PEM fuel cells and electrolysers: potential and routes for improvement of the technology (in France)

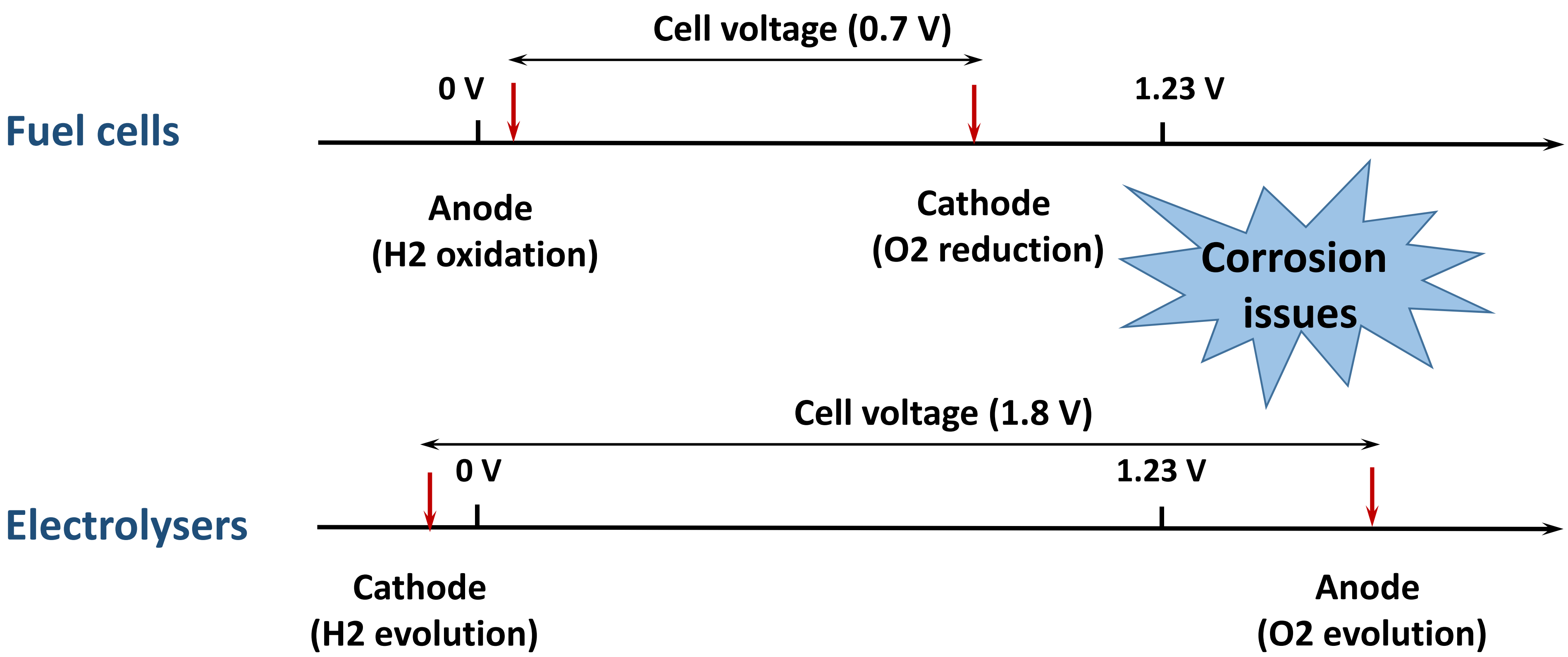
Francois Lapicque
Reactions and Chemical Engineering Laboratory
CNRS – Université de Lorraine, Nancy, France

- **Background and a recent view of lab-scale research**
- **A couple of applications, mainly in France**

Fuel cells

Electrolysers

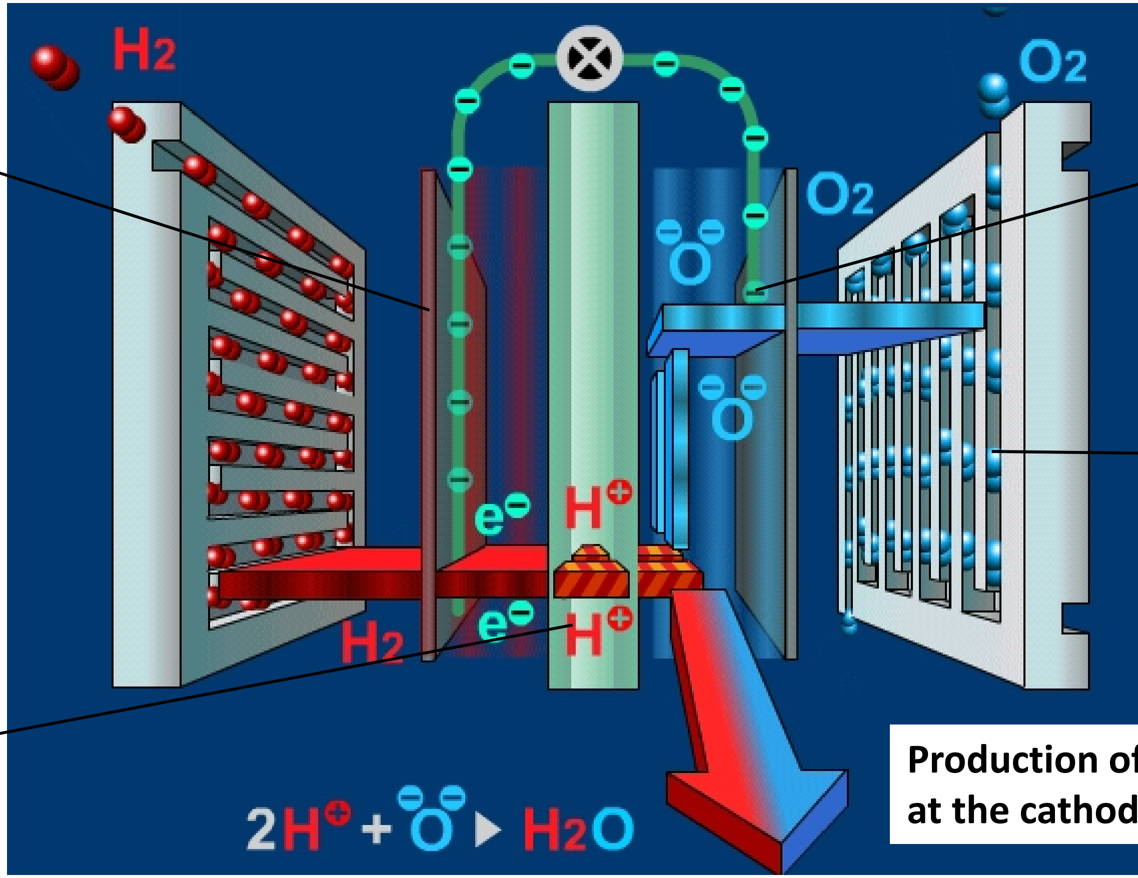
Fuel cells and electrolysers (PEM technology)



View of the inner part of a hydrogen PEM fuel cell

Distribution of gases through µm porous materials (GDL)

Electrodes for electrocatalytic Reactions (2-10 nm)



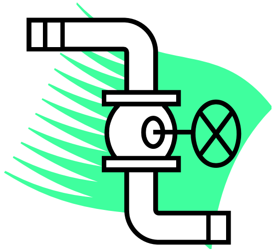
Feed reacting gases through bipolar plates (1 mm)

Transport of H+ through the ionomeric membrane (20 µm)

Production of water at the cathode

A brief introduction to fuel cell glossary

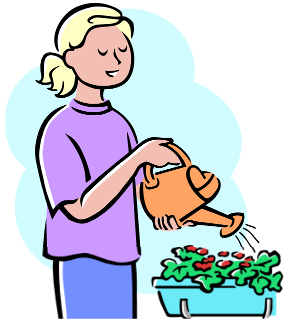
Bipolar plate = Inlet/outlet reactant pipe



GDL = Gas Diffusion Layer

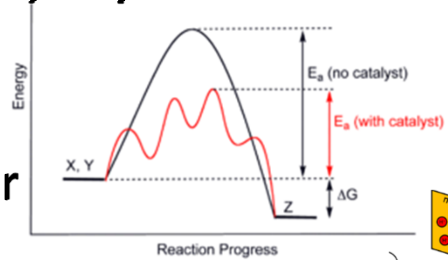
= Distributor of watering can

MPL = Super fine distributor of watering can



Catalyst = Pt cluster (3nm) deposited

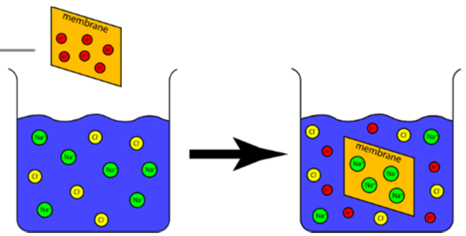
on Carbon support



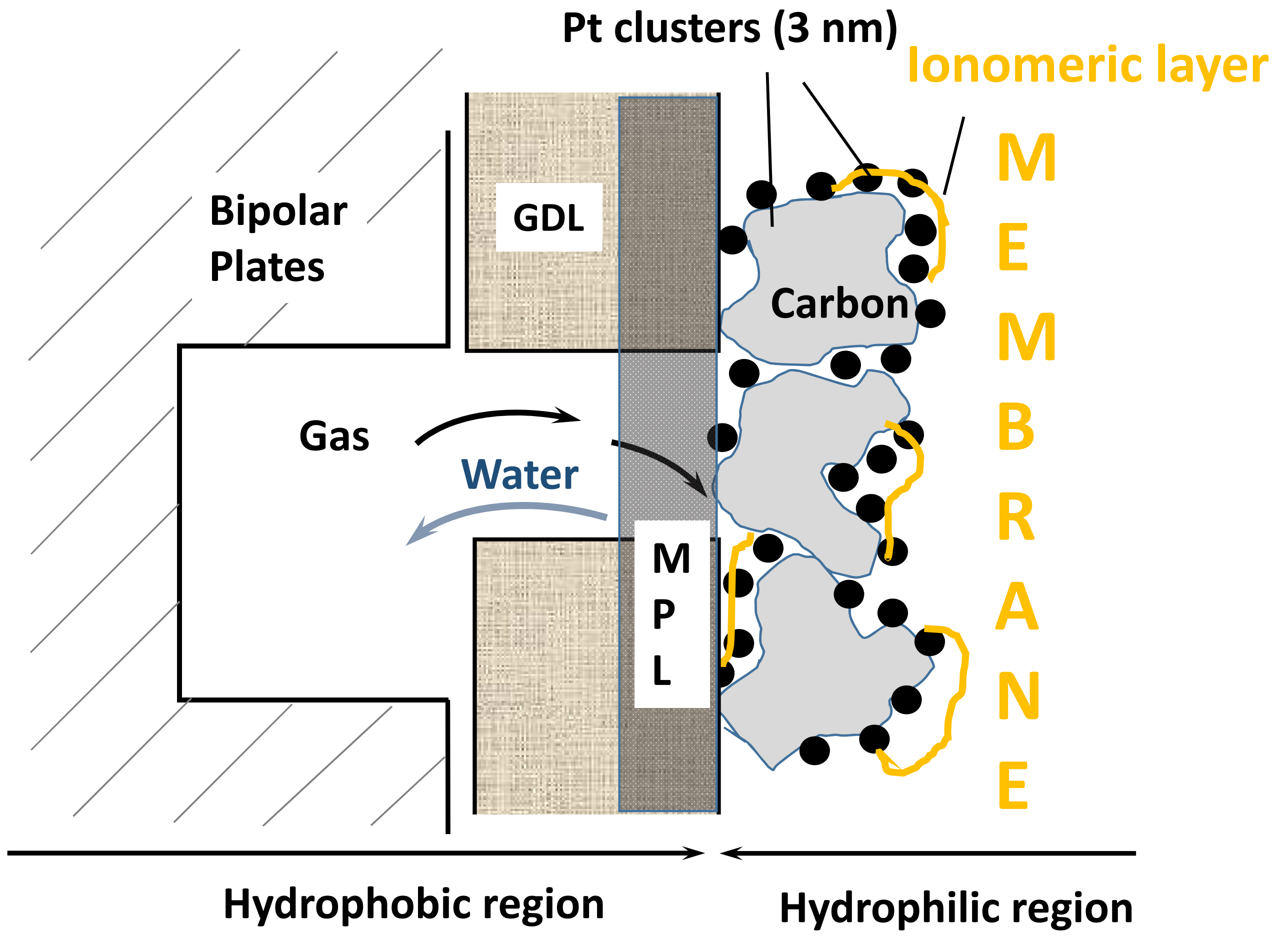
Electrode = Catalyst layer

Membrane = Ionomer

= Ion-exchanging material

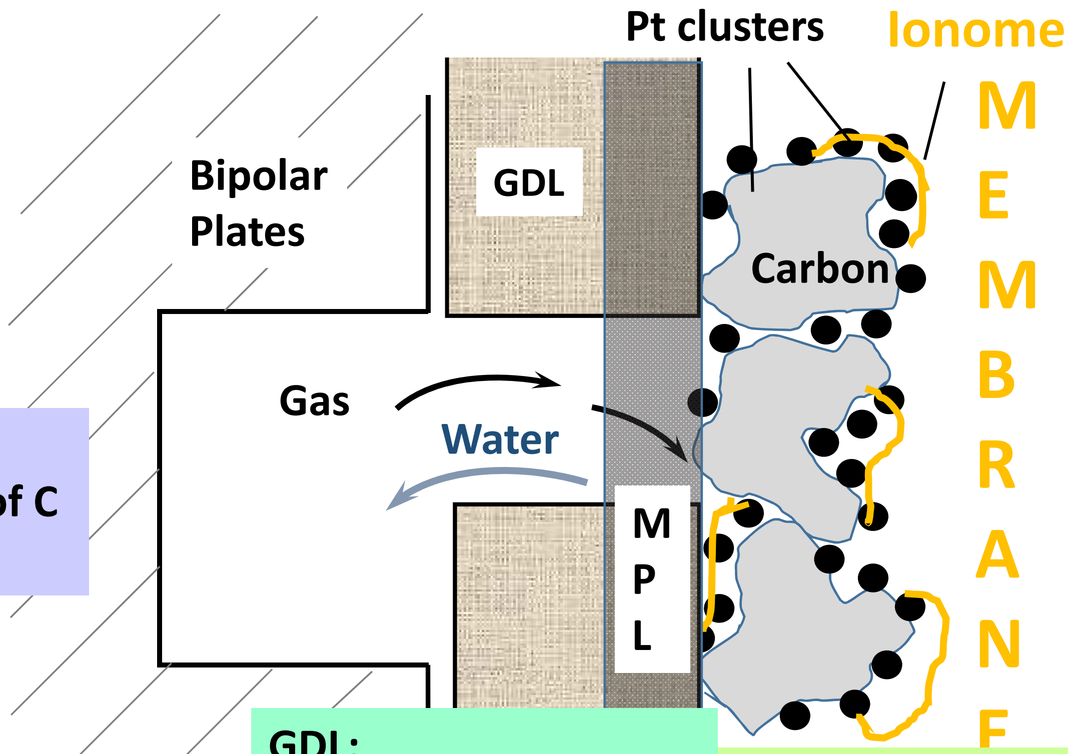


View of half a cell (one electrode)



Dimension (pores) 1 mm 30 µm 1µm 30 nm

Ageing troubles in PEMFC (one electrode)



Plates:
Corrosion of C or metals

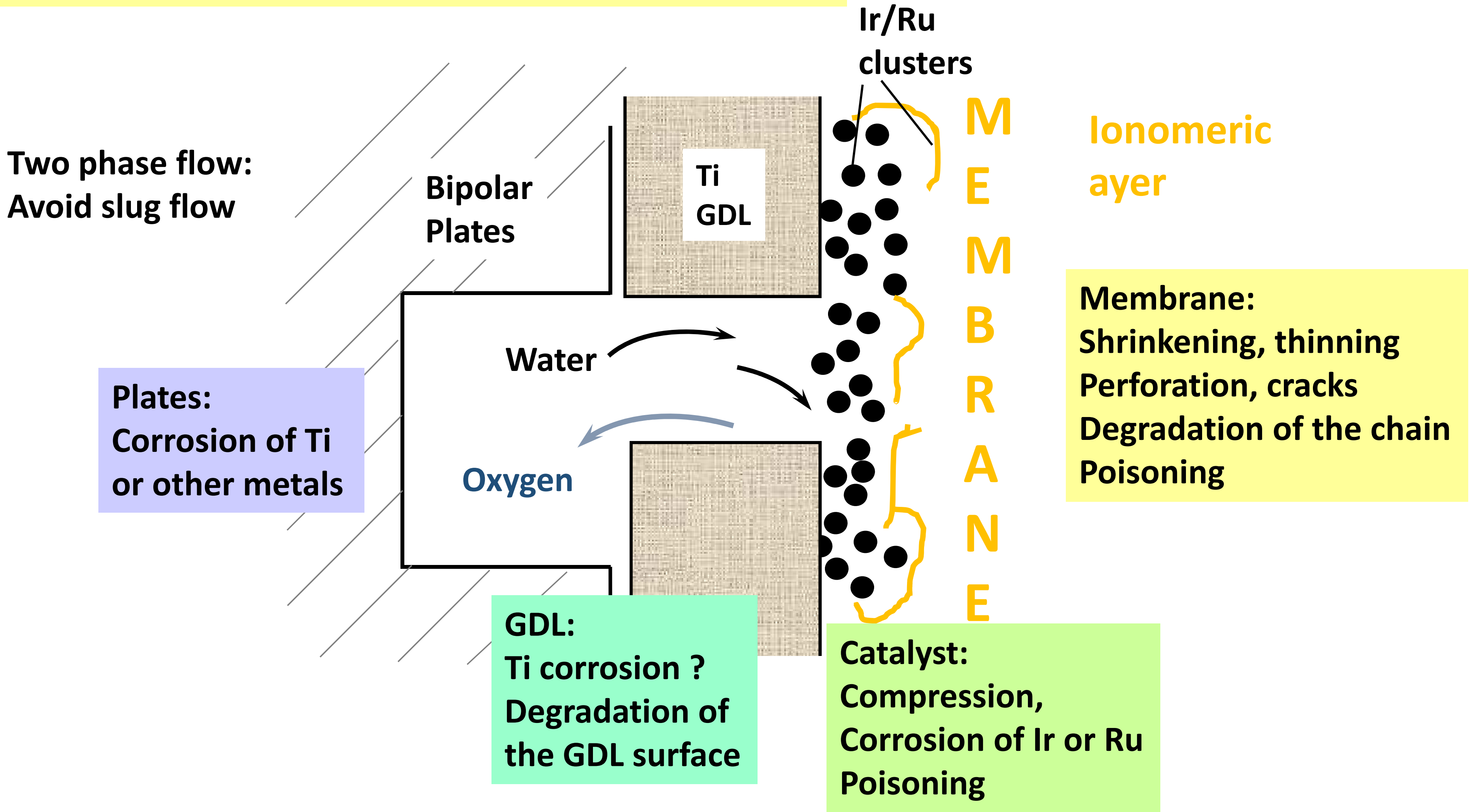
Membrane:
Shrinkening, thinning
Perforation, cracks
Degradation of the chain
Poisoning

GDL:
Carbon corrosion
Degradation of water-repellent layer

Catalyst:
Compression,
Corrosion of Pt and/or C
Poisoning

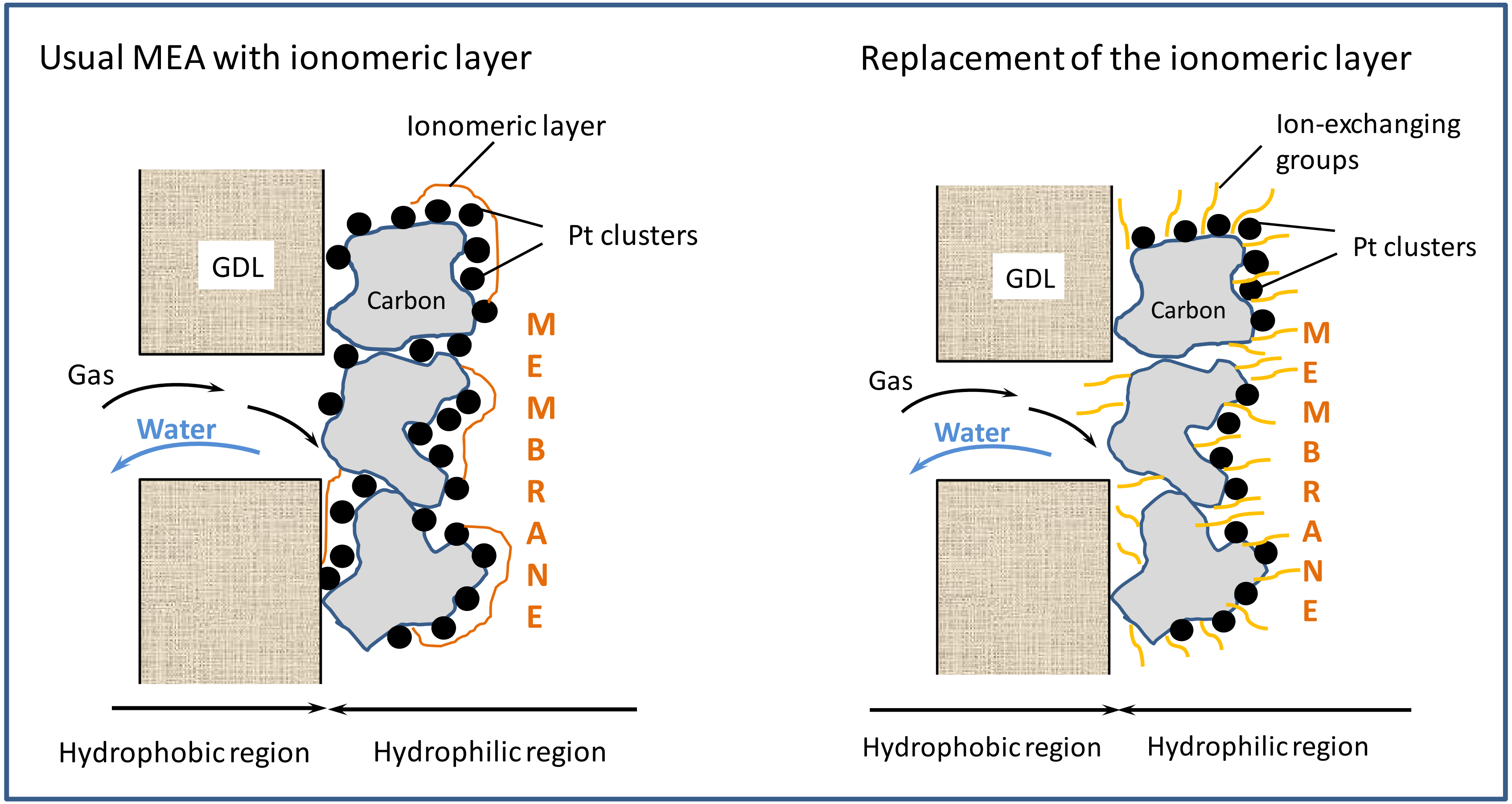
Delamination

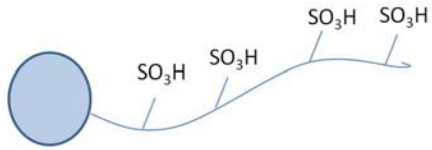
Ageing troubles in PEM electrolysers (anode)



Material improvement:

Carbon functionalization of more efficient electrodes in PEMFC (IJL, LRGP, LEMTA, Univ. Lorraine)





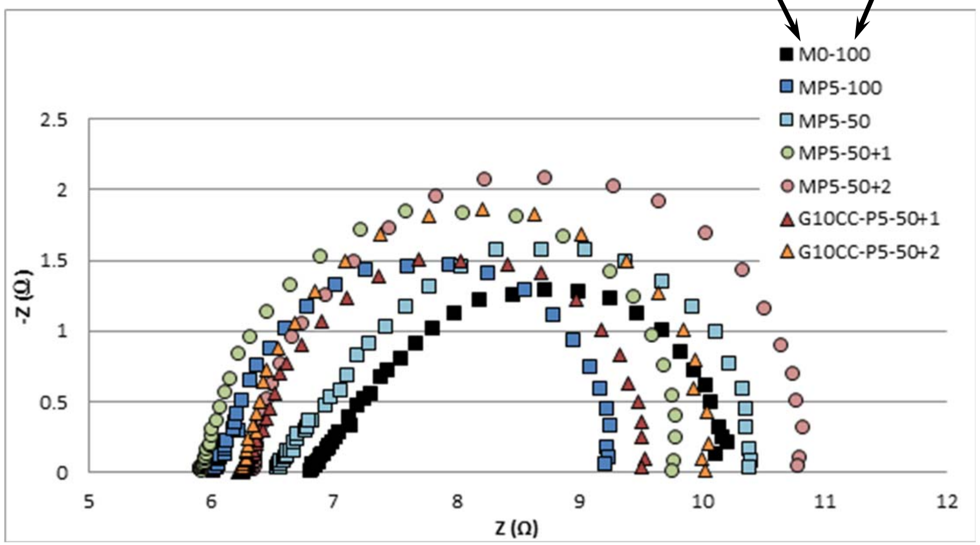
PSSA

*** Higher performances**
*** Lower Nafion amounts required for MEA manufacture**

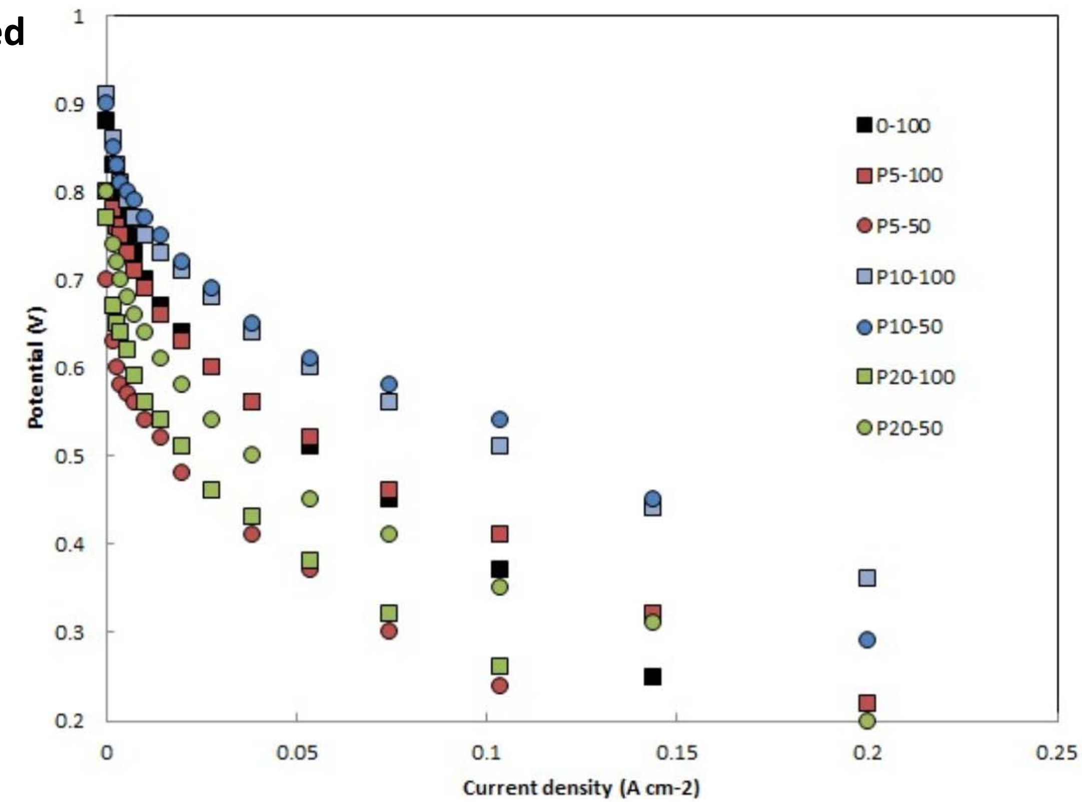
Half-cell tests
(0.5 cm2)
EIS measurements

Functionalisation fraction

Percents of Nafion added



Tests in 5 cm2 fuel cells



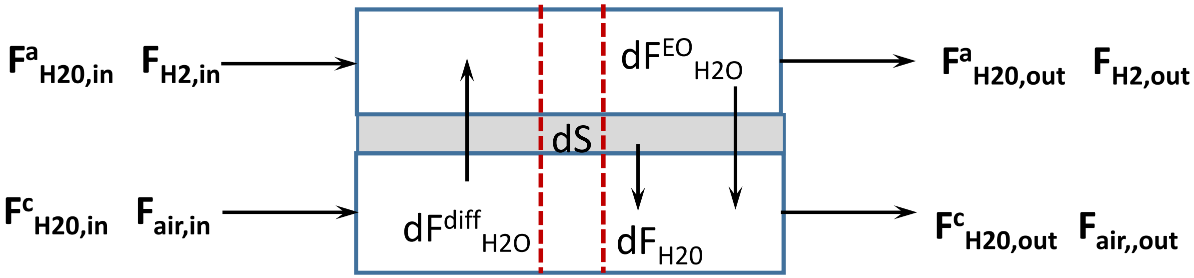
Y-Z. Xia (PhD)

Fuel cells are continuous reactors

Changes in variables along the electrode length

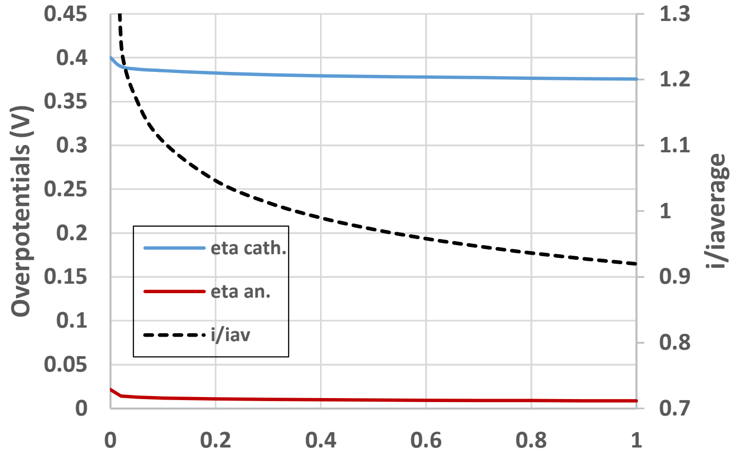
Anode

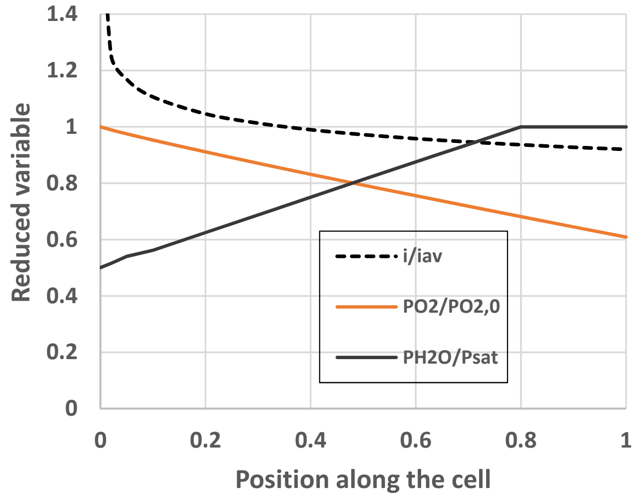
$$dF_{H_2} = -\frac{idS}{2\mathfrak{I}}$$



Cathode

$$dF_{O_2} = -\frac{idS}{4\mathfrak{I}} = -\frac{dF_{H_2O}}{2}$$

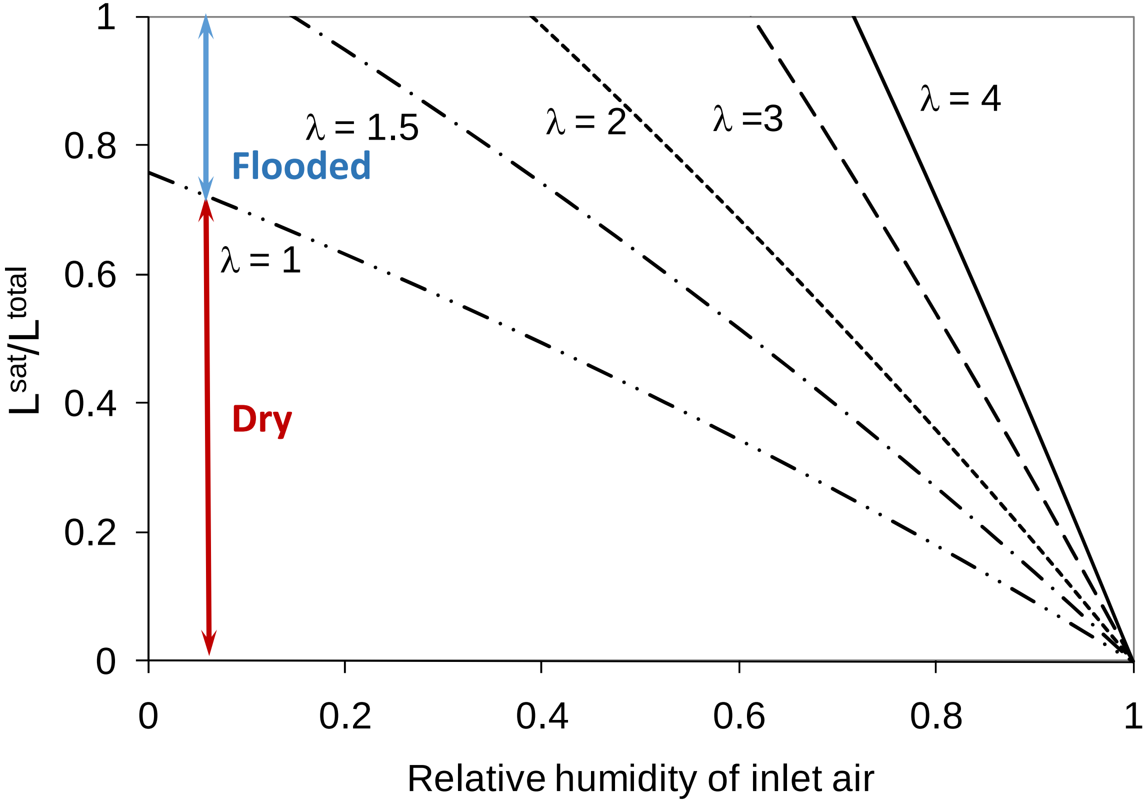




Where does liquid water appear in the cathode chamber?

Consider a PEMFC fed with dry hydrogen and humidified air (T_{hum})

$$\frac{L^{sat}}{L^{tot}} = \frac{\lambda_{O2}}{2y_{O2,in}} \frac{\dfrac{y^{sat}(T_{cell})}{1-y^{sat}(T_{cell})} - \dfrac{y^{sat}(T_{hum})}{1-y^{sat}(T_{hum})}}{\dfrac{1-\alpha}{y^{sat}(T_{cell})} + \dfrac{1}{2\left(1-y^{sat}(T_{cell})\right)}}$$

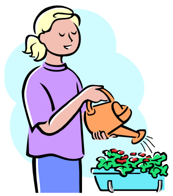


For α=0.36

α, overall coefficient for water transport, from the cathode to the anode

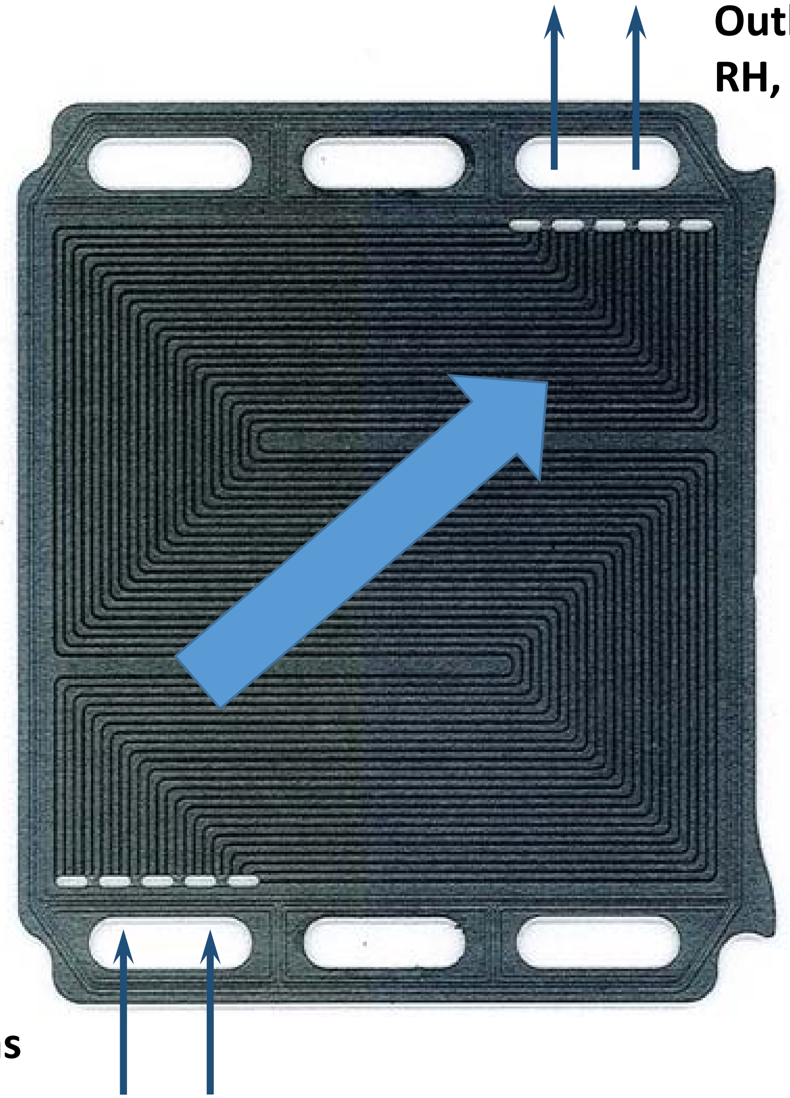
λ: Air stoichiometric factor
λ = 1, no air excess

Improving FC components for optimal water management: LRGP + CEA Tech (2014-2017)

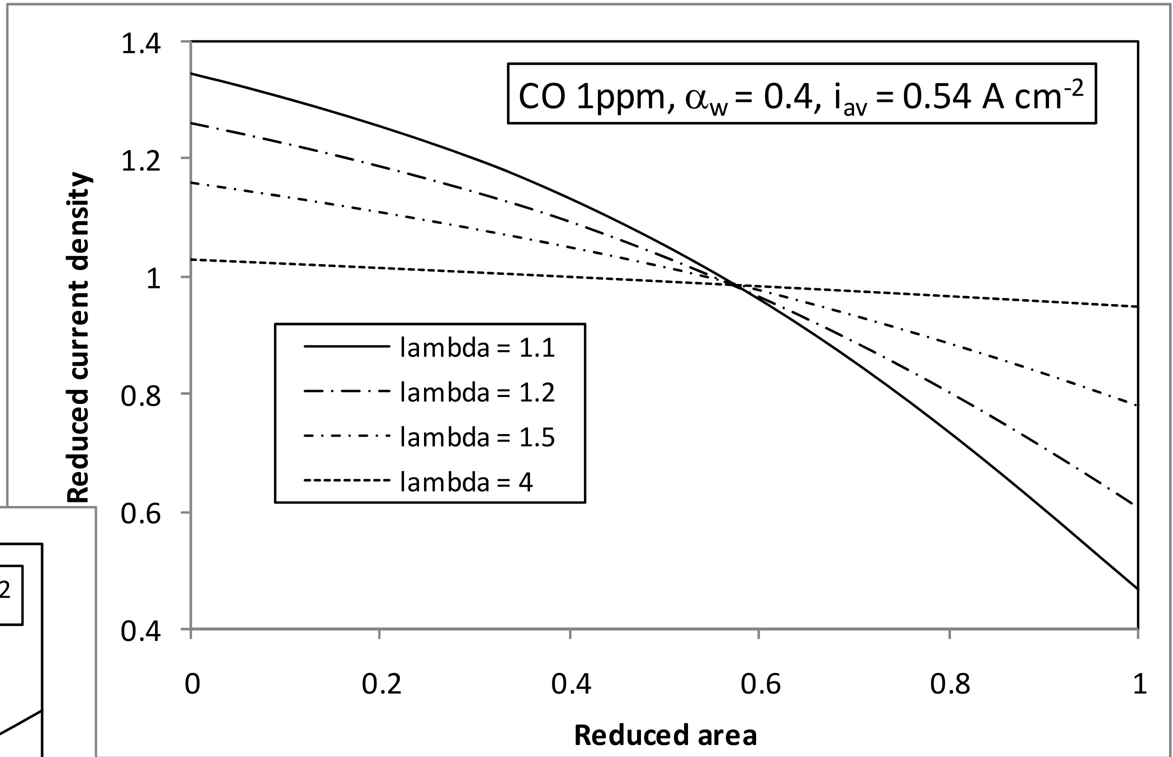


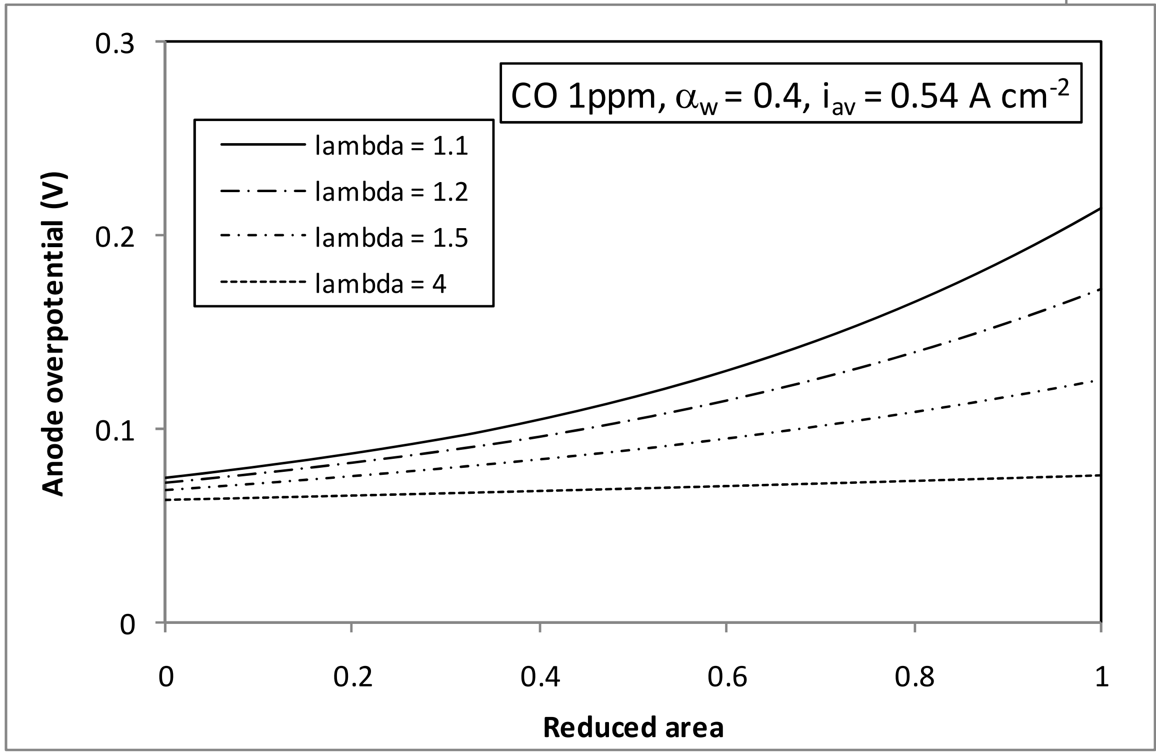
Increasing hydrophobicity of the microporous layer

Improve catalyst tolerance to liquid water



Fuel cell fed with CO-poisoned hydrogen: Effects of CO enrichment in the cell on cd distribution and anode overpotential (Bonnet et al. Chem. Eng. Sci. 2010)





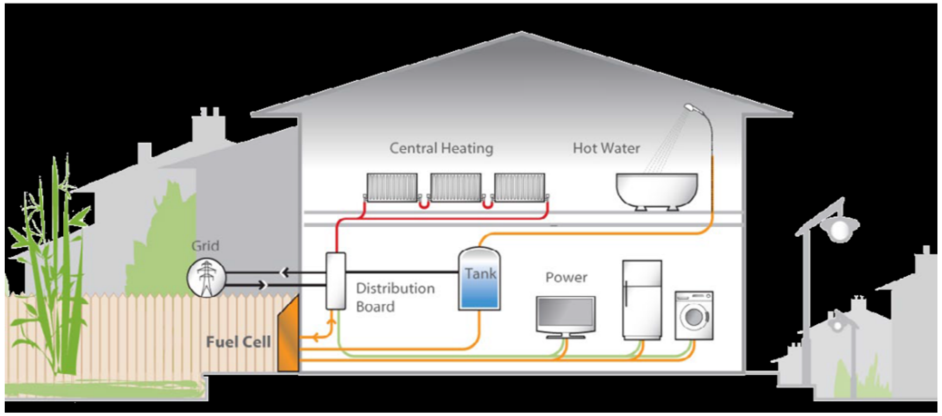
Research for improvement in PEM fuel cells: a few trends

Methods of investigation
Understand ageing mechanisms

Improved components	**Membrane**
	GDL/MPL
	Catalytic layer

Integration in real systems for energy conversion
Interaction between ancillaries and the stack

Fuel cells for residential heat and power (FuelCellToday, May 2012)



Power efficiency (FC) up to 45%
Total efficiency/fuel conversion
up to 98%

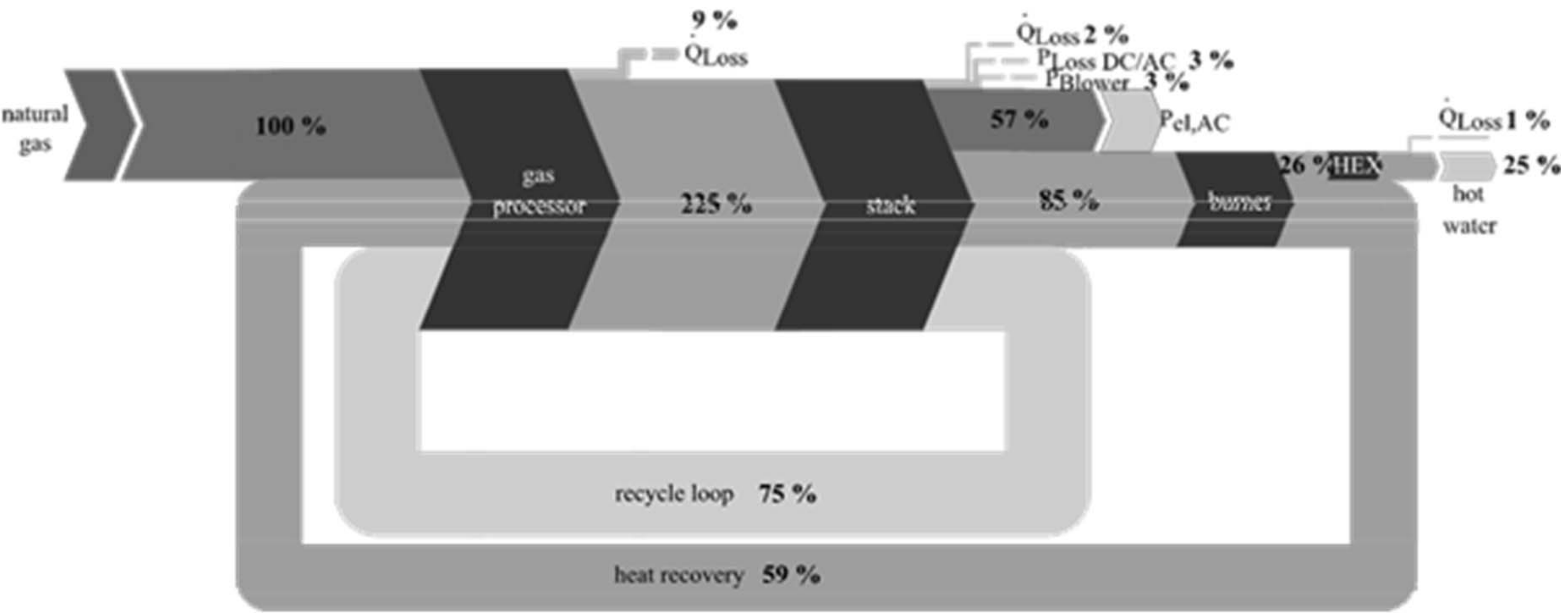
PEMFC
Run in the day,
switched off nights/no need
Grid connection required to start
Off-grid systems possible
with batteries

SOFC
Also high efficiency
Continuous run preferred
High tolerance to poisoning gas
Easier flow sheet of the system

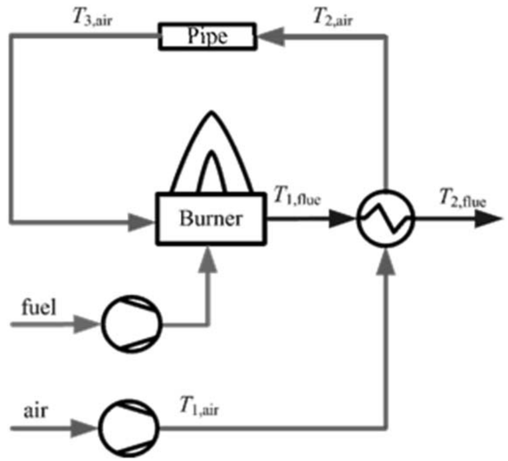
But a number of similar engineering aspects

Improving and modelling a 10 kW SOFC system (R. Bosch, Uni. Stuttgart and LRGP)

Recycling the anode gas (M. Carré et al.):
Higher yields
Far lower fluctuations of the stack voltage



An innovative device:
Cheap Gas processor test for possible use of any NG
(Gallet Segarra et al.)



The first PEFC cogeneration system Panasonic & Viessmann

Planned commercialisation in Europe: April 2014

Water tank and
Backup boiler unit
19 kW

Fuel cell unit
750 We, 1000 Wth
Power efficiency: 37% (LHV)
Combined efficiency: 90% (LHV)
60000 hours (4000 start/stops
AC 230V, 50 Hz

Fuel cell-based micro-combined heat and power: comparison between Denmark and France

(Pade et al., 2013)

Thermal control strategy: the cell is operated depending on the heat required in the house
With possible export and import of electricity

(case of old houses)	Denmark	France
Electricity production (kWh/year)	5462	5231
Electricity export (kWh/year)	1696	2294
Full load hours (h/year)	5432	5231
Heat demand covered by FC	35%	32%
Feed-in tariff for viability (c€/kWh)	33.3	28.2

NB: for new houses, the head demand covered attains 60-65%
NB: Price for excess electricity from the FC owner is far lower in Denmark than in France

Fuel cell-based µCHP: comparison between Denmark and France

(Pade et al., 2013)

Virtual power plant: the cell is run independent of the heat demand
But depending on the electricity price

(case of old houses)	Denmark	France
Electricity production (kWh/year)	17451	17559
Full load hours (h/year)	8725	8780
Heat demand covered by FC	30%	31%
Price premium for viability (c€/kWh)	21.7	13.3

Any French cars powered by fuel cells?
Not really but…

Air Liquide and Hyundai Motor : 2 FCE Vehicles

2015: 1000 vehicles constructed in South Korea

Air Liquide largely involved in design and supply of hydrogen filling stations

La Poste testing hydrogen fuel cell range extenders in Renault Kangoo Z.E. mail delivery vehicles

CEA-Liten, UTBM, Symbio Fuel cells Renault, Community of Belfort

The HyKangoo features an ALP-10 fuel cell stack, along with a 38-liter hydrogen tank. Average fuel consumption at full power is 0.3 kg/h.

Symbio Fuel cells ALP-5 (5 kW) module

FC system: range extension up to 100 km
in Eastern France (North Jura and Southern Vosges)

Hy-Kangoo (batteries + FC)

Sailing Zero CO2

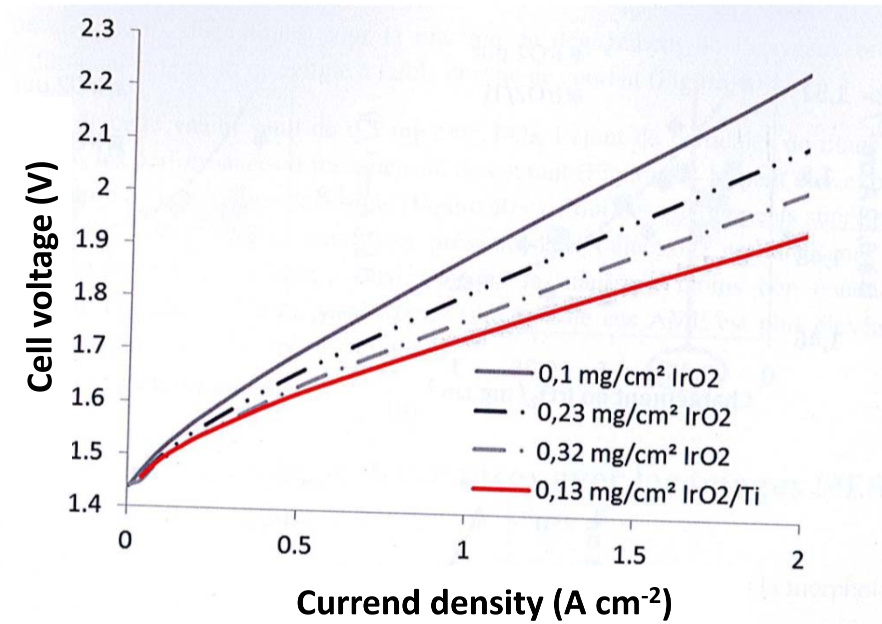
CEA, Univ. Grenoble, Solvicore, Region PACA

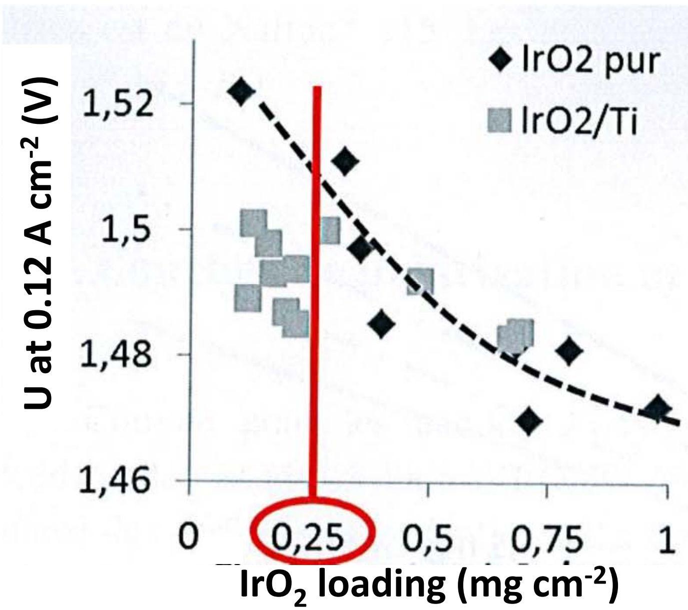
Combined Wind
PV panels
Batteries and converters
Fuel cell (with hydrogen)

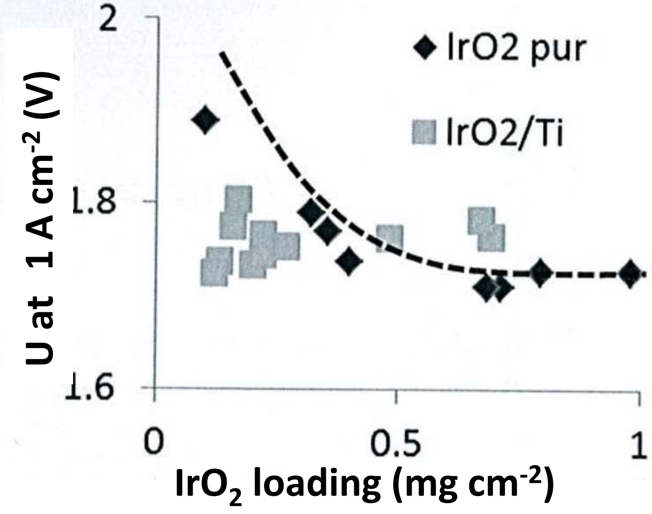
Propulsion of a 12 m sailboat
Significant market in France

PEM water electrolysis
Searching more efficient anode catalysts

Ti-supported IrO_2 particles
(Rozain et al. 2013)







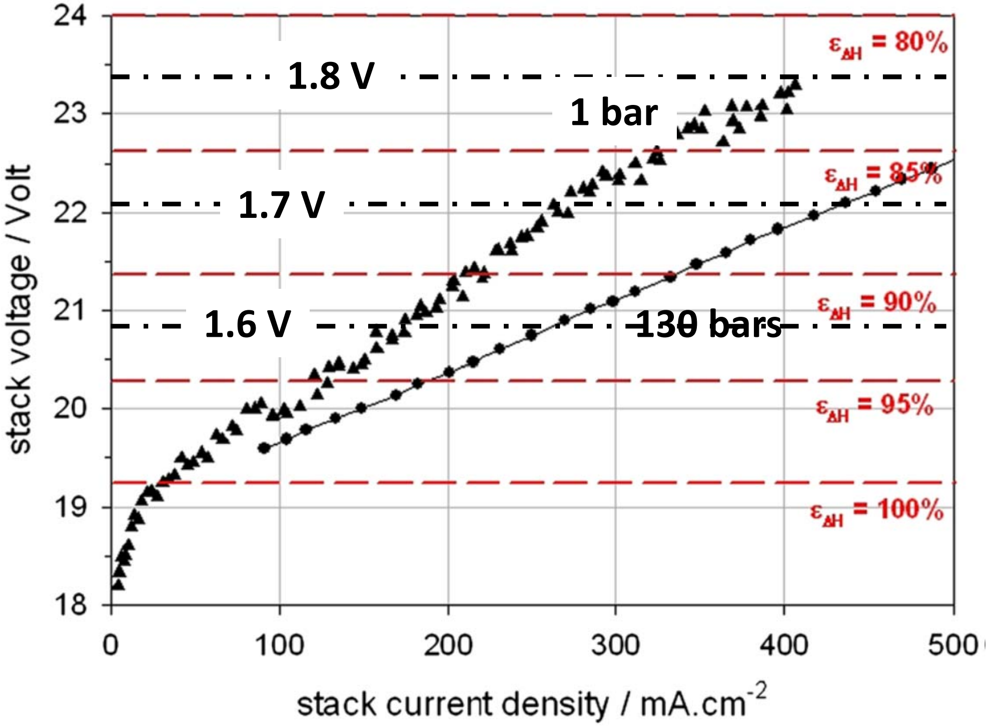
An issue to be solved:
Durability of Ti-IrO2

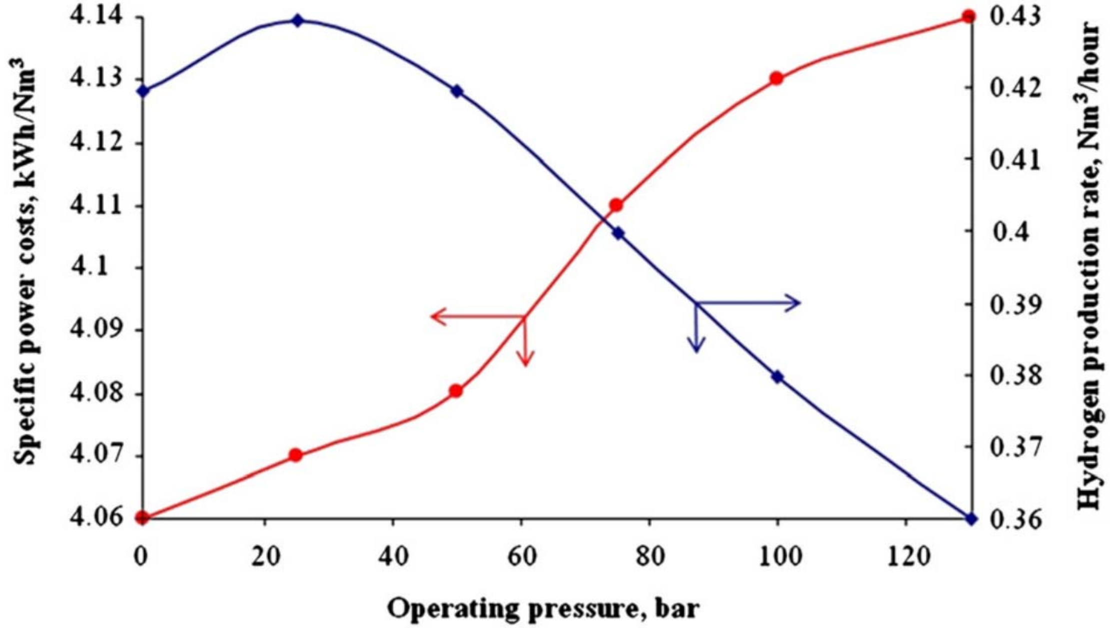
PEM water electrolysis
(Millet, Paris Sud + Kurchatov Institute)

13-cell stack 1.6 Nm3 H2/h

Bipolar modulus for electrolysis at 130 bars

PEM water electrolysis
(Millet, Paris Sud + Kurchatov Institute)





PEM electrolyser stack
for 15 Nm^3/h H_2

4-modules for water electrolysis (60 Nm3/h H2 each) : 1.2 MW
14 bars, feeding with tap water at 35°C, 3-5 bars

Hélion

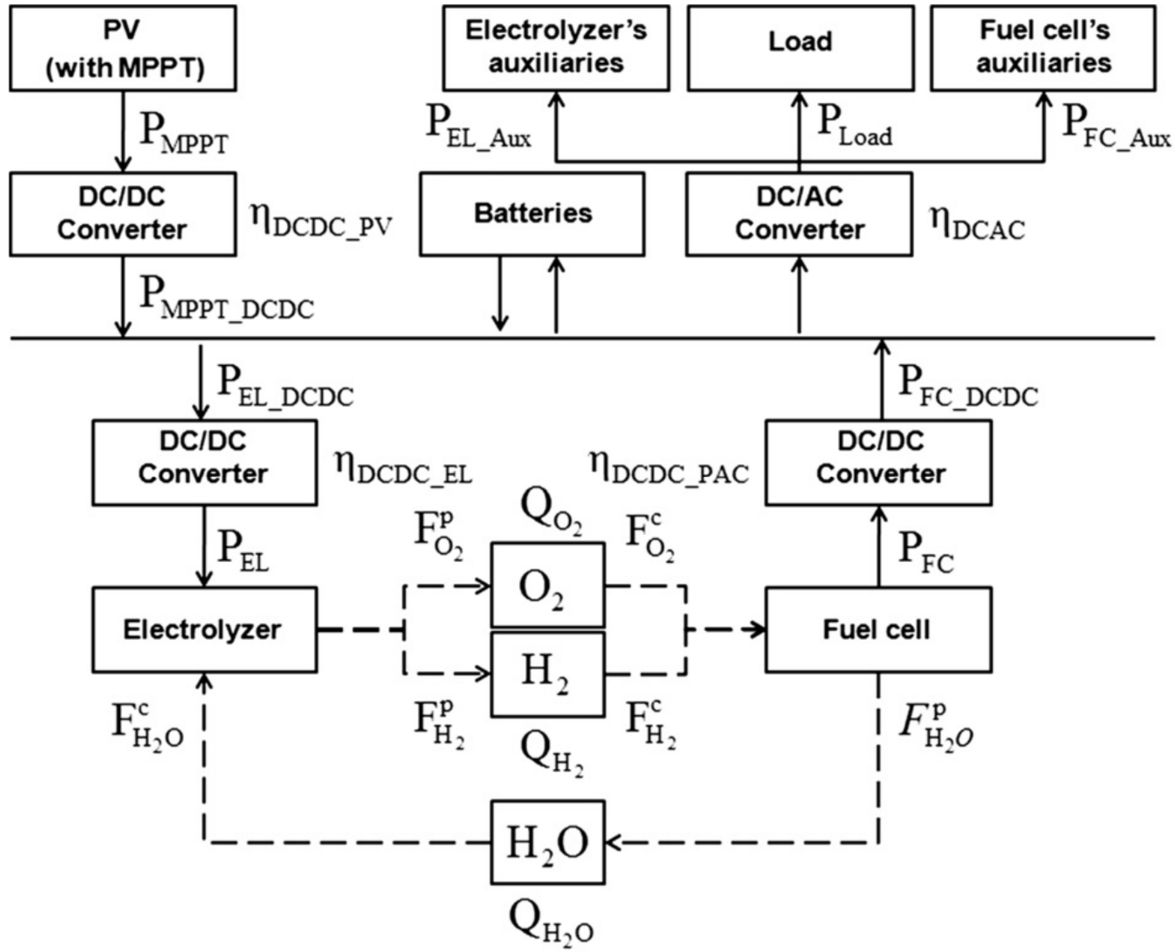
**PEM electrolysis,
with possible coupling
to other energy sources**

Greenergy box

Coupling PEM fuel cells to electrolysers and photovoltaic cells

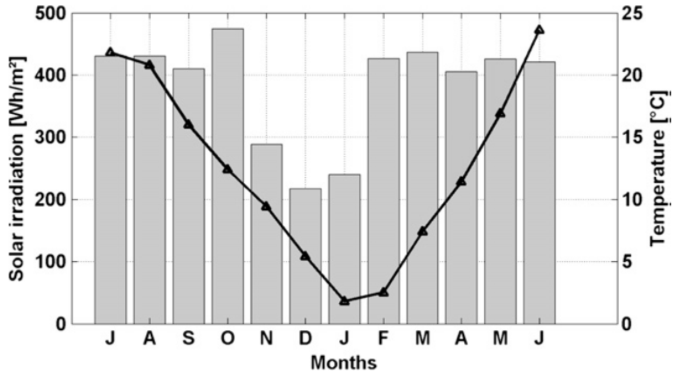
Pepite Project (Univ. Corsica, CEA etc.)
Planned 1 MW, in fact less

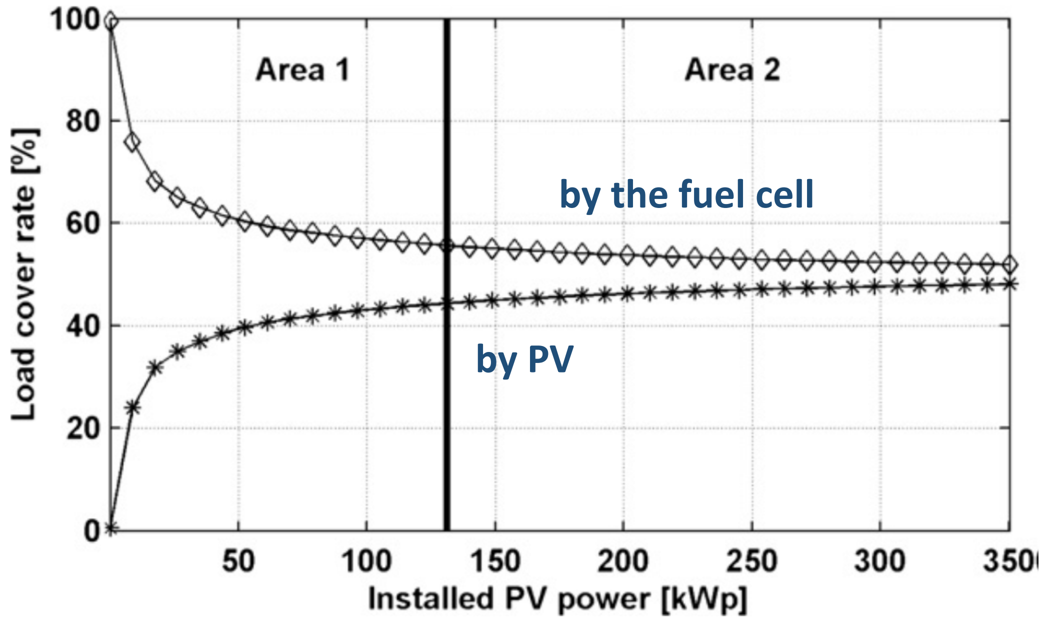
Optimisation of Renewable Intermittent Energies with Hydrogen For autonomous electricification: The ORIENTE project (CEA, CNRS, Univ. Corsica, Hélion)
(Darras et al. Int. J. Hydrog. Energy 2010)

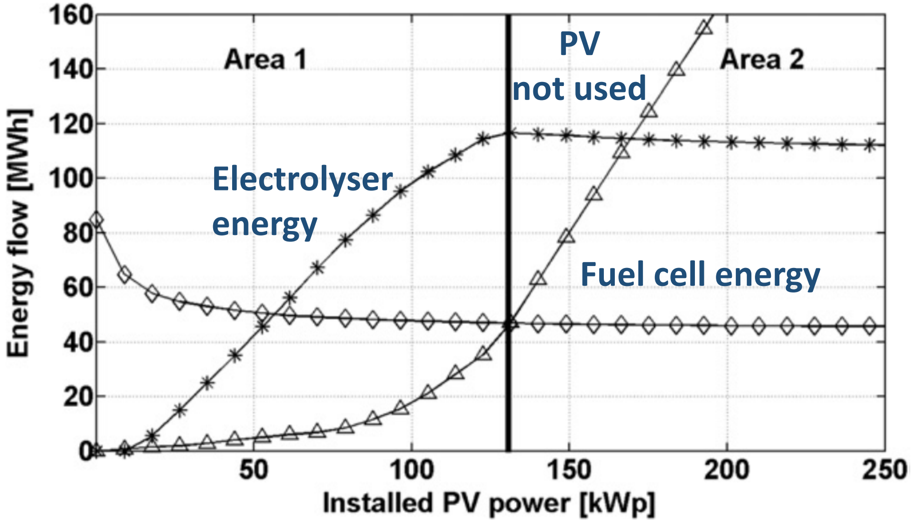


- **Model of the system**
- **Optimal size of the system for sustainable operation**

ORIENTE: the results obtained







PV 131 kW
Electrolyser: 101 kW
FC: 10.6 kW
H2 storage: 398 kg

MYRTE project: Mission hYdrogen & Renewable for the inTegration on the Electrical grid

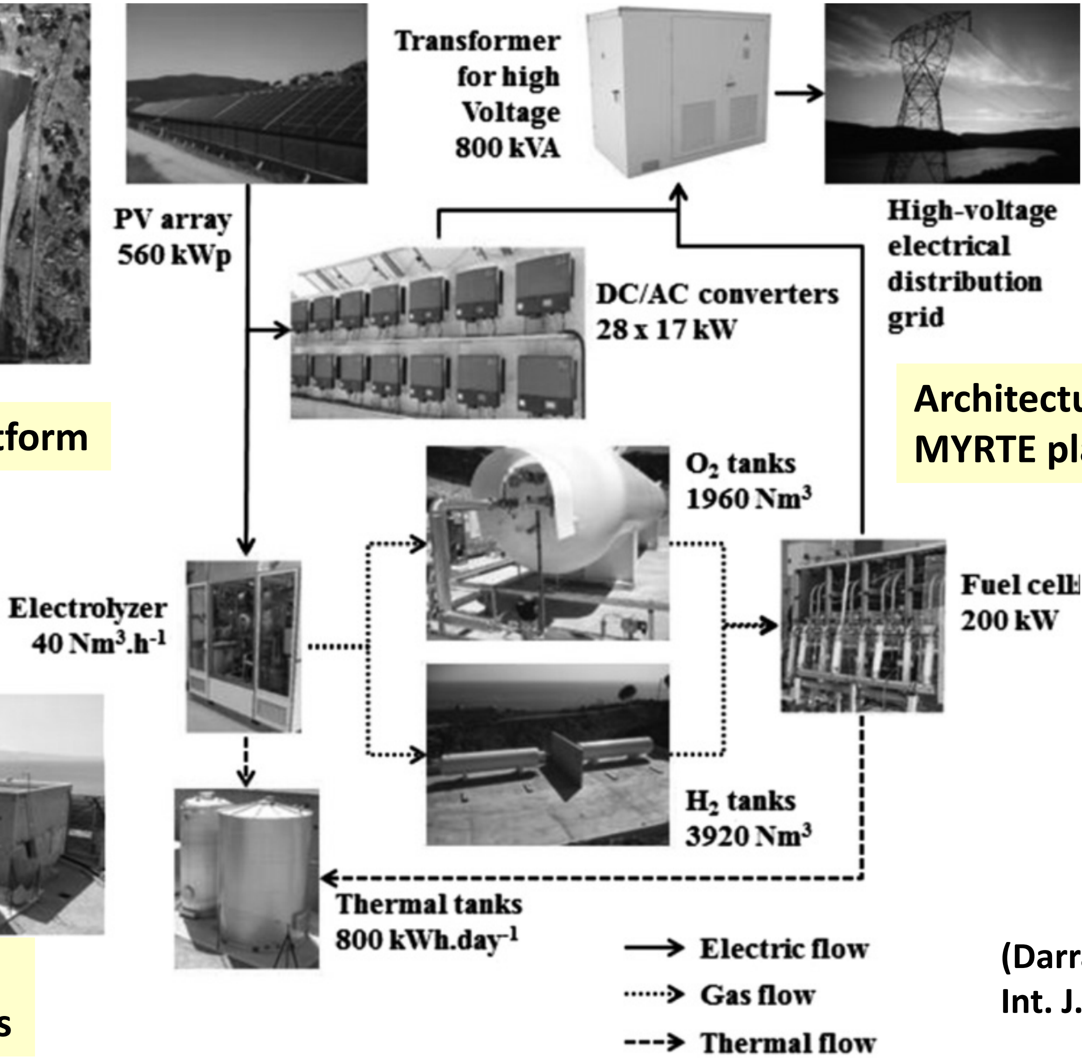
CEA, Univ. Corsica, Hélion

* **Test hydrogen technology in real situation**
* **Develop optimal strategy between PV array (solar panels and inverters) and a H2 chain (electrolysers, tank and fuel cells)**

View of the site (area close to 1 ha)

Electrolysers and fuel cells

View of the MYRTE platform

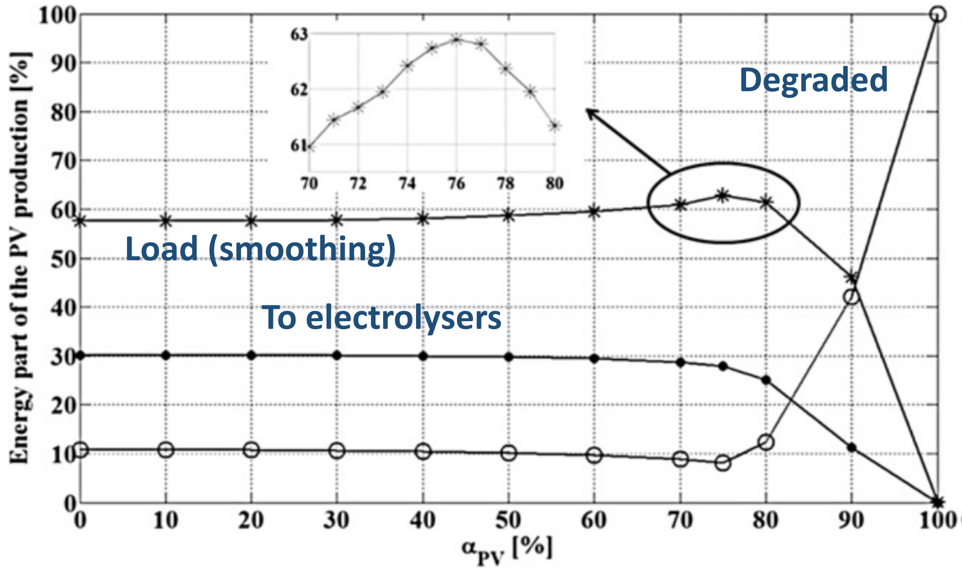


Architecture of the MYRTE platform

Thermal management
Building with FC and eletcrolysers

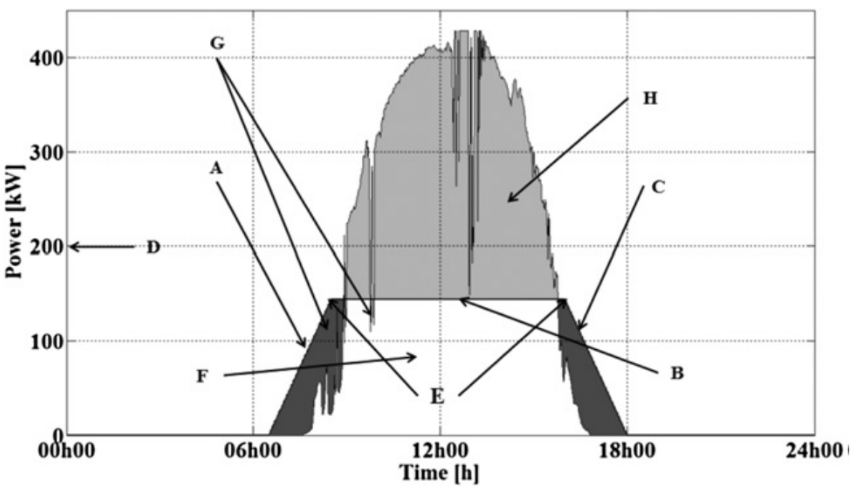
(Darras et al,
Int. J. Hydr. Energ. 2012)

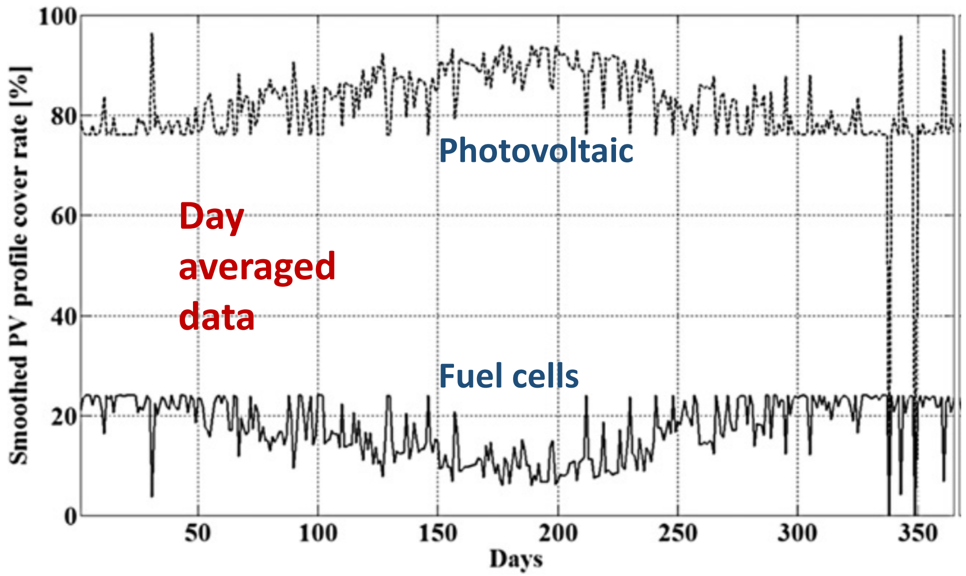
The Myrte project: First results
(Darras et al.)



Annual averaged data

Smoothing and truncation of sun energy





Acknowledgements

Dr. Caroline Bonnet,
lecturer at Univ. Lorraine

Yohann Chatillon
Yuzhen Xia
Meriem Belhadj
Maxime Carré
Anna Segarra-Gallet
+ undergraduate students from ENSIC and WPI

Région Lorraine
ANR
ICEEL Carnot Institute