CHANNEL

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Thulile Khoza, AEM webinar, 6th July 2021

Development of the most Cost-efficient Hydrogen production unit based on ANioN exchange membrane ELectrolysis

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 875088. This Joint undertaking receives support from the European Union's Horizon 2020 research innovation programme and Hydrogen Europe and Hydrogen Europe Research

AEMWE an emerging electrolyser technology and has the potential to combine the best of both worlds…..

PEM Electrolysis

- High currrent density ↑
- Compact design ↑
- Pressurized H_2 (e. g. 30 – 200 bar) ↑
- Rapid power-up/power-down rates ↑
- Expensive materials & catalysts ↓

High CAPEX, low OPEX

Alkaline Electrolysis (AEL)

- Lower current density ↓
- Large system size ↓
- No pressurized H_2 ↓
- Cheap materials & catalysts ↑

Low CAPEX, higher OPEX

Best of two worlds

AEM Electrolysis

- High current density ↑
- Compact design ↑
- Pressurized H_2 (up to 30bar) ↑
- Rapid power-up/power-down rates ↑
- Cheap materials & catalysts ↑

Low CAPEX & low OPEX

AEM: Anion exchange membrane | PEM: Proton exchange membrane | AEL: Alkaline exchange membrane | EL: electrolysis

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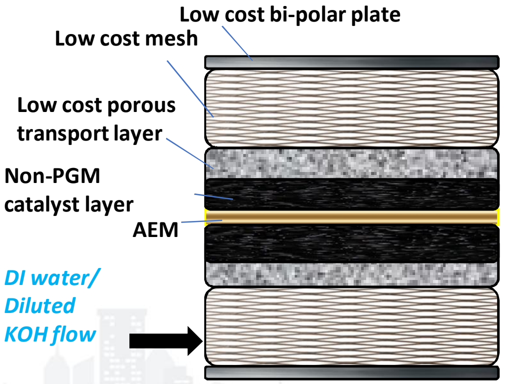
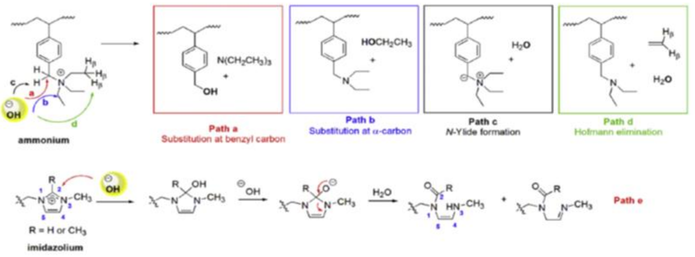
Challenges for AEMWE

- Anion exchange membrane, conductivity, chemical and mechanical stability
- Active and durable PGM-free catalysts
- Electrode design and three phase boundary
- Current collector and BPP materials and design



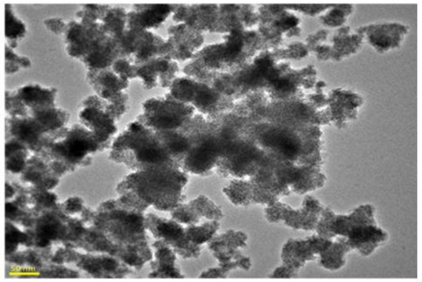
- *CCM vs. CCS configuration, PTLs/GDLs structure, materials and coatings, the use of mesh or flow fields.*

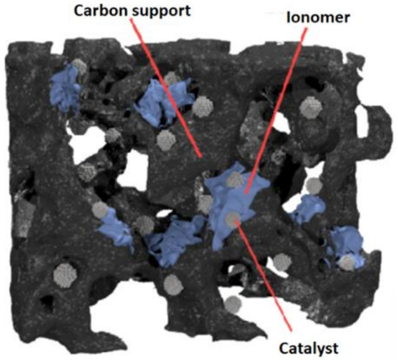
S. Gottesfeld, D. R. Dekel, M. Page, C. Bae, Y. Yan, P. Zelenay, Y. S. Kim, Journal of Power Sources 375 (2018) 170-184



- *QA-based polymers cationic groups are susceptibility to hydroxide attack, leading to reduced IEC. Low KOH concentrations, DI water operation preferred.*

- *Ni and Ni based alloy nanostructures with high surface area may become unstable over time, loss of active area/dissolution*





- *AEI conductivity and stability, binding properties, catalyst poisoning and membrane interface*

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development of the most Cost-efficient Hydrogen production unit based on ANioN exchange membrane ELectrolysis

- **Topic: FCH-02-4-2019: New Anion Exchange Membrane Electrolysers**
- **Duration: 2020-2022**
- **Total budget: 2 M€**
- **From TRL 2 to TRL3**

The aim of CHANNEL is to design, construct and test a cost-efficient, 2 kW AEM water electrolyser stack and balance of plant able to operate at differential pressure.

The electrolyser will be based on low-cost materials, including non-PGM electrocatalysts, porous transport layers and bi-polar plates, performing at < 1.85 V per cell at 1 A cm^{-2}, using diluted KOH electrolyte at a system capital cost of < 600 €/kW

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Specific Objectives

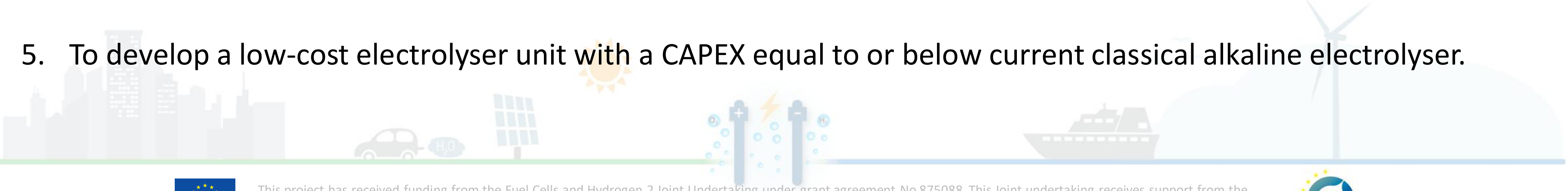
1. To further develop best-in-class EVONIK polymer materials and deliver > 40 units of large area AEM membranes > 500 cm^2 fulfilling the membrane and ionomer KPI's according to the FCHJU objective 2.4-2019;

2. To further optimise nanostructured Ni-based electrocatalysts with respect to activity and durability for the HER and OER;

3. To optimise coating methods, catalyst loading, as well as ionomer type and loading in order to obtain the single cell performance of $< 1{,}85$ V per cell at 1 A cm^{-2} and outstanding durability, also including studies focused to understand the interaction between catalyst and ionomer, as well as the electrode-membrane interface;

4. To design and integrate the newly developed components in a 100 cm^2 active area, 10 cell, 2 kW stack platform, with cell voltages $< 1{,}85$ V per cell at 1 A cm^{-2} below 50°C, using diluted electrolytes (≤ 1 M KOH) and an operating differential pressure of 30 bar.

5. To develop a low-cost electrolyser unit with a CAPEX equal to or below current classical alkaline electrolyser.



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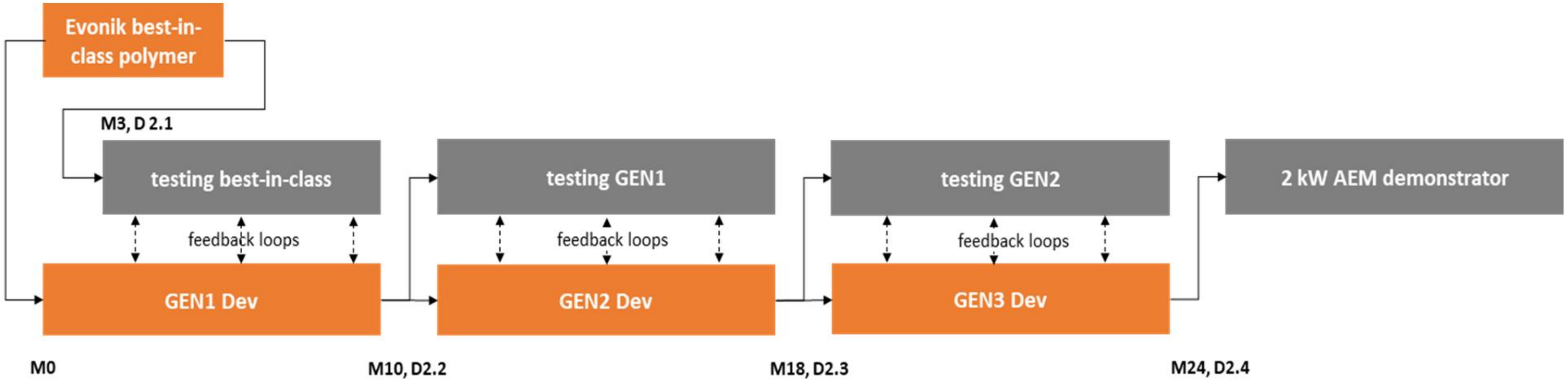
As part of the CHANNEL consortium, Evonik is working on the best-in-class polymer & membrane



KPI	UNIT	OBJECTIVE FCHJU 2.4-2019	OBJECTIVE CHANNEL
Area specifc resitance ASR, T = RT	Ωcm²	< 0,07	< 0,06
OH conductivity, T = RT	mS/cm	50	> 50
OH conductivity, T = 60°C	mS/cm	not specified	> 90
Ex-situ stability (AST protocol, 1 M KOH, T = 60 °C, 600 hr)	mS/cm	not specified	> 80
hydrogen crossover (T = 60°C)	$[mol/m.s.Pa]x10^{-15}$	not specified	< 15
water uptake, T = RT	w-%	not specified	< 10
Dry/wet swelling machine Direction (MD)	%	< 1	< 1
Dry/wet swelling traverse Direction (TD)	%	< 4	< 4
Mechanical strength (in dry conditions, T = RT, RH = 50%)	MPa	15	15
Elongation at break (in dry conditions, T = RT, RH = 50%)	%	100	100
Mechanical strength (DMTA, in fully hydrated, swollen conditions, T = 30°C)	MPa	not specified	> 0,1
Mechanical strength (DMTA, in fully hydrated, swollen conditions, T = 60°C)	MPa	not specified	> 0,1
Ionomer OH conductivity, T = 60°C	mS/cm	20	> 60
In-situ stability ASR remains	h	2000	> 5000

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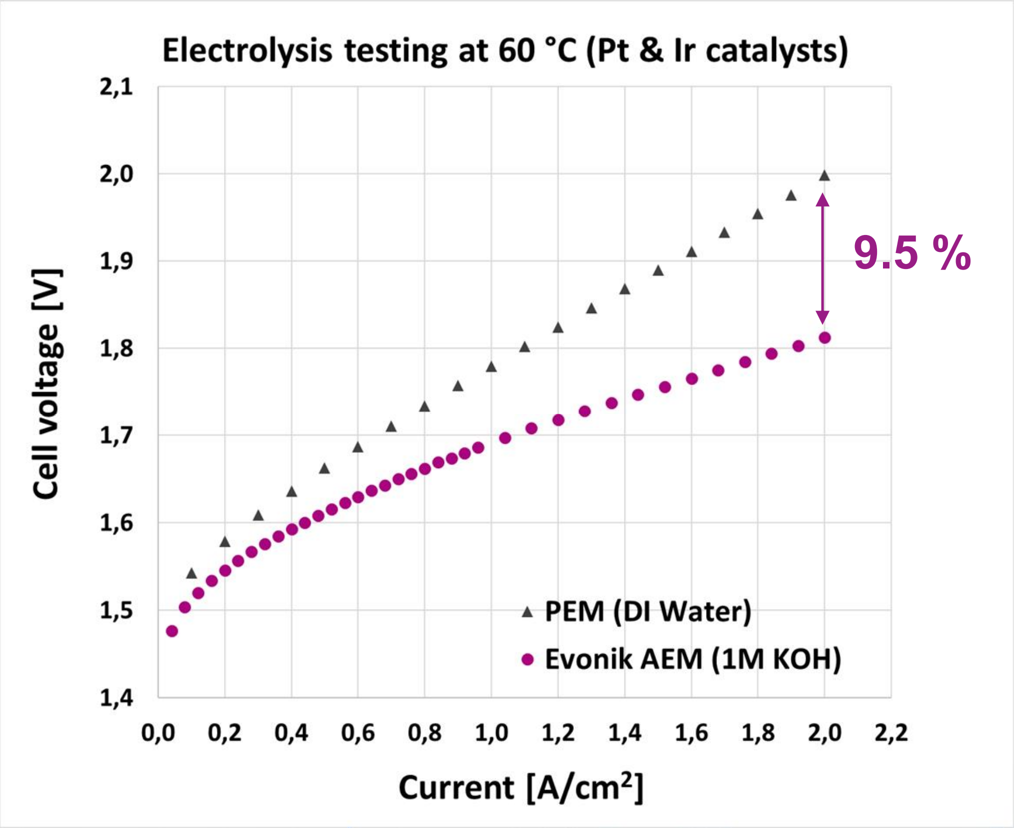
Evonik AEM outperforms PEM benchmark Nafion N-115



- Evonik AEM outperforms in 1M KOH electrolyte benchmark PEM membrane Nafion N-115 in DI-H_2O @ 60°C by 0.186 V @ 2 A/cm^2 (lab scale, single cell, 25 cm^2 active area)

- **Application of Evonik AEM in 1M KOH electrolyte @ 60°C & @ 2 A/cm^2 can enable reduction of operational costs up to 9.5% in comparison to PEM water electrolysis**

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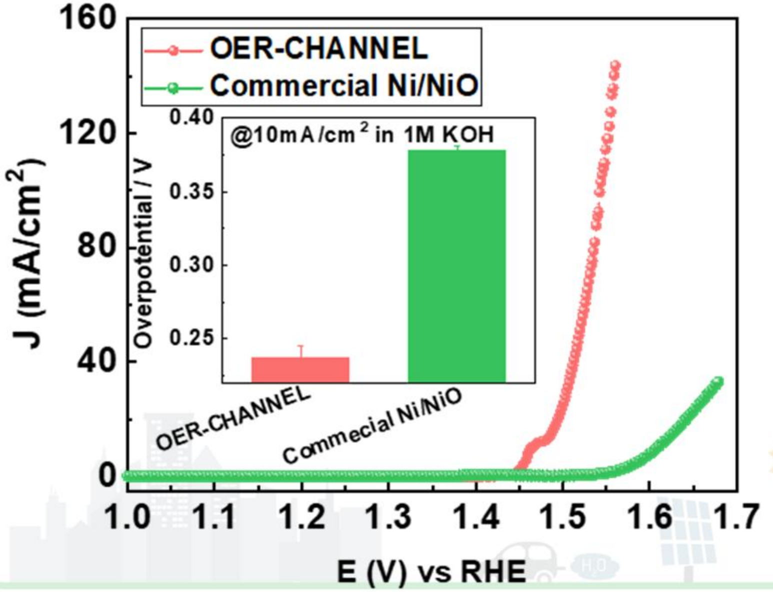
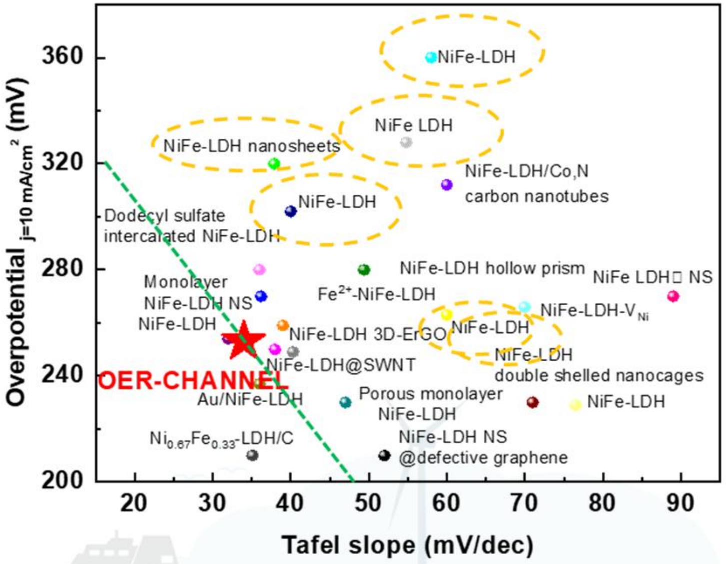
OER Development
Electrochemical performance

***Ex situ* testing- RDE**

- OER-CHANNEL catalyst present an overpotential＜300 mV at 10 mA/cm$^2_{geo}$



- OER-CHANNEL catalyst is stable for more than 500 hours at 1.6 V – degradation of less than 20 mV
- OER-CHANNEL catalyst showed higher performance compared to Ni-based catalysts presented in the literature.



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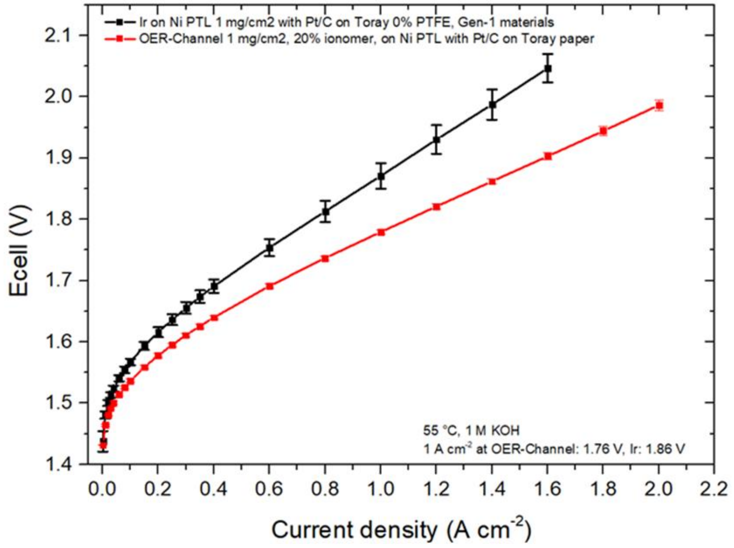
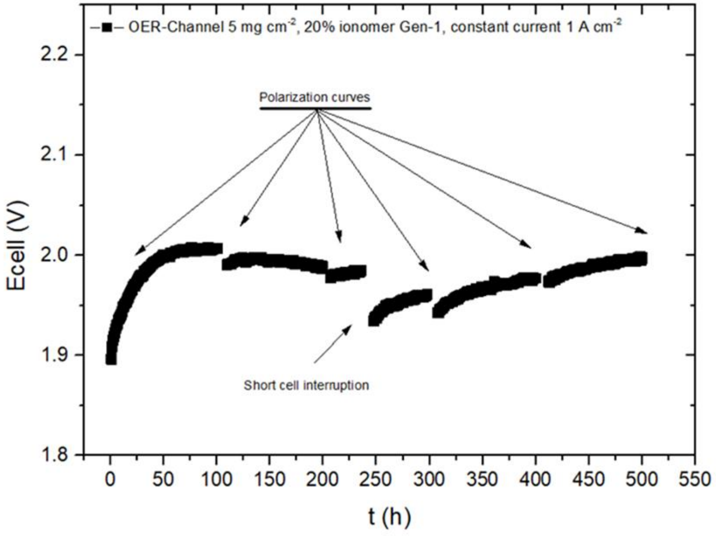
OER catalysts development
Electrochemical performance

In situ testing- single cell performance

- OER- CHANNEL catalyst loading: 5mg cm^{-2}
- OER-CHANNEL catalyst present cell voltage of < 1.8 V at 1 A cm^{-2}
- 500h cell testing present stable and robust catalyst and electrode structure with insignificant degradation rates





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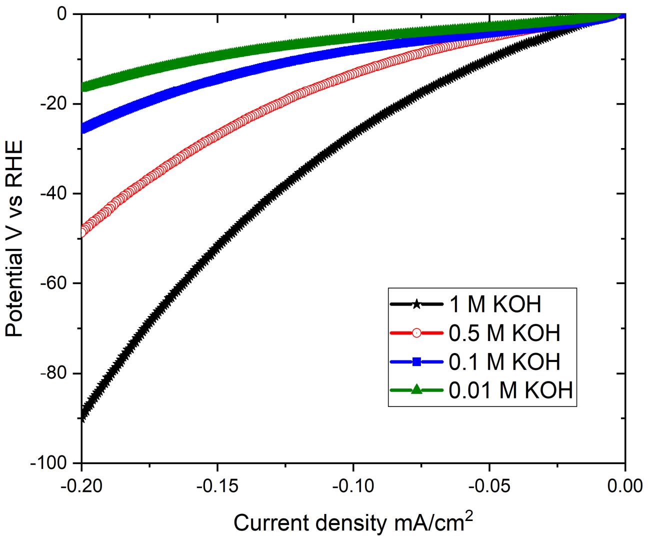
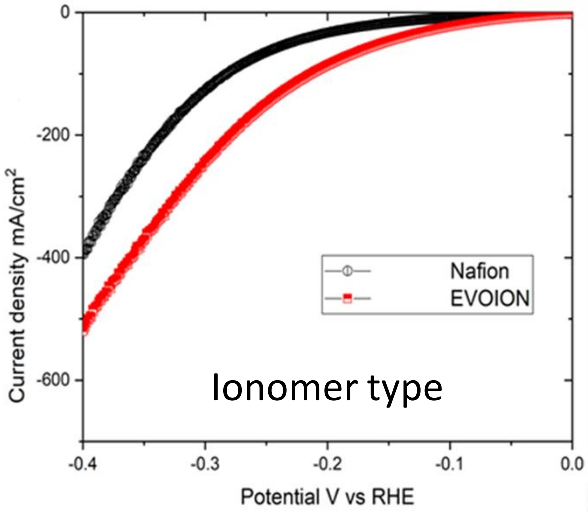
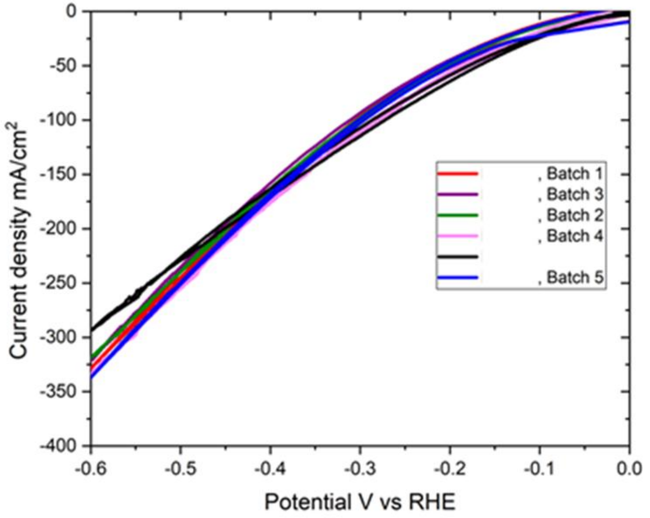
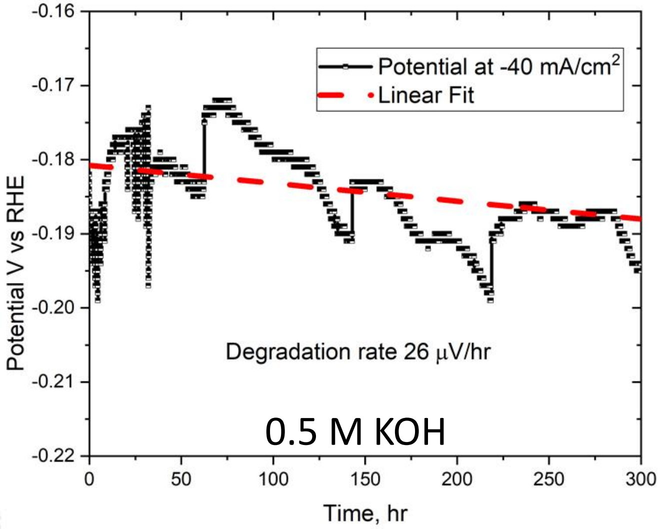
HER catalyst development

- HER-CHANNEL catalyst achieves <150 mV overpotential at 10 mA cm^{-2}_{geo} in <1 MKOH.
- The catalyst shows only 26 µV/hr degradation rate.
- HER catalysts achieve performance comparable to Pt/C in alkaline



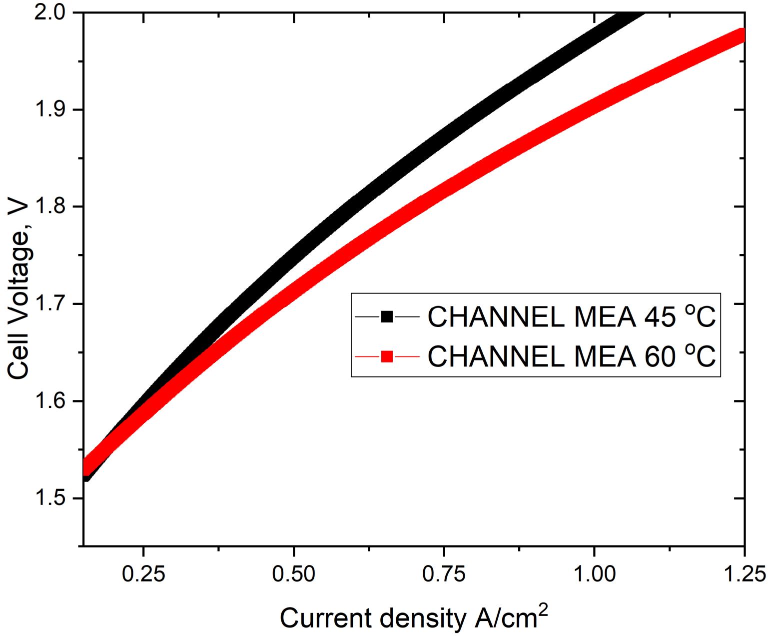


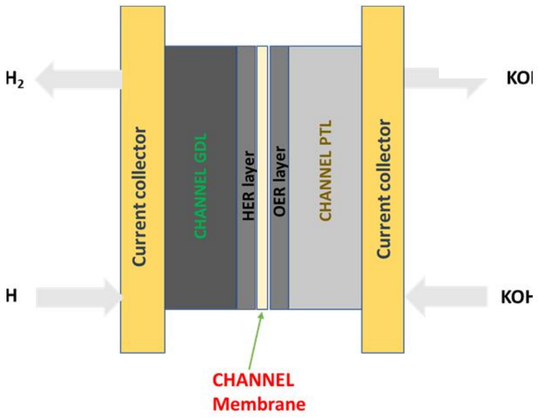


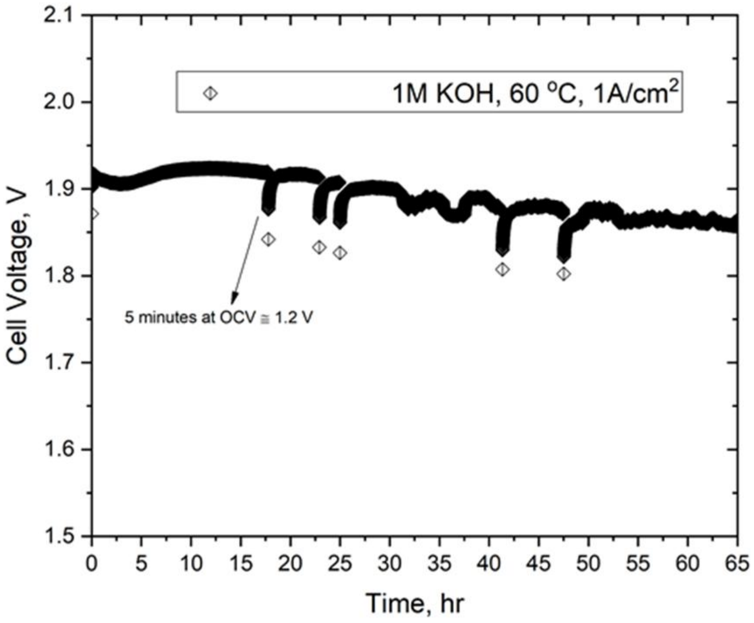


CHANNEL Full non-PGM electrolyzer

Performance of 1 A cm^{-2} at 1.9 V with good stability.







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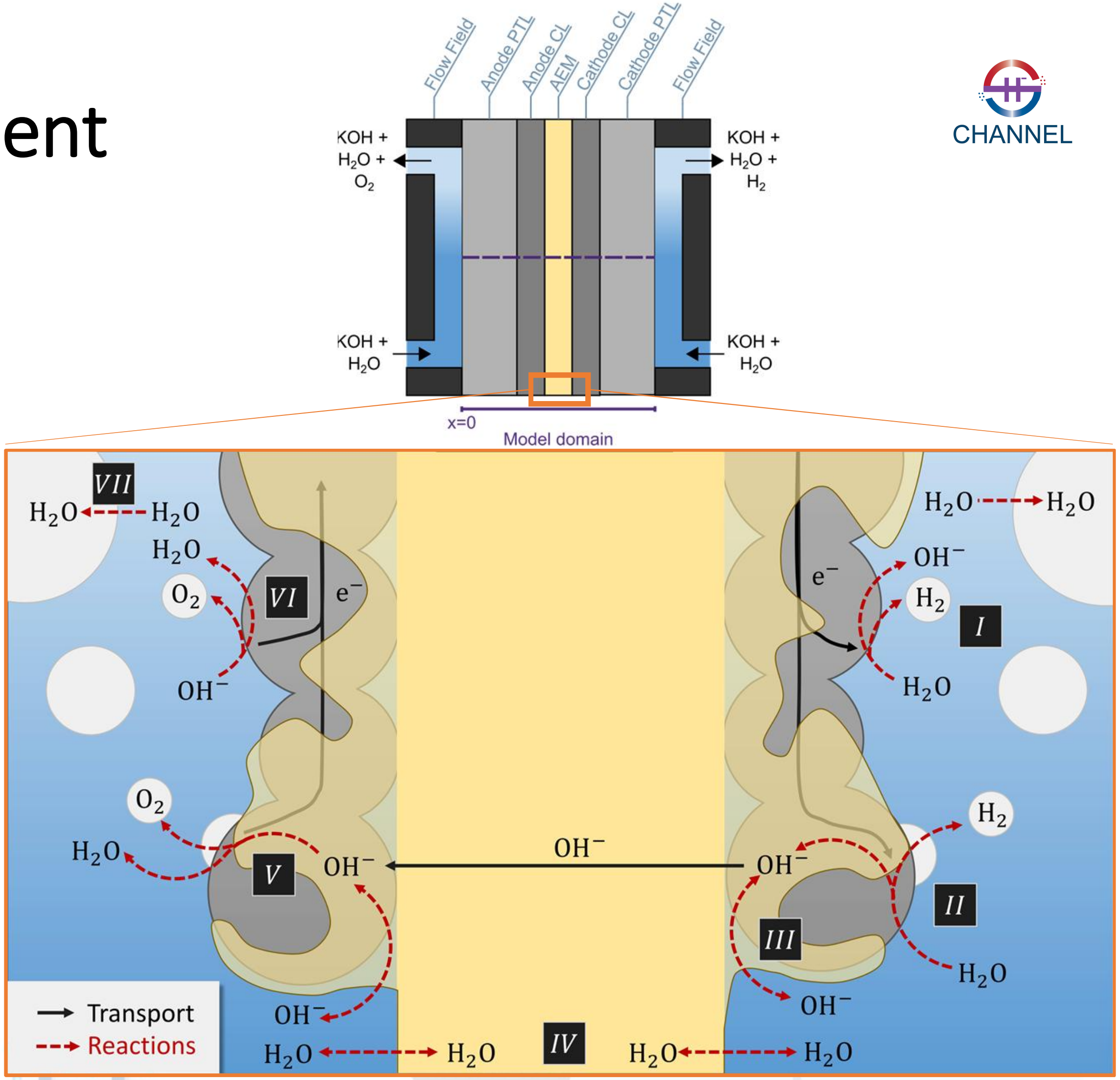
Development of 1-D transient AEM electrolyzer model

- Unique challenges for AEM electrolysis include:
  - Parallel ion conduction pathways
    - Liquid electrolyte (I, VI)
    - Solid ionomer (II, V)
    - Ion exchange (III)
  - Water absorption, desorption, and transport in AEM (IV)
  - Evaporation and condensation (VII)
- Coupled equations are solved using custom MATLAB scripts



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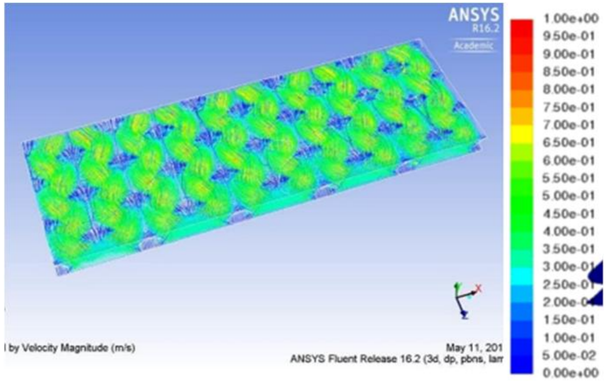
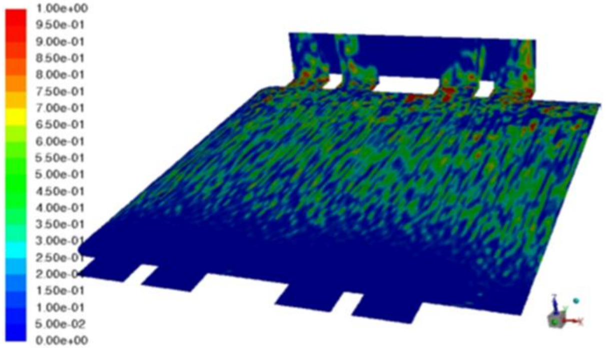
Stack development

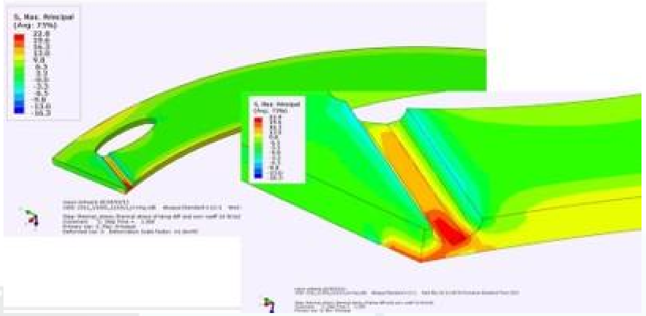
- 100 cm^2 active area stack
- *Cell voltages of <1.85 V per cell at 1 A cm^{-2} below 50°C, using diluted electrolytes (≤ 1 M KOH)*
- *Operating differential pressure 30 bar*
- *Maintain stable performance for 2,000 h with a degradation gap of less than 50 mV*

In addition, all electronic conductive components, PTLs, foams, mesh and BPPs, must maintain low ICR

- *$< 20\ m\Omega\ cm^2$ after ex-situ AST test in KOH and validated in 25 cm^2 AEM single cell*







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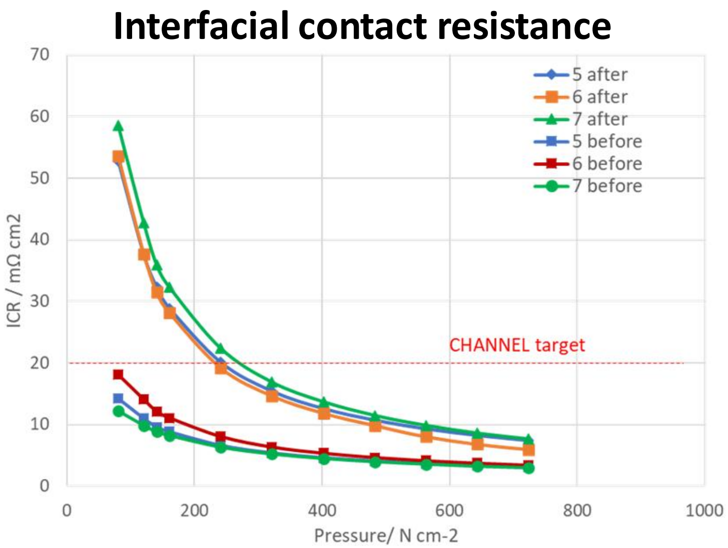
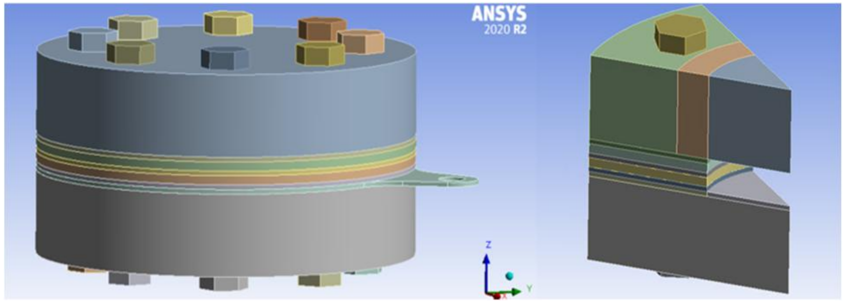
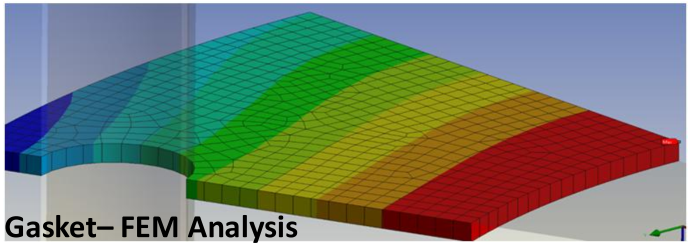
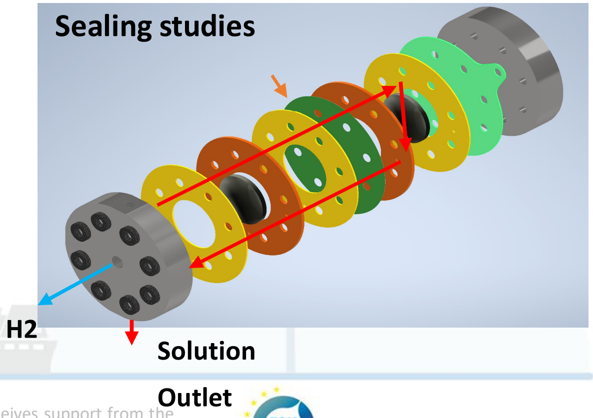
Bipolar plates / PTLs / Flow field

- Bipolar materials
  - Ti
  - SS AISI 304L
  - Inconel 625
  - SS AISI 316L
  - Nickel
- PTL materials
  - SS AISI 316L
  - Nickel
  - Titanium






Gasket– FEM Analysis


Sealing studies

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Summary

- OER and HER CHANNEL catalysts exhibit excellent performance in *ex situ* and in *in situ* electrochemical testing
- Production of both electrocatalysts is cost efficient and simple
- Development of 1-D transient model to predict durability of catalyst layers over time, and probing local effects
- Preliminary stack design concluded and validation of PTLs and Bipolar plate materials, including sealings
- Construct prelimanary stack underway

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Future work

- Further optimisation of membranes and ionomers to reach the KPIs
- Further optimization of non-PGM electrocatalysts and catalyst layers to achieve the performance of < 1,85 V per cell at 1 A cm^{-2} , while testing with non-PGMs.
- Scaling-up of synthesis batches to larger quantities without compromising electrocatalytic performance
- Understanding catalyst and ionomer interaction to reach better chemical compatibilities
- Testing of the preliminary short stack before end of 2021, and finalising the final 2kW stack design
- *Develop a beyond the state-of-the-art AEM electrolyser system including power supply, system control, gas drying unit achieving:*
  - ➢ *An electrolyser cost < 600 €/kW at 500 kW system level*
  - ➢ *An energy consumption < 4.7 kWh/Nm^3 at a system level*
  - ➢ *A 100% EU supply chain and increased EU competitiveness in production of green hydrogen from renewable energy sources.*
- Explore the upscale and commercialisation of the newly developed technology.

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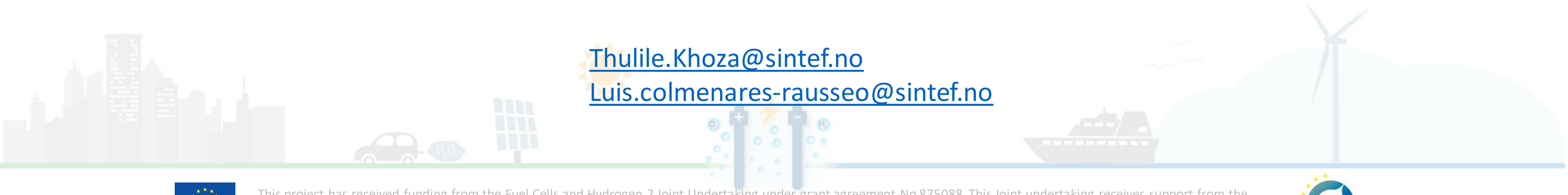

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