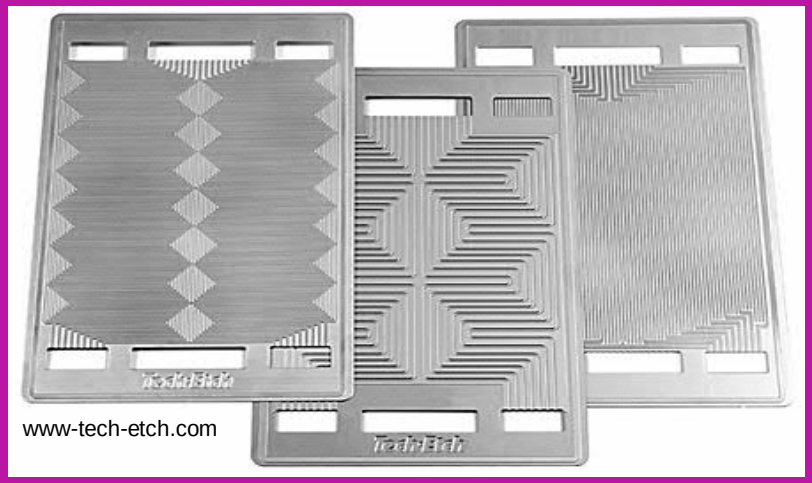
Module C2: Durability
Supportive materials

AAE-E3120 Circular Economy for Energy Storage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Prof. Annukka Santasalo-Aarnio

Aalto University
School of Engineering

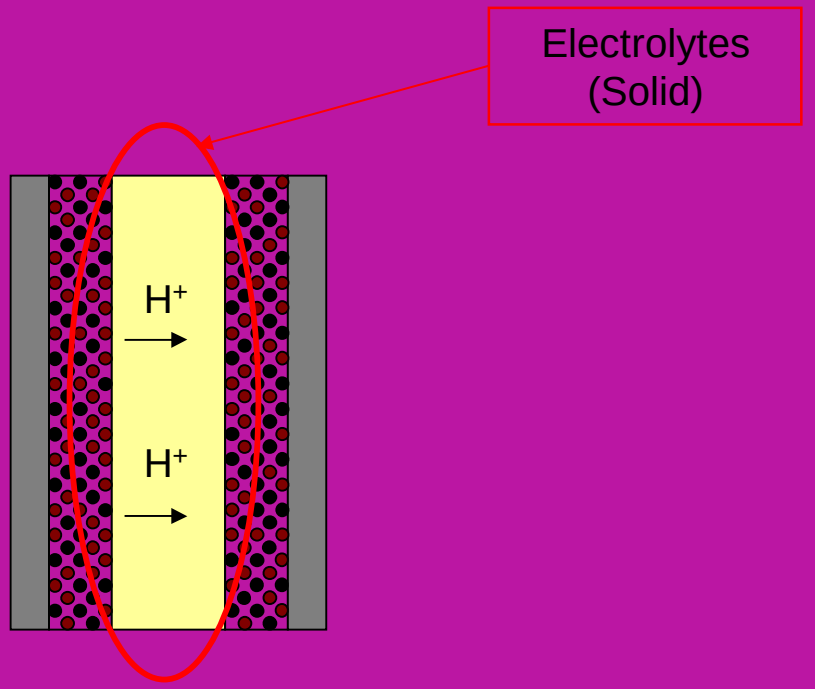
Learning outcomes

- **Recognize the material choice effect to degradation mechanisms of the system**
  - Separator/Electrolytes (in electrochemical systems)
  - Support materials

- **Develop new design for recycling approach for energy storage application and justify with scientific argumentation**
  - High durability (how to ensure with material selection?)

Degradation

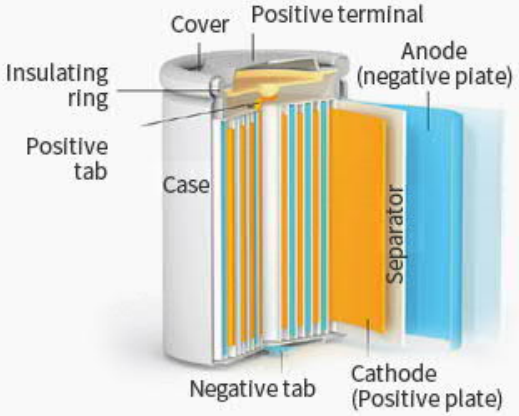
Separators and Electrolytes



Separators

Separate the electrode reactions

- Prevents reactant mixing -> parasitic reactions
- Prevent unwanted diffusion of products at electrodes
- Separator degradation -> cell failure… (partial or full)



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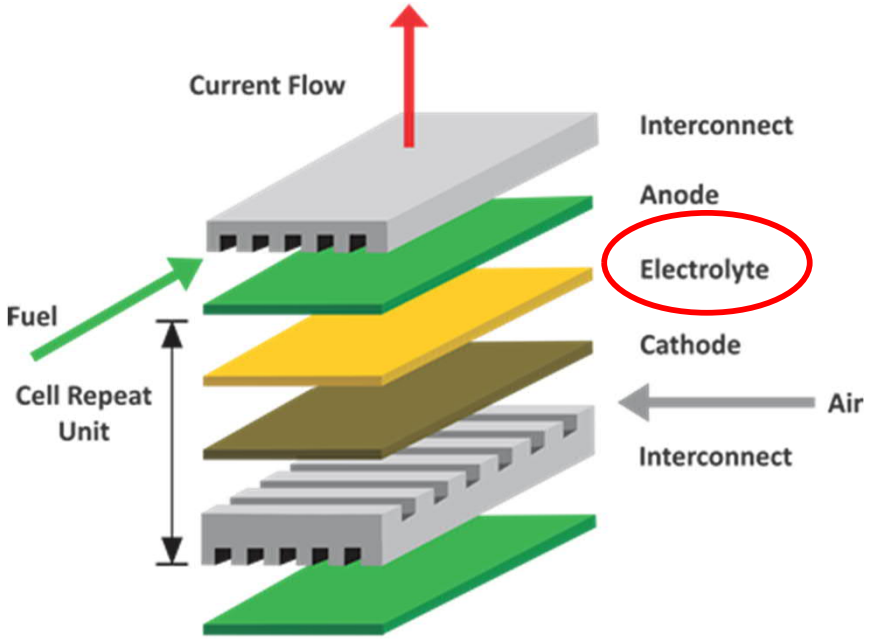
High temperature applications

Solid Ceramic Electrolyte



Planar SOFC configuration

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Ceramic materials
Temperature fluctuations
- thermal suitability with the other materials
- contamination
- dissolution of parts into electrodes

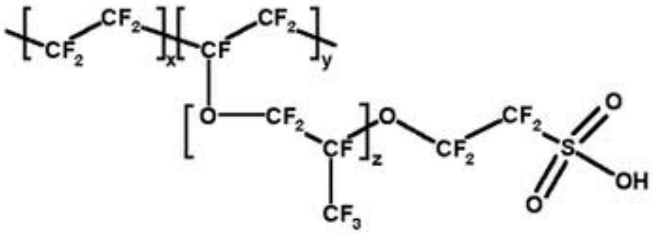
Polymer membrane electrolyte (PEM)

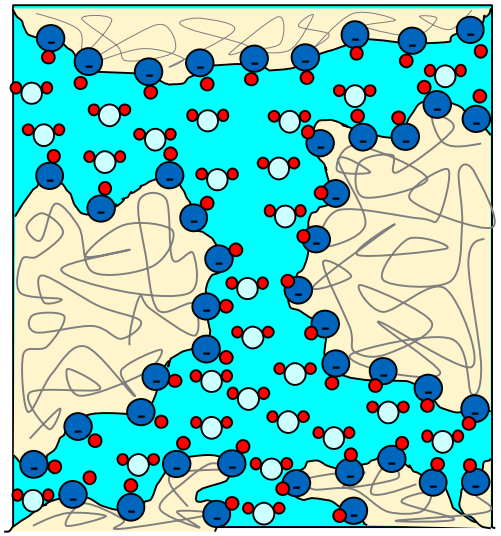
Case example: Nafion membrane

- Proton conductive membrane material

- Used in many **electrochemical devices**
- Electrolysers
- Fuel Cells
- Flow batteries

- Required liquid water
  - (limits operating temperature, 90ºC)



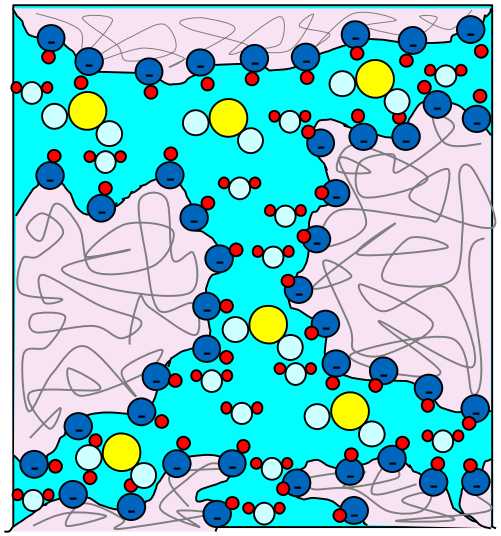


Polymer membrane electrolyte (PEM)

Molecule Crossover

- Small, neutral molecules
  - Alcohols (DMFC)
  - SO_2 (SO_2 depolarised electrolyser)

- Prevention:
  - Different electrolyte material
  - Finding reactant that have charge (neg.) Formic acid (PEM FC)
  - Protective layer to prevent molecules to enter the electrolyte

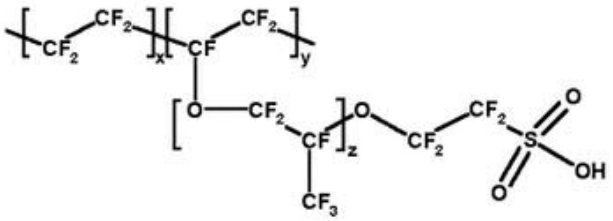


A. Santasalo-Aarnio et al. J. Solid State Electrochem (2016)
DOI: 10.1007/s10008-016-3169-8

Polymer membrane electrolyte (PEM)

Durability

- Nafion has high chemical durability
  however, does not last well dry conditions



Case – Dry conditions

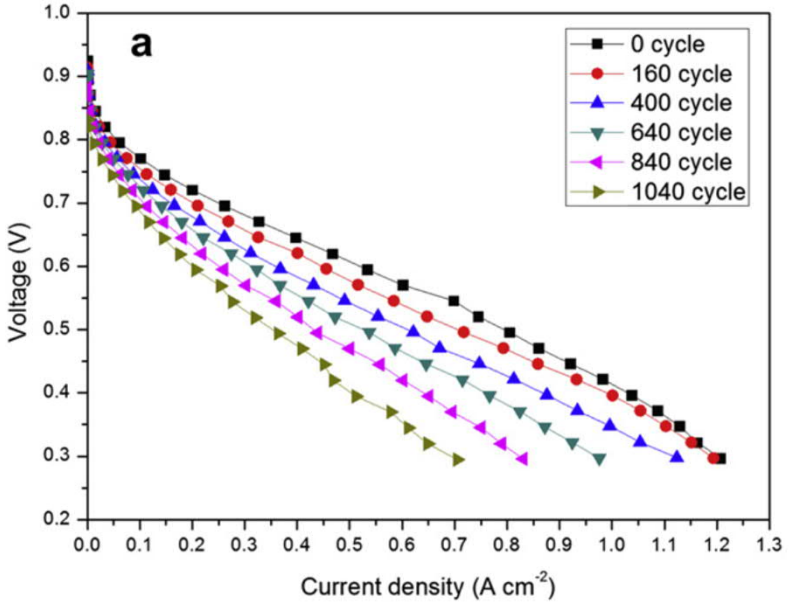
- Accelerated membrane test

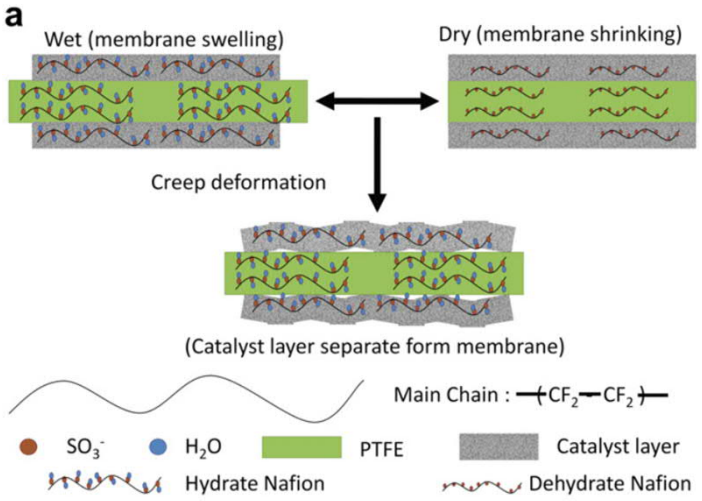
- Step 1: The MEA was operated in OCV mode for 30 s under 100 % Humidity (R.H);
- Step 2: The MEA was operated in discharge mode at 0.6 V for 150 s under R.H. 100%;
- Step 3: The MEA was operated in discharge mode at 0.6 V for 150 s under R.H. 0% (bypass).

T.-C. Jao, Int. J. Hydr. Ene 37 (2012) 13623-13630.

Polymer membrane electrolyte (PEM)

Durability





Membrane electrode assembly (MEA)

A M C

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T.-C. Jao, Int. J. Hydr. Ene 37 (2012) 13623-13630.

Accelerated tests in durability

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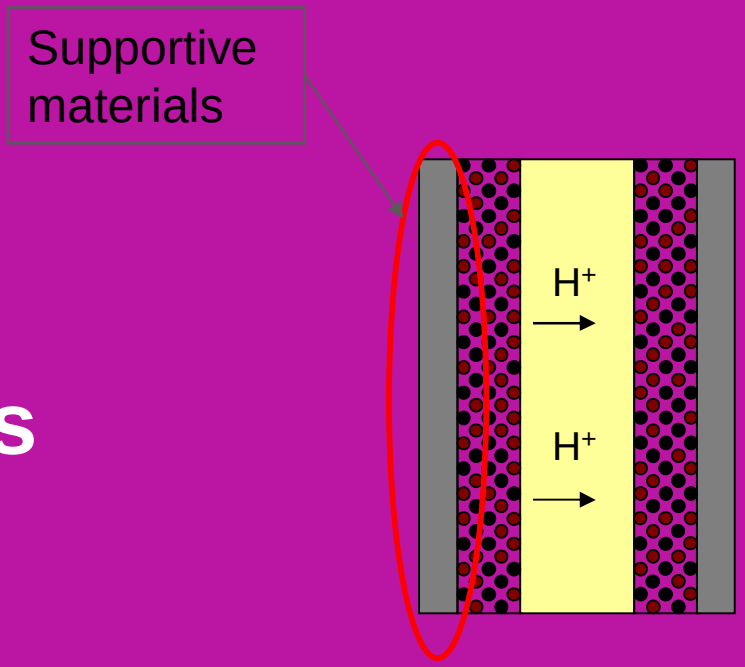
We saw accelerated test also in the case of active materials (C1 video). Do you think that with electrolytes, they produce more valuable results?

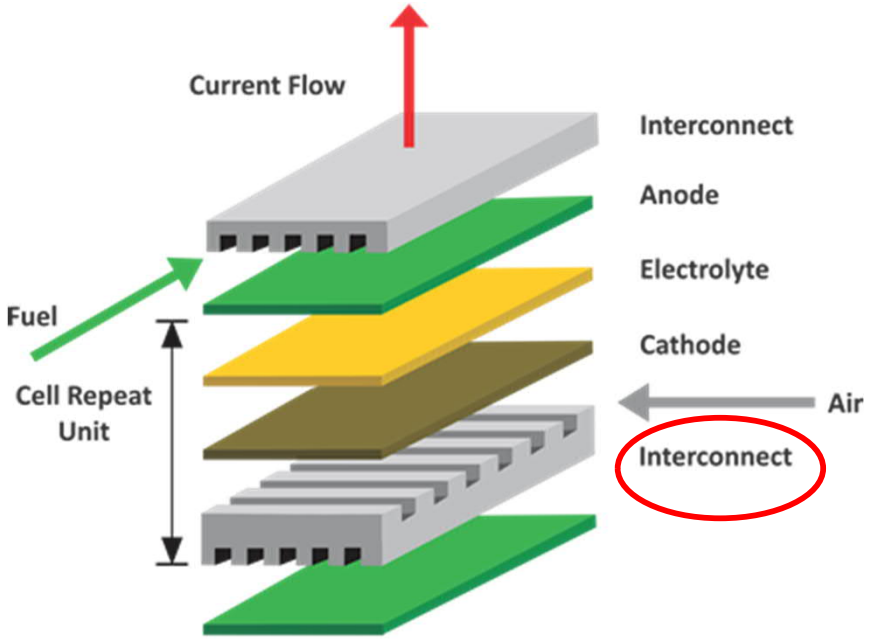
Degradation

Supportive materials



High temperature applications

Metallic interconnects



Planar SOFC configuration

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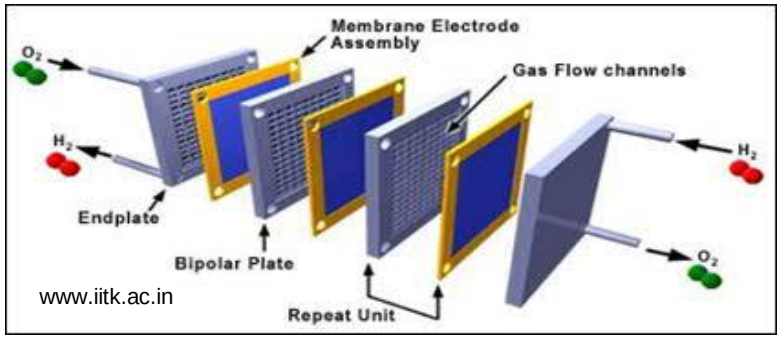
Metallic/Ceramic materials
Temperature fluctuations

- thermal suitability with the other materials
- contamination
- dissolution from their structure

Stacks -> Bipolar plates

Electrolysers + fuel cells

- For high voltage -> stack of cells in series
- Bipolar plates
  - Stainless steel
  - Carbon



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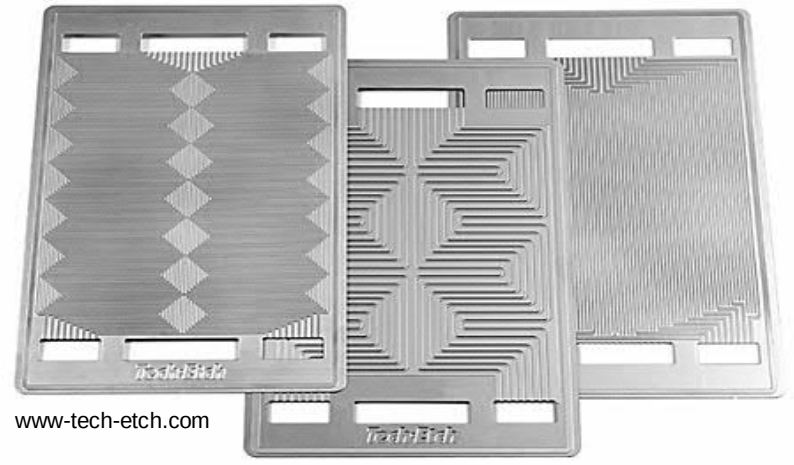
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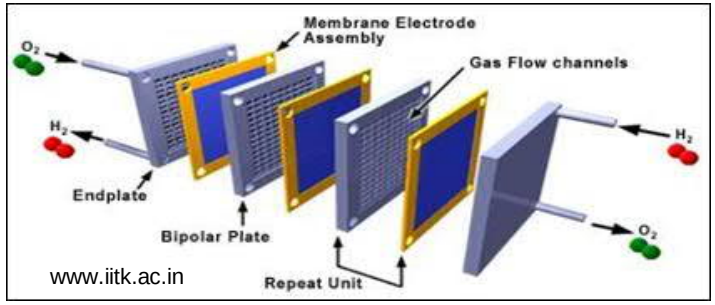
Stacks -> Bipolar plates

- **Carbon used in fuel cells**
  - a support material for catalyst (video C1)
  - Carbon cloth used for gas diffusion layer material in PEMFCs
  - Bipolar plates in multicell stacks (light)



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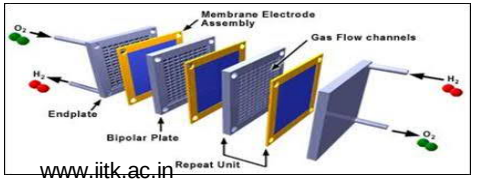

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Carbon corrosion

$$C + 2H_2O \rightarrow CO_2 + 4H^+ + 4e^-$$

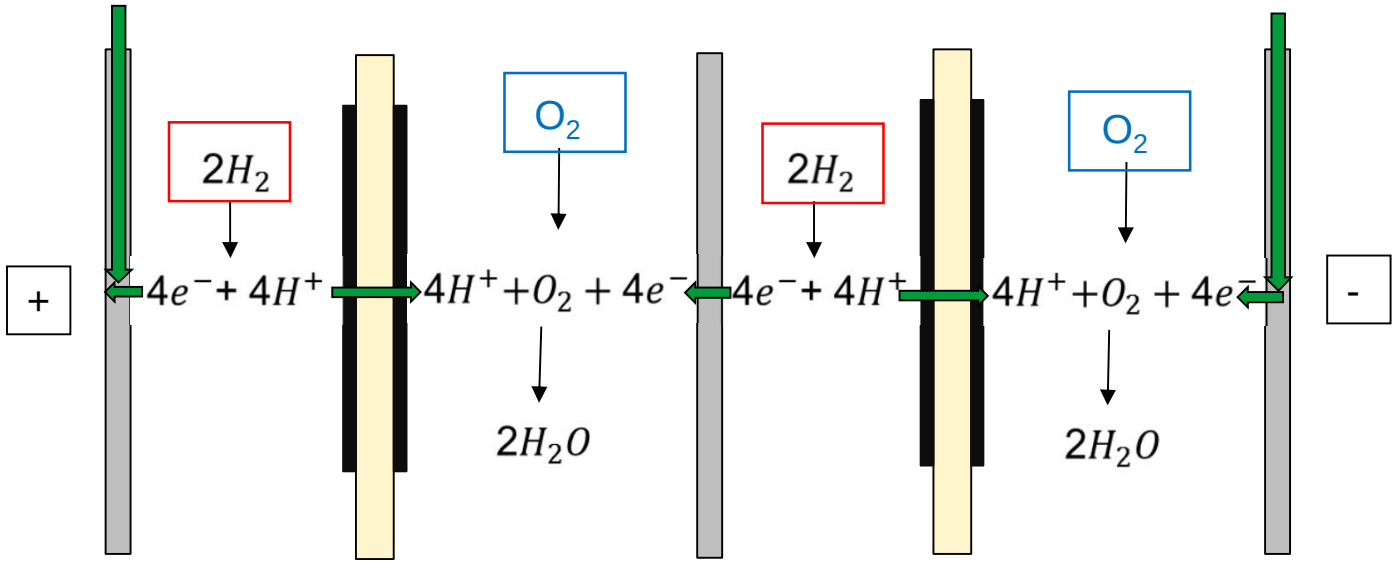
Replacing reactions in electrochemical systems

Possible electrochemical reactions at PEMFC anode

Fuel Cell	$H_2 \rightarrow 2\,H^+ + 2\,e^-$	E^0= 0 V [1]
Carbon	$C + 2H_2O \rightarrow CO_2 + 4H^+ + 4e^-$	E^0= 0.5 V [2]
Water splitting	$2\,H_2O \rightarrow 2\,H^+ + 2\,e^- + O_2$	E^0= 1.23V [1]

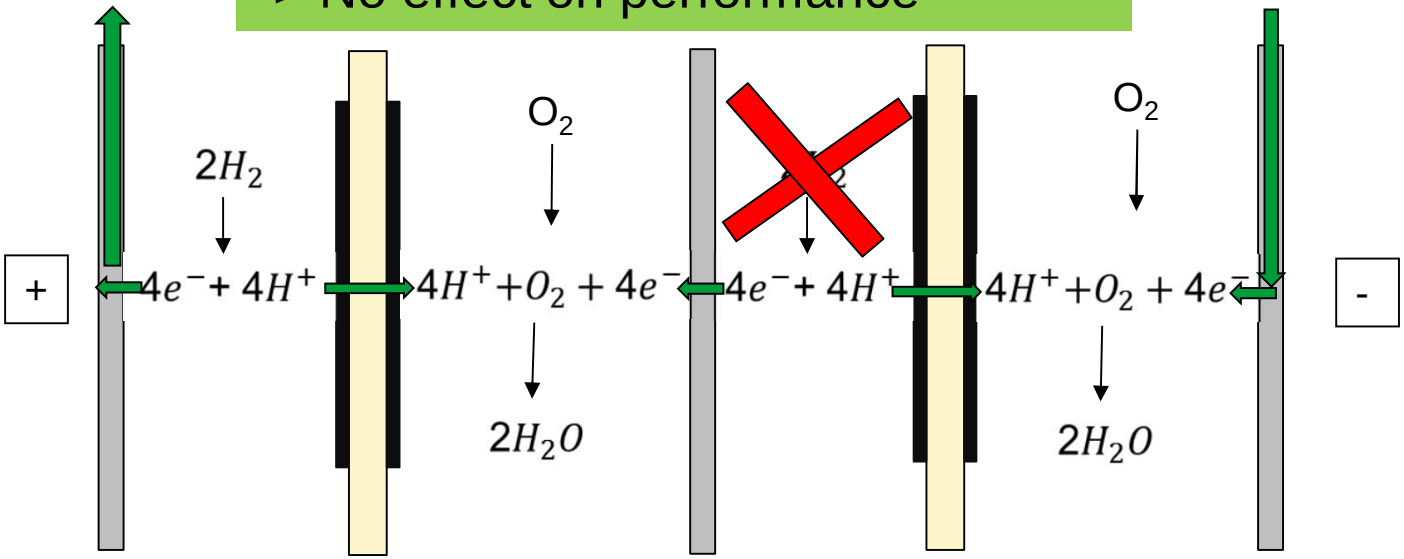
1) R.C. Weast, CRC handbook, 56th Edition (1975)
2) C.A. Reiser *et al. Electrochemical and Solid-State Letters*, **8** (2005) A273-A276

Case: PEM FC in a Car



Case: PEM FC in a Car

H_2 loss in one cell in the stack
-> No effect on performance



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What happend in the cell?

Case: PEM FC in a Car

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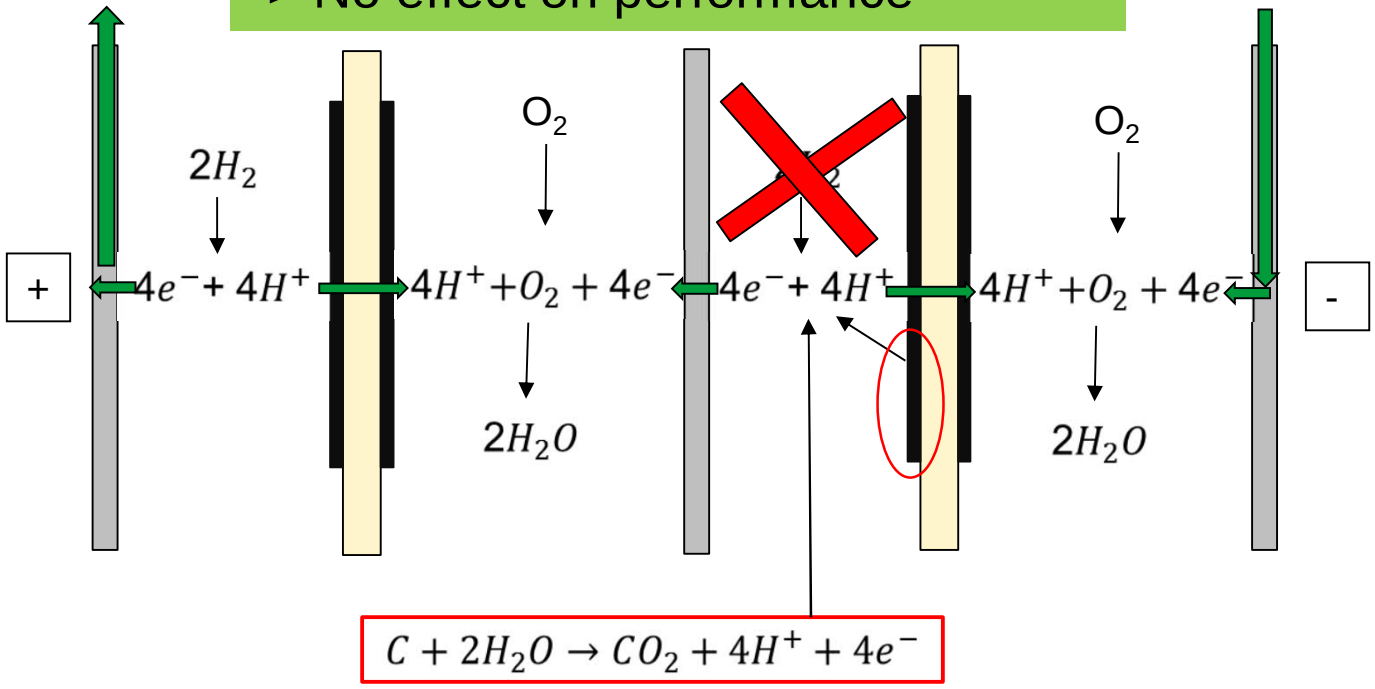
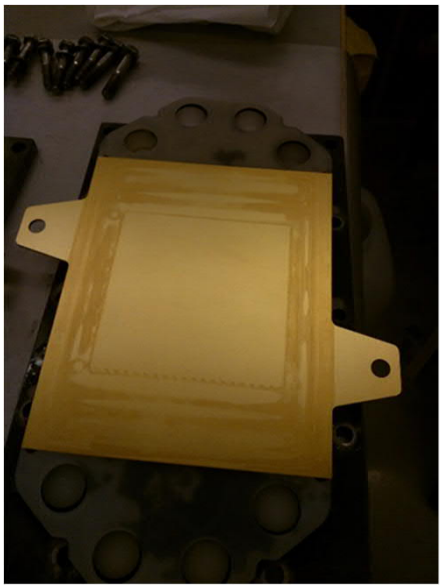
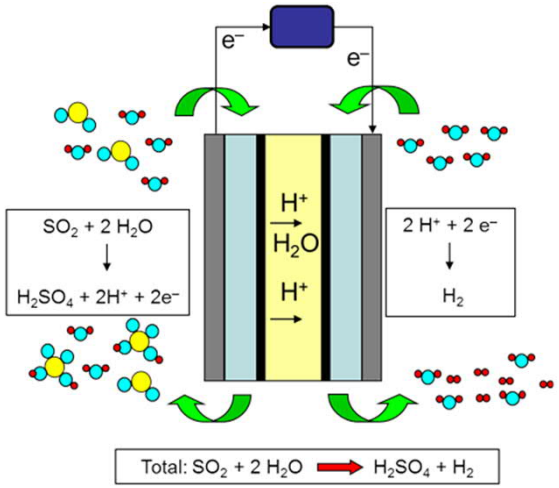


Case 2: Bipolar plates - electrolyser

SO_2 depolarized electrolyser (SDE)

- Bipolar Plates: Stainless steel 904L plates with 100 nm Au coating (catalyst for anode + cathode reactions)





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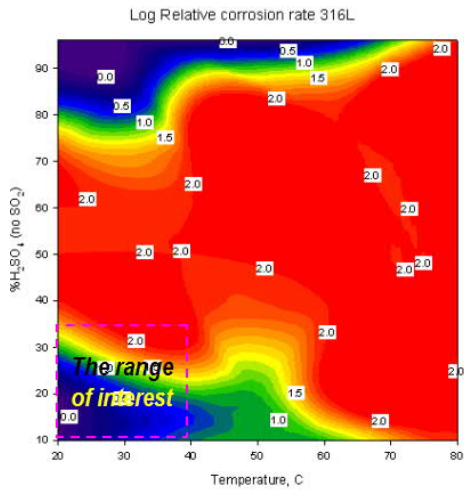
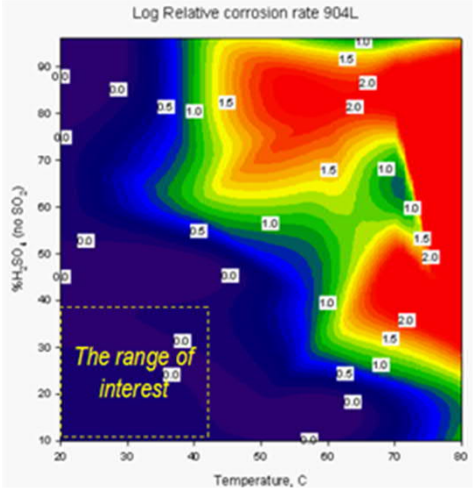
Case 2: Bipolar plates - SDE

Corrosion conditions





Corrosion rate (log mm/year)

Stainless steel 316L
Marine grade

Stainless steel 904L
NiCrMoCu 25/20/5/1

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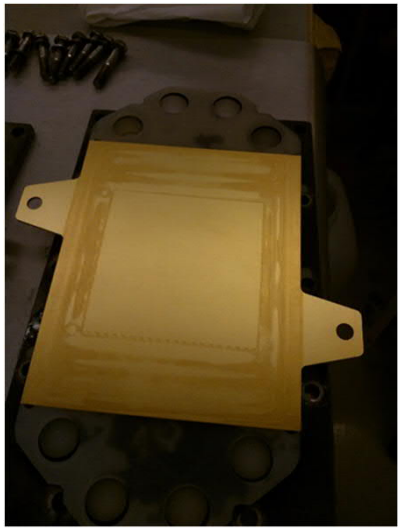
Case 2: Bipolar plates - SDE

Corrosion in SDE

- Stainless steel 904L plates with 100 nm Au coating
- Catholyte 15 wt% H_2SO_4
- Anolyte: 15 wt% H_2SO_4
  Saturated SO_2
- Stack of 5 cells
- 25 ºC
- Constant current experiments 11 A



Case 2: Bipolar plates

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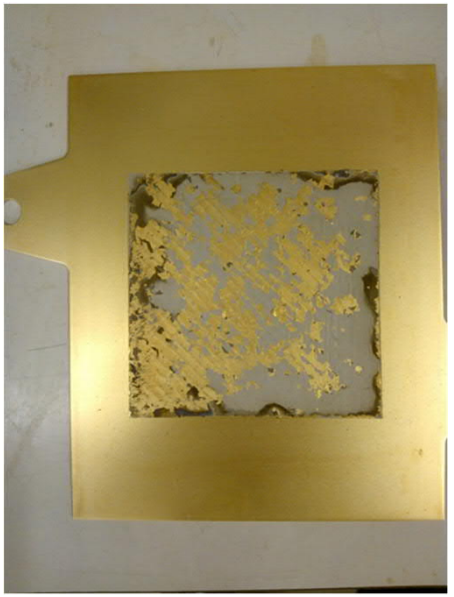
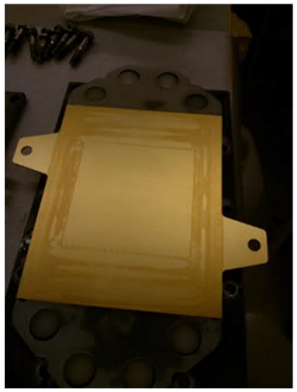
Lecture Journal

What happend in the cell?





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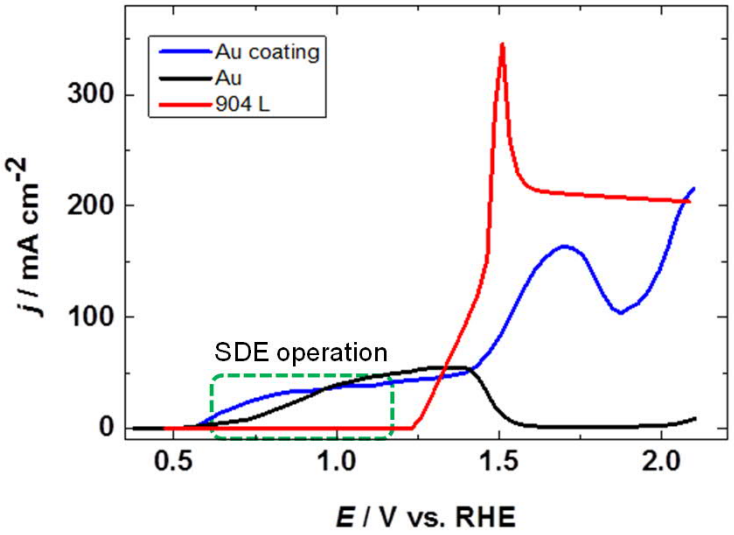

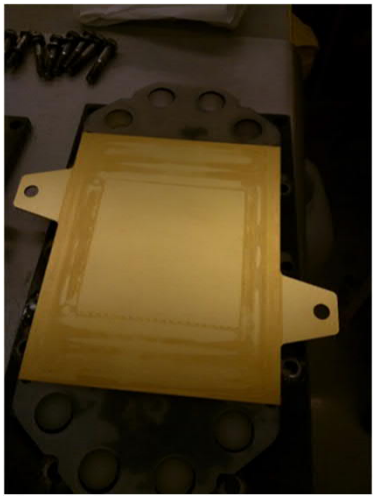

- Stainless steel 904L plates with 100 nm Au coating
- Plate at high potential, **dissolution of steel** under the coating

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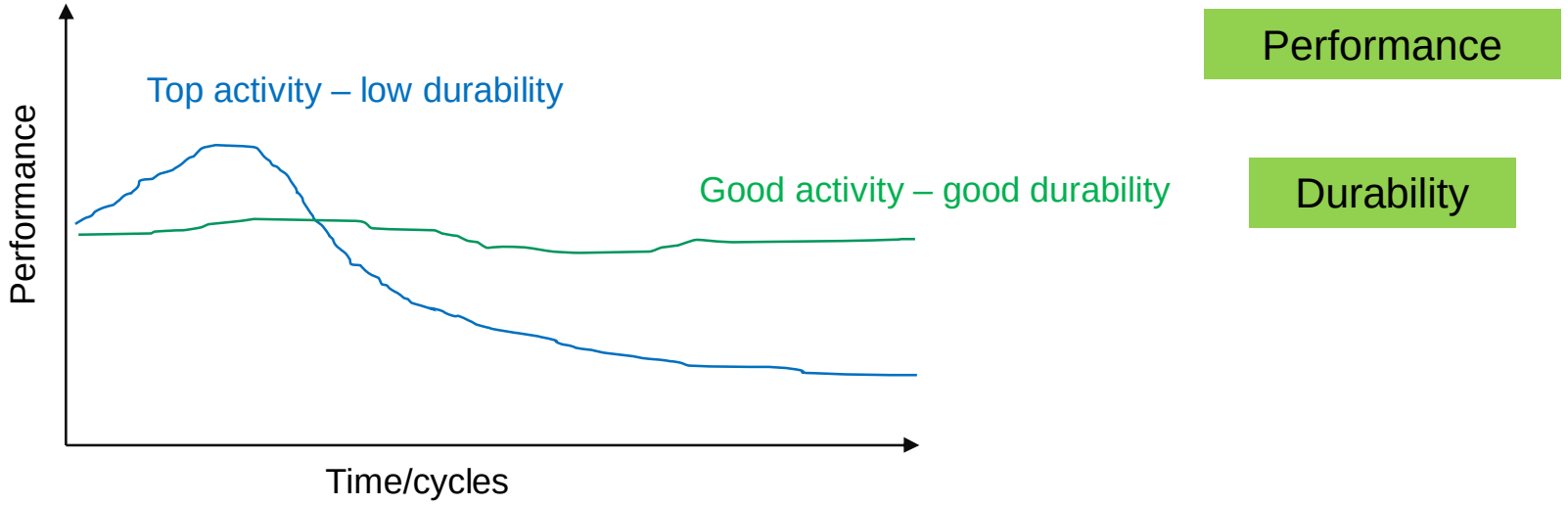
What is valued in active material performance?



High durability leads to **safe applications** for commercial use. Critical elements used for **longer time** (as recycling always energy intensive and costly).

Take a home message

Supportive material degradation will eventually cause partial or **full failure of the system.**

They can also cause **hazard** for reactant/product release in the atmosphere**.**

Even though not directly related with **ACTIVITY,** supportive material durability is important to keep in mind when planning the design.