



Axane commitment for a sustainable, reliable, and field proven power source through partnership with laboratories and design efforts

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Summary

1- Axane activities and partnership presentation

=> Complementary expertises

=> Strategy of choice for studying MEA's degradation

2- First degradations phenomena experienced with former configuration

=> Local pinholing of membrane identification/localization

=> Local performance and degradation measurements

3- New configuration and new challenges

4- Conclusions

Axane activities and partnership's targets

Highest Durability to date



NRJ Container # 21 reached 14.100 operating hours without failure
System was stopped at the end of the contractual operation period



- Commercial scaled global offer (FC systems, H₂ logistic, services and maintenance)
- From 0.1 to xx kW
- Off-grid, bad-grid (telecom antenna), events (sport, meetings), forklifts, specific applications without ambient air, automotive
- Several hundred systems deployed since 2001, mainly in France and Europe
- System's availability (2012) > 99,4%
- >14 000 h of operation without maintenance
- No MEA failure with standard configuration (~100000h of cumulated operation on whole park)

Axane ↔ Laboratories

Study MEAs degradation mechanisms and develop mitigation strategies for Axane system

- Analyse of system working data
- Develop *in-situ/ex-situ* diagnosis and characterisation tools
- Optimisation of MEA components and operating conditions
- Promoting study of real-operated MEAs (aged in system) => specific degradation phenomena



Axane activities and partnership's targets



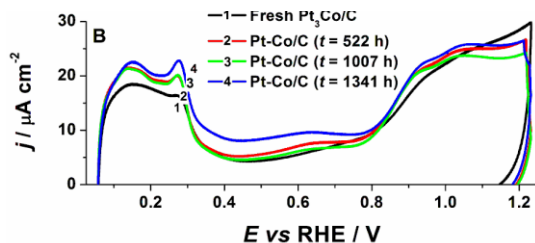
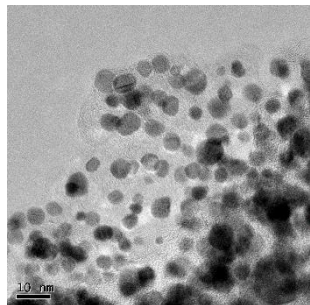
- Stack and system design
- Manufacture stack and system
- Optimize operating conditions



- Fluids transport studies
- Local MEA behaviour
- Internal currents

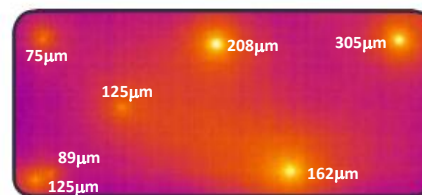
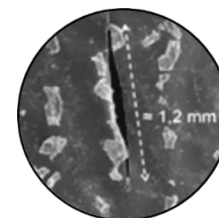


- Electrocatalyst characterizations
- Microscopy (SEM, TEM, EDS)
- Electrochemistry (model electrodes)



Laboratoire Matériaux Organiques à Propriétés Spécifiques

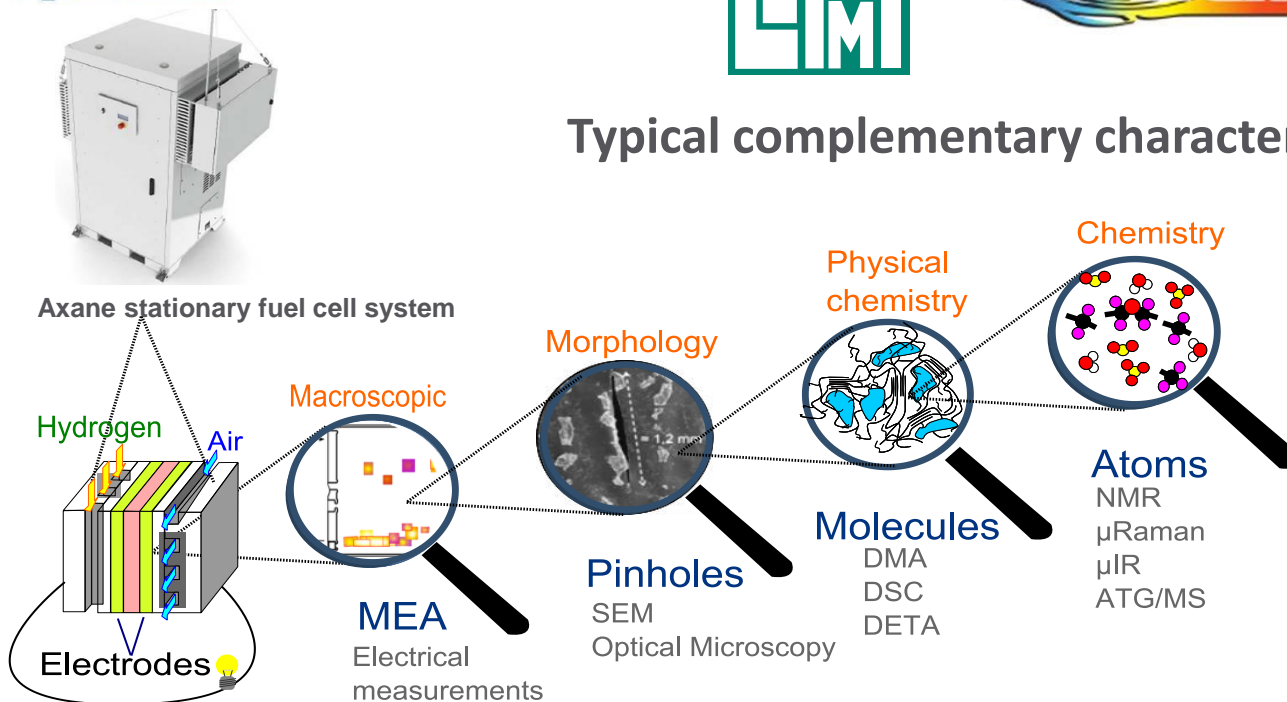
- Membrane characterizations
- Chemistry (μ R, μ Raman, ATG/MS)
- Physical chemistry (DMA, DETA)
- Macro. techniques (relaxometry, thermography)



Axane activities and partnership's targets



Typical complementary characterization techniques applied on PEMFC ageing study



MEA degradations are related to materials (membrane, catalyst layers, MPL/GDL) but also to hardware design, operating conditions and fluid management (air/H₂ stoichiometry, pressure...)

Each set of parameters may lead to specific phenomena

➔ all these aspects have to be considered

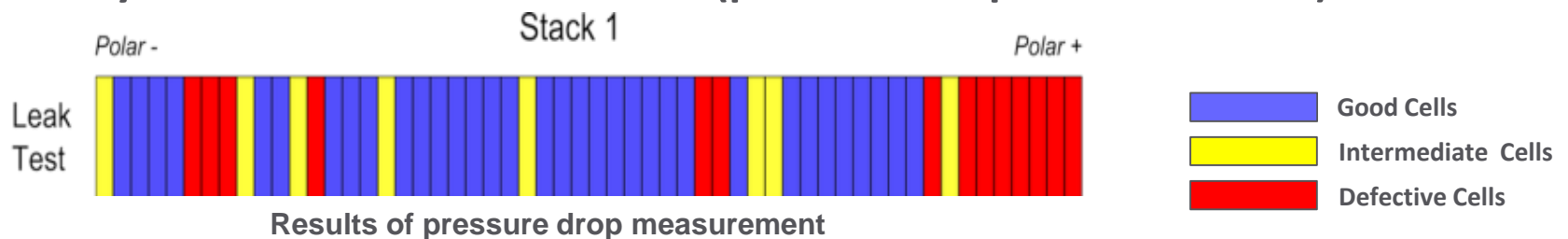
First degradations phenomena experienced



Two 55-cells stack shut down after failure of air humidifier after 1500h

=> System fault due to H₂ leak

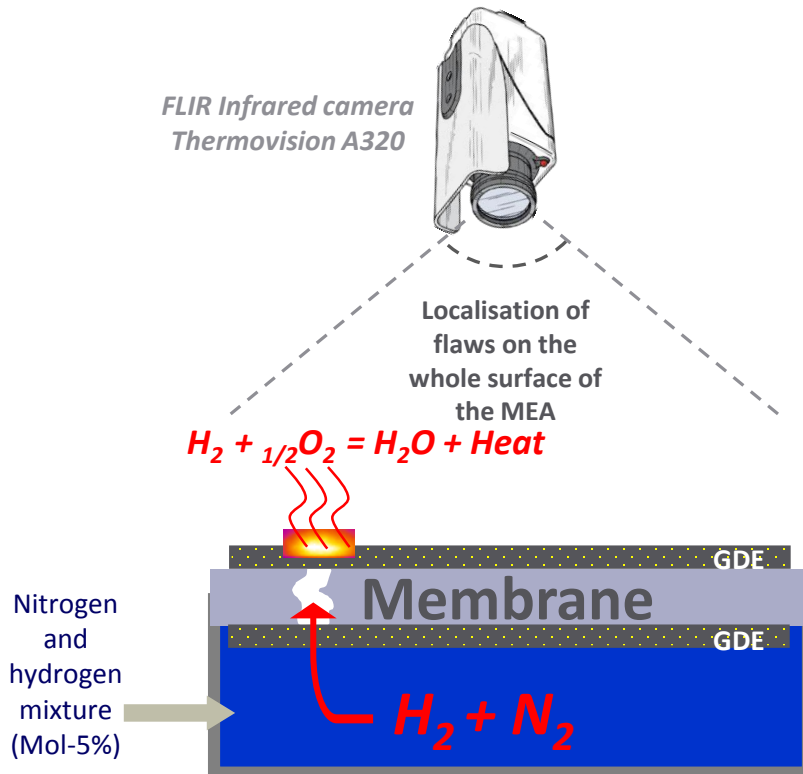
=> Every cell tested to localised leak (pressure drop measurement)



➤ Several membranes failed after 1500 h

➤ What did cause such defects?

Infrared Thermography



Temperature \rightarrow defect size

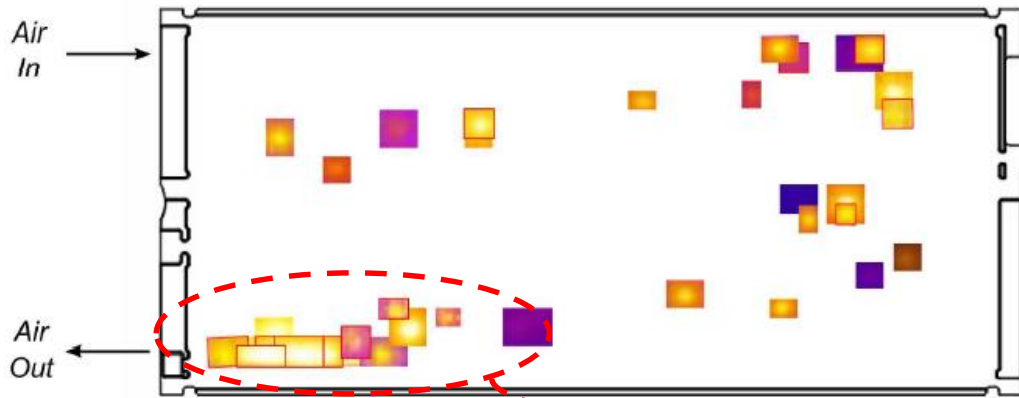
$$\Delta T = T_{\max} - T_{\min}$$

The flaws are classified as a function of the generated heat recorded by the camera

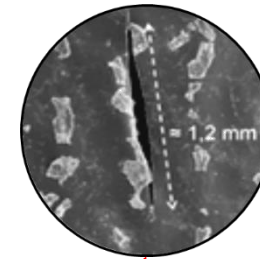


➤ Localisation and quantification of membrane defects

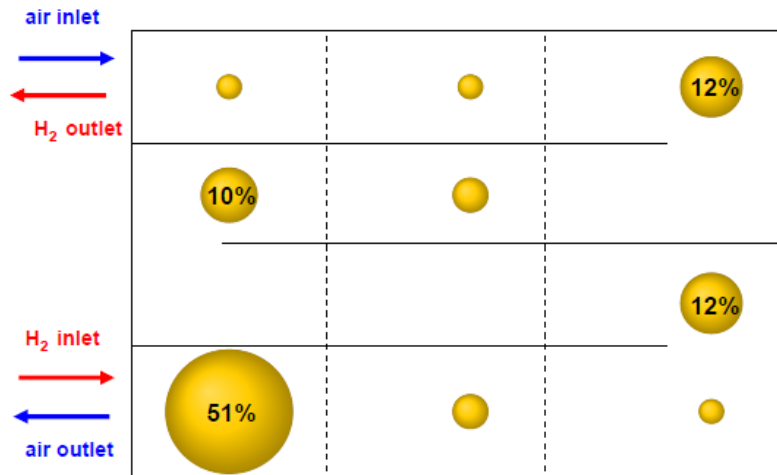
Stack 1 → total flaws detected on the 55 cells¹



Responsible for stack shut-down



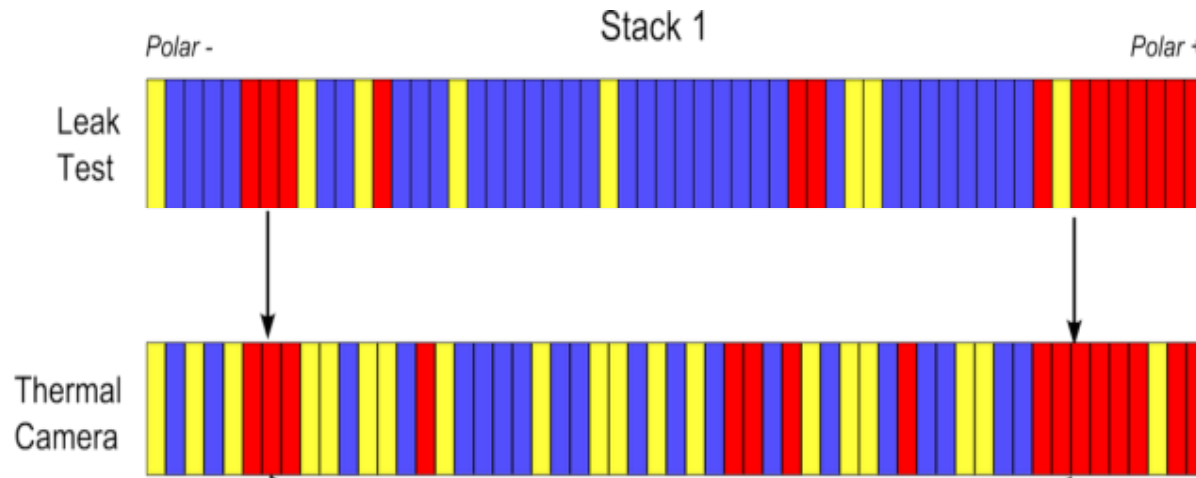
Cracks with length ranging from 0.5 to 1.2 mm promoting unsafe level of H₂ leak



- Critical defects appeared more frequently near air outlet (H₂ inlet)
- Cathode flooding? May be promoted by humidifier failure (=> insufficient air flow)
- Larger pinholes look like mechanical tears => mechanical constraints
- Degradation specific to cell design

De Moor, G., Bas, C., Charvin, N., Moukheiber, E., Niepceron, F., Breilly, N., André, J., Rossinot, E., Claude, E., Albérola, N. D., and Flandin, L., 2012, "Understanding Membrane Failure in PEMFC: Comparison of Diagnostic Tools at Different Observation Scales," Fuel Cells, pp. n/a-n/a

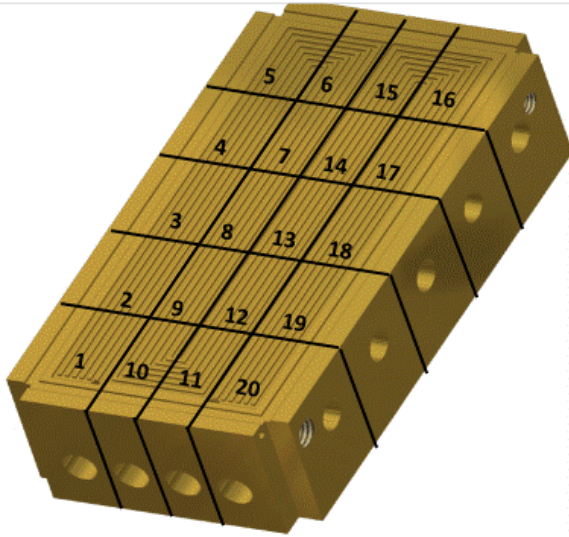
=> All MEAs of stack 1 were characterised with thermal camera setup



- Pressure drop and thermal camera results are consistent
- Infrared thermography is much more sensitive (IR able to disqualify « leak proof » MEAs with local membrane weaknesses)

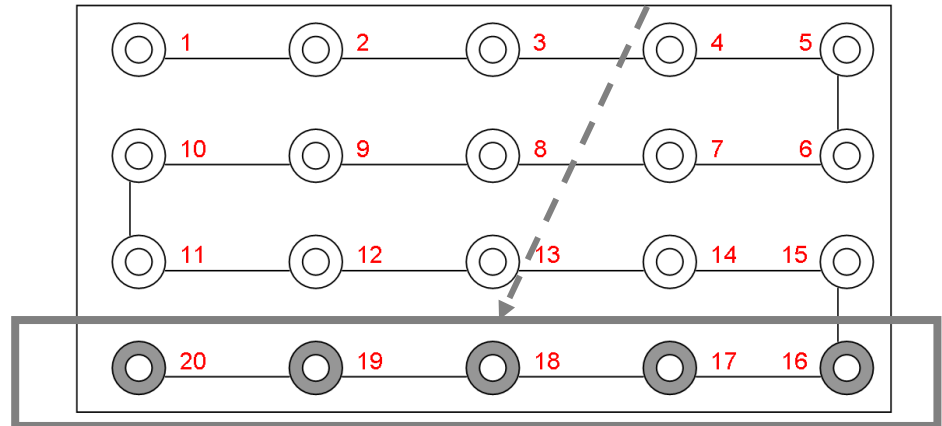
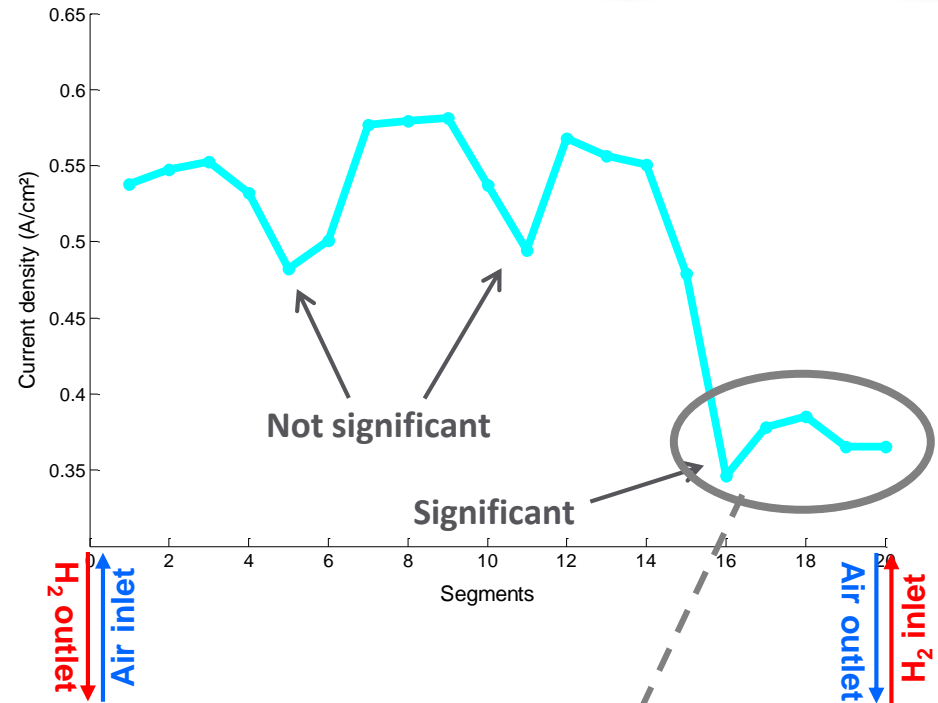
De Moor, G., Bas, C., Charvin, N., Moukheiber, E., Niepceron, F., Breilly, N., André, J., Rossinot, E., Claude, E., Albérola, N. D., and Flandin, L., 2012, "Understanding Membrane Failure in PEMFC: Comparison of Diagnostic Tools at Different Observation Scales," Fuel Cells, pp. n/a-n/a

First degradations phenomena experienced

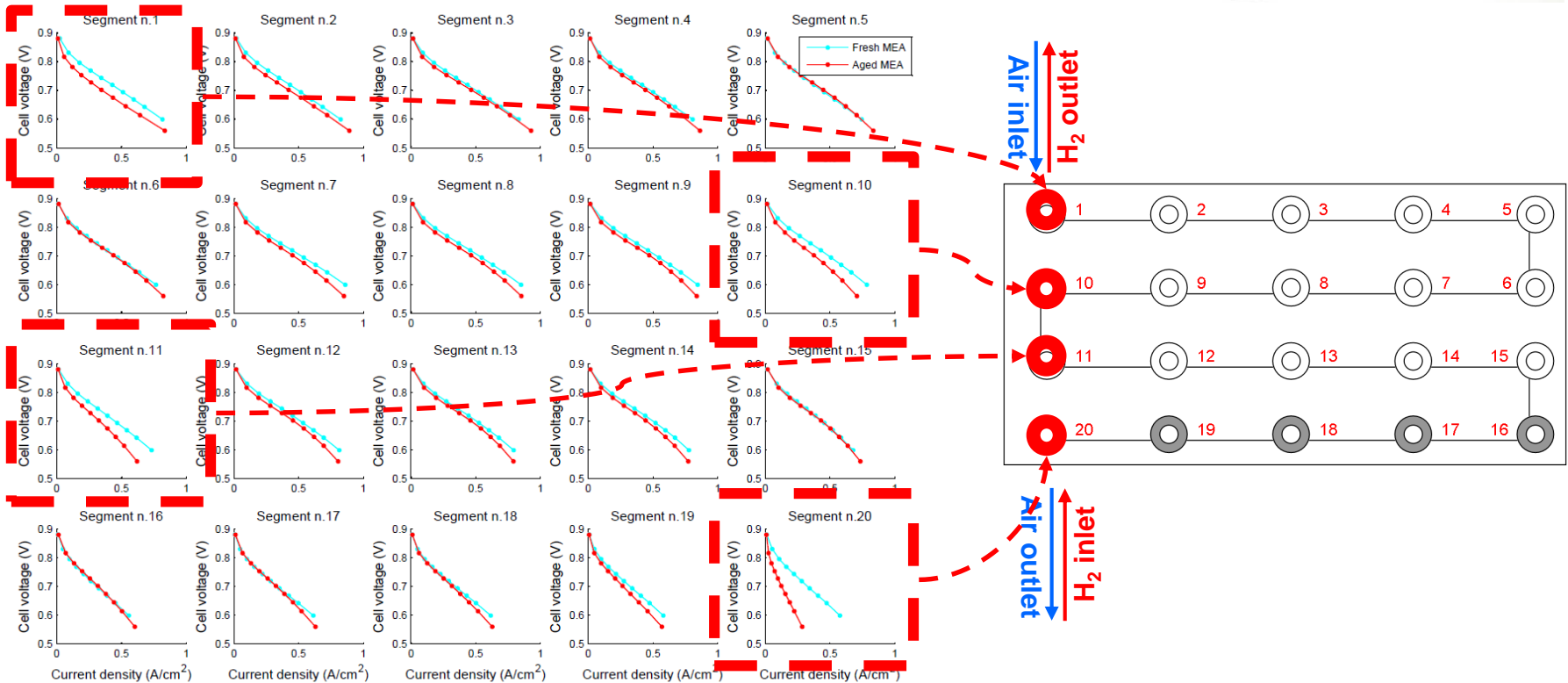


- Segments with a lower current density at nominal operating point.
- Oxygen starvation, flooding.

Heterogeneous channel length linked to gas port positioning (same cell side) !



First degradation phenomena experienced



- Carbon corrosion at cathode inlet (start & stop)
- Segments between inlets and outlets are also more degraded
- Assumption: dry H₂ bypass => anode purges lead to strong drying => dry/wet cycling, may be related to PEM defects
- Degradation phenomena still related to the hardware design

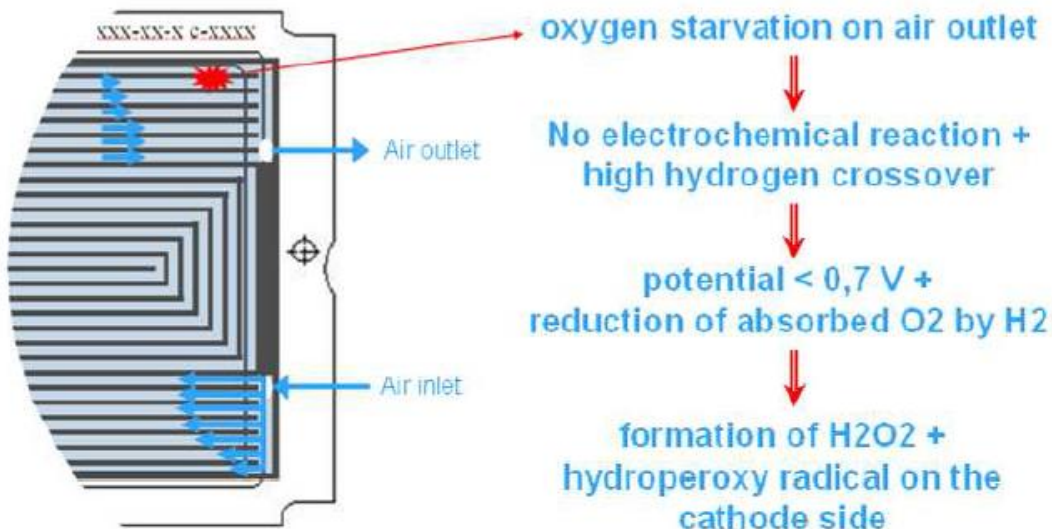
A. Lamibrac, G. Maranzana, O. Lottin, J. Dillet, J. Mainka, S. Didierjean, A. Thomas, C. Moyne, *Experimental characterization of internal currents during the start-up of a Proton Exchange Membrane Fuel Cell*, Journal of Power Sources, Vol. 196, N°22, pp. 9451-9458, 2011.

A closer look at air outlet / H2 inlet area



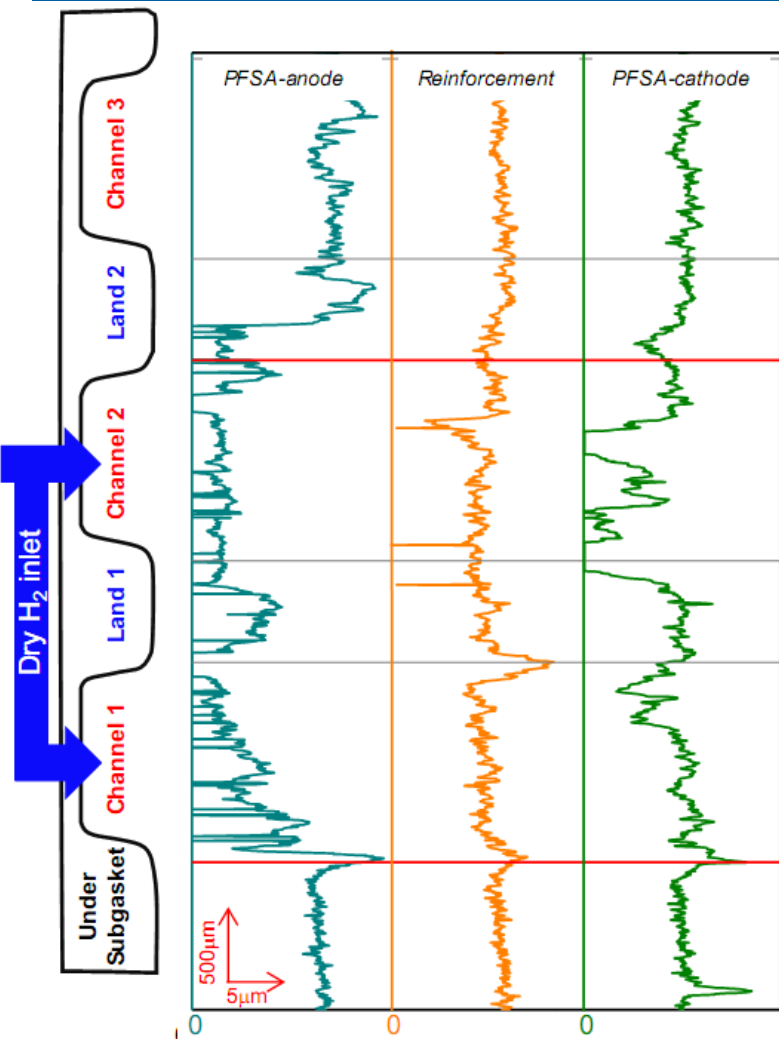
air bubble

Bubble mapping device applied to localize pinholes through MEAs

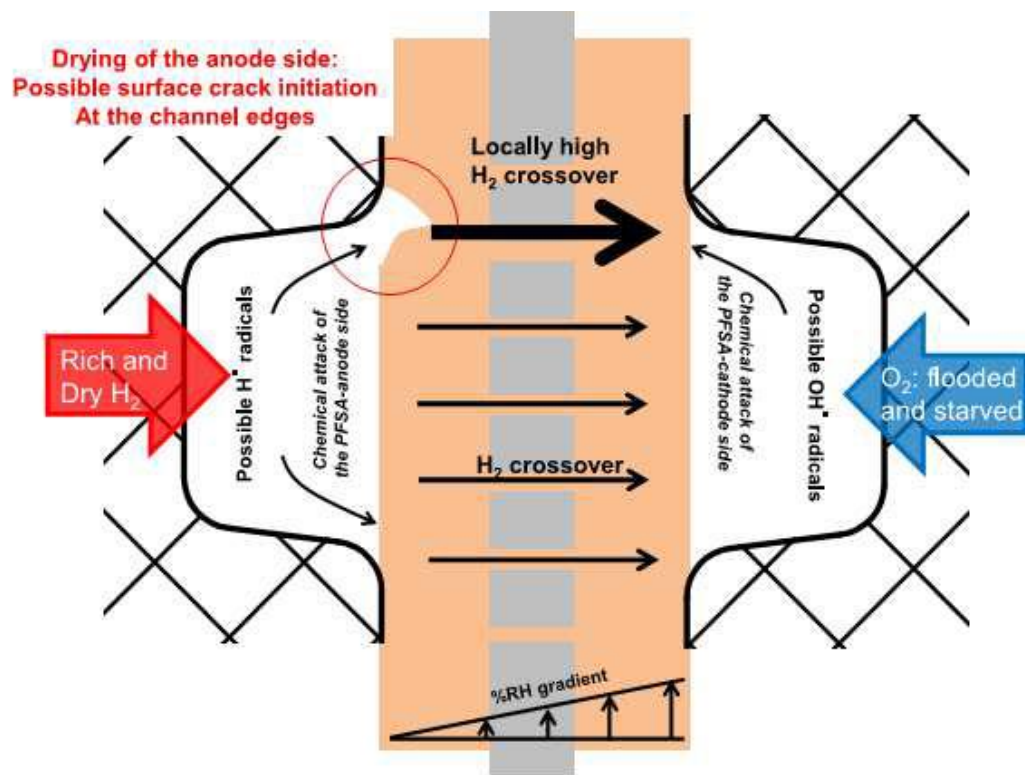


Specific degradation mechanism in this area ?

A closer look at air outlet / H2 inlet area



3-layered membrane after 12800 hours of operation



Chemical degradation initiated on anode side, cathode side degradation enhanced after ~70% thickness loss on the anode

G. De Moor, PhD - Approche multi-échelle des mécanismes de vieillissement des coeurs de pile à combustible (Oct. 2015)

First degradation phenomena experienced - Conclusions

Fast and specifically localised membrane pinholing

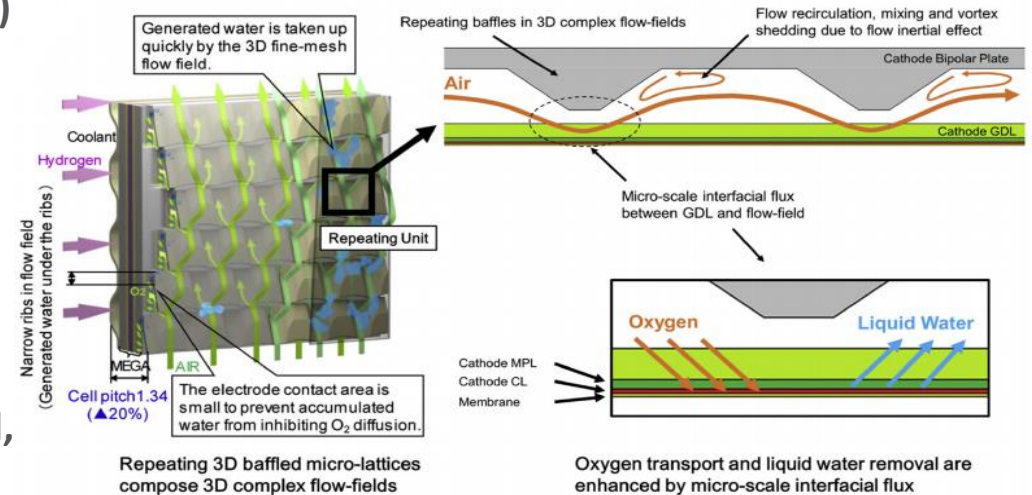
Local study of pinholes and correlation with MEA performance suggested :

- local mechanical constraints and chemical degradation due to local drying (Air outlet/ H₂ inlet)
- dry/wet cycles on anode side (between inlets and outlets)
- local flooding (outlet section of air channels)

Ways of improvement:

- => tougher membrane material (mechanical reinforcement, chemical stabilizers...)
- => better air and H₂ management :

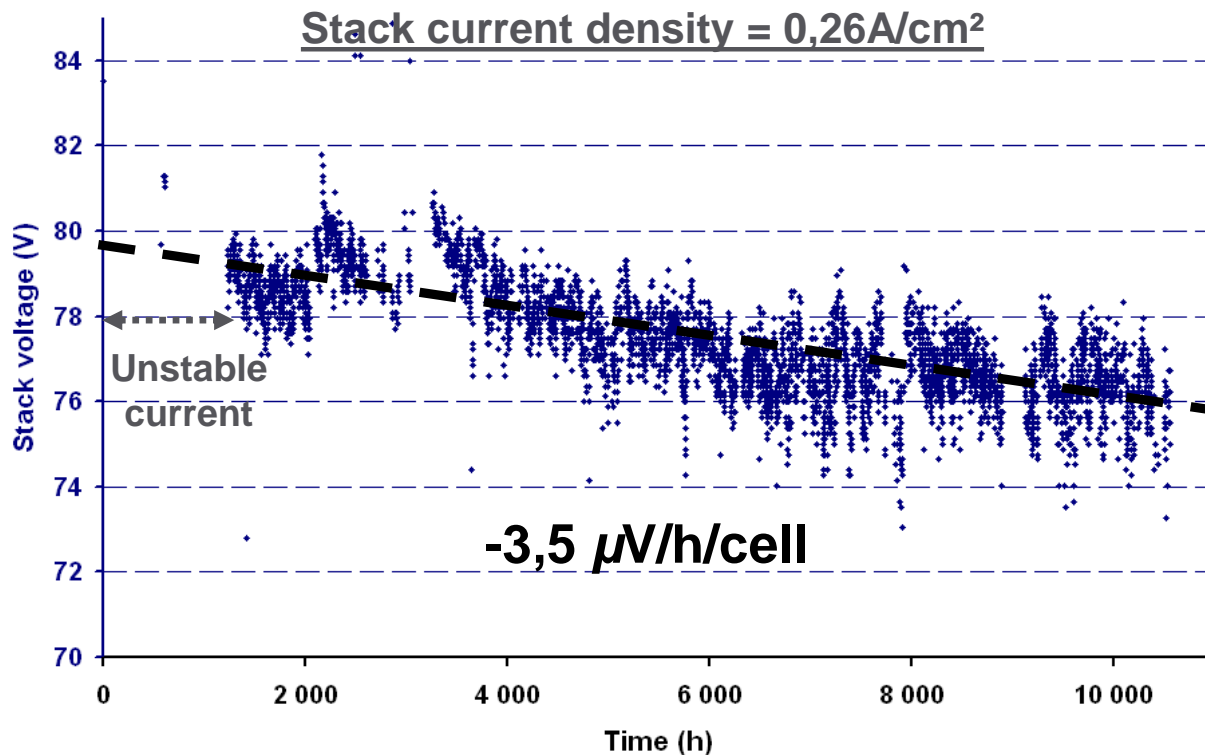
- Threshold air flow to ensure water removal,
- when possible, hydrogen humidification thanks to recirculation,
- cell re-design bearing in mind the goal to homogeneously “feed” the cells at both local and global scale: ensuring proper channel to channel distribution, reduce channel and land width, help O₂ rich flow reach cathode outlet while avoiding inlet drying.



J. Kim *et al.* JPS 365 (2017) pp.419-429

New MEA and improved system management

- Large increase of membrane lifetime
- Low performance degradation probably related to catalyst layer degradation
- Catalyst layers undergo heterogeneous ageing too¹
- New target: ↗ performances and ↘ CL aging in various operating condition
=> ↗ stack efficiency => ↘ H₂ consumption



¹Dubau L., Durst J., Maillard F., Chatenet M., André J., Rossinot E., 2011, "Heterogeneities of aging within a PEMFC MEA," Fuel Cells, pp. n/a-n/a

Conclusions

- **Multidisciplinary diagnosis and characterisation techniques are useful for a better understanding of MEA degradation**
- **They also enabled to identify ways of improvement**
- **Specific operating conditions and hardware design lead to specific degradation phenomena...which is critical to mitigate MEA degradation**

Thank you very much for your kind attention !

