# Anion Exchange Membrane Electrolysis for Renewable Hydrogen Production on a Wide-Scale


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https://anione.eu/

# PROJECT OBJECTIVES

*Overall objective:*

To develop **high-performance** (energy consumption < 50 kWh/kg $H_2$), **cost-effective** (0.75 M€ / t/d $H_2$) and **durable** (degradation <5 µV/h at 1 A $cm^{-2}$) anion exchange membrane water electrolysis technology.

*Approach:*

Advanced CRM-free electrocatalysts, anion exchange membrane (AEM) and ionomer dispersion in the catalytic layers for hydroxide ion conduction in a system operating with diluted KOH.

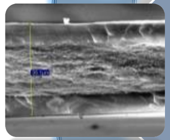
ANIONE aims to validate, as proof-of-concept, a 2 kW AEM electrolyser with a hydrogen production rate of approximately 0.4 $Nm^3$ $H_2$/h .

*Goal:*

Allow a **scalable production of low-cost hydrogen** from renewable sources through a **reduction of capital costs**, while assuring **high conversion efficiency** and proper **life-time**.

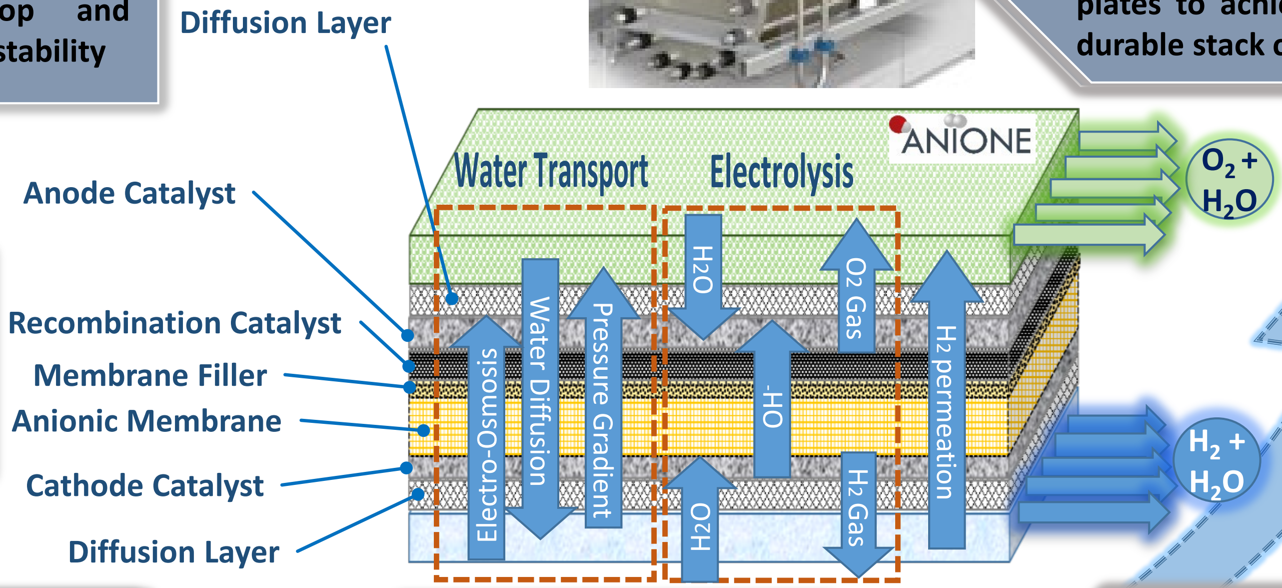
# Stack components optimization for AEM electrolysers

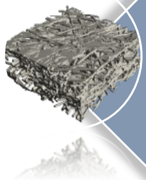
TRL 2



Reinforced AEM membrane with lower thickness to reduce ohmic drop and improve mechanical stability

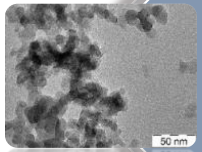
Flow-field free stack design amenable to scale up; protective coatings of steel plates to achieve low cost and durable stack components



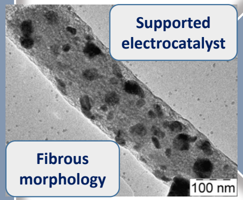



Redesign diffusion layers to improve gas diffusion and overcome reversible degradation

TRL 4




Cross-over management through recombination catalyst; Use of radical scavengers



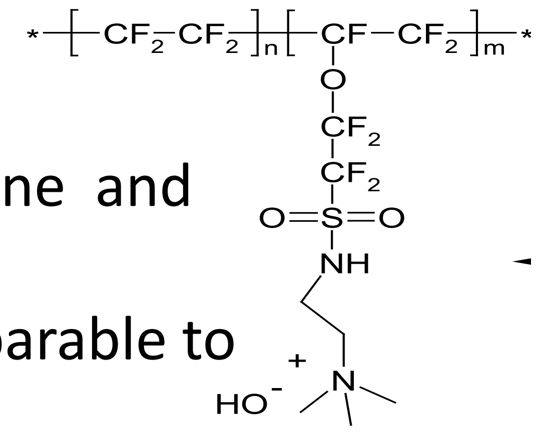

CRM-free nanostructured catalysts to increase intrinsic activity and stability, reducing mass transport

Increase current density to reduce capital costs, allow compact stack design and efficient use of materials

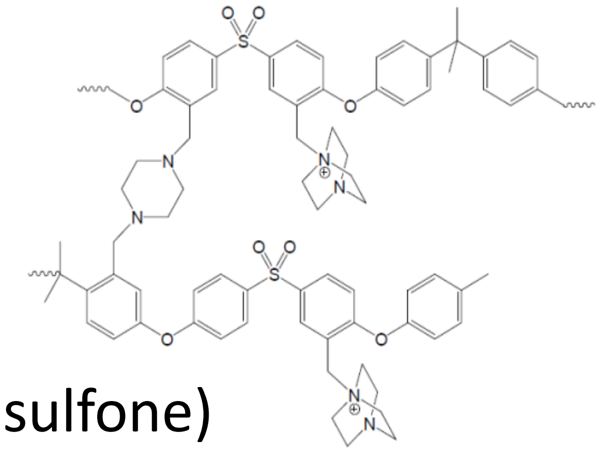
# PROJECT FOCUS: AEM



Focus on two parallel approaches for the anion exchange membrane:



- ✓ Short side chain **perfluorinated AEM** comprising a perfluorinated backbone and pendant chains, covalently bonded to the perfluorinated backbone, with quaternary ammonium groups to achieve conductivity and stability comparable to their protonic analogous (Nafion ®)
- ✓ **Hydrocarbon AEM membranes** consisting of either poly(arylene) or poly(olefin) backbone with quaternary ammonium hydroxide groups carried on tethers anchored on the polymeric backbone



And a back-up solution:

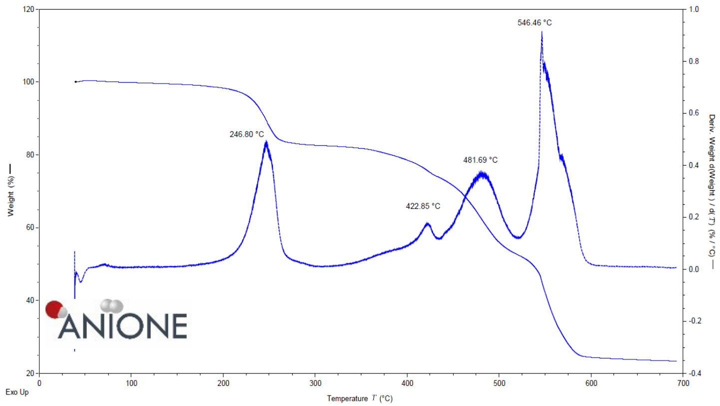
- ✓ Modify commercial hydrocarbon membranes and ionomers based on DABCO (1,4-diazabicyclo[2.2.2]octane $N_2(C_2H_4)_3$) cross-linked poly(sulfone) resins as alternative membranes (back-up solution).

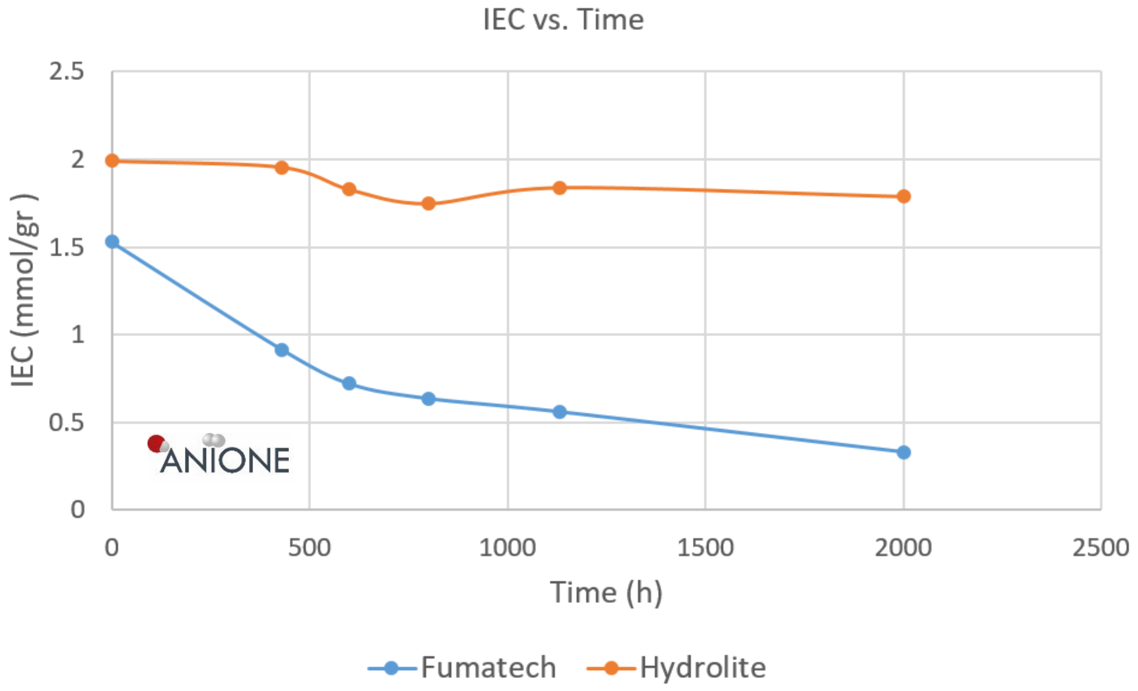
Tal-Gutelmacher et al., Membranes 2021, 11, 686.

Carbone et al. Chemical Engineering Journal (2022) 140765.

# MEMBRANE DEVELOPMENT IN ANIONE

## HYDROLITE MEMBRANE VS. BENCHMARK MEMBRANE




### IEC vs. Time (1 M KOH 80 °C)

| Type of membrane/time in 1M KOH 80 °C (Hour) | 0 | 430 | 600 | 800 | 1130 | 2000 |
|---|---|---|---|---|---|---|
| **IEC (mmol/gr) of FAA3-** | 1.53 | 0.915 | 0.72 | 0.635 | 0.56 | 0.33 |
| **IEC (mmol/gr) of Hydrolite** | 1.99 | 1.955 | 1.83 | 1.75 | 1.875 | 1.79 |

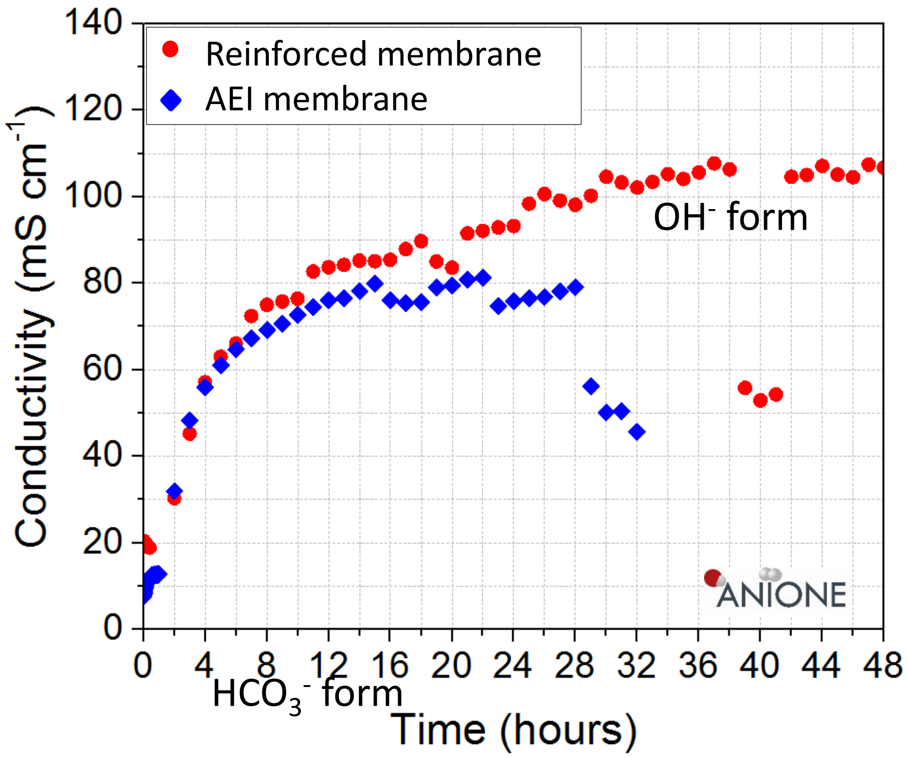
- % of IEC remained after 2000h using Fumatech membrane is: 21.56
- % of IEC remained after 2000h using Hydrolite membrane is: 89.94

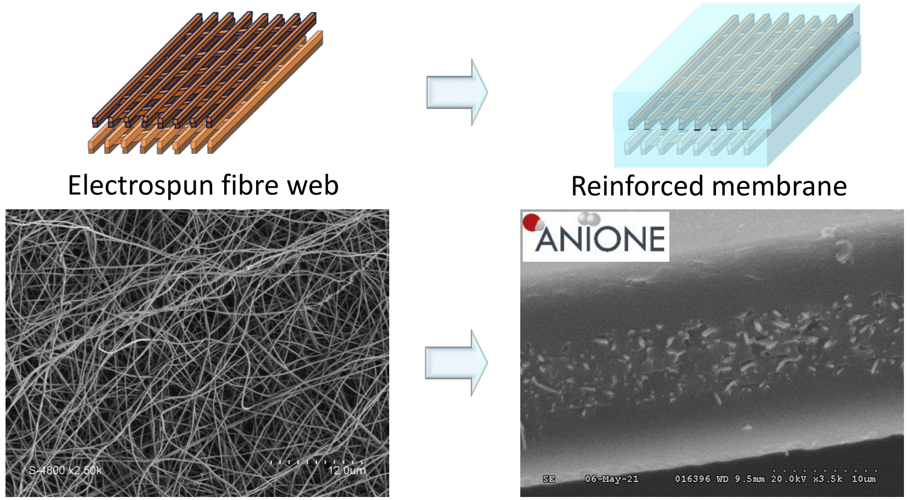
**Excellent retention of the IEC for the Hydrolite membrane after prolonged immersion in KOH**
**Good thermal stability**

# Reinforced composite membranes

## $HCO_3^-/OH^-$ conductivity and stability determination

50 °C, 100 % RH

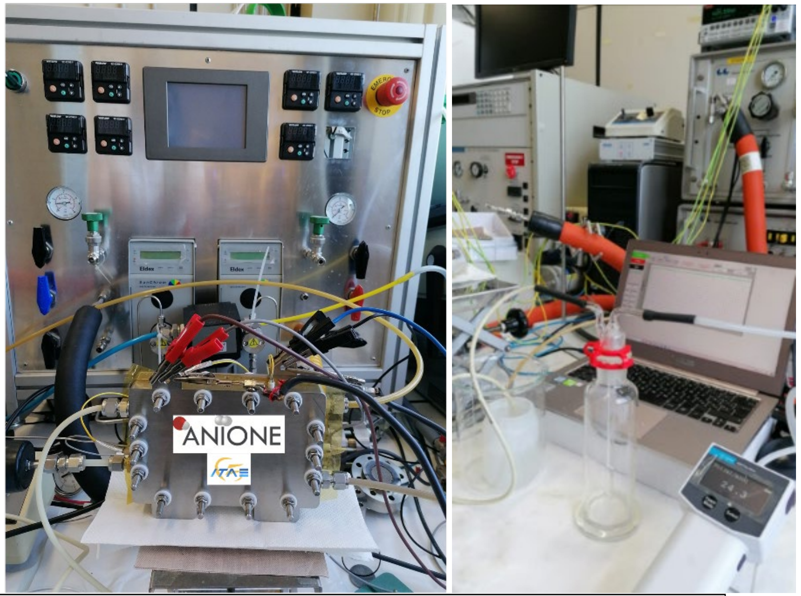


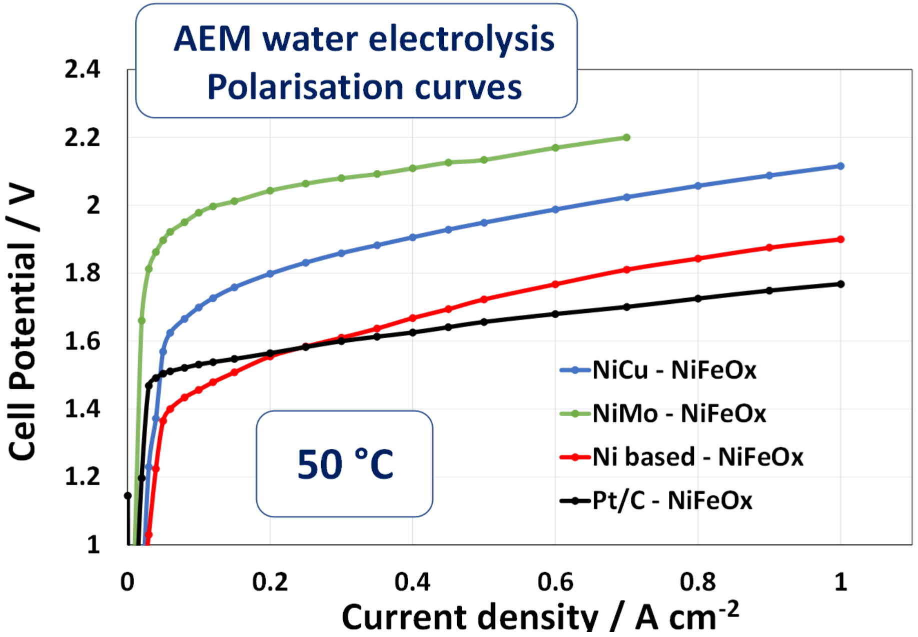




- Measurements show a factor 8 increase in conductivity between $HCO_3^-$ form and $OH^-$ form
- The stability increased with the reinforced membranes: full exchange achieved and conductivity of **105 mS cm$^{-1}$**

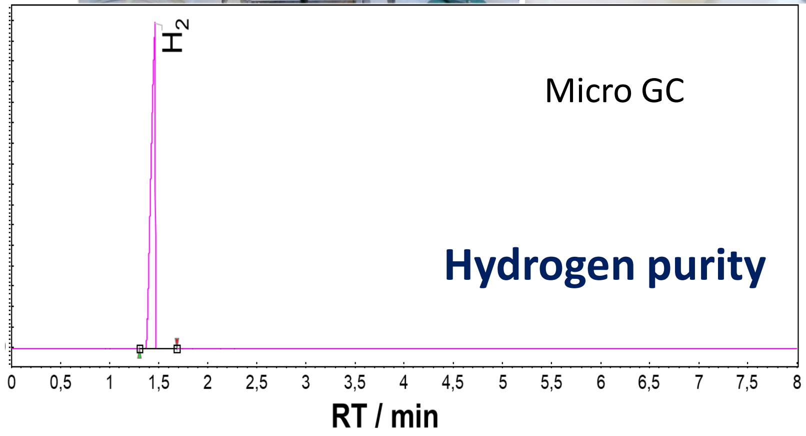
# AEM Polarisation curves, Faradaic efficiency, durability and hydrogen quality

AEM ELECTROLYSIS single cell testing in ANIONE

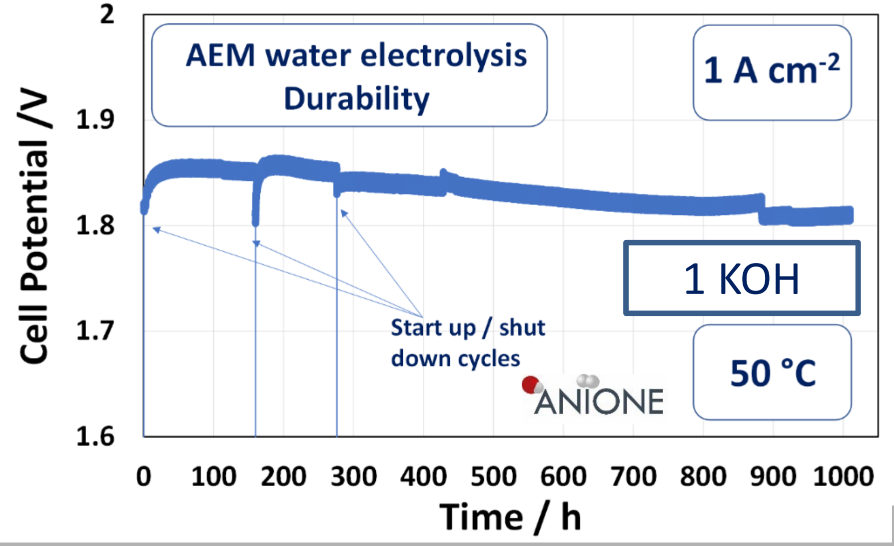



***Effect of catalyst composition on AEMEL performance***



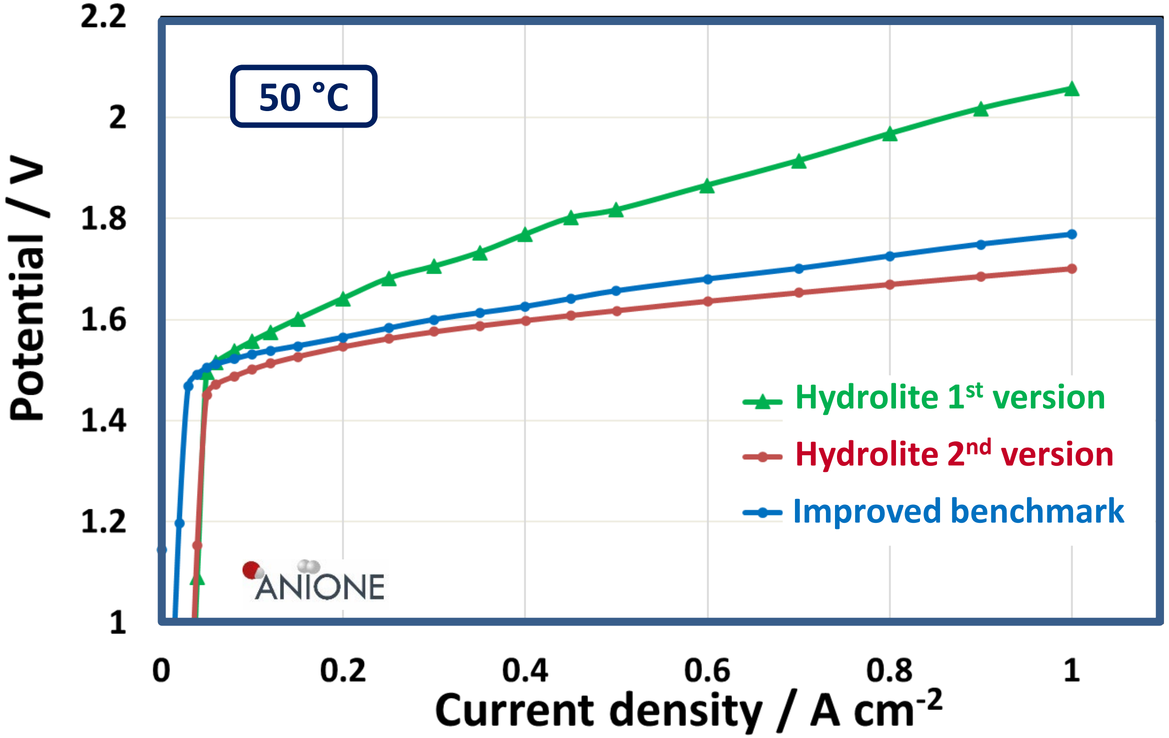

***AEMEL durability***

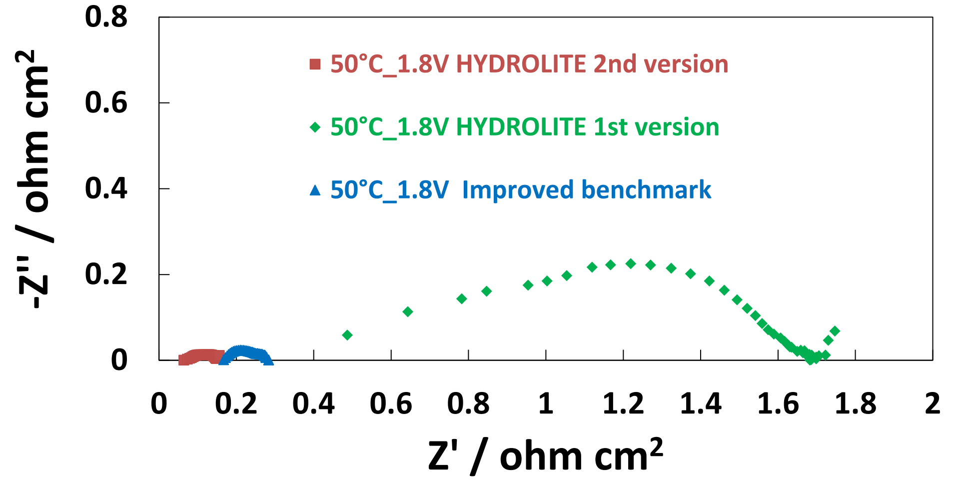


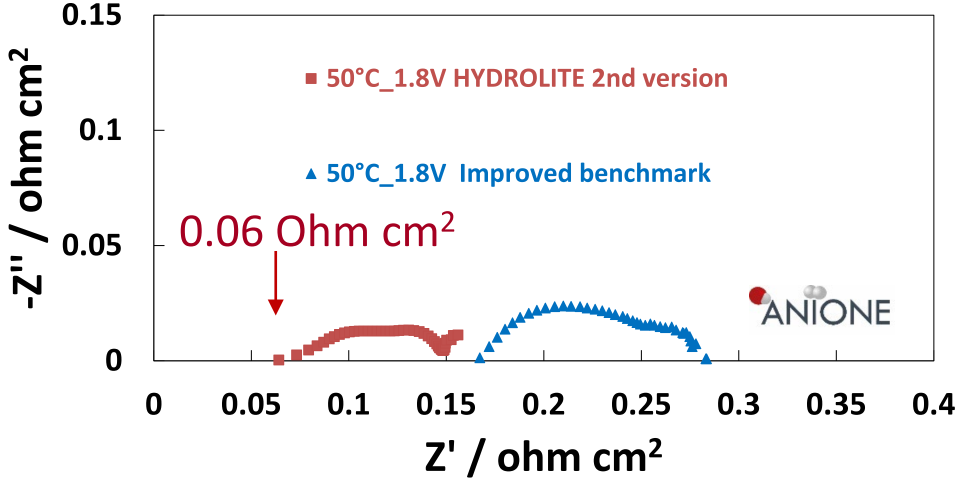

Zignani et al. Electrochim. Acta 413 (2022) 140078

# Hydrocarbon membrane development

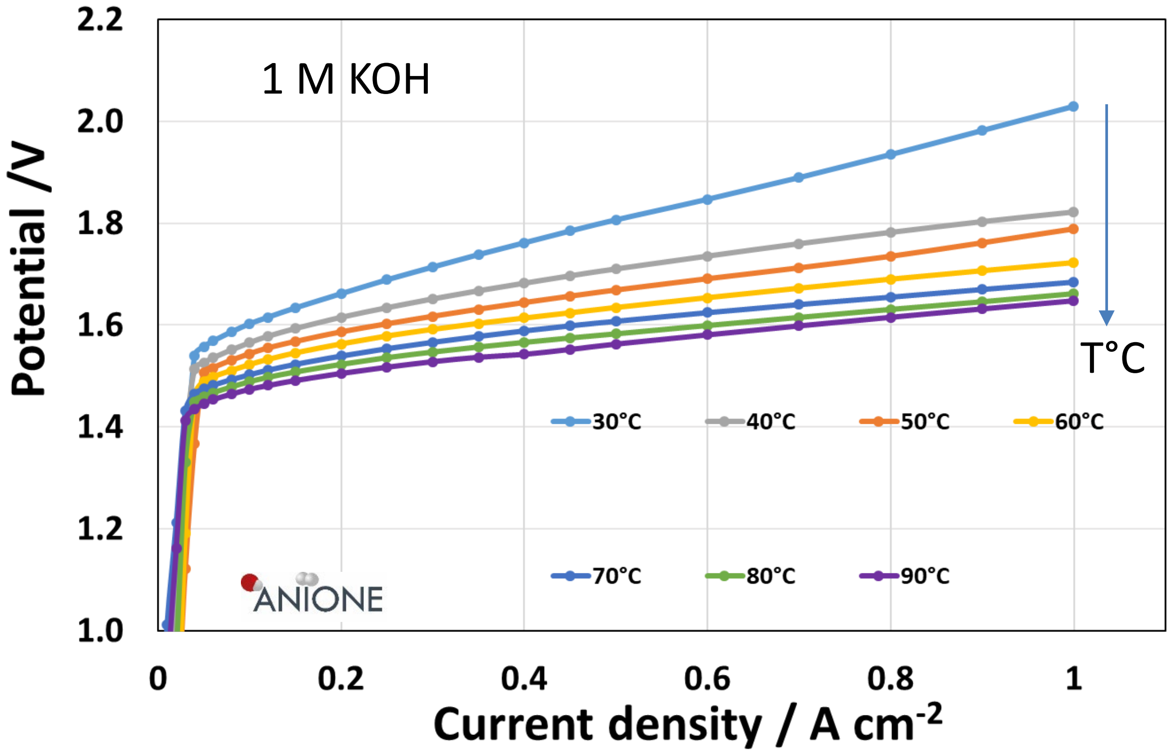
## Performance of 1.7 V at 1 A cm$^{-2}$ achieved

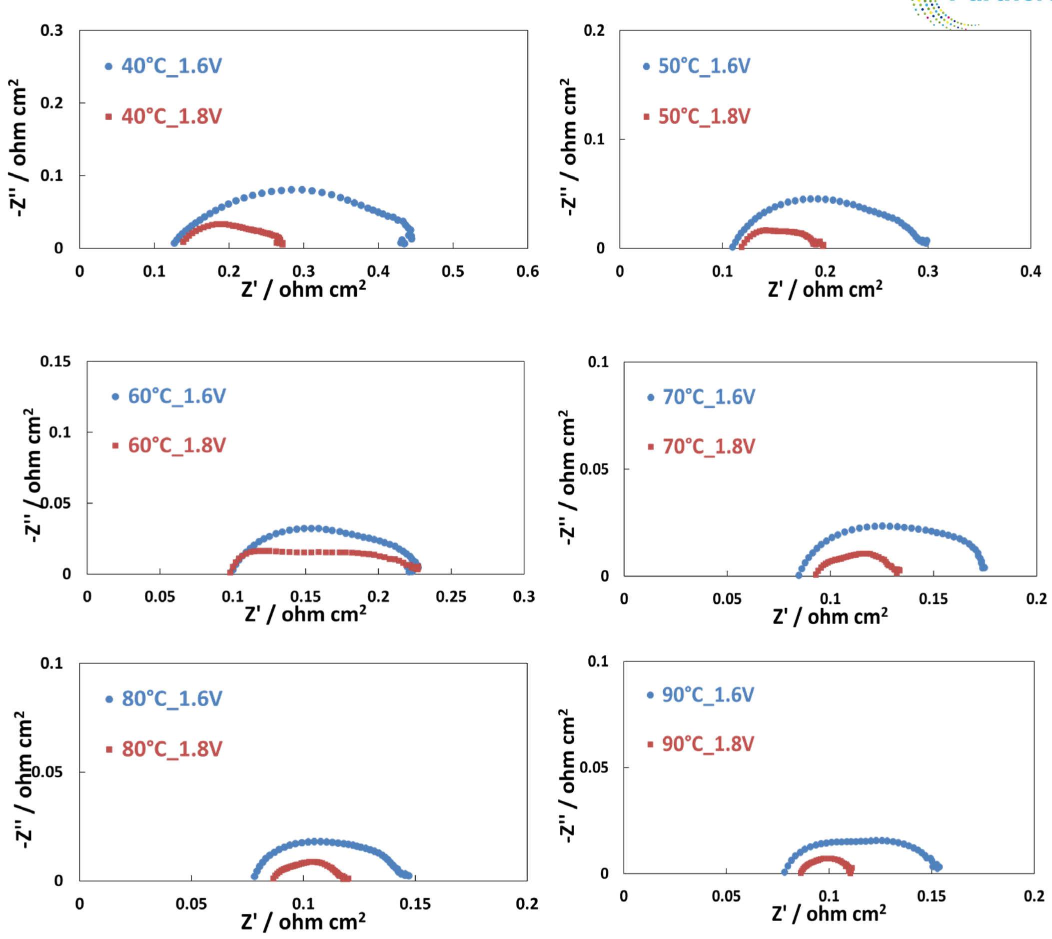


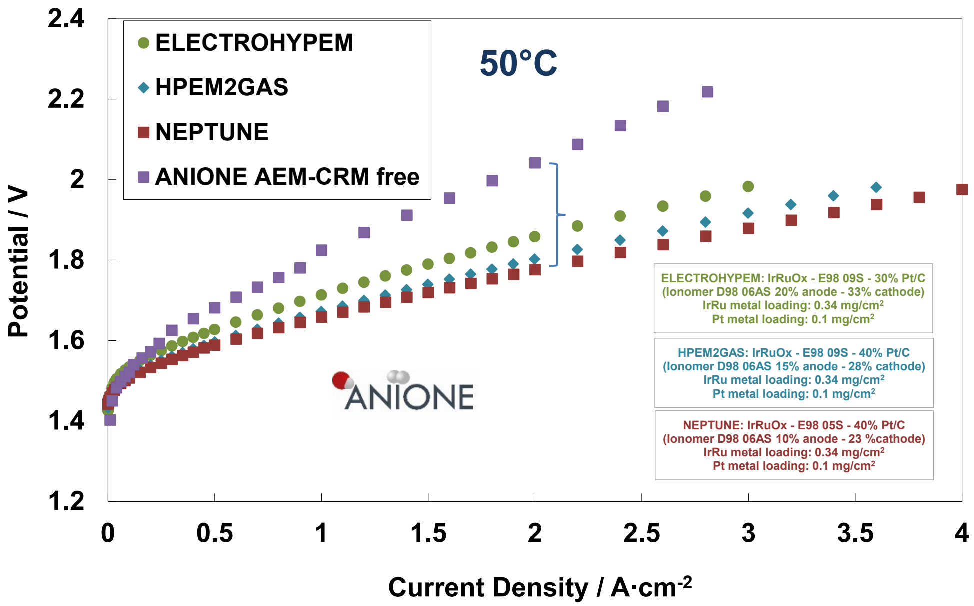
# COMPOSITE AEM MEMBRANES AND OPERATING TEMPERATURE




Larger effect of temperature on the decrease of polarisation resistance vs. ohmic resistance

# Comparison of PEMWE and AEMWE performance



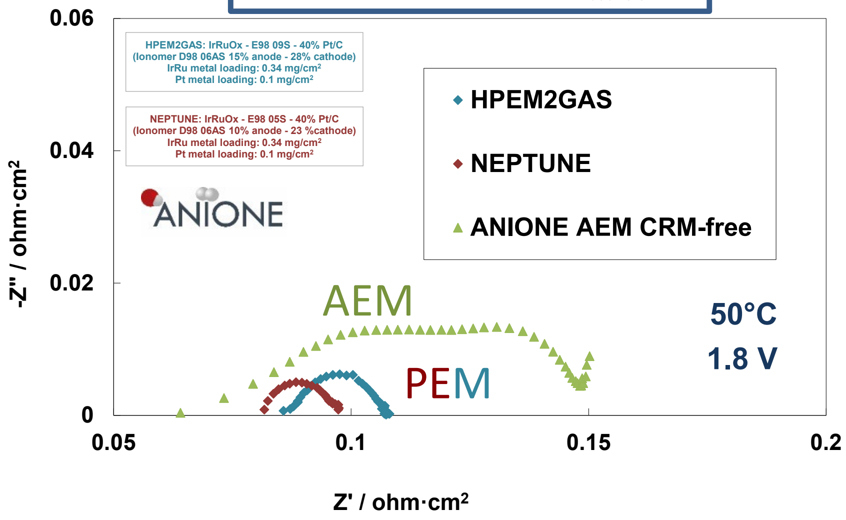

**300 mV performance gap between AEM and PEM at 2 A $cm^{-2}$**

ANIONE AEM technology:

- ✓ Non-PGM eletrocatalysts
- ✓ CRM-free materials,
- ✓ Hydrocarbon membrane
- ✓ Titanium-free

PGM content in PEMWE
<0.5 mg PGM $cm^{-2}{}_{MEA}$

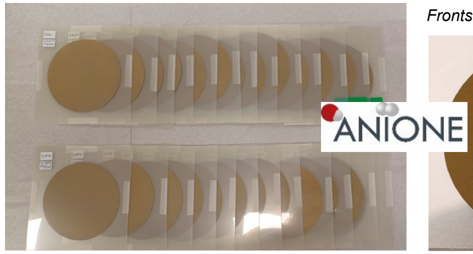
**Performance gap associated to larger polarisation resistance for AEM compared to PEM**



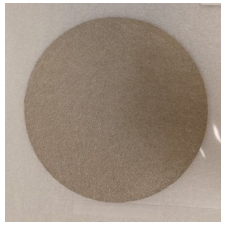
# LARGE BATCH MEA COMPONENTS FOR STACK ASSEMBLING

### 27 wet membranes for stack assembly

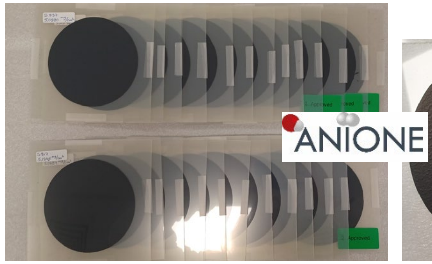

### 25 Anodes: NiFe unifomly coated on 1 side



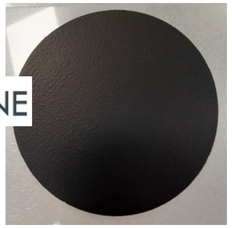

*Frontside (NiFe Catalyst)*

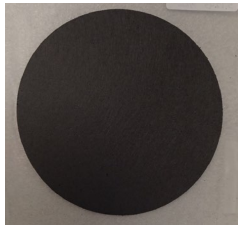


*Anode 2.5 $mg_{NiFe}$/cm2 on densified Ni-felt GDE*

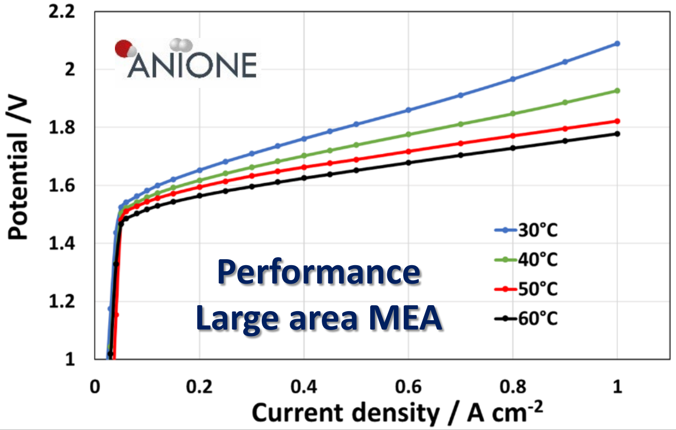


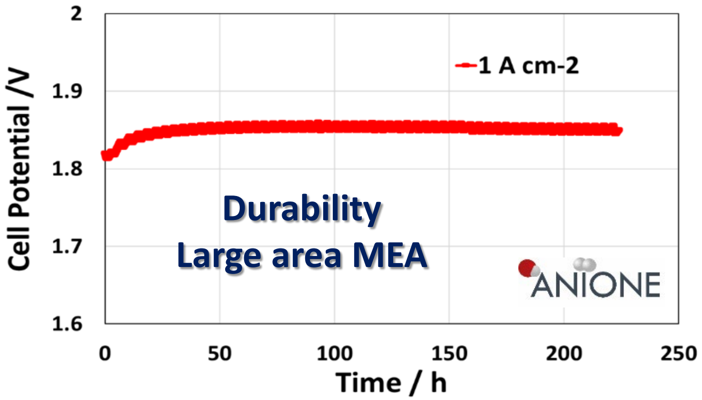

*Frontside (Catalyst)*





*Cathode 5 $mg_{NiMo/KB}$/cm2 on SGL GDE*

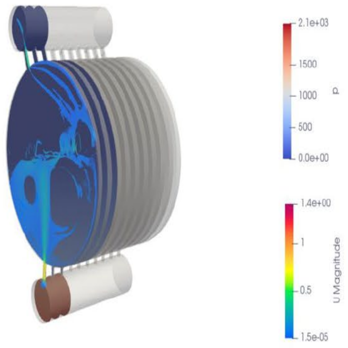


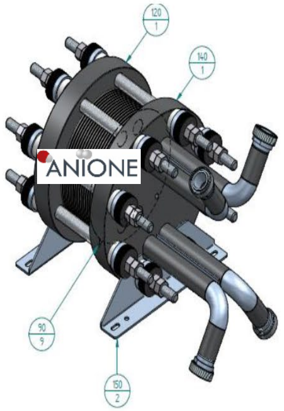



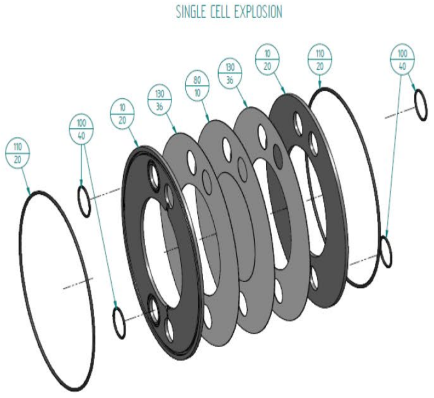
# Stack engineering – WP6

**Compact PEM-like stack configuration: 10 cells of 100 $cm^2$ operating at high current density (1 A $cm^{-2}$), at a nominal temperature of 50°C and pressurised mode.**

- Computational Fluid Dynamics
  - Pressure drop
  - Porous properties
  - Flow
- Full stack assembly
  - MEA received
  - Pressure drop to be measured
  - Leack & pressure test
    - External (Hydrostatic)
    - Internal ($N_2$)
    - Short stack

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Clean Hydrogen Partnership

Cummins

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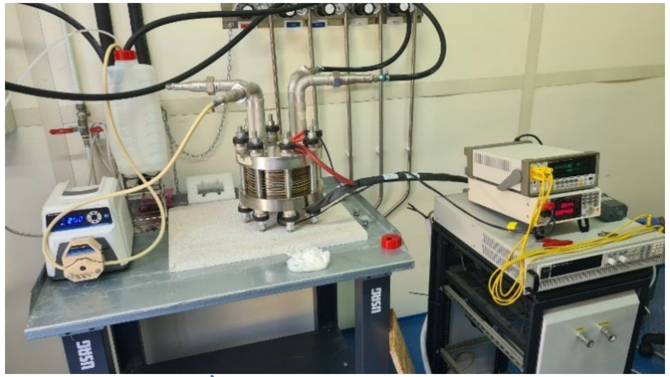
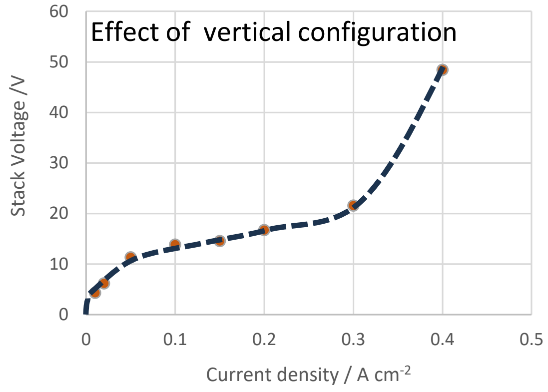
ANIONE

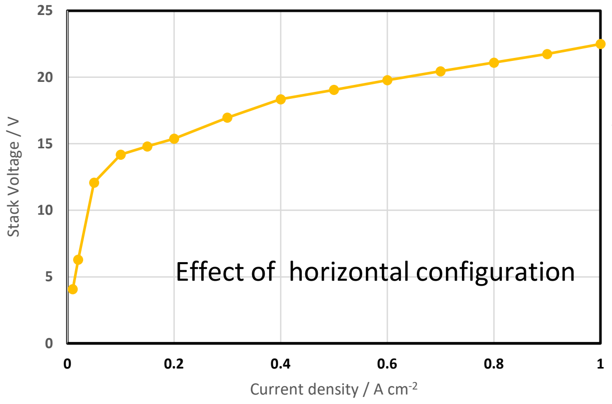
# Stack testing – WP6



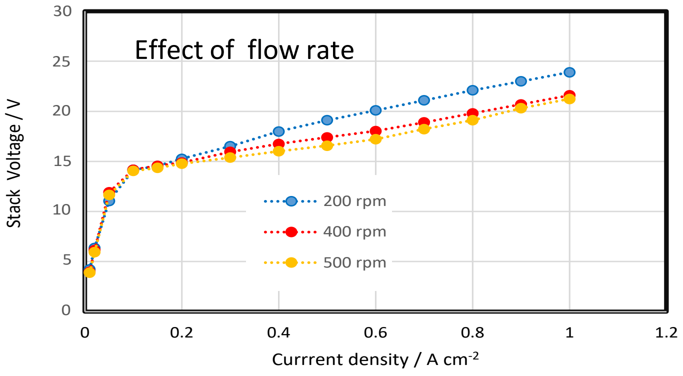
Vertical Stack, anode feed 1 M KOH, KOH flow 0.5 l/mir



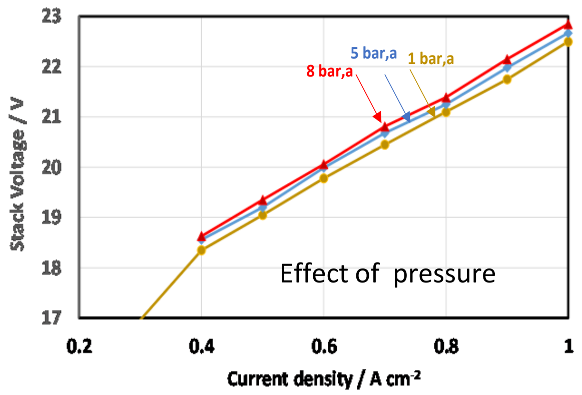

Horizontal Stack, anode feed 1 M KOH, flow 0.5 l/min




Stack voltage at 50°C



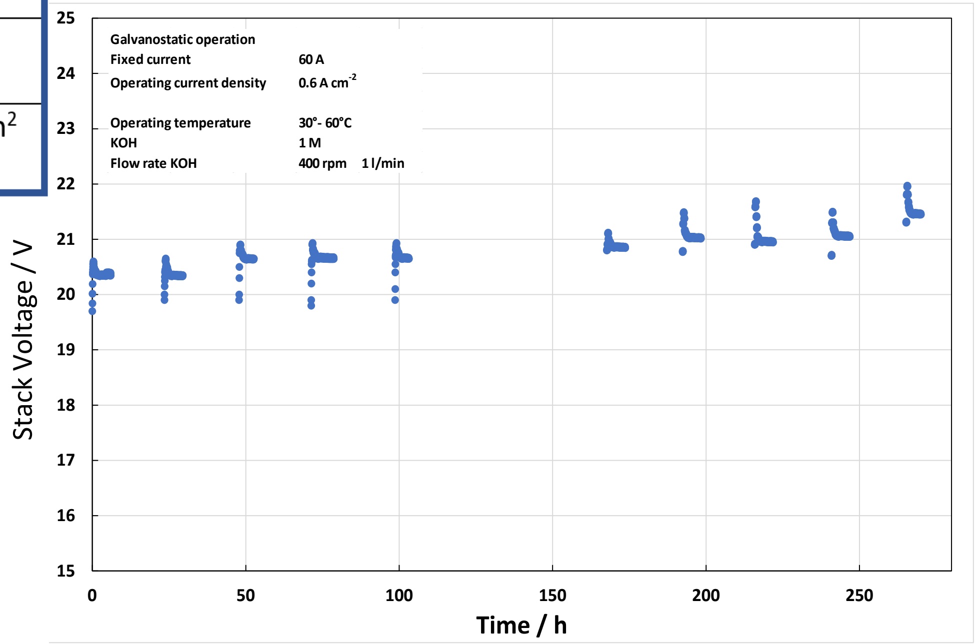

Differential pressure
Horizontal Stack, anode feed 1 M KOH, flow 0.5 l/min



# Stack testing – WP6

| Parameter | Result | Target |
|---|---|---|
| Stack Performance | 21 V for the stack (i.e. ~2.1 V/cell) at 1 A $cm^{-2}$ (100 A) at ~ 50 °C with recirculation rate of 1M KOH 1.25 ml/min/$cm^2$ | 1.8-2 V/cell at 1 A $cm^{-2}$ –MS10 |
| Voltage efficiency | 71% vs. HHV at 1 A $cm^{-2}$ (100 A) at temperatures up to 50 °C with recirculation rate of 1M KOH 1.25 ml/min/$cm^2$ | 86% vs. HHV –MS10 |
| Stack Capacity | 0.398 ± 0.0.05 $Nm^3$/h at 1 A $cm^{-2}$ (100 A) | Hydrogen production rate > 0.4 $Nm^3$/h –MS10 |
| Faradaic efficiency | 97 % at 1 A $cm^{-2}$ (100 A) | >99 % at 1 A $cm^{-2}$ –MS7 |
| Stack Energy efficiency | 69 % vs HHV | 80 % vs HHV –MS11 |
| Stack energy consumption of about 57 kWh/kg $H_2$ | 57 kWh/kg $H_2$ | 50 kWh/kg $H_2$ –MS11 |
| Stack power | >2 kW | 2 kW (10-cells with 100 $cm^2$ active area) –MS10 |

## Cycled Durability



# Summary DISS/COMM activities performed

Below a summary of the communication and dissemination activities performed so far (M1-M36)

| Target | Media/activities and status at M36 | Objectives |
| --- | --- | --- |
| **Dissemination** | | |
| **Scientific community** | - Journal publications → 4 publications<br>- 16 conference / workshop presentations/Conferences supporting the organisation of AEM-HUB online workshop on 9 March 2023<br>- Newsletters → 6 newsletters | - Communication on the project advances and potential output<br>- Clustering with interested research teams and industries for future collaboration<br>- Clustering with related FCH2 JU funded projects to mutually add value |
| **Dissemination & Communication** | | |
| **Industry, policy makers, Public bodies** | - Meetings & exhibitions → 2 (AEM-HUB meeting) in M1-M36<br>- Final workshop (1) → final event planned for M44, planning from M39 | - Communication about specific ANIONE advances<br>- Investigation of future/potential exploitation opportunities |
| **Communication** | | |
| **General Public** | - Website → >36,000 views in M1-M36<br>- Brochure → project flyer distributed in first reporting period<br>- Press releases/ article in national magazine → 1 | – Communication on latest science and technology achievements<br>– Raise public awareness on ANIONE goals and objectives with regard to EU policy for energy and transport applications from the perspective of meeting Europe's energy, environmental and economic challenges (societal impact) |

# Exploitation activities

Based on information identified in the proposal and the 'Innovation radar' exercise performed after M18 the following exploitation results/innovations are being investigated

| Project Exploitable result (ER) | Explanation |
|---|---|
| **CNR:** Highly performing and electrochemically stable NiFe oxide, oxygen evolution, anode electrocatalyst for AEM water electrolysis | NiFe oxide , oxygen evolution, anode electrocatalyst for AEM water electrolysis characterised by low overpotential (<140 mV Vs. thermoneutral potential at 1 A cm-2) and high electrochemical stability with no observable degradation rate during the first 2000 hours of electrolysis operation at 1 A cm-2. The catalyst is characterised by a crystallite size lower than 10 nm and agglomerate size lower than 10 microns with suitable properties for spray coating processes. |
| **CNR:** Highly performing and electrochemically stable carbon supported NiMo, hydrogen evolution, cathode electrocatalyst for AEM water electrolysis | Carbon supported NiMo, hydrogen evolution, cathode electrocatalyst for AEM water electrolysis characterised by low overpotential (< 90 mV Vs. reversible potential at 1 A cm-2) and high electrochemical stability with no observable degradation rate during the first 2000 hours of electrolysis operation at 1 A cm-2. The metallic particles of the catalyst are characterised by a crystallite size lower than 5 nm with mesoporous morphology and suitable properties for spray coating processes. |
| **CNRS:** Highly OH- conducting and stable thin membrane based on Hydrolite ionomer reinforced with a web of polybenzimidazole nanofibers for AEM water electrolysis | Composite thin (ca. 30 µm) membrane based on Hydrolyte ionomer reinforced with an electrospun web of polybenzimidazole nanofibres presenting high OH- conductivity (ca. 80 mS/cm at 50 °C and 100 % RH) and stability in stress test conditions (CO2 purging with on/off current of 100 µA at 50 °C and 100 % RH). Its low thickness enables low resistance in the device, therefore high electrolysis performance. |
| **HYDROLITE:** Highly conductive and chemically stable hydrocarbon membrane for AEM water electrolysis | Hydrocarbon based anion exchange ionomer and membrane with high ( >50 mS/cm) ionic conductivity, good chemical stability < 10% loss of ion exchange capacity (IEC) after 2000 h in 1M KOH at 80°C, good mechanical strength and low crossover (<1% H2 content in the oxygen stream during electrolysis operation).. |
| **IRD:** MEA engineering and automated multilayer catalyst-coated membrane methods | Validate sustainable energy production and storage based on scale up AEM MEAs with a minimum use of CRMs (TRL5-6) |
| **IRD:** Enhanced catalyst coated electrodes-based MEAs for AEM water electrolysis | MEAs based on catalyst-coated electrodes including nanosized NiMo/C cathode and NiFe-oxide anode electrocatalysts showing electrolysis performance of 1.7-1.8 V at 1 A/cm2 and 50°C and stable performance during 2,000 hrs steady state and 1,000 hrs cycled (0.2 -1 A/cm2) operations. |
| | |

# Thank you!



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