EUROPEAN COMMISSION – FCH JU

HORIZON 2020 PROGRAMME - TOPIC H2020-FCH-02-4-2019
New Anion Exchange Membrane Electrolysers

GRANT AGREEMENT No. 875024

ANIONE

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

ANIONE – Deliverable Report

D1.3 – Annual Data Reporting (Year 2)

Clean Hydrogen Partnership

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) under Grant Agreement No 875024. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation program, Hydrogen Europe and Hydrogen Europe Research.

Co-funded by the European Union

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Disclaimer/ Acknowledgment

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Publishable summary

Deliverable D1.3 - Annual Data reporting (Year 2) provides concise information about the activities and project achievements in the second year of the ANIONE project. The deliverable consists of: 1) Quantitative project data in a structured format collected through the TRUST (Technology Reporting Using Structured Templates) platform provided by the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership); 2) A dedicated questionnaire requested by the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) each year (Programme Review Days) to collect complementary key qualitative and quantitative information on projects' objectives, activities and achievements; 3) visual material related to the projects' activities.

The project activities were widely disseminated through the project website, newsletters, social media, and participation to (online) conferences.

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Abbreviations

Abbreviation	Full Name	Abbreviation	Full Name
BoP	Balance-of-Plant	LCA	Life Cycle Analysis
CAPEX	Capital Expenditure	MEA	Membrane Electrode Assembly
CRM	Critical Raw Materials	MS	MileStone
DoA	Description of Action	OER	Oxygen Evolution Reaction
EDX	Energy Dispersive X-ray	PEM	Proton Exchange Membrane
FCH JU	Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership)	RP	Reporting period
HER	Hydrogen Evolution Reaction	SEM	Scanning electron microscope
IEC	Ion Exchange Capacity	SoA	State-of-the-Art
IPR	Intellectual Property Rights	WP	Work package
JRC	Joint Research Centre	XRD	X-ray powder diffraction

1 Introduction

Deliverable D1.3 - Annual data reporting (Year 2) is requested by Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership).

ANIONE was asked in March 2022 to provide a dataset of the relevant parameters associated with the project research carried out in the first year by filling in a questionnaire on the Technology Reporting Using Structured Templates (TRUST) submission system. A subset of the information recorded in the TRUST system is provided in this deliverable for convenience.

In addition to the TRUST survey, separate questionnaires on project progress, Dissemination activities and Exploitation of Results have been submitted to the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) as part of the Programme review Days 2022 (PRD) survey. A copy of the information provided is included in this deliverable.

Deliverable D1.3 also provides a sample of visual material related to the project's activities. The project activities were widely disseminated through the project website, newsletters, social media, and participation to (online) conferences.

2 ANIONE data for the TRUST system

The data provided below are a subset of the information recorded via the TRUST system for the second year of the ANIONE project.

2.1 TRUST DATA - SINGLE CELL LEVEL OR LOWER

Parameter Display Name	Input type	Measurement Type	Value	Data Provider Comment
Technology	list		AME - alkaline membrane cell	
Active cell area	quantity	cm²	100	Single cell
Operating temperature	quantity	°C	50	Nominal 50°C. Range covered from ambient temperature to 90 °C
Rated stack durability	quantity	h	40000	Estimation for the stack from single cell degradation rate results
Operating pressure	quantity	bar	30	Single cell
Hydrogen purity	quantity	%	99.999	Achievable after DEOXO
Nominal hydrogen weight capacity	quantity	kg/day	0.863	Estimated value for the stack from single cell results. No stack tests have been yet initiated.
Input voltage	quantity	V	20	Estimated value from single cell results. No stack tests have been yet initiated.
Stack nominal capacity	quantity	kW	2000	Estimated value from single cell results. No stack

				tests have been yet initiated.
Rated stack electrical efficiency (HHV, DC current)	quantity	%	79	Estimated value from single cell results. No stack tests have been yet initiated.
Number of cells in each stack	quantity		11	Estimated value from single cell results. No stack tests have been yet initiated.
KPI - Catalyst at the cathode	freeText		NiMo	Non precious non CRM catalyst
KPI - Catalyst at the anode	freeText		NiFe oxide	Non precious non CRM catalyst
KPI - Stack CAPEX (per kW)	quantity	EUR/kW	360	Aimed cost/ Rough estimation for the stack from single cell results and materials used
KPI - Est. stack CAPEX (per kW) @ 100MW annual production	quantity	EUR/kW		N.A. No estimation done in this phase
KPI - Reversible capacity of the Electolyser (Specific System)	quantity	%		N.A.
ASR - Active Specific Resistance	quantity	Ω cm2	0.3	Determined at cell level; estimated from polarisation slope
Start date for reporting	date		01/01/2021	
End date for reporting	date		31/12/2021	
Hours of operation	quantity	h	1000	Single cell
Hours of operation - cumulative	quantity	h	2000	Single cell
Quantity of hydrogen produced	quantity	t		N.A. No stack tests have been yet started.
Electricity consumed	quantity	kWh		N.A. No stack tests have been yet started.
KPI - Stack electricity consumption for H2 production	quantity	kWh/kg		N.A. No stack tests have been yet started.
Stack Thermal Energy Consumption	quantity	kWh/kg		N.A. No stack test has been yet started.
Power density	quantity	W/cm^2	1.8	Single cell
KPI - Current density	quantity	A/cm^2	1	Single cell
Stack availability	quantity	%		N.A. No stack tests have been yet started.
Operating time per day	quantity	h/day		N.A. No stack tests have been yet started.
KPI - Cold start ramp time	quantity	s		N.A. No stack tests have been yet started.
KPI - Hot idle ramp time	quantity	s		N.A. No stack tests have been yet started.

Cell voltage	quantity	V	1.8	Single cell
Transient response time	quantity	s		N.A. No stack tests have yet been initiated.
Stack electrical efficiency (HHV, DC current)	quantity	%		N.A. No stack tests have yet been initiated.
KPI - Production loss rate for HT Electolyser	quantity	%		N.A.
Voltage degradation rate in %/kh	quantity	%/1000h/cell	3	Results refer to single cell testing; no stack tests has yet been initiated.
KPI - Efficiency degradation per 1000 h for LT Electrolyser	quantity	%/1000h	3	Results refer to single cell testing; no stack tests has yet been initiated.
KPI- Cathode catalyst loading per W	quantity	mg/W	2.8	Cell level; Non precious non CRM catalyst
Cathode catalyst loading per H2 capacity	quantity	g/(kg H2/d)	6.5	Cell level; Non precious non CRM catalyst
Anode catalyst loading per H2 capacity	quantity	g/(kg H2/d)	4	Cell level; Non precious non CRM catalyst
KPI - Anode catalyst loading per W	quantity	mg/W	1.7	Cell Level; Non precious non CRM catalyst
KPI - Reversible efficiency of the Electrolyser (Specific System)	quantity	%		N.A.
Degradation - ASR	quantity	mΩ cm2 / 1000h	5	Cell level; Non precious non CRM catalyst

2.2 TRUST DATA - STACK KPIs derived from single cell data

Parameter Display Name	Input type	Measurement Type	Value	Data Provider Comment
Start date for reporting	date		01/01/2021	
End date for reporting	date		31/12/2021	
Deployment date	date			Not yet in operation
Country	freeText			Not yet in operation
Town	freeText			Not yet in operation
Technology	list		AEMEL - Anion exchange membrane	
Electrolyser manufacturer	freeText		Hydrogenics	Part of Cummins
Stack manufacturer	freeText		Hydrogenics	Part of Cummins
Stack nominal capacity	quantity	kW	2	
Number of stacks	quantity		1	
Nominal system electrical power	quantity	kW		Not yet in operation
Overload capacity	quantity	%	100	
System minimum power	quantity	%		Not yet in operation
Hydrogen production capacity	quantity	kg/h	0.04	Estimated value for the stack from single cell results. No stack tests have been yet initiated.
Operating pressure	quantity	bar	30	Nominal

Operating temperature	quantity	°C	50	Nominal
Power usage of BoP	quantity	kW		Not yet in operation
Area occupied by unit	quantity	m^2/MW		Not yet in operation
KPI- Electricity consumption @ nominal capacity	quantity	kWh/kg	50	Estimated value for the stack from single cell results. No stack tests have been yet initiated.
KPI - Capital cost €/(kg/d)	quantity	€/(kg/d)	750	Aimed value no cost analysis is finalised yet.
KPI - Capital cost €/kW	quantity	€/kW	360	Aimed value no cost analysis is finalised yet.
KPI - O&M cost	quantity	€/(kg/d)/y		Not yet in operation
KPI - Heat demand @ nominal capacity (only SOEL)	quantity	kWh/kg		N.A.
KPI - Reversible capacity (only for SOEL)	quantity	%		N.A.
KPI - Hot idle ramp time	quantity	sec		Not yet in operation
KPI - Cold start ramp time	quantity	sec		Not yet in operation
KPI - Degradation	quantity	%/1,000 hrs	3	Estimated value for the stack from single cell results. No stack tests have been yet initiated.
KPI - Current Density	quantity	A/cm^2	1	Estimated value for the stack from single cell results. No stack tests have been yet initiated.
KPI - Use of critical raw materials as catalysts	quantity	mg/W	0	CRM-free catalysts are used
KPI - Roundtrip electrical efficiency (only for SOEL)	quantity	%		N.A.
KPI - Ramp Duration	quantity	sec		Not yet in operation
KPI - Stability	quantity	%		Not yet in operation
KPI - Ramp Precision	quantity	%		Not yet in operation
KPI - Reliability	quantity	%		Not yet in operation
Fraction of renewable energy input	quantity	%		Not yet in operation
Hours of operation	quantity	h		Not yet in operation
Quantity of hydrogen produced	quantity	t		Not yet in operation
Cost of the hydrogen produced	quantity	€/kg		Not yet in operation
Stack electrical efficiency (HHV, DC current)	quantity	%	80	Estimated value for the stack from single cell results. No stack tests have been yet initiated.
System electrical efficiency (HHV, AC current)	quantity	%		Not yet in operation
System availability	quantity	%		Not yet in operation

2.3 TRUST DATA - SAFETY

Parameter Display Name	Input type	Measurement Type	Value	Data Provider Comment
Start date for reporting	date		01/01/2021	
End date for reporting	date		31/12/2021	
KPI - Safety Management Plan	list		NO	Considering the limited size of the stack to be validated and related hydrogen production, the safety measures are those usually adopted in research laboratories. These are equipped with hydrogen sensors and related alarms and fire extinguishing measures.
Incident/Event	list		NO events	
HELLEN or HIAD database event	list		NO	
Number of incidents/events	quantity		0	
Maximum Stored Hydrogen Inventory Mass	list		<1 kg	The production rate for the stack is 0.04 kg H2/h. The produced hydrogen is vented to the external environment for this proof-of-concept prototype
Hydrogen Storage State	list		>100 bar litre	The production rate for the stack is 0.04 kg H2/h. The produced hydrogen is vented to the external environment for this proof-of-concept prototype
Average Hydrogen Consumption (or Production) Rate	list		Other (please specify in the comment field)	30 kg/month
Type of project, "location"	list		Research in industry lab	Stack tested by Hydrogenics
Public visibility, impact of a potential accident	list		Low	Low hydrogen production rate
Available safety expertise in consortium	freeText		1	Hydrogenics is involved
KPI - Safety Workshops	quantity		0	No safety workshops organised
Management capabilities and pro-active attitude	freeText		N.A.	No safety officer in the project due to the low production rate

3 Input for FCH JU Programme Review Days survey

3.1 ANIONE progress towards project targets and objectives M12-M24

The major project achievements in the second year of the project are:

- **Highly conductive and chemically stable, hydrocarbon ionomer/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 2,000 h in 1M KOH at 80°C, good mechanical strength and low crossover (<1% H2 content in the oxygen stream during electrolysis operation).
- **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}.
- **Enhanced catalyst coated electrodes-based membrane electrode assemblies for AEM water electrolysis:** Membrane-electrode assemblies 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 cm^{-2} and 50°C and stable performance during 2,000 hrs steady state and 1000 hrs cycled (0.2 -1 A cm^{-2}) operations.

The major project difficulties during implementation in the second year of the project are:

- The pandemic has delayed significantly project activities in terms of materials screening and catalyst/membrane/stack development.
- Restrictions due to the pandemic have not allowed organising progress meetings and joint meetings with other project in person.
- The pandemic has impeded participation to conventional dissemination events in person.

The following **quantitative targets** related to the project objectives have been identified in the second year of the project:

ID	Target Source (AIP, AWP, MAIP, MAWP, project own objective, etc.)	Parameter	Unit	Target	Achieved to date by the project	SoA result achieved to date [by another group/project]	Year for SoA target [of another group /project]	Full reference	Comments
1	AWP 2019 Project own objective: Cell performance at 45°C	Cell voltage at 1 A cm^{-2}	V	2 V	1.75 V	1.67 V	2020	Adv. Energy Mater. 2020, 2002285	SoA performance is achieved using carbon paper as anodic diffusion layer which is unstable under OER.
2	AWP 2019 Project own objective: Degradation rate	Voltage increase at 1A cm^{-2}	mV/h	0.005mV/h	<0.005mV/h	2 mV/h	2020	Adv. Energy Mater. 2020, 2002285	SoA performance is achieved using carbon paper as anodic diffusion layer which is unstable under OER.
3	AWP 2019	Membrane conductivity	$mScm^{-1}$	50 $mScm^{-1}$	105 $mScm^{-1}$	80 $mScm^{-1}$	2021	Sustainion® X37-50 Grade RT [1]	SoA conductivity: measured in 1 M KOH

[1] https://www.fuelcellstore.com/sustainion-x37-50-gradertmembrane

The following **non-quantitative objectives** related to the project have been addressed in the second year of the project:

ID	Objective name	Status and short comments
1	Enhanced oxygen evolution catalysts	Development of advanced non-CRM, Ni-Fe-based catalyst for the oxygen evolution reaction showing reduced overpotential and enhanced stability
2	Enhanced hydrogen evolution catalyst	Development of advanced non-CRM, Ni based catalyst for the hydrogen evolution reaction showing reduced overpotential and enhanced stability
3	Advanced cost-effective membrane	Development of cost-effective advanced anion exchange membranes with proper hydroxide ion conductivity and stability
4	Process implementation	Development of AEM electrolysis operating mode showing enhanced stability
5	AEM electrolysis hardware components	Implementation of advanced AEM electrolysis components in terms of diffusion layers and current collectors

The following steps in the project implementation are expected for the period April 2022 – Oct 2024:

ID	Future Plans - Main Expected Steps	Status and short comments
1	Further improvement of AEM membrane conductivity Large area Stack assembling and testing	Promising results have been achieved with functional materials. These need to be validated at stack level

3.2 ANIONE Dissemination Activities M12-M24

ID	Dissemination Activity	Started (year)	Type of dissemination activity	Target audience of the activity	Status of the activity
1	**Performance and stability of a critical raw materials-free anion exchange membrane electrolysis cell** by S. Campagna Zignani , M. Lofaro , A. Carbone , C. Italiano , S. Trocino , G. Monforte , A.S. Arico, Electrochimica Acta 413 (2022) 140078	2021	(c) Scientific Publication	(a) Scientific / Research Communities	(a) Delivered
2	**Design Strategies for Alkaline Exchange Membrane–Electrode Assemblies: Optimization for Fuel Cells and Electrolyzers,** By A. Ashdot, M. Katten, A. Kitayev, E. Tal-Gutelmacher, A. Amel, M. Page, Membranes, 11090686, 2021	2021	(c) Scientific Publication	a) Scientific / Research Communities	(a) Delivered
3	Green hydrogen production by innovative membrane electrolysis technologies by Antonino Salvatore Aricò, Stefania Siracusano, Sabrina Campagna Zignani, Alessandra Carbone, Electrolysers, Fuel Cells & H2 Processing, Green hydrogen production by innovative membrane electrolysis technologies Proceedings of EFCF 2021 Conference,	2021	(c) Scientific Publication	(a) Scientific / Research Communities	(a) Delivered
4	Hydrogen value chain and the role of electrolysisTech Share Day Conference (TSD 2021) - Session on Environmentally Sound Technologies (EST) by Antonino S. Aricò	2021	(a) Conference	(a) Scientific / Research Communities	(a) Delivered
5	Membrane development for electrolysis 4th International Workshop on Degradation -Issues of Fuel Cells and Electrolysers by Deborah Jones	2021	(a) Conference	(a) Scientific / Research Communities	(a) Delivered
6	Advanced materials for electrolysis technologies in 4th International Workshop on Degradation - Issues of Fuel Cells and Electrolysers by Antonino S. Aricò	2021	(a) Conference	(a) Scientific / Research Communities	(a) Delivered
7	Novel CRM-free materials for alkaline water electrolysis 9th World Hydrogen Technologies Convention (WHTC 2021) by Sabrina C. Zignani	2021	(a) Conference	(a) Scientific / Research Communities	(a) Delivered
8	I2- A0401 Green hydrogen production by innovative membrane electrolysis technologies - EFCF 2021 on Low-Temperature FUEL CELL, ELECTROLYSER & H2 Processing. Lucerne – on line event by Antonino S. Aricò	2021	(a) Conference	(a) Scientific / Research Communities	(a) Delivered
9	Anione project in FCH Webinar on Anion Exchange Membrane electrolysers byAntonino S. Aricò	2021	(a) Conference	(a) Scientific / Research Communities	(a) Delivered

3.3 Exploitation of results and Intellectual Property

ID	Type of exploitation activity	Result that the activity refers to	Activity initiation (year)	Audience / Target Group of the activity
1	Highly conductive and chemically stable, hydrocarbon ionomer /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).	2021	(e) Other - INNOVATION RADAR
2	Highly conductive and mechanically stable, reinforced hydrocarbon membrane for AEM water electrolysis	Hydrocarbon membranes reinforced with PBI/sPSU/sPEEK nanofibers for AEM water electrolysis characterised by enhanced mechanical behaviour and lower in-plane dimensional swelling than the corresponding non-reinforced membranes, and OH- conductivity at 50 °C of 90-105 mS/cm.	2021	(e) Other - INNOVATION RADAR
3	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}.	2021	(e) Other - INNOVATION RADAR
4	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 1A cm^{-2}.	2021	(e) Other - INNOVATION RADAR
5	Enhanced catalyst coated electrodes-based membrane electrode assemblies for AEM water electrolysis	Membrane-electrode assemblies 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 cm^{-2} and 50°C and stable performance during 2000 hrs steady state and 1000 hrs cycled (0.2 -1 A cm^{-2}) operations.	2021	(e) Other - INNOVATION RADAR

The project’s potential for exploiting results in new fields are: Developed electrocatalysts catalyst can be used as well in conventional alkaline electrolysis and in low temperature co-electrolysis systems. Developed membrane can be used as well in co-electrolysis systems. Developed membrane-electrode assemblies can be used as well in conventional alkaline electrolysis and in low temperature co-electrolysis systems.

3.4 Interactions with other projects, sectoral organization and initiatives

Project/Body/ Organization name	Project partners involved	Description of the interaction and the expected results
CHANNEL and NEWELY FCH JU Projects	All	To optimise the dissemination of results in the field of AEM electrolysis technology, links have been established to related projects CHANNEL and NEWELY. In the framework of the Horizon Results Booster (HRB), the three projects have collaborated to set up a join project group called AEM HUB (documented in D7.3). The projects in the group are committed to collaborate on dissemination activities and to maximise the awareness of results in the field of AEM electrolysis technology.

4 Summary of work progress and visual material related to ANIONE's activities in M12-M24

4.1 WP1: Project management and coordination

The activity of the second year in the framework of WP1 has been focused on the monitoring of the technical progress, coordinating input/output flows between the various work packages and tasks; the organisation of consortium meetings and Quality Assurance procedures to verify the consistency of Deliverables and coordination of the periodic review report submitted after M18 and the review meeting hosted in M21.

4.2 WP2: Specifications, harmonisation, life-cycle and cost analyses

The activities related to WP2 concern the harmonisation of characterisation and test protocols and the Lifecycle and cost analyses for AEM electrolysis have been revised in the light of the recent experiments and results and found to be updated. This has regarded the protocols for the anion exchange membrane characterizations, in particular the ex-situ and in-situ characterizations in terms of IEC, water uptake, swelling, hydrolytic stability, H_2 crossover, thermal stability. The focus is on the use of the true conductivity measurements instead of conventional ones.

4.3 WP3: Innovative anion exchange ionomers, reinforcements and membranes

The WP3 activities comprise of an optimization and scale up process of ionomer based on hydrocarbon, development of per-fluorinated ionomer, scavengers' investigation and scale up of reinforced membranes. In the second year, the membrane preparation was defined through a selection of the best solvent and operative conditions such as time and temperature. In Figure 1 (left) is reported the comparison of anion conductivity measured after the exchange in KOH1M (named OH) or KHCO3 (named true OH) for the selected membrane. A maximum conductivity of 38 mS/cm was reached at 80°C.

In Figure 1 (right) is reported the anion conductivity of the scavenger-based membrane compared to a bare recast one and benchmark.

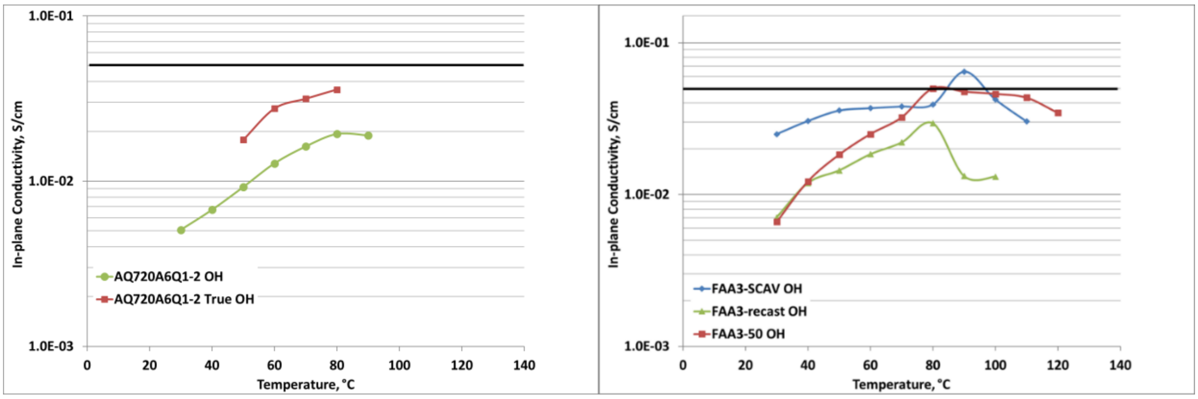

Figure 1 - Left: Anion conductivity measurements; Right: Anion conductivity of benchmark, recast and composite membrane

4.4 WP4: Enhanced anode and cathode catalysts for AEM electrolysis

Among others, the WP4 activities in M12-M24 have analysed the effect of carbon is to avoid agglomeration. XPS analysis (Figure 2) essentially indicates metallic Ni, Ni^{2+} and Mo^{4+} oxidation states. It is expected that during operation further reduction occurs.

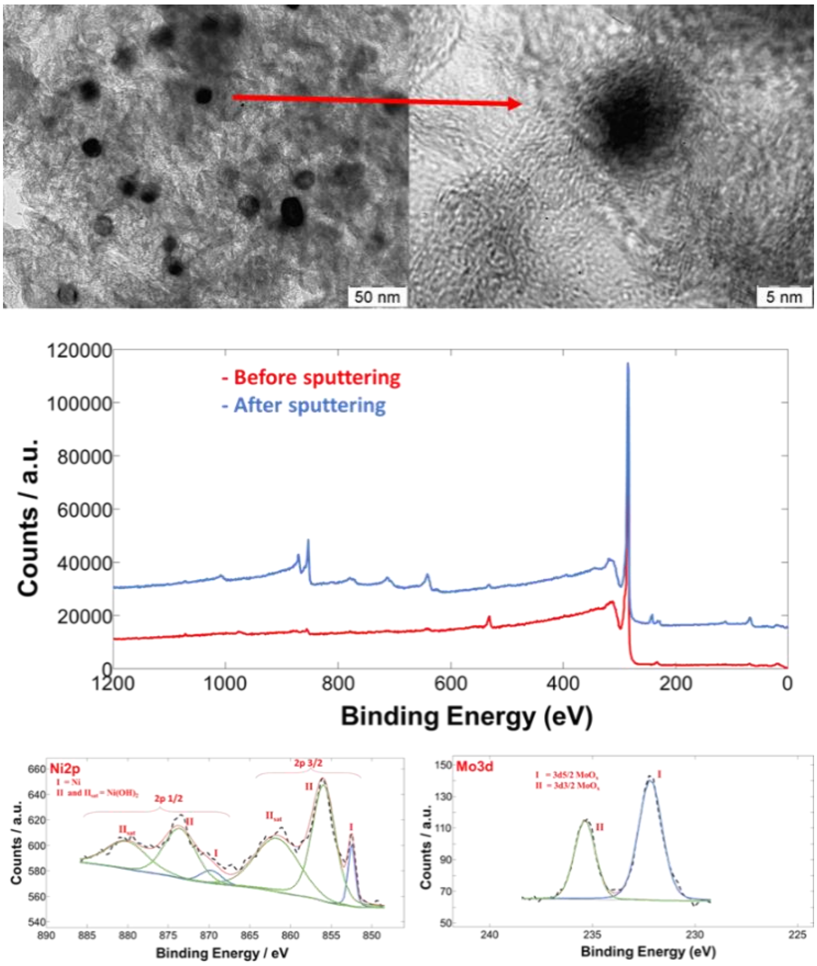

Figure 2 - TEM images at different magnifications showing the distribution of fine particles and XPS survey analysis of CNR-ITAE NiMo/C catalyst before and after sputtering with Ar

4.5 WP5: MEA engineering and cell testing

The WP5 activities comprise the design of advanced MEAs for AEM electrolysis applications with the overall aim of improving performance and durability while simultaneously reducing cost.

In M12-M24, IRD has manufactured two sets of GDEs with varied ionomer content for a percolation study to be done by CNRS-ITAE. It was during the GDE coating noted that high catalyst loading in combination with a high ionomer content resulted in pronounced mudcrack formation (Figure 3). The GDEs have not been hot laminated, as a simple soaking test in DI water have proved a satisfying electrode adhesion to the GDL. To cut the membrane in a dry stage is easy, but it may afterwards prove to be difficult to respect acceptable tolerances upon membrane hydration due to the inherited swelling. It has therefore been decided to stamp out a fully hydrated membrane at IRD and ship the wet hydrated membrane to Hydrogenics. A stamping tool has been acquired.

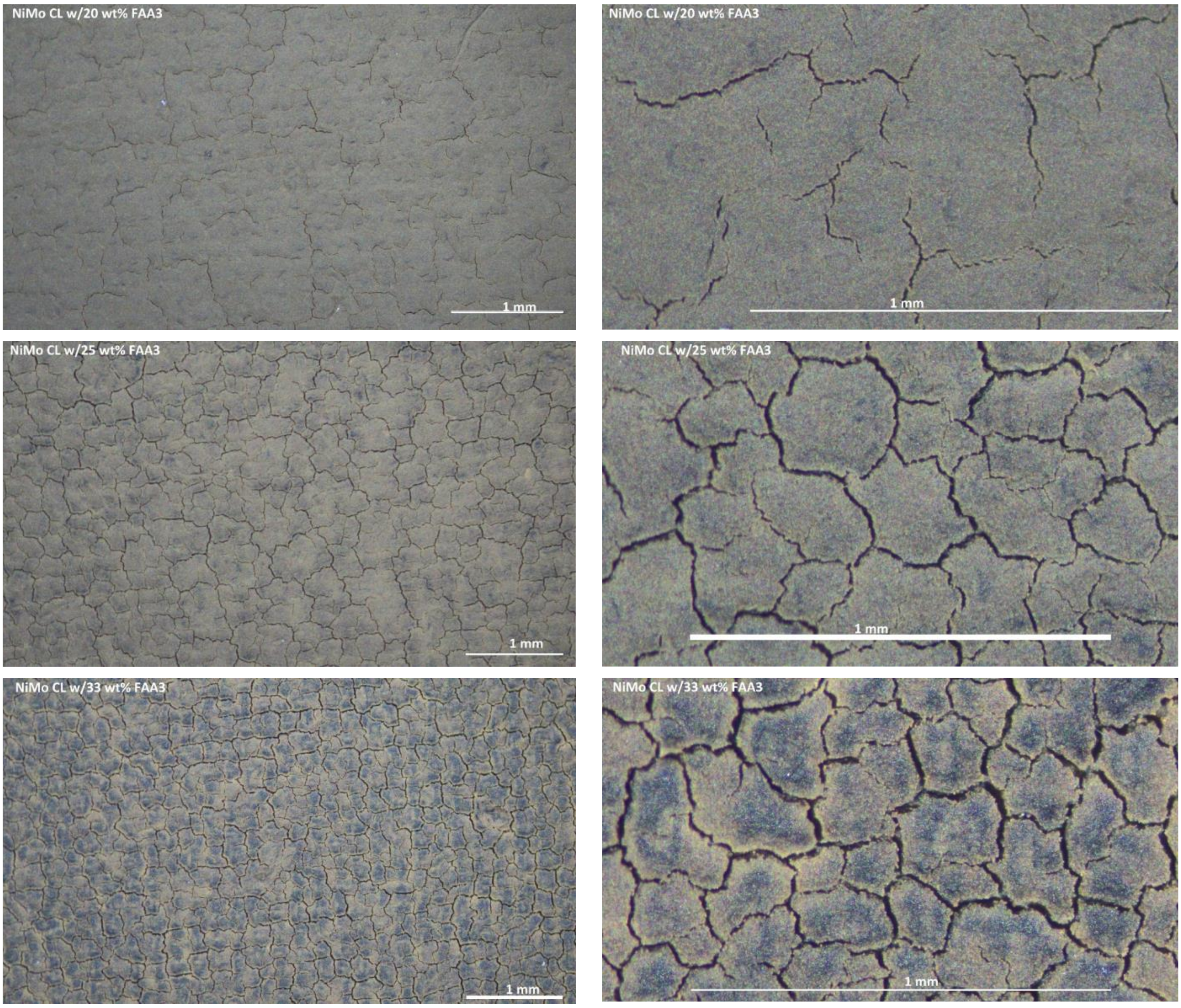

Figure 3 - Mudcracks in the NiMo-cathodes.

4.6 WP6: Stack engineering, BoP design, prototyping and testing

The aim of WP6 includes the design, engineering and testing of a 2 kW AEM electrolysis system. In the M12-M24 period, Hydrogenics (Part of Cummins) has designed a specific cell stack architecture, including MEA design, to test the AEM membranes for high pressure operation (30 barg) based on their previous compression and cell sealing experience. The design of the Balance of Plant (BoP), including HAZOP study, was developed to assess the cell stack in a wide range of operating conditions in terms of temperature (up to 90 °C) and balanced pressure (30 barg).

4.7 WP7: Dissemination, Communication and Exploitation

WP7 concerns he dissemination, communication, and exploitation of project results. This is a continuous process throughput the project. In the period M12-M24, the project activities were widely disseminated through the project website, newsletters, social media, and participation to (online) conferences. An overview is included in Sect. 3.2.

5 Deliverables

In the period M12-M24, seven deliverables are planned (see below). D3.3 and D4.2 have been delayed from M24 to M28 and M29, respectively. D4.3 have been delayed from M24 and is submitted in M27.

Del. No	Deliverable title	Lead Beneficiary	Submission month
D3.2	Provision of selected reinforced membranes and ionomers for characterisation	CNRS	M15
D1.2	Annual data reporting (Year 1)	CNR-ITEA	M18
D5.1	Engineered membrane electrode assemblies for AEM electrolysis operation	IRD	M18
D7.3	Dissemination Plan including knowledge management protocol	UNIRESEACH	M18
D3.3	Data-set on membranes and ionomer dispersions. Supply of down-selected membranes and ionomer dispersions manufacturing large area MEAs	HydroLite (formerly PoCellTech)	M24 Delayed to M28
D4.2	Manufacturing of catalysts meeting the specifications and provision for large area MEAs and stack	TFP Hydrogen (formerly PV3)	M24 Delayed to M29
D4.3	Publishable report on electrocatalysts and recombination catalyst development for AEM electrolysis	CNRS	M24 Submitted M27

6 Milestones

Five milestones are expected in the M12-M24 period. The milestone details are listed below:

MS No	Milestone title	Related WP	Lead	Due Date	Means of verification	Status
MS2	Innovative AEM electrolysis membranes for operation in a wide range of temperature and pressure	WP3	CNRS	M15	Thin (≤ 30 µm) fibre reinforced Membranes containing specific additives for operation up to 90 °C and 30 bar, with hydroxide conductivity ≥ 50 mS cm-1 and area specific resistance ≤ 70 mOhm cm^2 and low gas cross over (< 1 vol% H_2 in the O2 stream at the anode)	ACHIEVED
MS3	Enhanced electrochemical and mechanical stability for the anionic exchange membrane	WP3	CNR-ITAE	M24	Area specific resistance (ASR) increase lower than 5% in 2,000 h electrolysis operation. Mechanical elongation at break >100%; modulus ~ 15 MPa.	ACHIEVED
MS4	Membrane scaling-up and optimisation	WP4	CNR-ITAE	M24	Provision of large-area membranes (active area ≥100 cm^2) meeting specifications.	ACHIEVED
MS6	Catalysts scaling-up and optimisation	WP4	TFP Hydrogen (formerly PV3)	M24	Provision of large-batch (>100 g) catalysts meeting specifications	ACHIEVED
MS7	Enhanced performance for engineered MEAs	WP5	IRD	M18	Performance of 1 Acm^{-2} at ECell <1.8 V under pressure. Faradaic efficiency > 99%.	ACHIEVED

7 Conclusion

The activities carried out in the second year of the ANIONE project were summarised. The aim is to provide a concise overview and monitoring of the general activities carried out in the second year of the project, of the submitted deliverable, and achieved milestones. Also, the data requested by the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) via the TRUST system and PRD surveys are presented.

The major project achievements in the second year of the project are:

- **Highly conductive and chemically stable, hydrocarbon ionomer/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).
- **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}.
- **Enhanced catalyst coated electrodes-based membrane electrode assemblies for AEM water electrolysis:** Membrane-electrode assemblies 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 cm^{-2} and 50°C and stable performance during 2000 hrs steady state and 1000 hrs cycled (0.2 -1 A cm^{-2}) operations.

The major project difficulties during implementation in the second year of the project are:

- The pandemic has delayed significantly project activities in terms of materials screening and catalyst/membrane/stack development.
- Restrictions due to the pandemic have not allowed organising progress meetings and joint meetings with other project in person.
- The pandemic has impeded participation to conventional dissemination events in person.

Three deliverables (D4.3, D3.3, D4.2) for the second year have been slightly delayed (till M27, M28, and M29, respectively). All milestones planned for the second year have been achieved.

8 Risk Register

No risks linked to D1.3 have been identified.

Risk No.	What is the risk	Probability of risk occurrence[1]	Effect of risk[1]	Solutions to overcome the risk
WP1	n/a			

[1)] Probability risk will occur: 1 = high, 2 = medium, 3 = Low

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Project partners:

#	Partner	Partner Full Name
1	CNR-ITAE	CONSIGLIO NAZIONALE DELLE RICERCHE
2	CNRS	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE
2.1	UM	UNIVERSITE DE MONTPELLIER
3	HydroLite (formerly PoCellTech)	HYDROLITE
4	TFP Hydrogen (formerly PV3)	TFP Hydrogen Products Ltd
5	IRD	IRD FUEL CELLS A/S
6	HYDROGENICS	HYDROGENICS EUROPE NV
7	UNR	UNIRESEARCH BV

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