*Development of a hydrogen **electrochemical compressor** for aerospace applications*

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Hydrogen compressor technologies

MECHANICAL COMPRESSORS
RECIPROCATING, MEMBRANE, LINEAR AND IONIC LIQUIDS

BENEFITS

- Mature technologies
- Large flow rates, high pressure in discharge

INCONVENIENTS

- Multiple components in motion
- Metal embrittlement
- Possibility of contaminated hydrogen
- Structural complexity and maintenance
- Noise and vibration
- Dimension
- Not suitable for large compression ratios
- For a service station: 54% CAPEX, 28% energy consumption, 18% OPEX

NON-MECHANICAL COMPRESSORS
CRYOGENIC, METAL HYDRIDE, ELECTROCHEMICAL AND ADSORPTION/DESORPTION

BENEFITS

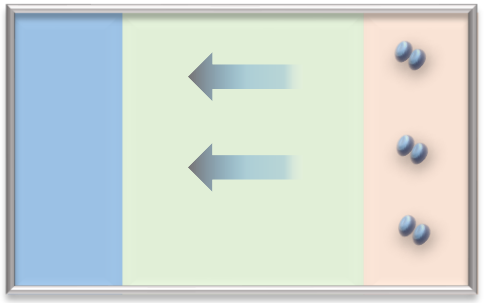
- No moving components, noise and vibration
- High efficiency (for some...)

INCONVENIENTS

- Cost
- Operational difficulties (operating temperature...)
- Fairly new, not mature technologies

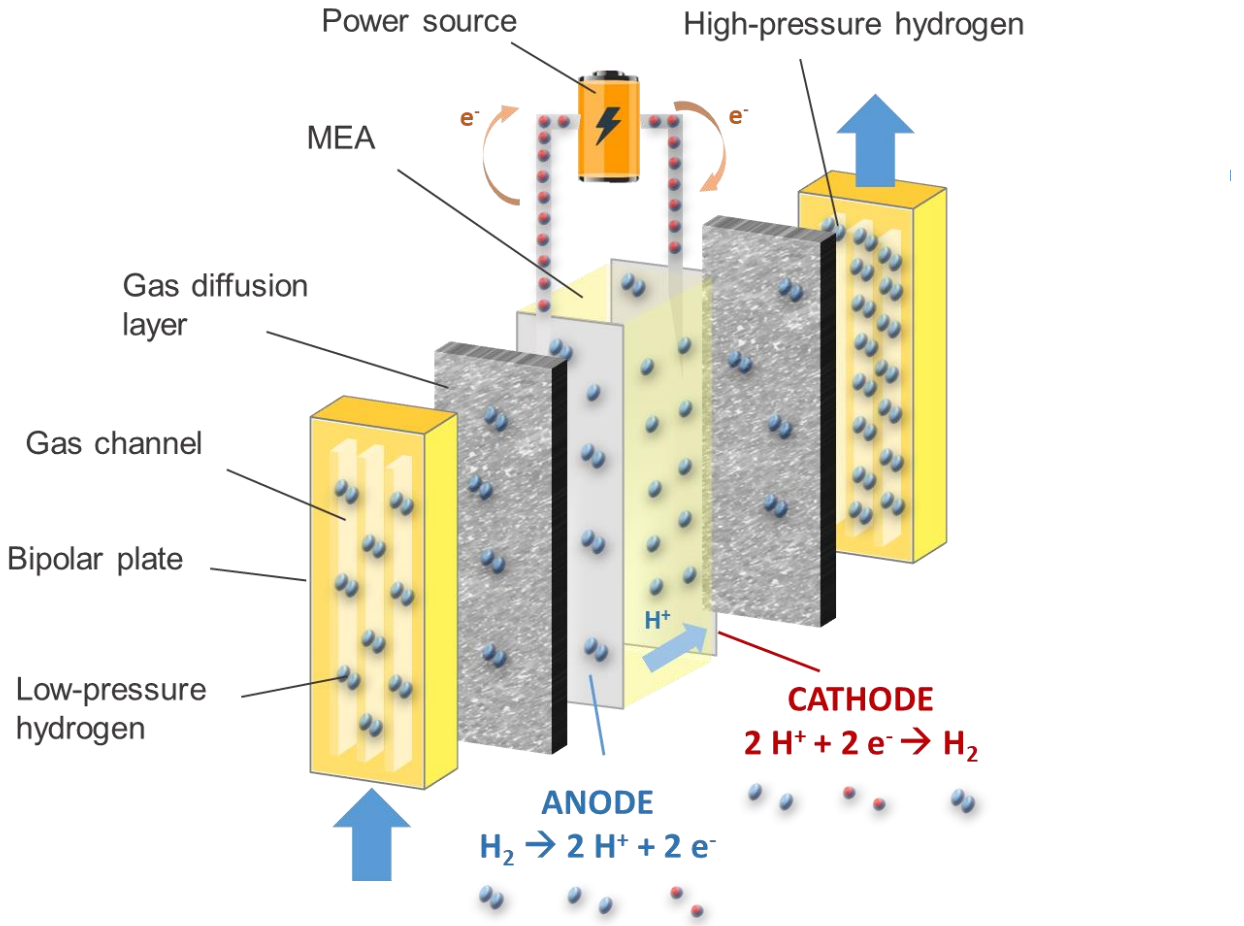
Hydrogen electrochemical compressor

- Same technology as fuel cells (*mature*)
- Several advantages
  - Low CAPEX and OPEX
  - **High purity hydrogen produced**
  - No moving parts
  - Compactness
- Very high efficiency: ≈ **60%** up to 40 bar
- Not suitable for high pressures (limit for an EHC ≈ **160 bar**)
  - **Hydrogen back-diffusion**



Through both membrane and non-membrane paths

ACTION:
Will be investigated

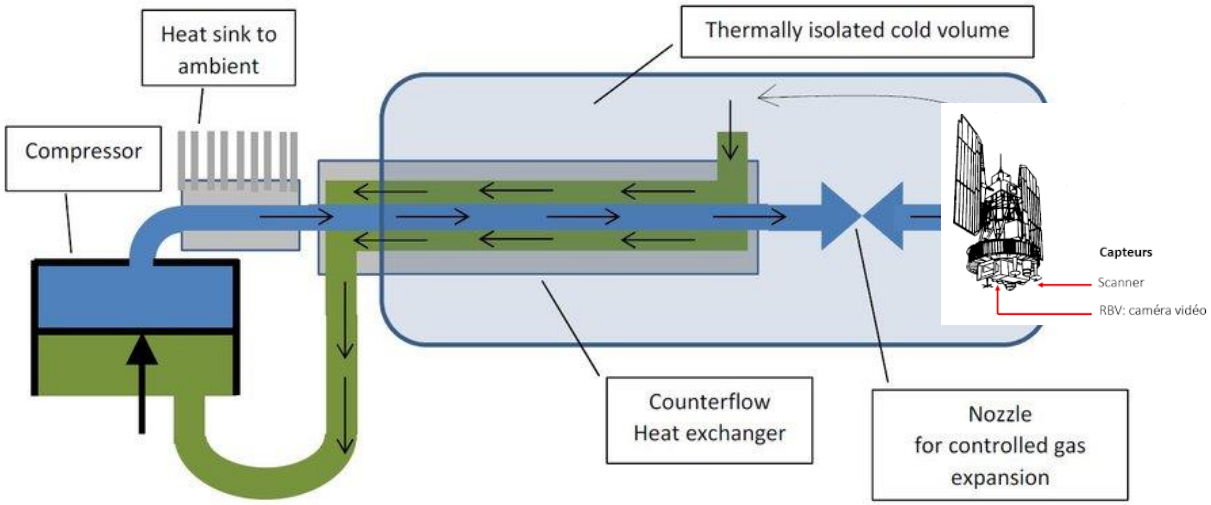


Hydrogen compressor in the space

- Mechanical compressors generate **vibrations detrimental to extraterrestrial observation**

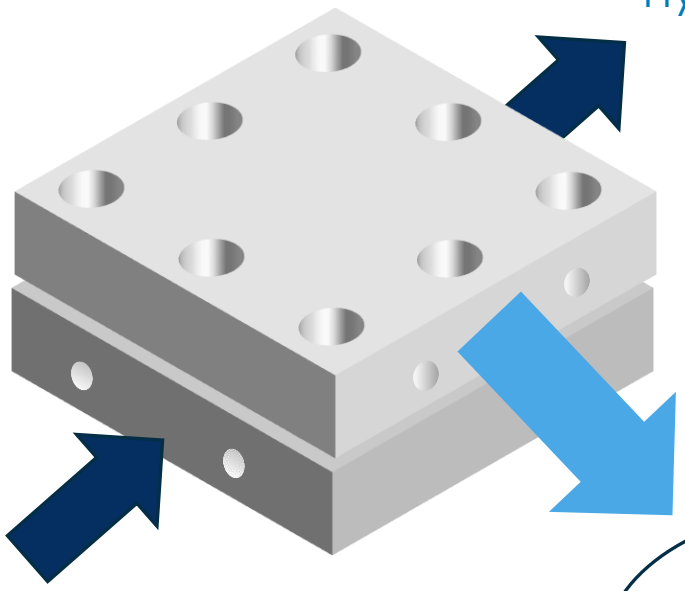
- We want to develop a compressor that is:
  - Compact
  - Silent
  - Does not generate vibration

► **Electrochemical compressor**



Water transport mechanisms in EHC

MARKET OVERVIEW

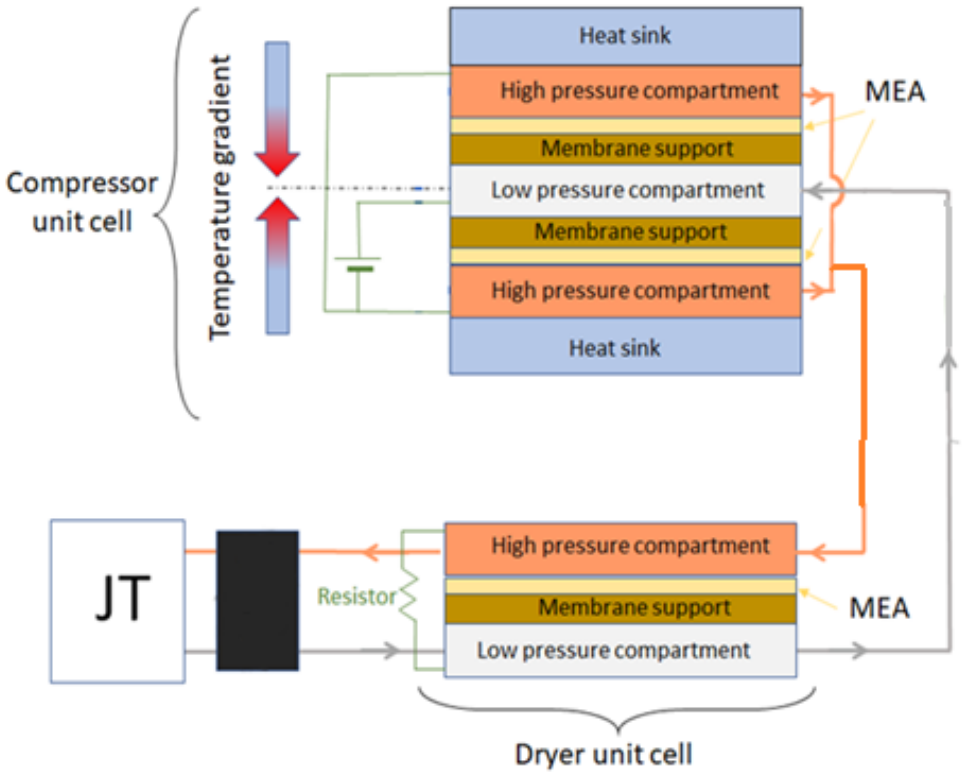


HyET Hydrogen — Efficient purification & compression

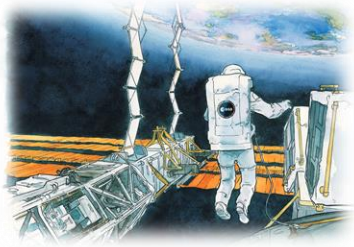
OPEN CIRCUIT EHC

- Allows using high stoichiometries to reach a **better and homogenous humification** of the membrane
- Purges are possible → **stable performance is achievable**

EHC in aerospace applications



- Coupling an EHC with a JT cryocooler is a new idea
- We will use a **closed circuit EHC**
- Water management is an important issue:
  →Water flooding can arise at the low-pressure compartment



*When the temperature of the low-pressure compartment is lower than that of the MEA, **liquid water may condense**, which may cause the flooding of the catalyst sites if water enters the MEA porous support.*

Purging is not allowed in a closed system!!

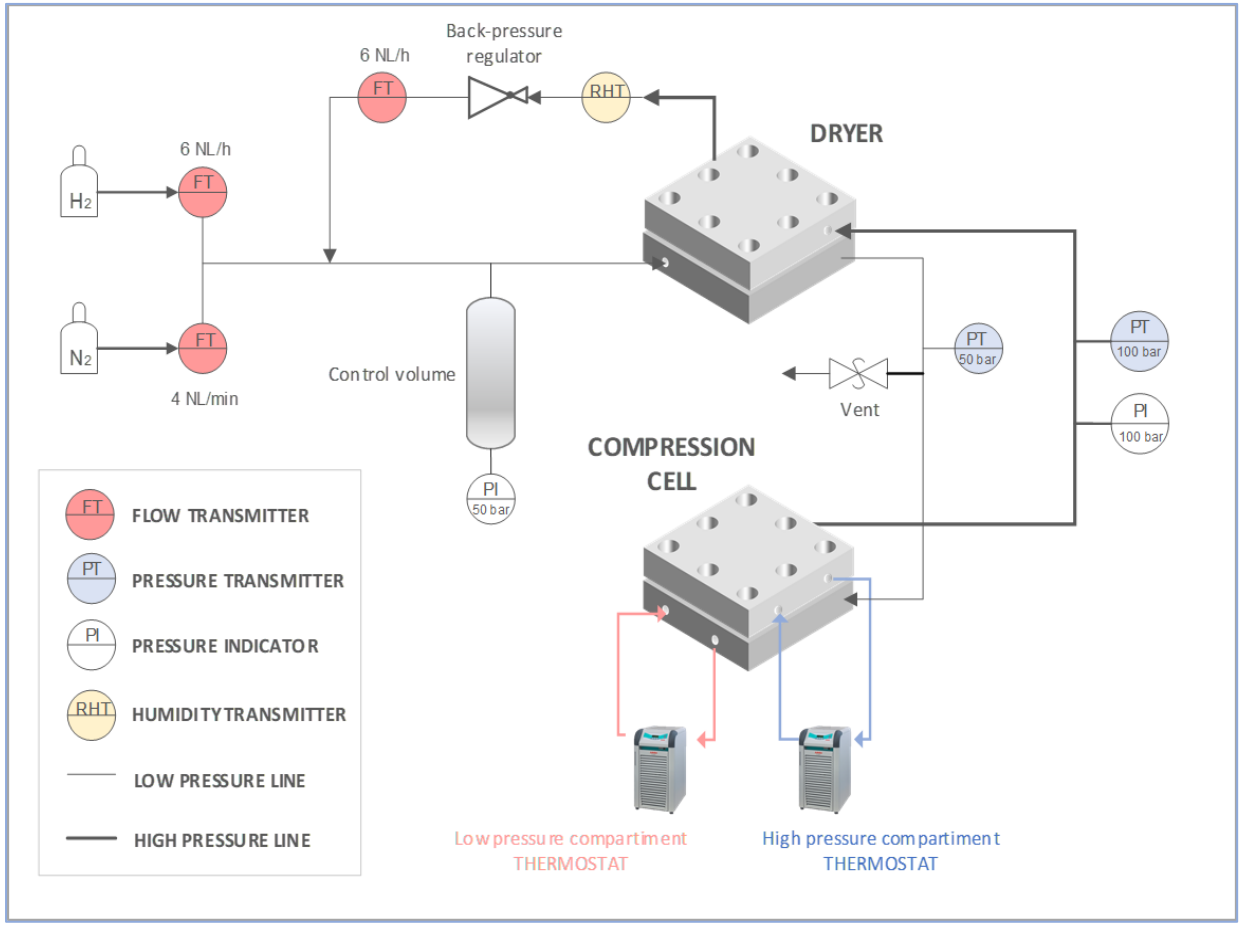
We have proposed to **set a temperature gradient** between the low-pressure and the high-pressure compartments.

HOW: low-pressure compartment warmer than the high-pressure one, decoupling of anode and cathode

EHC in aerospace applications

WE BUILT A PRELIMINARY EXPERIMENTAL SETUP ABLE TO COMPRESS H2 UP TO

100 bar!!!

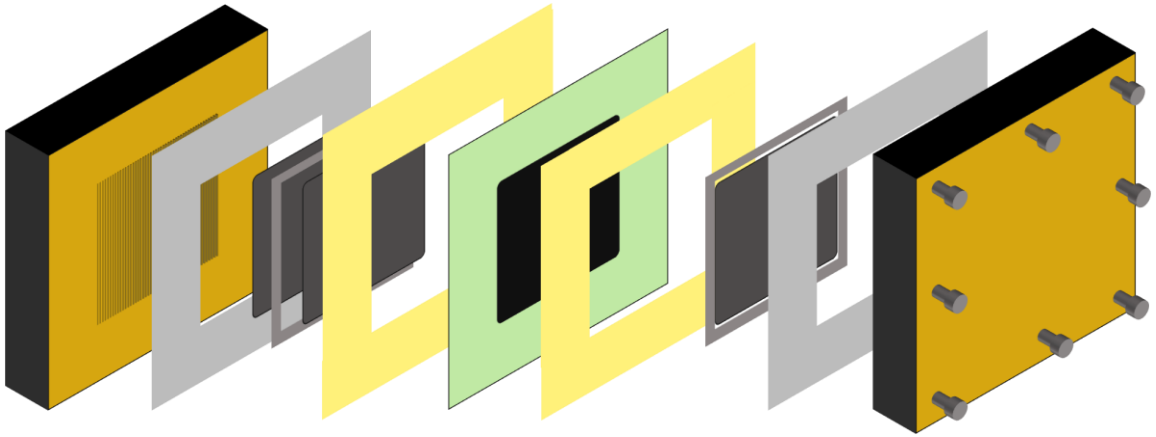


It consists in:

- An electrochemical compressor cell (**EHC**)
- A **membrane exchanger**, which will be placed upstream of the PSA unit in order to remove water from the hydrogen flow before JT expansion

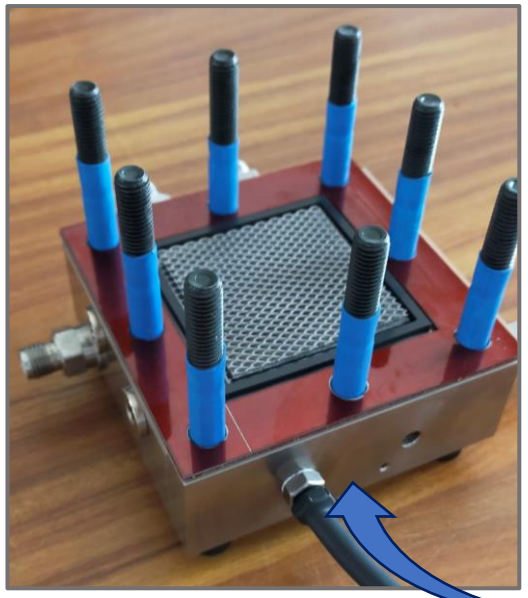
LEMTA-ESA EHC

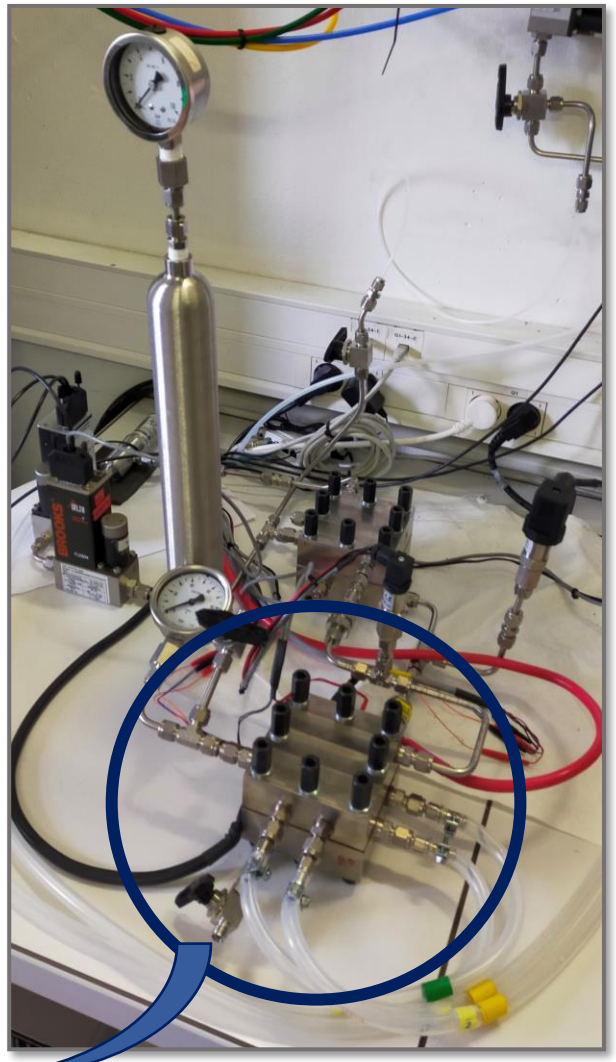
A COMPRESSING SANDWICH



CHECK LIST:

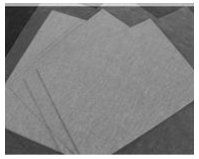
- H_2 pressure: 100 bar
- Temperature ≈ 20 °C
- H_2 flow: 10 mg/s
- Power supply ≈ 100 W
- **Dew point T outlet < -60 °C (JT…)**
- Adapt for aerospace applications (volume, weigth)



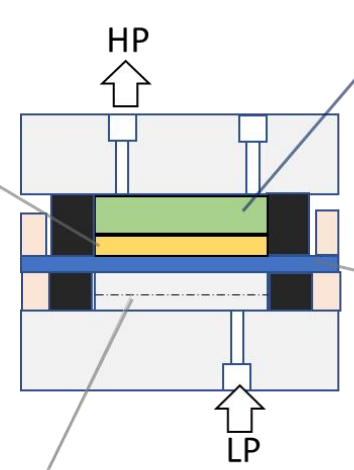


LEMTA-ESA EHC

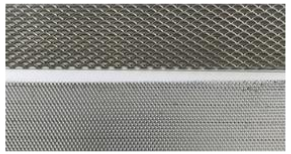
CORE MATERIALS



TITANIUM FELTS AND Pt COATING



TITANIUM DEPLOYED METAL



MEA
(**Nafion XL** and **Nafion HP**)
(28 µm) *(22 µm)*

SINTERED TITANIUM POROUS PLATE & PT COATING

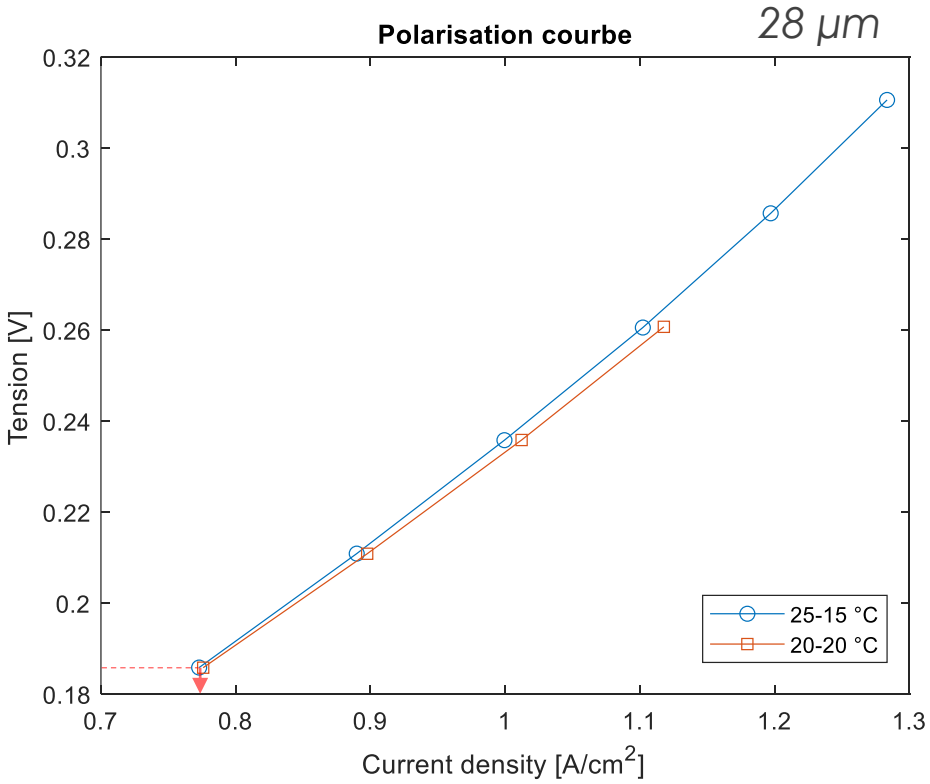
PTLs with different pore size
(0.5 – 1 – 5 µm)

- According to LEMTA experience, **Titanium seems to be the best choice** to be used in order to prevent the water contamination by metallic ions, which is observed whenever stainless steel is used instead.
- The **hydrophilicity of Titanium** is much higher than that of both iron and carbon fibers
- **Gold- and platinum- coated Titanium** components will be used, which will prevent the embrittlement by hydrogen

Results

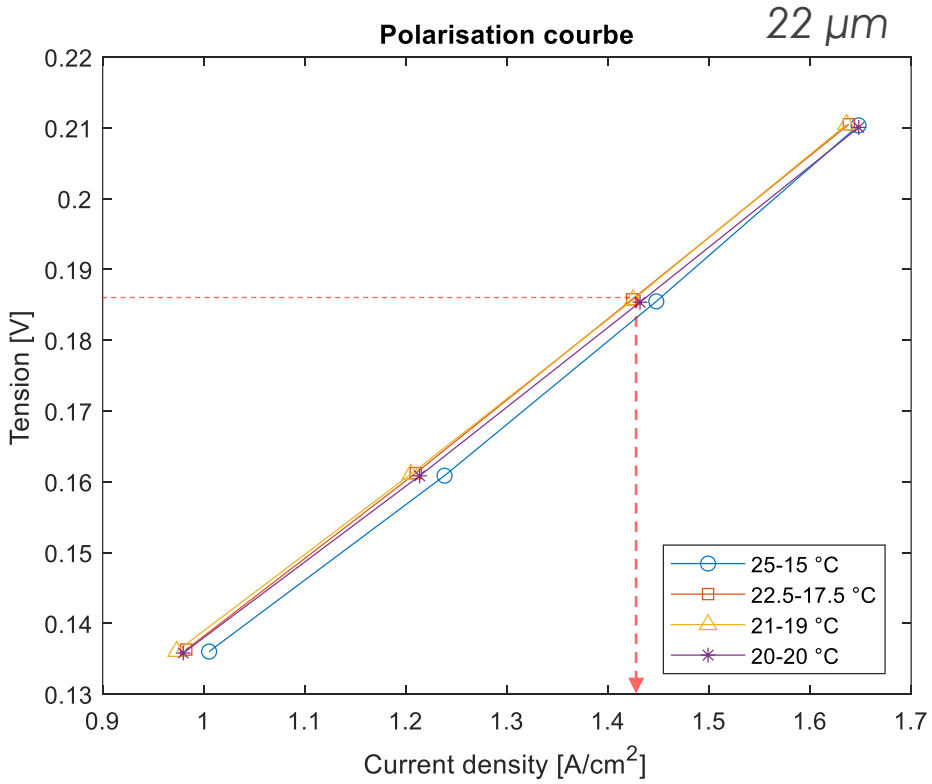
COMPARISON OF ELECTROCHEMICAL PERFORMANCES

NAFION XL



@ 0.185 V → 0.77 A/cm²

NAFION HP



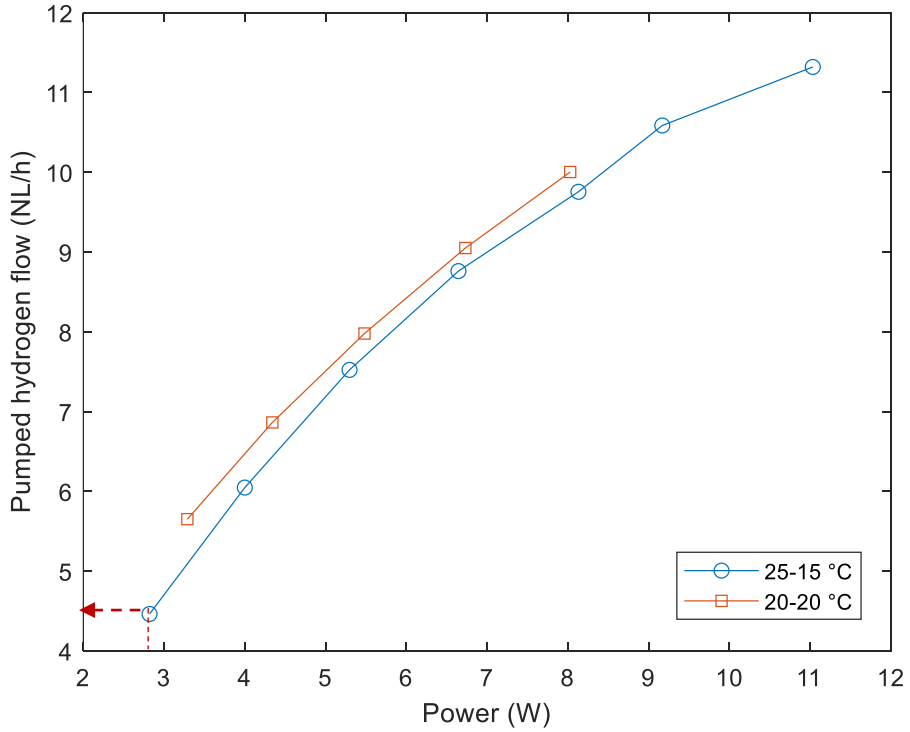
@ 0.185 V → 1.43 A/cm²

NAFION XL showed worse performances than NAFION HP

Results

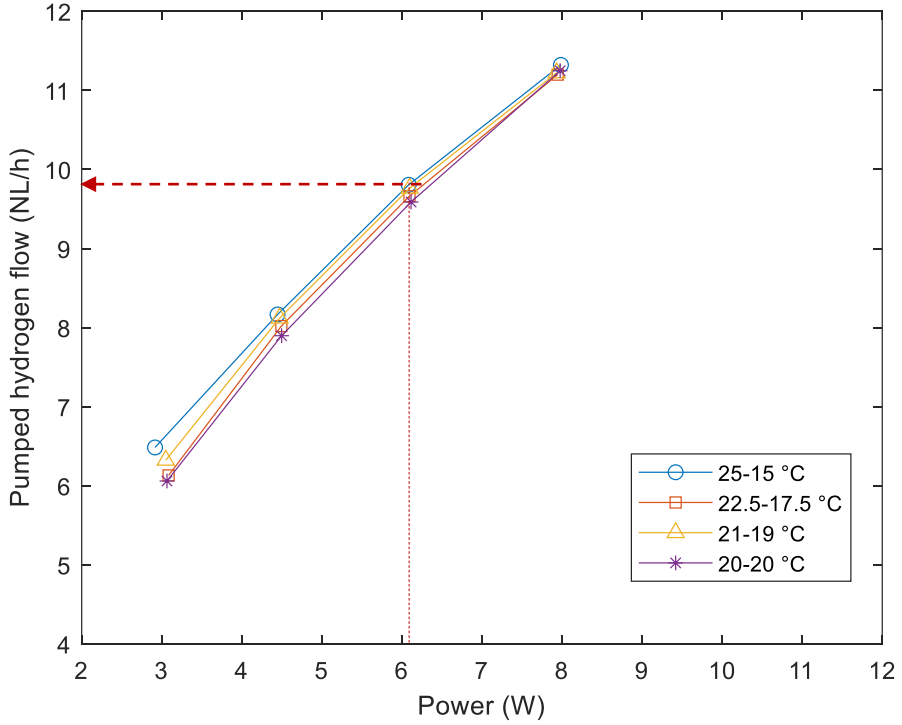
COMPARISON OF ELECTROCHEMICAL PERFORMANCES

NAFION XL



@ 0.185 V / 2.8 W → 4.5 NL/h (0.112 mg/s)

NAFION HP

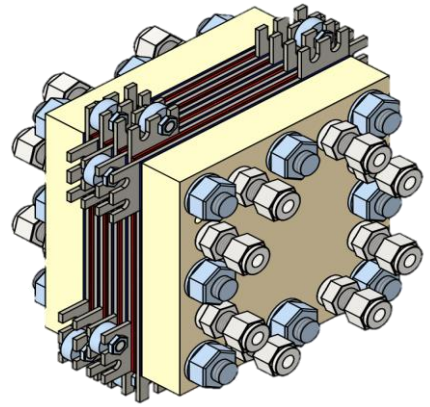


@ 0.185 V / 6.1 W → 9.85 NL/h (0.24 mg/s)

NAFION XL showed worse performances than NAFION HP (overall)

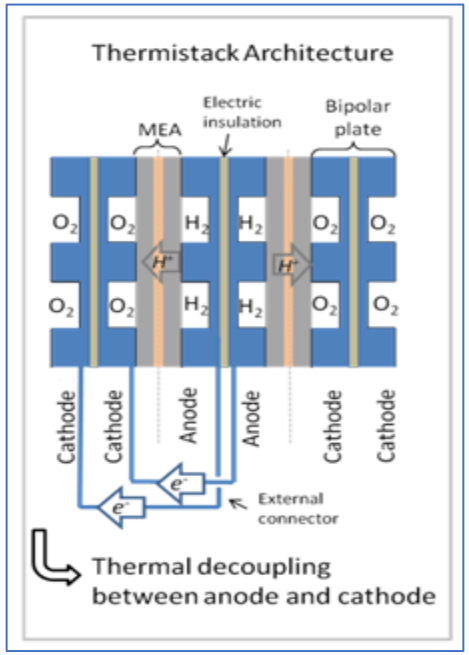
THERMISTACK architecture

To achieve the desired high pressure hydrogen flow, it is necessary to **connect several cells in series**. → **STACK, how many cells?**



The design of the EHC has been inspired by the "**THERMISTACK**" architecture developed and patented by the LEMTA laboratory in 2014 (Patent n. WO/2014/060198. 2014)

- in the "Thermistack" configuration, the **electrical connections** (whose role is to connect the cells in series), **are external**
- **Thermal decoupling** between anode and cathode



CONVENTIONAL ARCHITECTURE

Purging the low-pressure compartment can be a solution to avoid flooding, but it leads to a loss of hydrogen and water

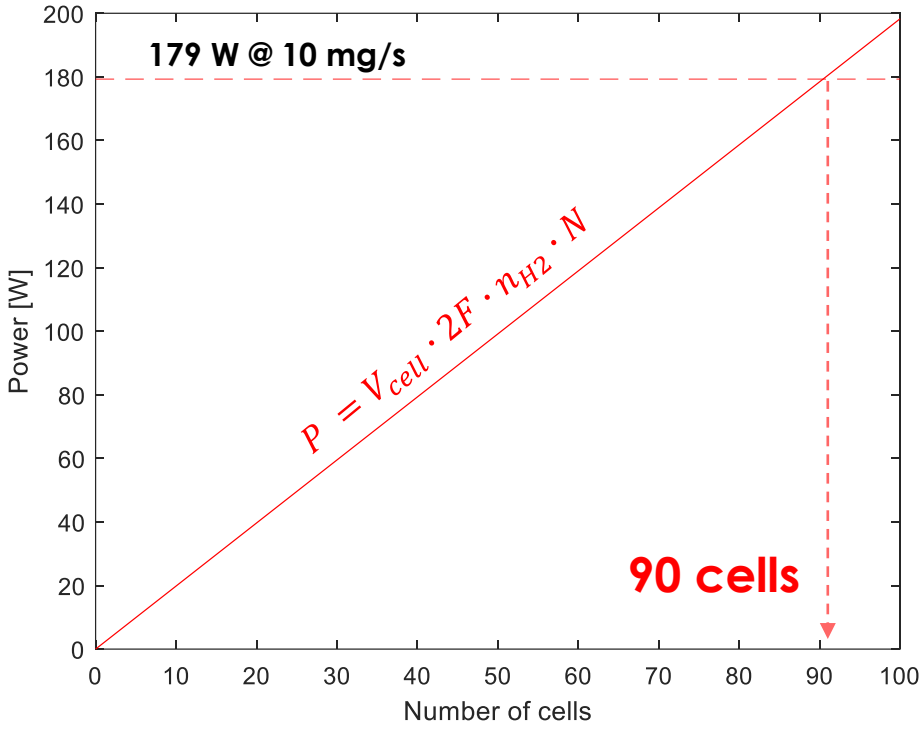
THERMISTACK

By cooling only the high-pressure compartment, any purge will be unnecessary, and the stability of operation will be ensured

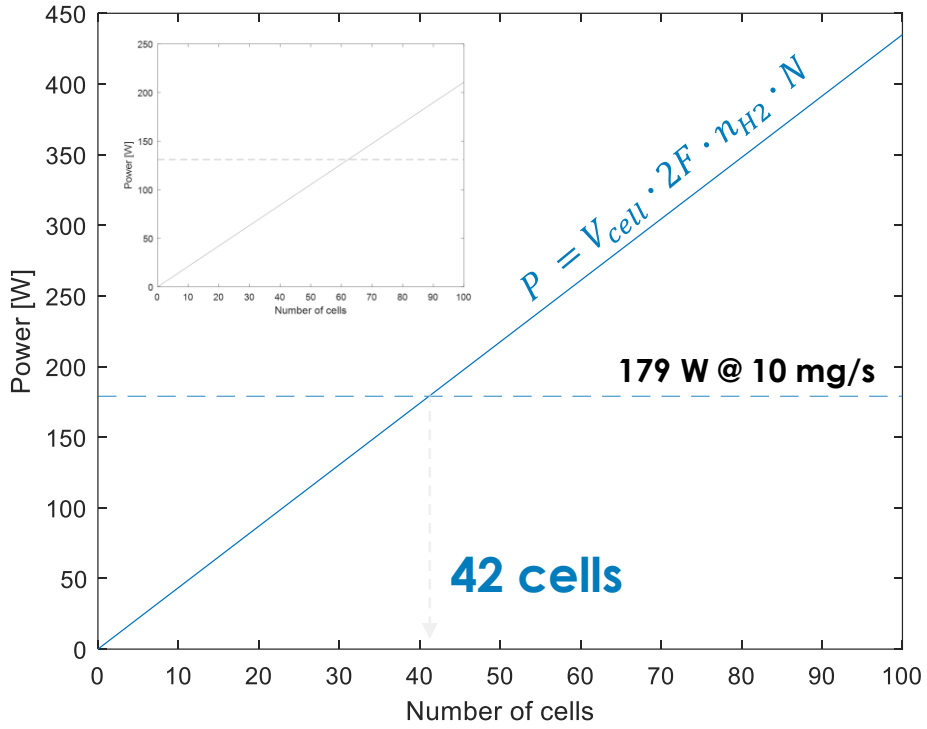
Results

COMPARISON OF ELECTROCHEMICAL PERFORMANCES

NAFION XL



NAFION HP



for a single cell surface of 25 cm²

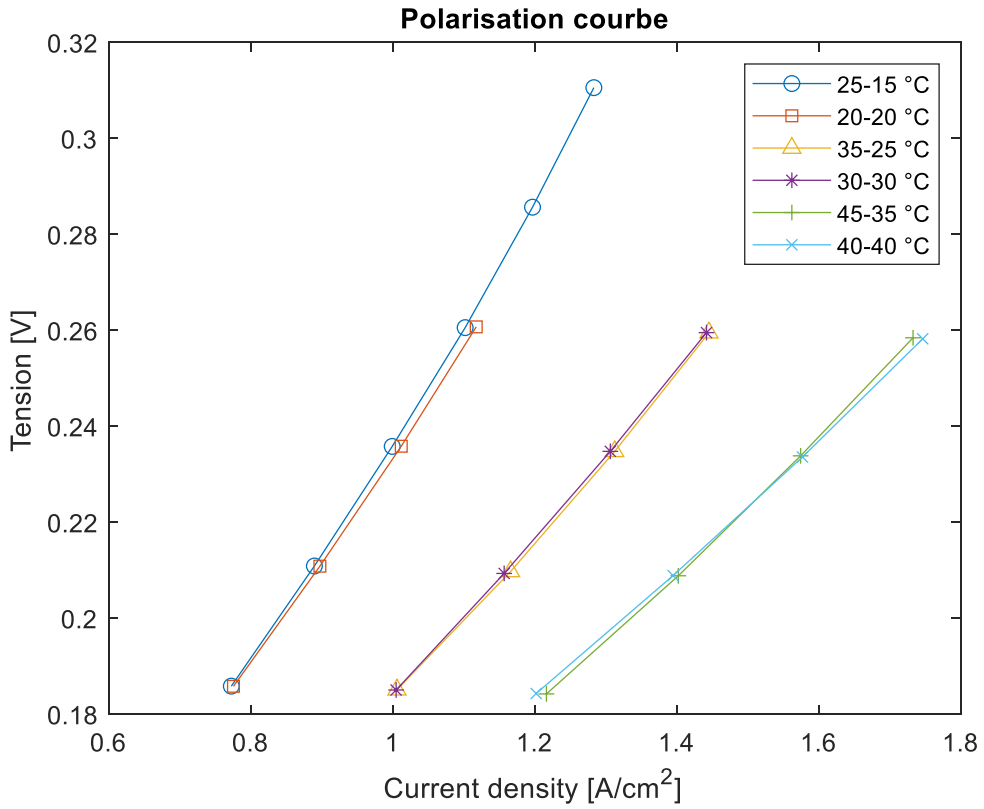
@ 0.185 V/cell → 179 W for compressing 10 mg/s

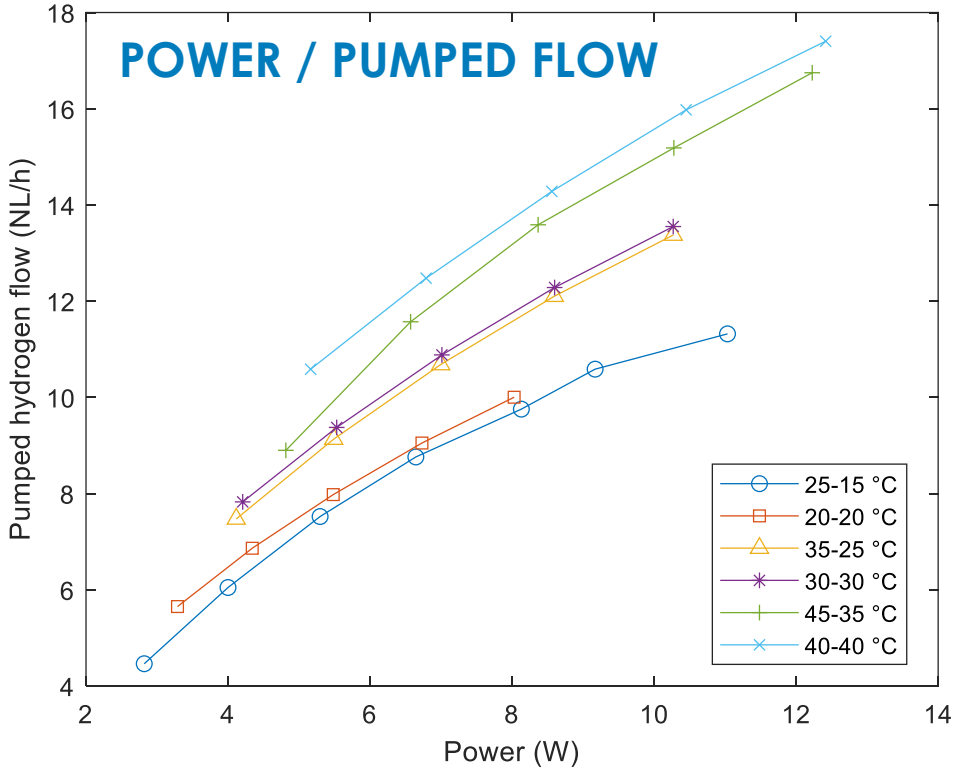
90 cells if using NAFION XL / 42 cells for NAFION HP

@ 0.15 V/cell → 131 W for compressing 10 mg/s BUT 62 cells

Results

IMPROVING THE PERFORMANCES of NAFION XL





Beneficial effect of the temperature increase

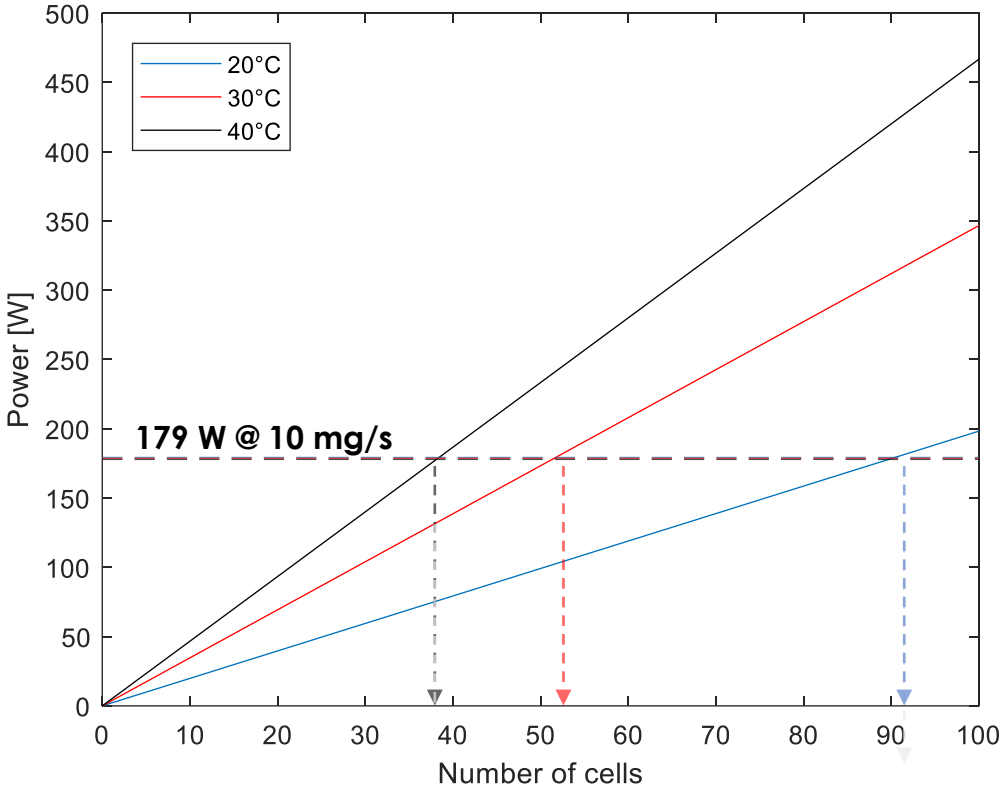
Negligible effect of T gradient

Higher current densities @ V

Higher pumped flows @ W

Results

IMPROVING THE PERFORMANCES of NAFION XL



for a single cell surface of 25 cm²

@ 0.185 V/cell → 179 W for compressing 10 mg/s

- **90 cells @ 20 °C**
- **51 cells @ 30 °C**
- **38 cells @ 40 °C**

Beneficial effect of the temperature increase

Conclusions and perspectives

- A PEM electrochemical compressor coupled to a water membrane exchange is the solution we propose in the framework of this project
- From preliminary tests, this system looks able to reach high pressures up to **100 bar** and dew point temperatures down to **-60 °C**, at 20 °C.
- Stack of about 40 cells has been designed to compress around **10 mg/s** of hydrogen.
- Preliminary studies have shown a durability of more than **37 days (**… but I decided that ☺)

Perspectives

- Further investigation is required to select the **best operating conditions** to reach the highest efficiencies (membrane-temperature-temperature gradients
- Building the stack