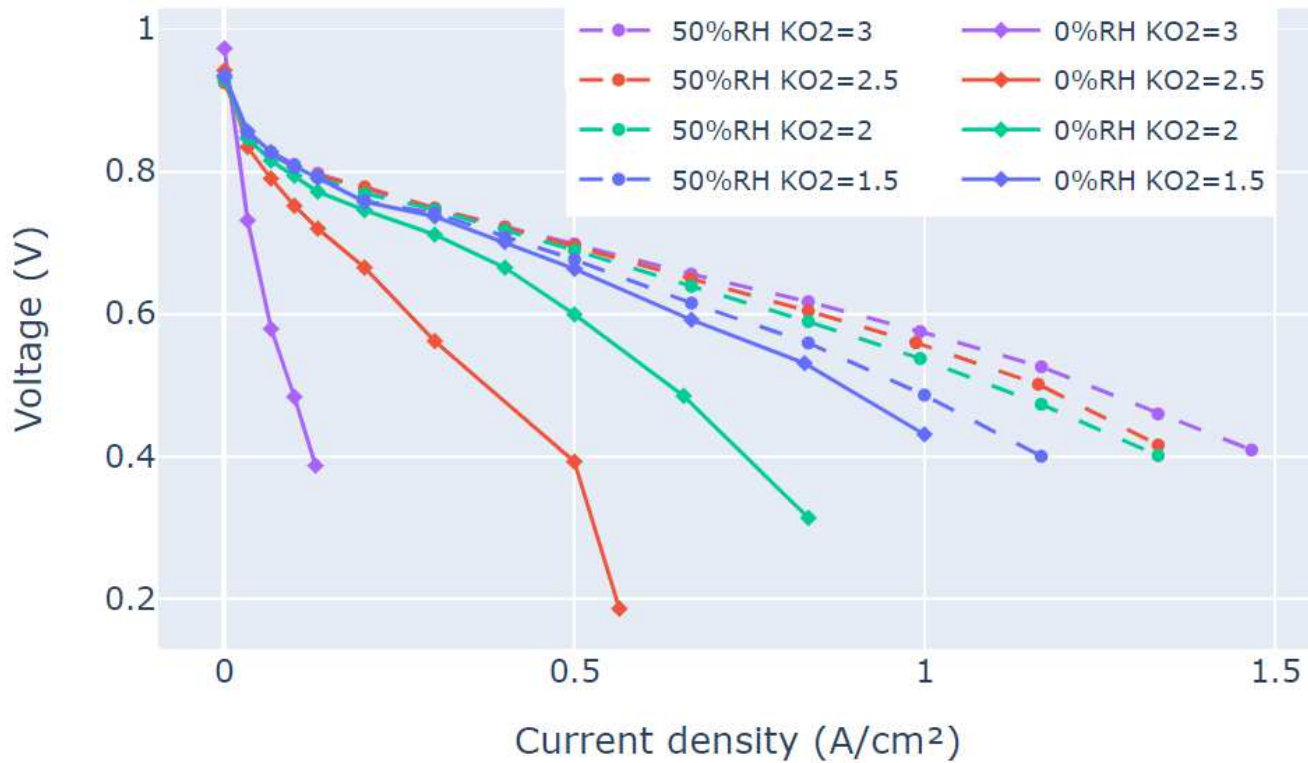


Polarisation curve





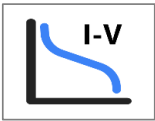
Influence of air stoichiometry



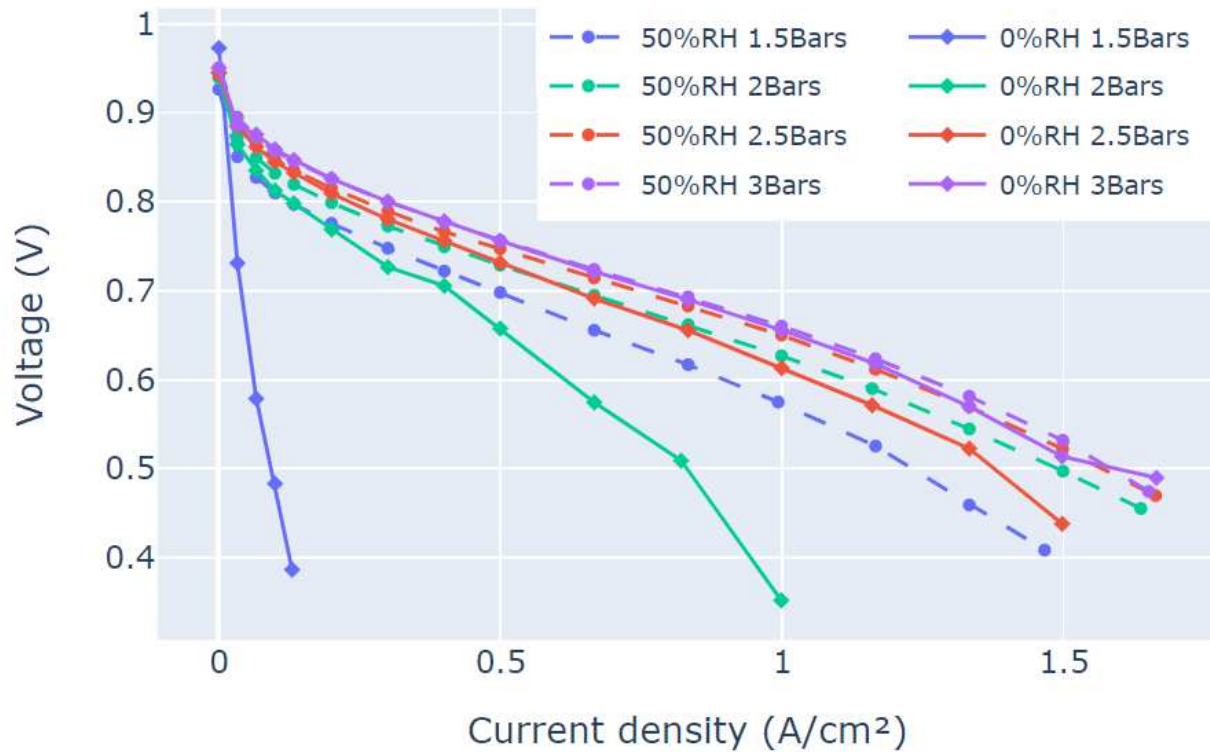
- **Performance increases** with air stoichiometry for the humid case
 - **Performance strongly decreases** with air stoichiometry for the dry case
- Increased flow of dry air **dries out the membrane**

Temperature (°C)	Pressure anode (Bar _{abs})	Pressure cathode (Bar _{abs})	Air stoichiometry	H2 stoichiometry	Air humidity (%)	H2 humidity (%)
70	1,5	1,5	1,5-3	1,2	0 & 50	50





Influence of pressure

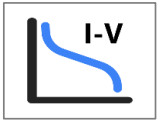


- Performance **increases** with pressure
 - Increased pressure **reduces the difference** between the dry and wet cases
- **Relative humidity increase** with pressure

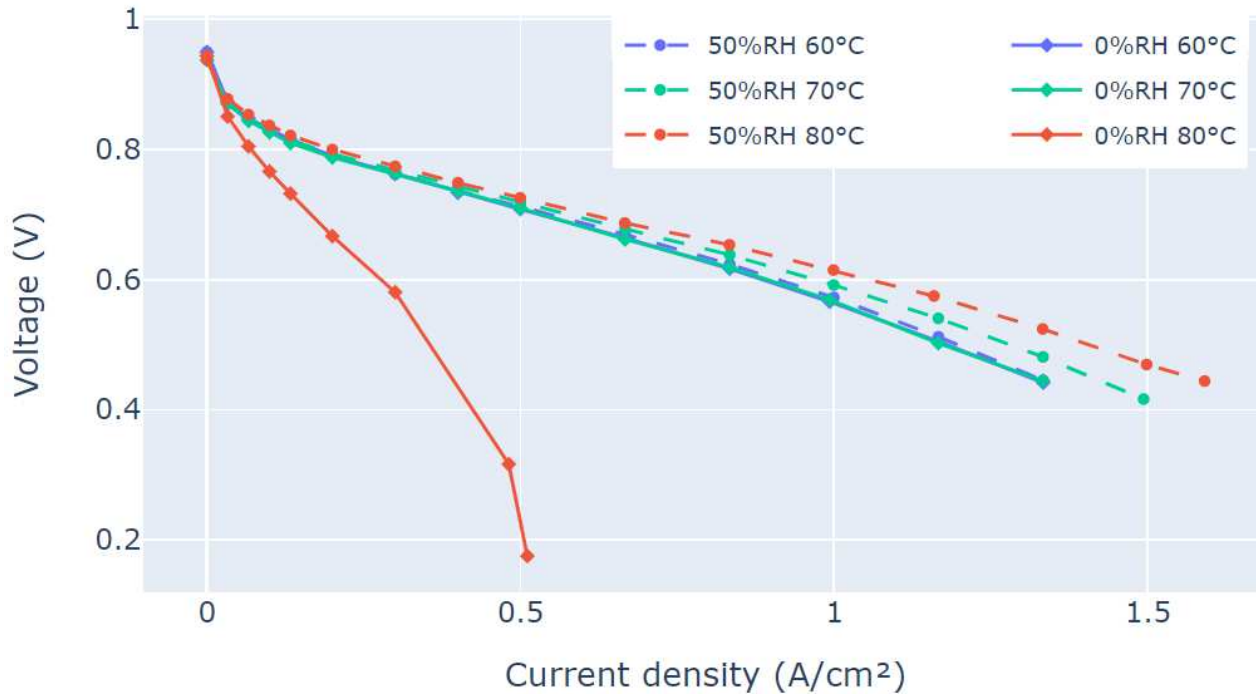
$$RH = \frac{x_{H_2O} \times P_{tot}}{P_{sat}(T)}$$

Temperature (°C)	Pressure anode (Bar _{abs})	Pressure cathode (Bar _{abs})	Air stoichiometry	H2 stoichiometry	Air humidity (%)	H2 humidity (%)
70	1,5-3	1,5-3	2	1,2	0 & 50	50





Influence of temperature



- Performance **decreases** with temperature for dry case
- Decrease temperature **reduces the difference** between the dry and wet cases

→ **Relative humidity decrease** with temperature

$$RH = \frac{x_{H_2O} \times P_{tot}}{P_{sat}(T)}$$

Temperature (°C)	Pressure anode (Bar _{abs})	Pressure cathode (Bar _{abs})	Air stoichiometry	H2 stoichiometry	Air humidity (%)	H2 humidity (%)
60-80	2	2	2	1,2	0 & 50	50

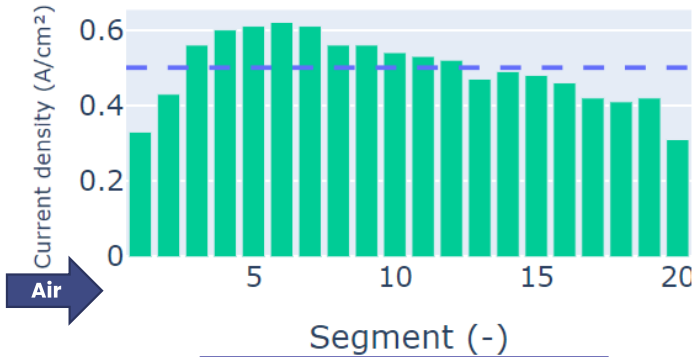




Stability study – current profile with **dry air**

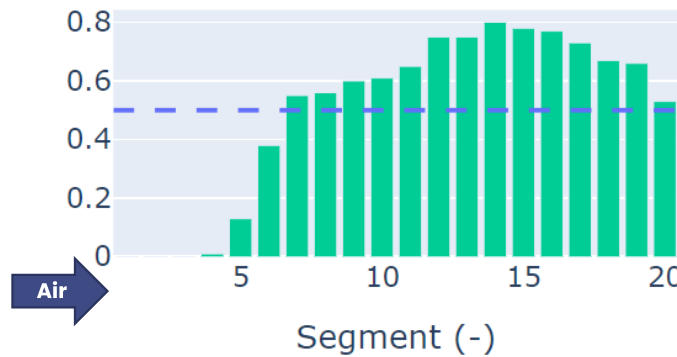


Stable



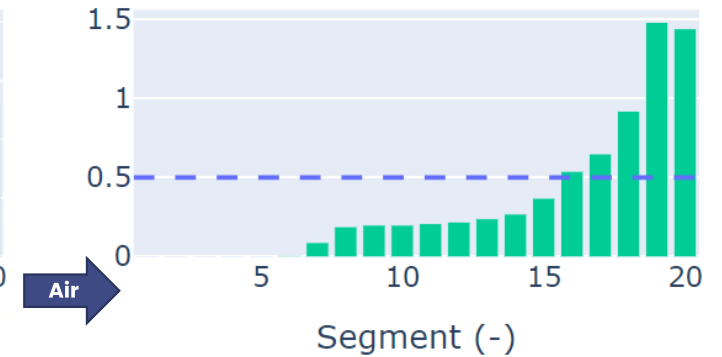
$P=2 \text{ bars} \ \& \ k_{air}=2$

Stable degraded



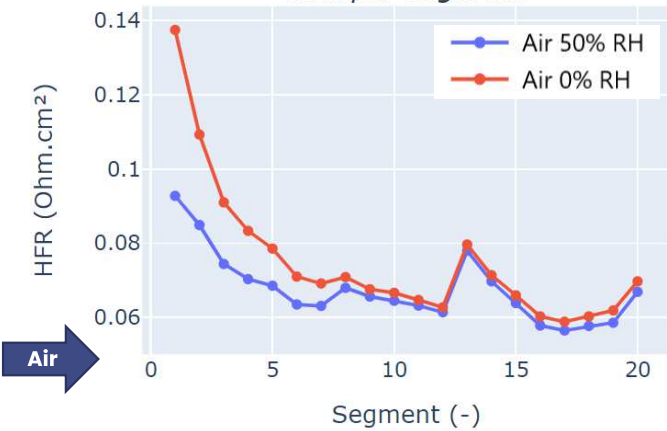
$P=1,5 \text{ bars} \ \& \ k_{air}=2$

Unstable

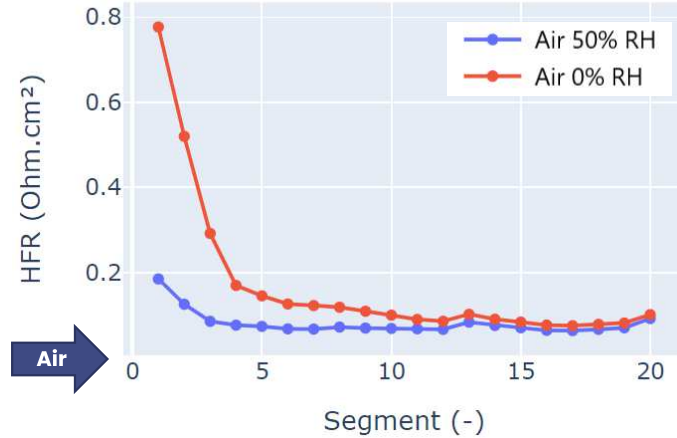


$P=1,5 \text{ bars} \ \& \ k_{air}=3$

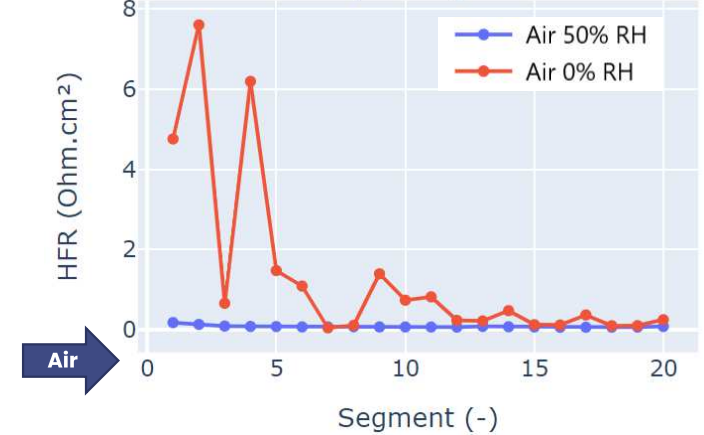
HFR per segment



HFR per segment



HFR per segment





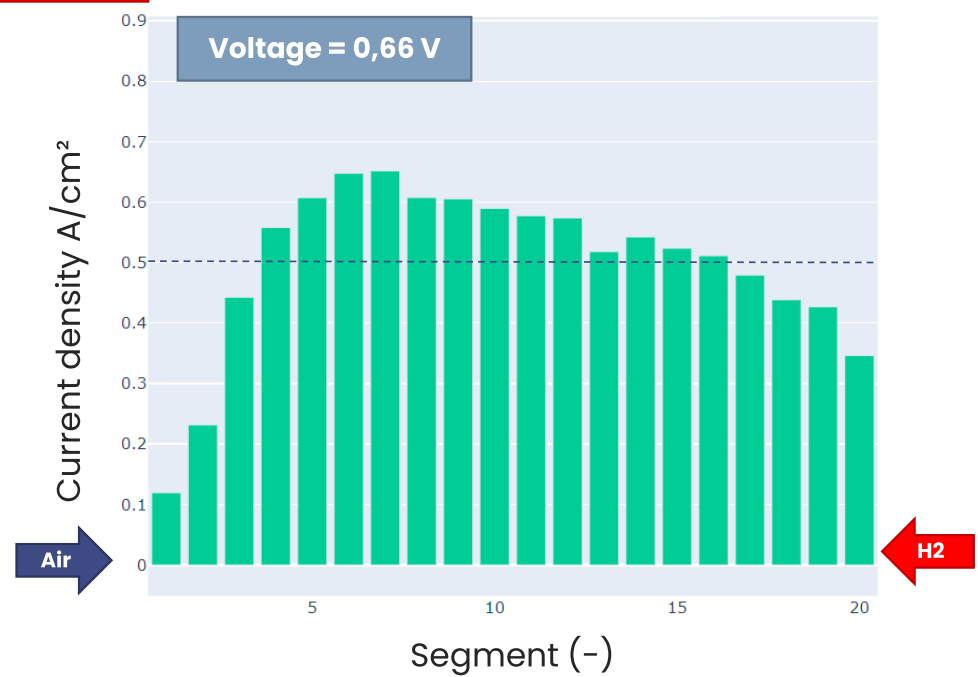
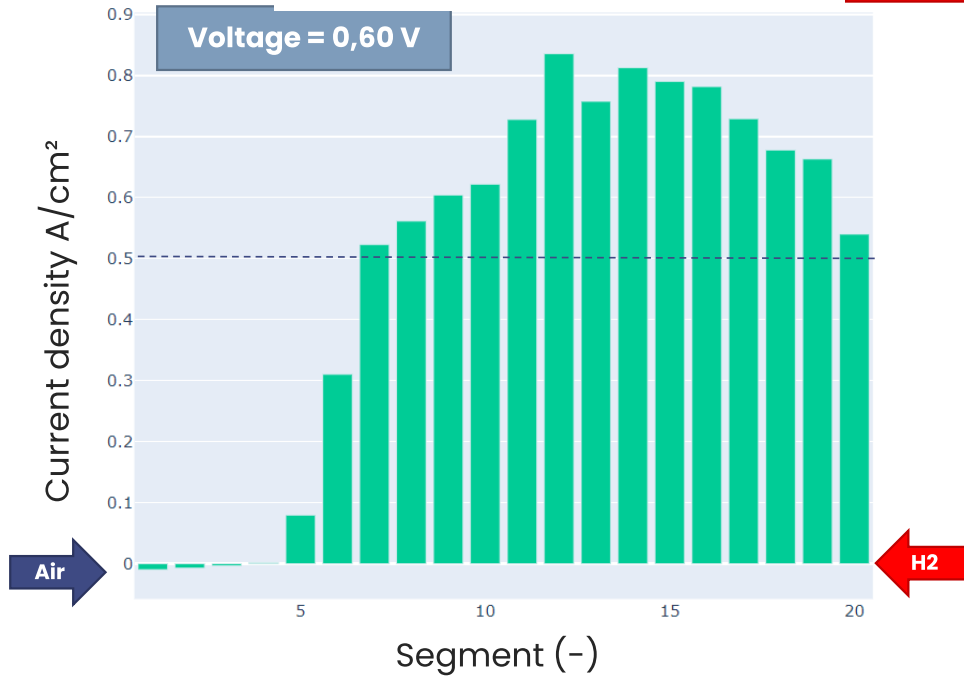
Stability – Dependence on operating history



Current profile for step 2

Current set point: 0,5 A/cm²

Current profile for step 4

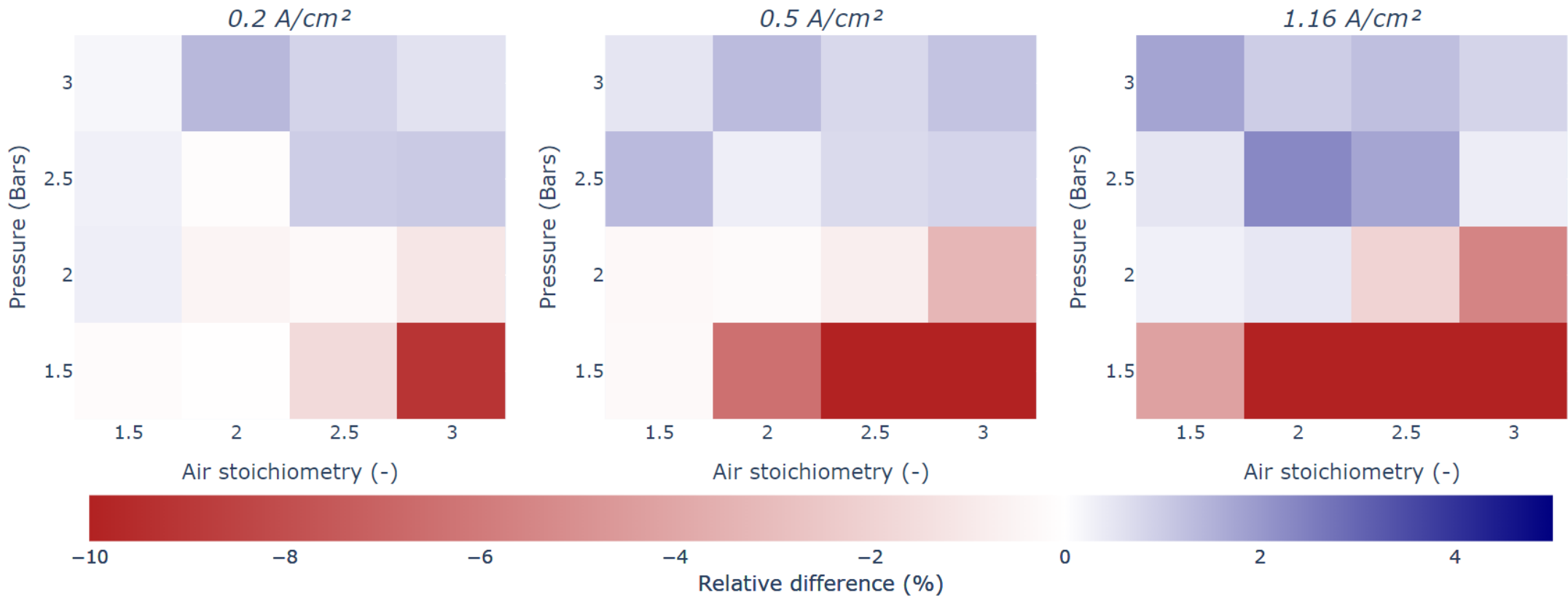


Temperature (°C)	Pressure anode (Bar _{abs})	Pressure cathode (Bar _{abs})	Air stoichiometry	H2 stoichiometry	Air humidity (%)	H2 humidity (%)
70	1,5	1,5	2	1,2	0	50





Performance comparison between dry and wet cases

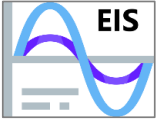


higher performance humidified air supply

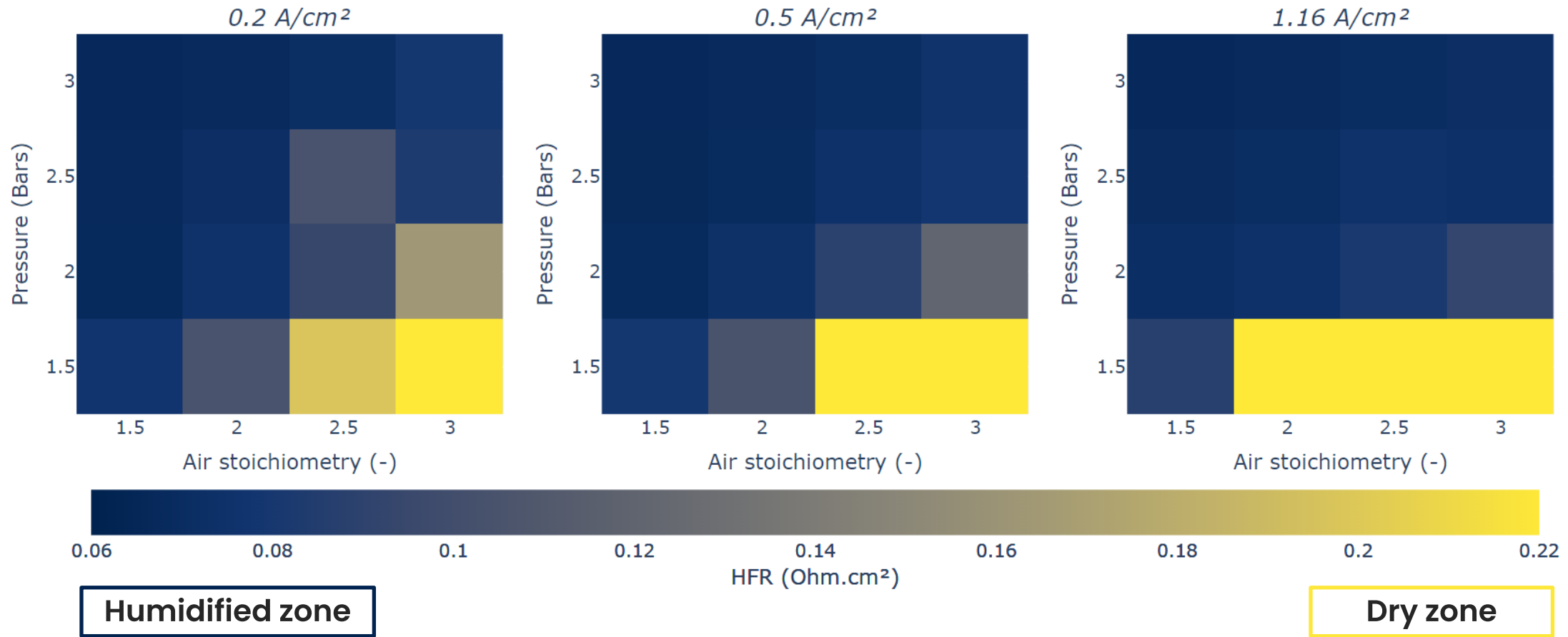
$$Relative\ difference = \frac{U_{humid} - U_{dry}}{U_{humid}} \times 100$$

higher performance dry air supply





Humidification - Current density dependency





Conclusions & perspectives

Experiments have shown that it is possible to ensure **stable and high-performance** operation of the cell when it is supplied **with dry air**

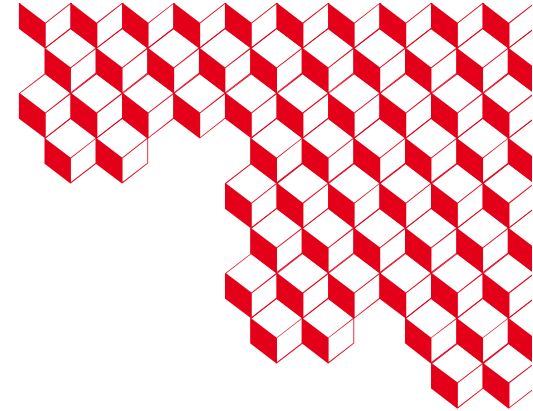
→ **Operating parameters** need to be adjusted :

- ❑ **High pressure** helps to saturate the gases with moisture from the water produced inside the cell.
 - ❑ **Low air stoichiometry** facilitates dry operation by reducing membrane drying.
 - ❑ **Increase hydrogen stoichiometry and relative humidity** improves the hydration of the membrane by the anode, which favors operation with dry air.
 - ❑ **Low temperature** helps to saturate the gases with moisture from the water produced inside the cell.
- Ageing tests will allow to determine whether operating with a dry air supply has an **impact on the durability** of the cell.
- Tests with **another MEA** and **modelling** work will complete the study.





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Contact:

Djabril.mohamed@cea.fr

