CHANNEL

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

Luis Colmenares-Rausseo, 28/09/2023

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) 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

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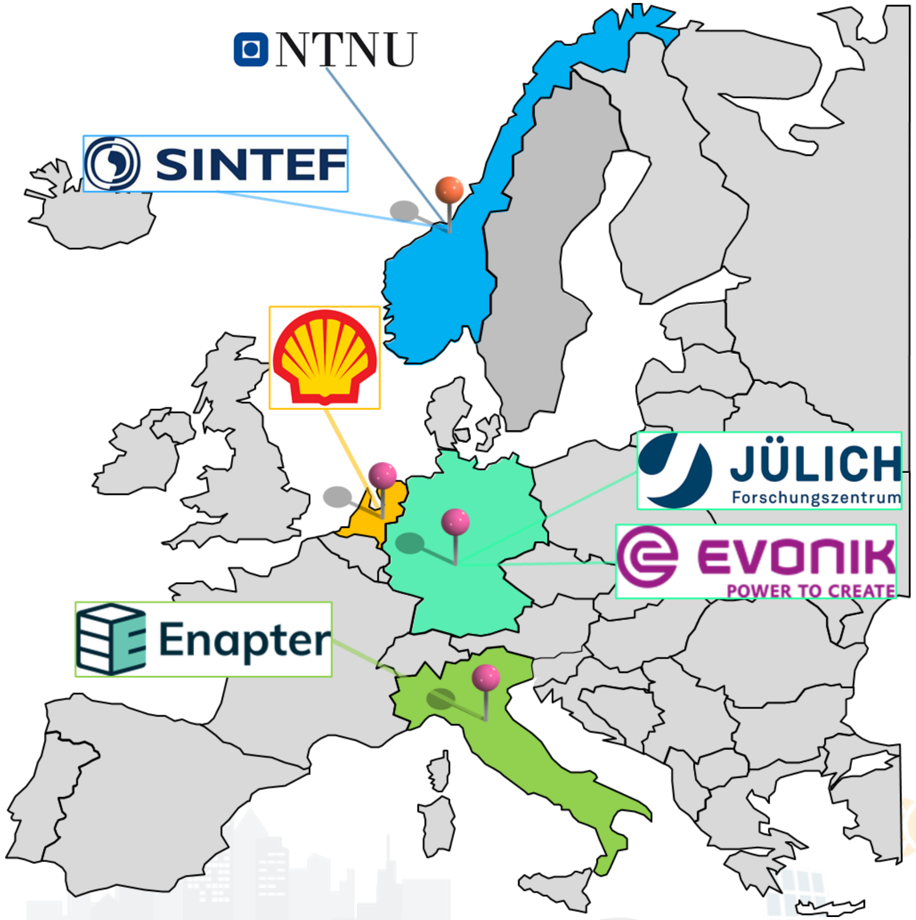

Main Objective

Design, manufacture and test a cost-efficient, 2 kW AEM water electrolyser stack

Electrolyser will be based on low-cost materials:

- ✓ PGM-free electrocatalyst (HER/OER) and cell components (PTL, BPP)
- ✓ Operate at differential pressure (up to 30 bar)
- ✓ Performing ≤ 1.85 V at 1 A/cm^2 using dilute KOH (< 1 M) or Deionized Water
- ✓ System capital cost: < 600 €/kW

- **Call topic:** FCH-02-4-2019: New Anion Exchange Membrane Electrolysers
- **Project duration**: 01/01/2020 – 30/06/2023 (42 months)
- **Total project budget**: 2M €
- **TRL**: 2 – 3
- **Coordinator**: SINTEF Industry – New Energy Solutions group

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Specific Objectives

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1. To further develop best-in-class EVONIK **polymer materials** to fulfil the **membrane** and **ionomer** KPI's according to the FCHJU objective 2.4-2019

2. Optimize nanostructured Ni-based **electrocatalysts** with respect to activity and durability for the **HER** and **OER**
   - *HER in RDE: <150 mV overpotential at 10 mA* cm^{-2}_{geo} *in <1 M KOH, and with less than 25 mV degradation over 1000 h at -0.2 V vs. RHE.*
   - *OER in RDE:< 300 mV overpotential at 10 mA* cm^{-2}_{geo} *in <1 M KOH, and with less than 25 mV degradation over 1000 h at 1.6 V vs. RHE.*

3. Optimize 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

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 , 30 bar differential pressure

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

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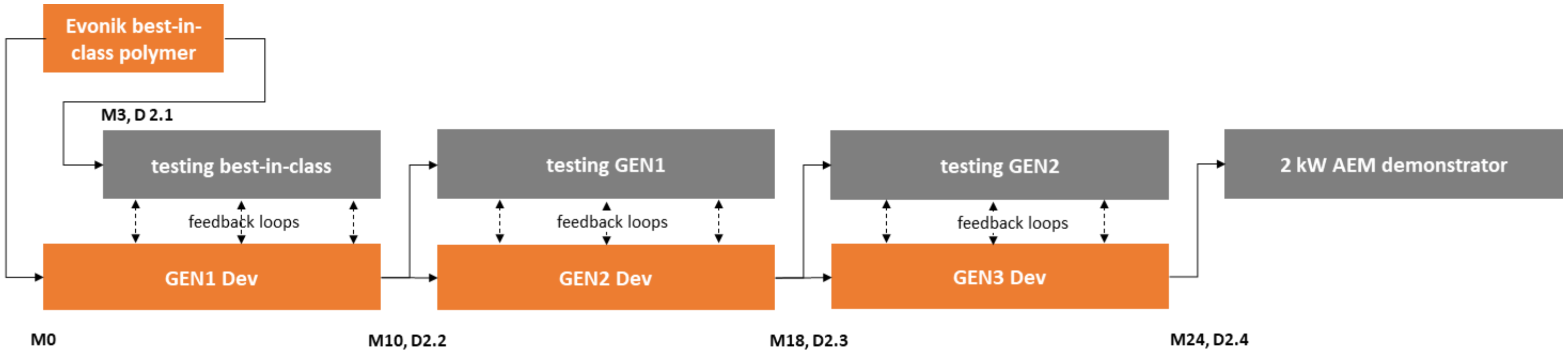
Membrane and ionomer development



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]x 10^{-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

To Take Away:

1. Anion-conductive materials (ionomer and membrane) were manufactured with a high quality (meeting almost all KPIs) and quantity to enable MEA preparation for the 2 kW AEMWE.
2. Several methods and protocols for testing anion conductive materials were adapted/developed and applied to measure KPI values, but also to support the standardization of methods especially for quality control of produced AEM materials.
3. AEM is good enough in terms of their KPIs, however, the question is related to their durability.
4. Thinner AEM can be manufactured, but questions concerning gas crossover, mechanical strength, and durability should be addressed properly.
5. A better understanding of the in-operando membrane degradation mechanics is needed.

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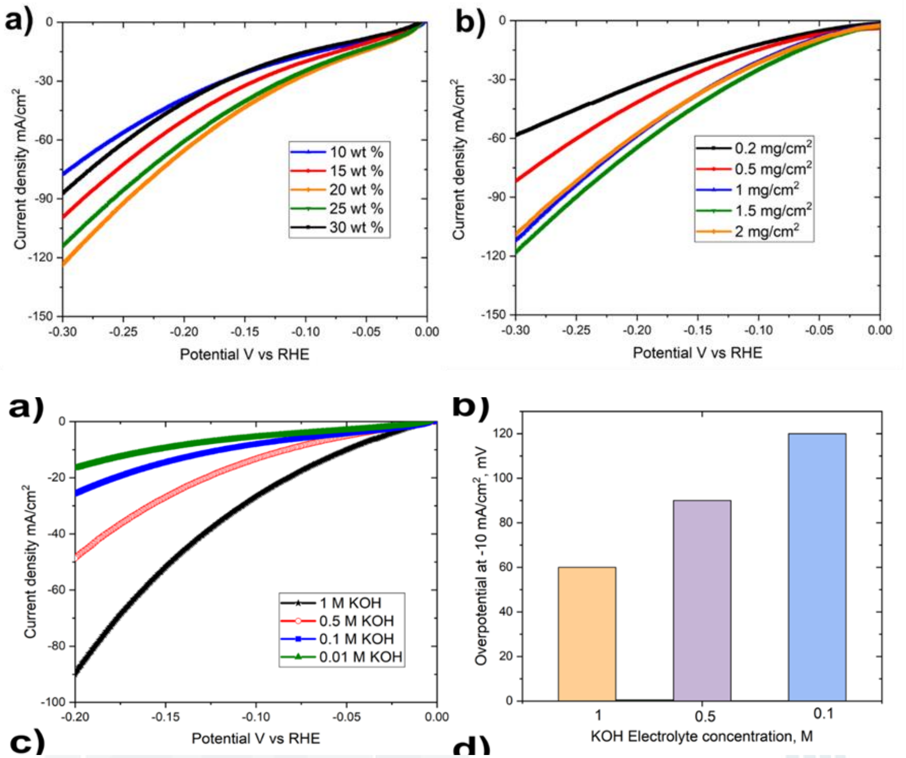
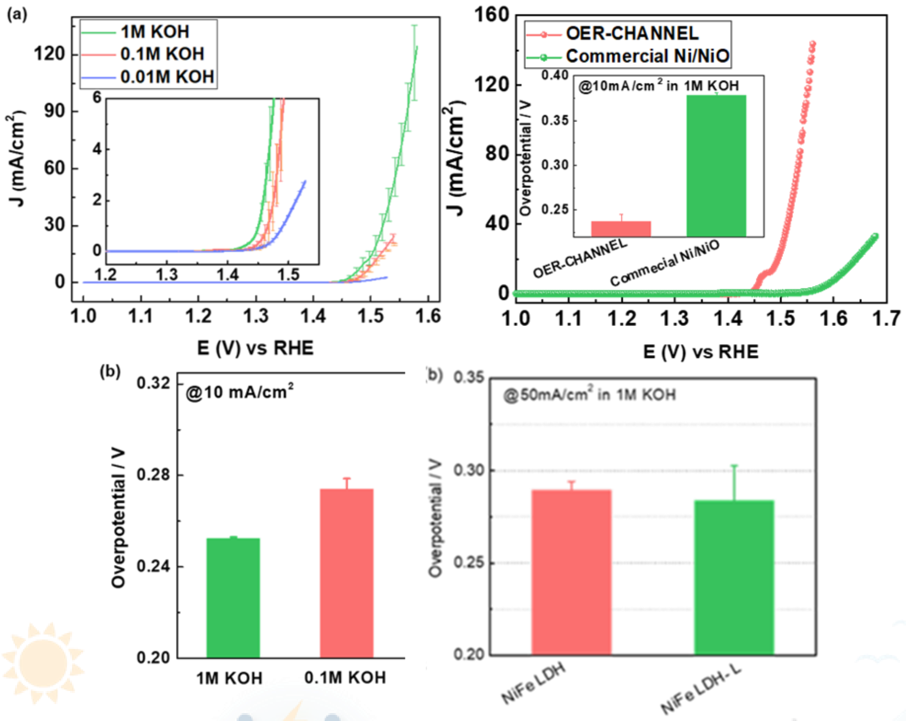
Catalyst development

CHANNEL Catalysts Target at 10 mA.cm^{-2}:

- **HER**: <150 mV overpotential and **OER**: <300 mV overpotential
- Both catalysts achieved performance and stability targets at 1M KOH besides to be scalable





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To Take Away:

1. Appropriated methods to determine the ECSA of Ni-based nano-catalysts are required.
2. A better understanding of the ionomer role and optimal ratio AEI-catalyst is needed as a function of the hydroxide concentration.
3. For PGM/CRM-free catalysts, the catalyst utilization would be more relevant than mass activity (cost-related), however high catalyst loading (thick electrodes) to compensate for lower mass activity (low-cost catalyst) needs to be carefully tuned to minimize mass transport constraints.
4. The development of in-situ methods for a better understanding of the catalyst activity and stability is recommended.

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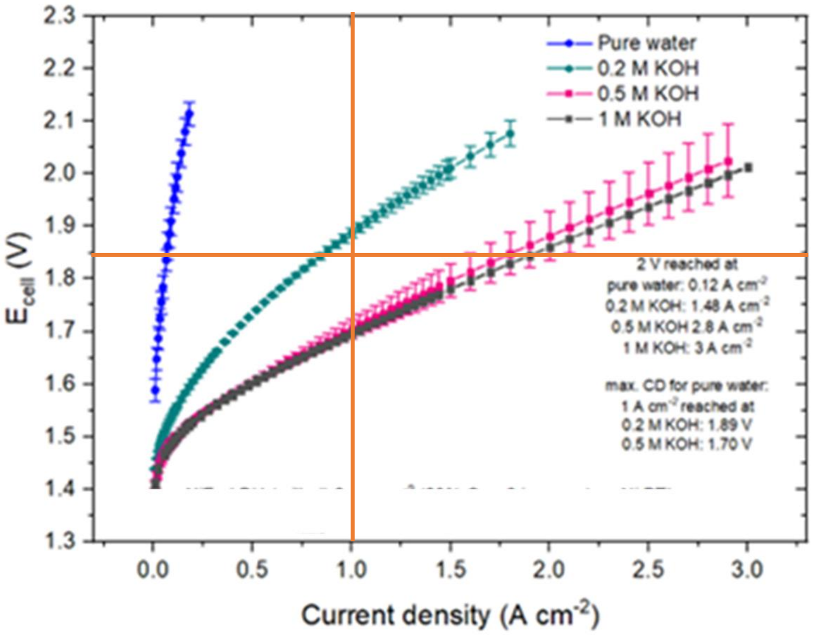
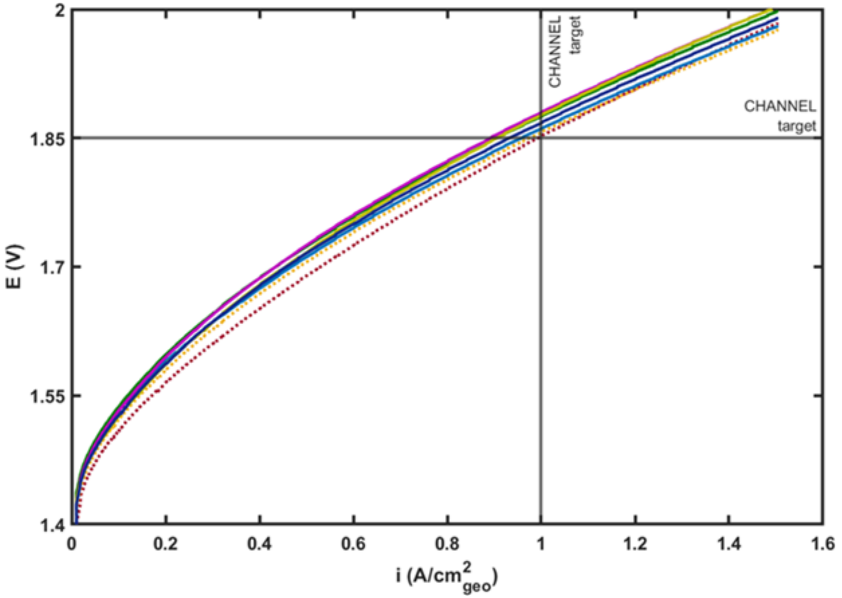
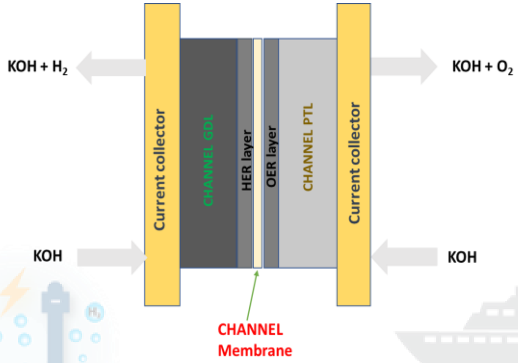
MEA and single cell performance





CHANNEL Target: 1.85 V at 1 A cm^{-2}, 60 °C, 1M KOH
Components long-term stability demonstrated over 1000 h



To Take Away:

1. The different procedures to prepare inks, electrodes, and assemble them with the membrane and other cell/stack components might have a direct impact on the performance, durability, and stability.
2. The electrode performance is quite sensitive to the ionomer content in the electrode, therefore crucial to understand the role of the anion-conducting ionomer within the catalytic layer.
3. The electrodes to be used must be also optimized for the chosen KOH concentration since the optimal ratio AEI to catalyst may vary as a function of the hydroxide concentration.
4. The binding properties of the ionomer must be considered.

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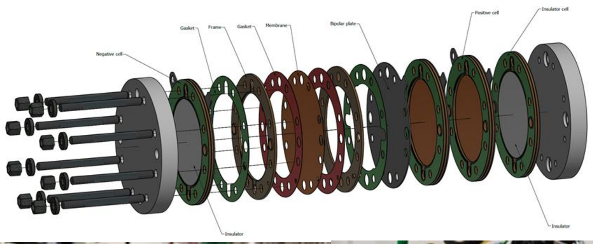
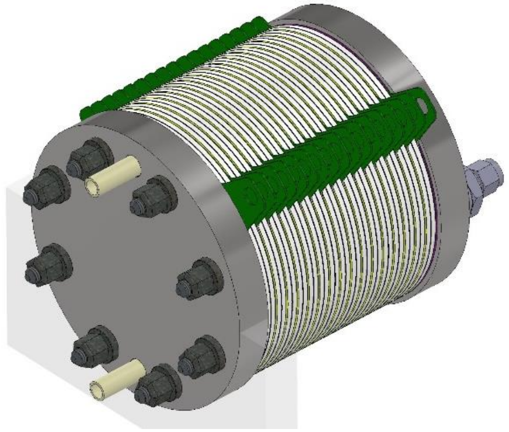
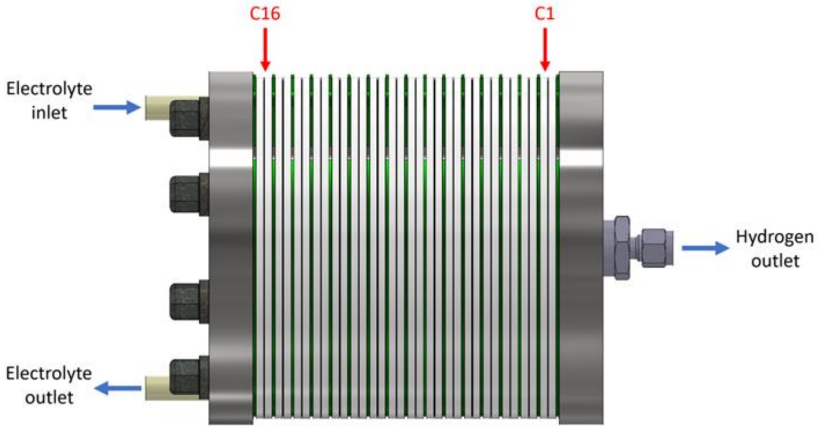


2 kW stack development

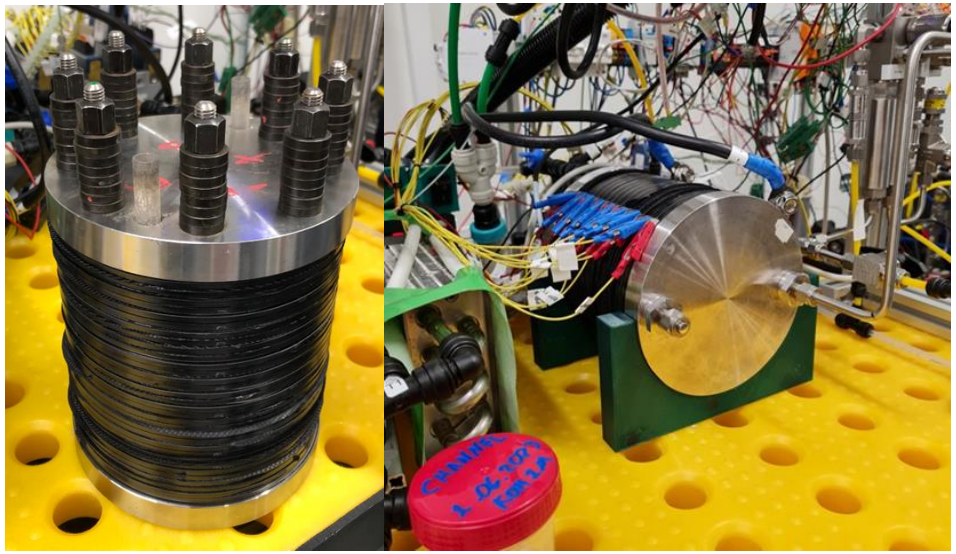




16 cells with active area of 64 cm^2

BoP for stack testing was also designed and optimized.

- Unfortunately, the performances expected for the stack were not fully reached at the end of the project.
- Components dimensioning and manufacturing, methodology transferring from lab scale to stack level, and design/engineering of the final prototype is not a simple task to commit.



- CHANNEL stack demonstrator was validated over 260 h at atmospheric pressure, 0.25 A/cm^2 and 55 °C resulting in a degradation rate of 38 µV/h.
- The problems encountered after disassembly and post-mortem analysis suggest some necessary improvements from the mechanical point of view and the assembling procedure for a fully operating stack.

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Summary

- CHANNEL successfully developed alternative low-cost non-PGM catalysts for hydrogen evolution reaction (HER) and oxygen evolution reaction (OER) exhibiting excellent performance, comparable or better than SoA catalysts.
- Membranes and ionomers with excellent chemical/mechanical properties and good compatibility with CHANNEL electrocatalysts.
- The optimized membrane and electrodes allowed to reach a full non-PGM single-cell performance target of <1.85 V at 1 A/cm^2 with a good stability of all components after a long-term test of more than 1000 h at $1A/cm^2$.
- Due to the low TRL of the stack prototype, manufacturing strategies and cost forecast for a 500kW system were calculated based on estimations of the stack manufacturer.

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Some of the CHANNEL Publications

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ACS APPLIED ENERGY MATERIALS
www.acsaem.org Article

Tuning Ni–MoO_2 Catalyst–Ionomer and Electrolyte Interaction for Water Electrolyzers with Anion Exchange Membranes

Alaa Y. Faid,* Alejandro Oyarce Barnett, Frode Seland, and Svein Sunde

Cite This: *ACS Appl. Energy Mater.* 2021, 4, 3327–3340 Read Online

ELSEVIER
International Journal of Hydrogen Energy
Volume 47, Issue 56, 1 July 2022, Pages 23483-23497

Ternary NiCoFe nanosheets for oxygen evolution in anion exchange membrane water electrolysis

Alaa Y. Faid [a], Alejandro Oyarce Barnett [b], Frode Seland [a], Svein Sunde [a]

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Composition-Dependent Morphology, Structure, and Catalytical Performance of Nickel–Iron Layered Double Hydroxide as Highly-Efficient and Stable Anode Catalyst in Anion Exchange Membrane Water Electrolysis

Wulyu Jiang, Alaa Y. Faid, Bruna Ferreira Gomes, Irina Galkina, Lu Xia, Carlos Manuel Silva Lobo, Morgane Desmau, Patrick Borowski, Heinrich Hartmann, Artjom Maljusch, Astrid Besmehn, Christina Roth, Svein Sunde, Werner Lehnert, Meital Shviro ... See fewer authors

First published: 13 July 2022 | https://doi.org/10.1002/adfm.202203520 | Citations: 8

ChemElectroChem
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The Influence of Loadings and Substrates on the Performance of Nickel-Based Catalysts for the Oxygen Evolution Reaction

Wulyu Jiang, Prof. Dr. Werner Lehnert, Dr. Meital Shviro

First published: 02 January 2023 | https://doi.org/10.1002/celc.202200991

Journal of Applied Electrochemistry (2022) 52:1819–1826
https://doi.org/10.1007/s10800-022-01749-z

SHORT COMMUNICATION

Unveiling hydrogen evolution dependence on KOH concentration for polycrystalline and nanostructured nickel-based catalysts

Alaa Y. Faid[1] · Faranak Foroughi[1,2] · Svein Sunde[1] · Bruno Pollet[2,3]

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