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

D1.2 – Annual Data Reporting (Year 1)

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (JU) under grant agreement No 875024. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation programme, Hydrogen Europe and Hydrogen Europe research.

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Publishable summary

Deliverable D1.2 - Annual Data reporting (Year 1) provides concise information about the activities and project achievements in the first 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 Joint Undertaking (FCH JU); 2) A dedicated questionnaire requested by the FCH JU 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.

Deliverable D1.2 also provides a concise monitoring of the general activities carried out in the first year of ANIONE. The project activities were widely disseminated through the project website, newsletters, social media, and participation to (online) conferences.

Contents

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

1 Introduction

Deliverable D1.2 - Annual data reporting (Year 1) is requested by the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) as part of the 2021 Annual Programme Review in order to provide a knowledge basis to updated Key Performance Indicators (KPIs) for the FCH JU general Programme review.

ANIONE was asked in March 2021 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 FHC JU as part of the Programme review Days 2021 (PRD) survey. A copy of the information provided is included in this deliverable.

Deliverable D1.2 also provides a concise monitoring of the general activities carried out in the first year of ANIONE. 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 and FCH JU PRD survey

The data provided below are a subset of the information recorded via the TRUST system for the first year of the ANIONE project and the FCH JU Programme Review Days 2021 (PRD) survey on project progress, Dissemination activities, and Exploitation of Results.

2.1 TRUST Research Objectives

Parameter name	Value	Classification	Comment
Technology	AME - alkaline membrane cell	DESCRIPTIVE	
Active cell area	100 cm2	DESCRIPTIVE	Single cell
Operating temperature	50°C	DESCRIPTIVE	
Rated stack durability	40000 h	DESCRIPTIVE	Estimation for the stack from single cell degradation rate results
Operating pressure	30 bar	DESCRIPTIVE	Aimed value; no high-pressure experiments have yet been done.
Hydrogen purity	99.999 %	DESCRIPTIVE	Aimed value after DEOXO; no purity tests have yet been done.
Input voltage	20	DESCRIPTIVE	Estimated value from single cell results. No stack test has been yet initiated.
Stack nominal capacity	2000 W	DESCRIPTIVE	Estimated value from single cell results. No stack test has been yet initiated.
Rated stack electrical efficiency (HHV, DC current)	79 %	DESCRIPTIVE	Estimated value from single cell results. No stack test has been yet initiated.
Number of cells in each stack	11	DESCRIPTIVE	Estimated value from single cell results. No stack test has been yet initiated.
KPI - Catalyst at the cathode	NiMo	DESCRIPTIVE	Non-precious non-CRM catalyst
KPI - Catalyst at the anode	NiFe oxide	DESCRIPTIVE	Non-precious non-CRM catalyst
KPI - Stack CAPEX (per kW)	360 Euro	DESCRIPTIVE	Aimed cost/ Rough estimation for the stack from single cell results and materials used
KPI - Est. stack CAPEX (per kW) @ 100MW annual production		DESCRIPTIVE	N.A. No estimation done at this level
KPI - Reversible capacity of the Electrolyser (Specific System)		DESCRIPTIVE	N.A.
ASR - Area Specific Resistance	0.3 Ohm cm^2	DESCRIPTIVE	At cell level; estimated from polarisation slope
Start date for reporting	01/01/2020	OPERATIONAL	
End date for reporting	31/12/2020	OPERATIONAL	
Hours of operation	1000 h	OPERATIONAL	At cell level
Hours of operation - cumulative	1200 h	OPERATIONAL	At cell level
Quantity of hydrogen produced		OPERATIONAL	N.A. No stack test has been yet started.

Electricity consumed		OPERATIONAL	N.A. No stack test has yet been initiated.
KPI - Stack electricity consumption for H2 production		OPERATIONAL	N.A. No stack test has yet been initiated.
Stack Thermal Energy Consumption		OPERATIONAL	N.A. No stack test has yet been initiated.
Power density	1.8 W / cm2	OPERATIONAL	At cell level
KPI - Current density	1 A/cm2	OPERATIONAL	At cell level
Stack availability		OPERATIONAL	N.A. No stack test has been yet initiated.
Operating time per day		OPERATIONAL	N.A. No stack test has yet been initiated.
KPI - Cold start ramp time		OPERATIONAL	N.A. No stack test has yet been initiated.
KPI - Hot idle ramp time		OPERATIONAL	N.A. No stack test has yet been initiated.
Cell voltage	1.8 V	OPERATIONAL	At cell level
Transient response time		OPERATIONAL	N.A. No stack test has yet been initiated.
Stack electrical efficiency (HHV, DC current)		OPERATIONAL	N.A. No stack test has yet been initiated.
KPI - Production loss rate for HT Electolyser		OPERATIONAL	N.A.
Voltage degradation rate in %/kh	3 %	OPERATIONAL	Results refer to single cell testing; no stack test has yet been initiated.
KPI - Efficiency degradation per 1000 h for LT Electrolyser	3 %	OPERATIONAL	Results refer to single cell testing; no stack test have yet been initiated.
KPI- Cathode catalyst loading per W	2.8 g	OPERATIONAL	Cell level; Non-precious non-CRM catalyst
Cathode catalyst loading per H2 capacity	6.5 g	OPERATIONAL	Cell level; Non-precious non-CRM catalyst
Anode catalyst loading per H2 capacity	4 g	OPERATIONAL	Cell level; Non-precious non-CRM catalyst
KPI - Anode catalyst loading per W	1.7 g	OPERATIONAL	Cell Level; Non-precious non-CRM catalyst
KPI - Reversible efficiency of the Electrolyser (Specific System)		OPERATIONAL	N.A.
Degradation - ASR	5%	OPERATIONAL	Cell level; Non-precious non-CRM catalyst

2.2 FCH JU Programme Review Days survey

ANIONE progress towards project targets and objectives M1-M12

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

- Development of advanced non-CRM, Fe-Ni-based catalyst for oxygen evolution reaction showing reduced overpotential of 170 mV at 1 A cm^{-2};
- Development of advanced non-CRM, Ni-based catalyst for the hydrogen evolution reaction showing reduced overpotential of 120 mV at 1 A cm^{-2};
- Development of cost-effective advanced anion exchange membranes with hydroxide ion conductivity higher than 50 mS cm^{-1}.

The major project challenges in the first year of the project are:

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

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

ID	Target Source (AIP, AWP, MAIP, MAWP, project won objectives)	Parameter	Unit	Target	Achieved to date by the project	SoA result achieved to date	Year for SoA target	Full reference (name for a group/project)	Comments
1	AWP 2019 Project own objective: Cell performance at 45°C	Cell voltage at 1 A cm^{-2}	V	2 V	1.85 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 1 A cm^{-2}	mV/h	<0.025 mV/h	<0.005 mV/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	Project own objective: Voltage efficiency	Voltage efficiency	% vs. HHV	74%	80%	88%	2020	Adv. Energy Mater.2020, 2002285	SoA performance is achieved using carbon paper as anodic diffusion layer which is unstable under OER.
4	AWP 2019	Membrane conductivity	mS cm^{-1}	50 mS cm^{-1}	20	80	2021	Sustainion® X37-50 Grade RT; https://www.fuelcellstore.com/index.php?route=product/search&search=sustainion	SoA conductivity: Measured in 1 M KOH

The following **non-quantitative objectives** related to the project have been identified in the first 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 high 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

ANIONE Dissemination Activities M1-M12

ID	Dissemination Activity	Started (year)	Type of dissemination activity	Target audience	Description of the objective(s) of the activity (with reference to a specific project output)	Outcome(s) of the dissemination activity (e.g. number of participants/trainees, projects of cluster etc)	Status of the dissemination activity?	Links / Comments
1	Launch of project website	2020	Other	Public	Disseminate project results though regular website updates (documented in D7.1)		Delivered	www.anione.eu
2	Project newsletter	2020	Other	Industry, Business Partners	Update on project results	234 recipients on mailing list	Ongoing	Newsletters are released twice a year. Two newsletters out in 2020.
3	Report on harmonised test protocols for assessing AEM electrolysis components, cells and stacks in a wide range of operating temperatures and pressure	2020	Collaboration with EU projects	Scientific / Research communities	Implementing for Anion Exchange Membrane Electrolysis the harmonised terminology, procedures and characterisation protocols developed by JRC with internally defined protocols and the joint protocols agreed among three H2020 FCH JU projects (ANIONE, CHANNEL and NEWLY). Documented in D2.1.	Identification of a benchmark of baseline components to assess progress of durability and performance.	Delivered	https://anione.eu/wp-content/uploads/2020/07/D2.1-%E2%80%93-Harmonised-test-protocols.pdf

Webpage of the result (URL or N/A)	**Exploitation activity**	**If other/ more than one, please specify**	**Horizon Results Platform** (Do you intend to publish)	**Innovation Radar** Do you intend to request analysis)	**Steps undertaken towards exploitation**	**Identified bottlenecks /obstacles during exploitation activities**	**Maturity of Market** (targeted by the result)	**Have you used any support service from the EC?**
N/A	IPR activities	IPR activities	YES	NO	Prototyping in laboratory	IPR related problems	Not existing: Not clear if a new market can be created	None
N/A	IPR activities	IPR activities	YES	NO	Prototyping in laboratory	IPR related problems	Not existing: Not clear if a new market can be created	None
N/A	IPR activities	IPR activities	YES	NO	Prototyping in laboratory	IPR related problems	Not existing: Not clear if a new market can be created	None

ID	Name of the Result	Year accomplished	Result Type	**Key exploitable results (KER)** Does this result have a high potential?	**Describe the potential**	**Expected time to impact** When do you expect the result to be exploited or used?	**Audience /Target Group**
1	NiFe-oxide oxygen evolution electrocatalyst	2021	Product (new or improved)	The result in not a KER	This advanced catalyst can be used as well in conventional alkaline electrolysis and in low temperature co-electrolysis systems	1-5 years	Industry/ Business Partners
2	Ni-based hydrogen evolution eletrocatalyst	2021	Product (new or improved)	The result in not a KER	This advanced catalyst can be used as well in conventional alkaline electrolysis	1-5 years	Industry/ Business Partners
3	New anionic membrane	2021	Product (new or improved)	The result in not a KER	This advanced membrane can be used as well in co-electrolysis systems	1-5 years	Industry/ Business Partners

3 Work progress and achievements during the period M1-M12

This section comprises a summary of the activities undertaken in the different Work Packages by the consortium partners during the project first year.

3.1 WP1 - Project management and coordination

Summary of progress and activities per partner

CNR-ITAE

The activity of the first 12 months 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 progress or final reports. In particular, the Consortium Agreement signatures were completed, and original singed copies were provided to all partners. Originals also saved at CNR-ITAE. The distribution of pre-financing to all partners and to Hydrogen Europe (as stated in the CA) was completed.

In addition, the D1.1 (Lead beneficiary UNR) was submitted, and an analysis of covid-19 related lock-down effects was made (UNR).

CNRS

CNRS has carried out project management tasks associated with the local organisation of the project, time recording, monitoring of expenditure, participation in project progress and steering committee meetings.

UM

- UM has carried out management activities associated with monitoring of costs.

HydroLite (formerly PoCellTech), TFP Hydrogen (formerly PV3), IRD, HYDROGENICS

Internal organisation of finance and technical work. Participation in several project web-meetings

UNIRESEARCH

Together with the project coordinator (CNR-ITAE), UNR has coordinated the activities related to the compliance of the project execution with the objectives in the Grant Agreement, the Consortium Agreement, and the relevant annexes.

Specifically, UNR has:

- Taken care of the day-to-day administrative and financial management (with CNR-ITAE).
- Set-up and maintained the web-based tool METT (for internal communication, documentation (archive), on-line manuals and procedures).
- Preparation of reporting templates; deliverable report, milestone report, technical and financial reports
- Monitored the status of Deliverables and Milestones.
- Kept track of the project progress, costs, and budget situation.
- Prepared, organised, administrated, and drafted the minutes and follow-up activities of meetings, including the project Kick-off meeting and the Consortium meetings/teleconferences.
- Reviewed the ANIONE status regularly (at least once a month) with the project management team (CNR-ITAE + UNR).
- Checked status of work and possible deviations due to Covid 19 among partners.
- Organised (with CNR-ITAE) the Consortium meetings with all the partners.

- Organised and administrated the first 6M internal reporting (financial + technical).
- Prepared and submitted D1.1 (project management plan).
- Setup a risk management protocol to identify and track technical, financial, and organisational risks (part of D1.1)

Deviations from Annex I → No deviations, the progress of the activities in WP1 are in line with the DoA.
Non achievement of objectives → No
Corrective actions → No

3.2 WP2 - Specifications, harmonisation, life cycle and cost analyses

Summary of progress and activities per partner

CNR-ITAE
The activities related to WP2 concern the harmonisation of characterisation and test protocols and the Lifecycle and cost analyses for AEM electrolysis. In the first year, the Project Officer's request for joint protocols (WP2) was addressed and two joint teleconferences with the FCH JU projects Channel and Newely (March and April 2020) were organised; the interaction with the JRC –IET on joint protocols was carried out and the initial exchange of samples among the partners was coordinated. The deliverable D2.1 (due at M6) was finalised and addressing techno-economic assessment and Life cycle analysis of the AEM electrolyser was started.
As described in D2.1, CNR-ITAE participated in the definition of 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.

CNRS
CNRS participated in the definition of protocols and benchmarks for the project, in particular for the D2.1 report (Harmonised test protocols for assessing AEM electrolysis components, cells and stacks in a wide range of operating temperature and pressure).
CNRS proposed a protocol based on electrolysis and CO_2 purging (N. Ziv and D. R. Dekel, *Electrochem. Commun.* **2018**, *88*, 109–113) to determine the "true" OH^- conductivity in case of membrane carbonation and transport of HCO_3^- instead of OH^-.

HydroLite (formerly PoCellTech)
No work done in the reporting period.

TFP Hydrogen (formerly PV3)
TFP Hydrogen participated in the definition of protocols and benchmarks for the project.

IRD
Contributed to the deliverable reports (D2.1)

HYDROGENICS
Minor project monitoring.

Deviations from Annex I → No deviations, the progress of the activities in WP2 are in line with the DoA.
Non achievement of objectives → No
Corrective actions → No

3.3 WP3 - Innovative anion exchange ionomers, reinforcements, and membranes

Summary of progress and activities per partner

CNR-ITAE

The activity of the first year was aimed to the synthetic approach to functionalize the sulfonyl fluoride terminal groups in the side chains of the Aquivion® scaffold (perfluorinated AEM) and to define a protocol of chemical treatment and alkaline ion exchange process for the FAA-3-50 benchmark membrane.

The functionalization reaction parameters (time and temperature) were defined in addition to the choice of the reactants and solvents. The desired product was obtained.

The polymer was characterized via NMR spectroscopy, TG analyses and titration to obtain ion exchange capacity.

First preparation of membranes was carried out.

The Covid-19 situation produced some delays in receiving reactants from the suppliers, leading to a limited production of anion exchange polymer and to a not complete characterization of the produced membranes.

The chemical treatments of the benchmark were fixed as follows: membrane exchange in NaCl 1M for 72 hrs to have it in the stable Cl- form, exchange in KOH 1M for 24 hrs to have it in hydroxide form and to have the highest anion exchange conversion (86%). **The MS2, scheduled for the 15th month, was reached with FAA3-50 membrane.** In fact, after the optimized exchange procedures, a hydroxide conductivity above 50 mS cm^{-1} was measured at 80°C with an Area Specific Resistance ≤ 70 mOhm cm^2, at the same temperature.

Ionomer dispersion preparation based on FAA-3 solid ionomer was defined after a screening of the best solvent composition. It was defined as the best formulation the alcoholic 5 wt% dispersion in Ethanol and n-propanol (1:1).

CNRS / UM

CNRS/UM work focused on the development of a reinforcement for anion exchange membranes based on the ionomer provided by HydroLite (formerly PoCellTech) (labelled as PO-AEI or Hydrolite-AEI). The conditions of preparation of a non-reinforced PO-AEI membrane by casting were optimized. Homogeneous membranes 45 µm thick were prepared.

Concerning the development of active reinforcements, CNRS prepared webs of nanofibers by electrospinning. Composite membranes were prepared, which have been characterized in comparison with non-reinforced PO-AEI membranes.

HydroLite (formerly PoCellTech)

Potentiometric method for measuring the IEC was used. The membranes were immersed in 1M NaCl solution for 30 min, in order to convert the counter ion into Cl- form (the solution was refreshed at least 3 times). In the next step, the membranes were washed with DI water in order to remove any excess of Cl- ions (the solution was changed at least 3 times). The membranes were immersed in 0.2 M $NaNO_3$ solution for 30 min, while collecting the solutions (repeating 4 times). This step confirms that the membranes are in NO_3- form and the Cl- ions are in the beakers. The Cl- ions solution was titrated using $AgNO_3$ solution. The membrane was exchanged into Cl- form once again and was dry in vacuum oven at 50ºC for 3 hr. The IEC was calculated using the following equation:

$$\mathrm{IEC} = \frac{\Delta V_{AgNO_3}\, C_{AgNO_3}}{m_d}$$

Where, md is the mass of the dry membrane (in the Cl^- form), $\Delta VAgNO_3$ is the consumed volume of $AgNO_3$ solution and C $AgNO_3$ is the concentration of $AgNO_3$ solution.

Ionic through Plane Conductivity

Ionic through plane conductivity using two electrodes was measured using membrane test station (MTS), the membrane was sandwiched between two GDLs that were closed between two electrodes. The membrane impedance was measured over the frequency range from 10 kHz to 10 mHz. The resistance of the membranes was determined from the Nyquist plot of the impedance measurements. The resistance was calculated by extracting the real part of the impedance at the minimum imaginary value. The measurements were done in N_2 environment, in humidified conditions.

Thermal Gravimetric Analysis (TGA)

TGA was used in order to evaluate the thermal properties of the membrane. The thermal stability of the membranes was analysed using a TGA (TA Instruments Corporation). Temperature was increased from room temperature to 800°C at a heating rate of 10ºC min^{-1} in a nitrogen environment.

Results

1. **<u>FAA3- membrane:</u>**

The potentiometric IEC of the FAA3- membrane in Cl- form was measured and 1.53 mmol/gr value was recorded. This IEC value is a bit lower than most of the anion exchange membranes and could lead to lower conductivity and lower water transport properties of the membrane.

The thermal properties of the FAA3- (Cl- form) membrane were tested (figure 1). Five decreasing steps were observed: the first one, around 56°C could be attributed to water, then at 200°C the functional groups are being released, and the last stages that ends at 600°C with a lost of 40% of the weight is the backbone of the membrane.

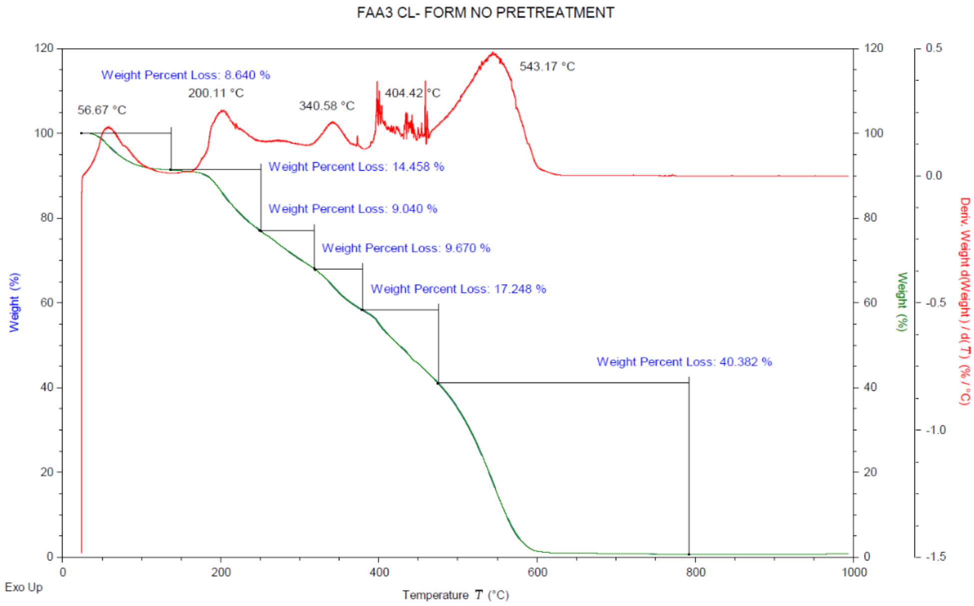


Figure 1

The through plane conductivity of the membrane was tested at 95% RH, at 30-90°C (OH-) and at (HCO_3^-) from. The HCO_3^- form (figure 2) showed that around 70°C the membrane reaches its max. conductivity of **9** mS/cm. At a bit higher temperature (80°C) we observe a small decrease in conductivity.

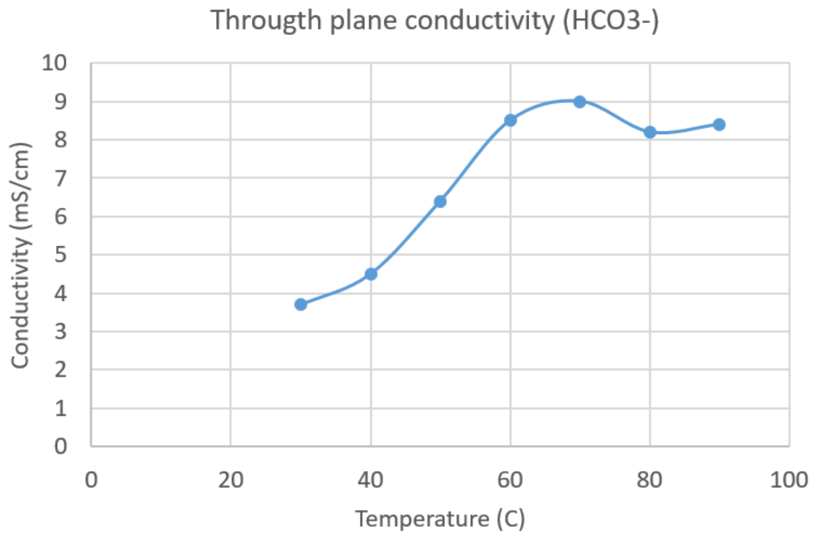


Figure 2

The through plane conductivity of the membrane was tested at 95% RH, at 30-90°C OH- form (figure 3) showed that around 80°C the membrane reaches its max. conductivity of 43 mS/cm. At higher temperature of 90°C we observed lower conductivity values, that could be attributed to chemical degradation of the membranes, since OH- environment could cause a loss of IEC that will have an impact of decreasing the ionic conductivity.

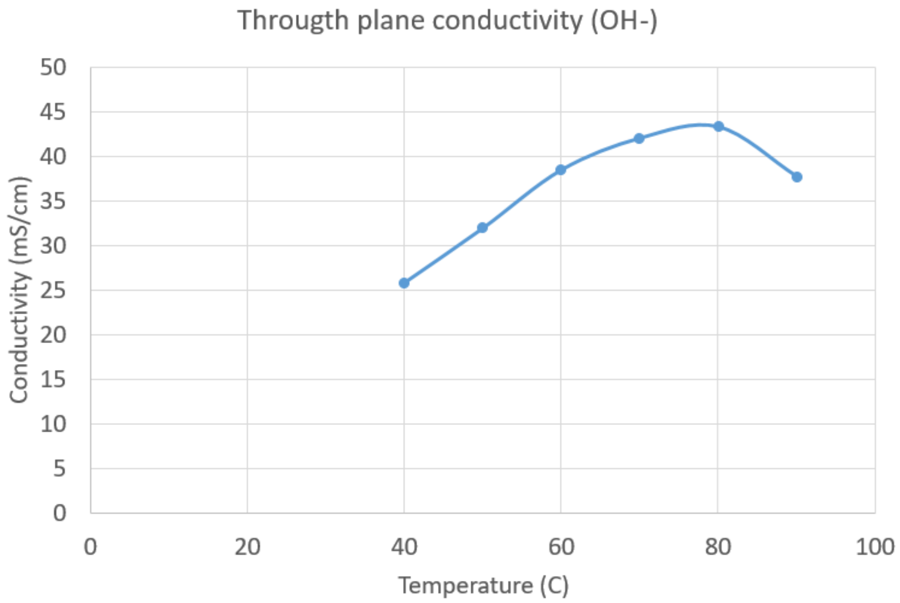


Figure 3

Investigation that was executed when using FAA3- membrane, showed that this type of membrane has few advantages for electrolyser, as good thermal properties (no loss of chemical groups till 200°C) and reasonable OH^- ionic through plane conductivity at 95%RH 80°C. However, the behaviour of the conductivity at 95% RH vs. temperature at OH- form, showed that at 80°C and above the membrane might lose its chemical stability (loss of IEC) and present lower performance.

1. **<u>Hydrolite's membrane:</u>**

The potentiometric IEC of the membrane in Cl- form was measured and 2.18 mmol/gr value was recorded.

TGA experiment was conducted, in the temperature range of 30-700°C as presented in figure 4. Loss of functional groups is observed at 246°C. Loss of tether and backbone are seen at 422°C and above. These TGA results show us that, this type of polymer is thermally stable till 246°C.

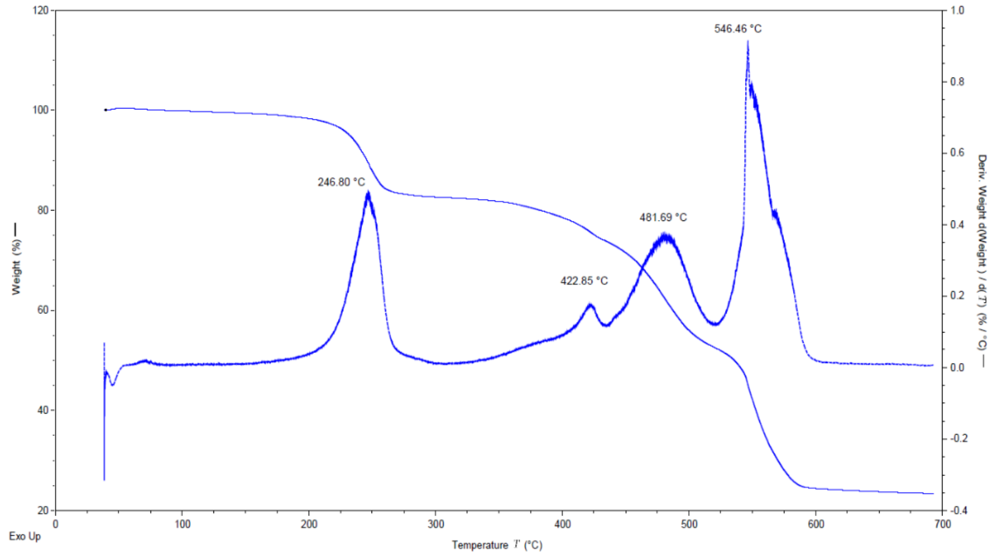


Figure 4

The through plane conductivity of the membrane was tested at 95% RH, at 30-90°C (OH^-) and at (HCO_3^-) from. The HCO_3^- form (figure 5) showed that around 80°C the membrane reaches conductivity of 14 mS/cm.

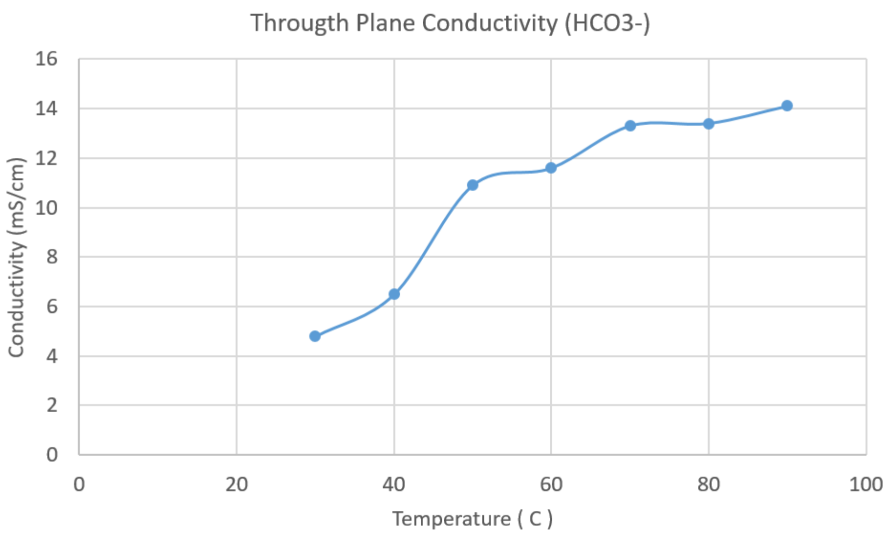


Figure 5

The through plane conductivity of the membrane was tested at 95% RH, at 30-90°C OH^- form (figure 6) showed that around 80°C the membrane reaches conductivity of 45 mS/cm.

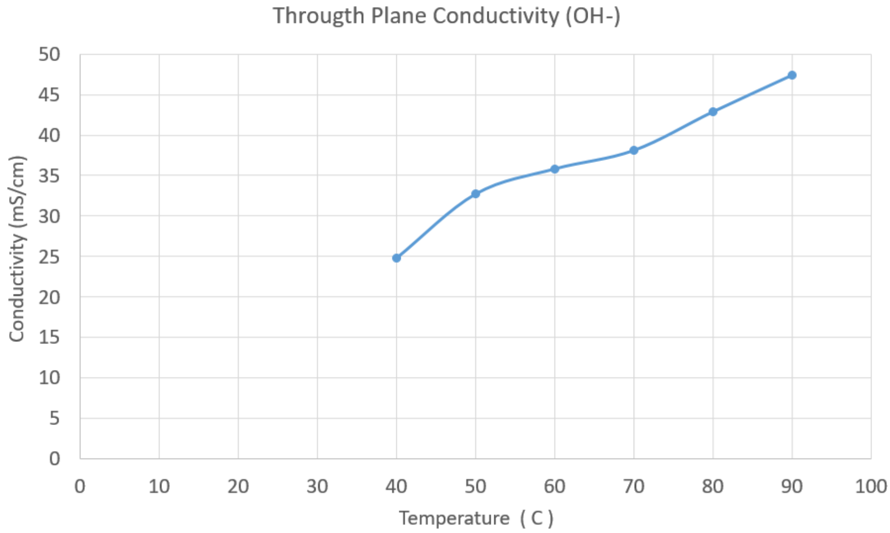


Figure 6

Currently, according to the TGA, IEC and conductivity results, Hydrolite's membrane showed better results of thermal stability, higher IEC and higher conductivity values.

Deviations from Annex I → No deviations, the progress of the activities in WP3 are in line with the DoA.
Non achievement of objectives → No
Corrective actions → No

3.4 WP4 - Enhanced anode and cathode catalysts for AEM electrolysis

Summary of progress and activities per partner

CNR-ITAE

At CNR-ITAE, during the first 12 months of the project, Ni-Fe oxide-based anode catalysts, metallic Ni, Ni-Cu, NiCuMo and NiMo based cathode catalysts have been synthesized and investigated for operation in the alkaline environment. For the electrocatalyst assessment, the procedures included specification of catalyst loading in the electrodes. Slurries of the anode (NiFe) and cathode (Pt/C as reference electrode for H_2 evolution acting as RHE, Ni, NiCu, NiCuMo as nonCRM) catalysts were prepared by dispersing the catalyst powder in ethanol in the presence of EM ionomer. The cathode inks were deposited on carbon paper SIGRACET Gas Diffusion Layers (GDL) with a total metal loading of 3 mg cm^{-2}, the anodic ink was deposited on a Ni felt with 2.5 mg cm^{-2} loading for NiFe. When Pt/C was used at the cathode the catalyst loading was 1 mg Pt cm^{-2}. Pt/C was essentially used as reference electrode since it has the lowest overpotential for the hydrogen evolution reaction (HER). The process of H_2 evolution at Pt/C, thus, reproduces that of a reversible hydrogen electrode (RHE). A FAA3-50 anion exchange membrane in the OH- form was used as separator between anode and cathode compartments. A cold-assembly procedure was assessed to prepare the membrane-electrode assemblies (MEAs) with 5 cm^2 geometrical area.
The performance targets have been almost achieved using NiFe anode and NiCu cathode catalyst showing 170 mV and 190 mV overpotentials at 1 A cm^{-2} at 50°C with a Tafel slope indicative of a one electron transfer rate determining step.
The durability target was fully achieved with the NiFe anode catalyst showing no degradation in a 1000 hrs durability test at 1 A cm^{-2}.
NiCu is promising in terms of performance but shows rapid degradation whereas NiMo is not yet properly optimised with regard to composition, surface and morphology. Additional steps are

necessary to improve these catalytic systems and their interface with the membrane developed in the project needs to be assessed.

CNRS
No work done in the reporting period.

TFP Hydrogen (formerly PV3)
TFP hydrogen have scoped, purchased, and set up the facility to make test electrodes. Started to look at catalyst synthesis. Purchased baseline catalysts and sent to CNR-ITAE for testing.

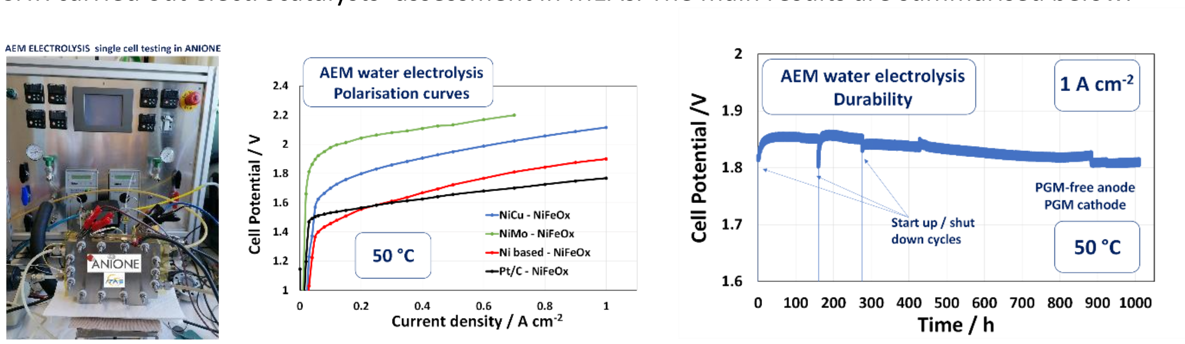
Oxygen evolution Ni-Fe based anode catalysts and hydrogen evolution Ni-Cu and Ni-Cu-Mo based cathode catalysts synthesised by CNR-ITAE were sent to TFP hydrogen for characterisation by XRD and SEM/EDX analysis. Crystal phases and crystallite sizes have been determined by XRD, elemental analysis and physical appearance have been determined by SEM/EDX for all received materials. This work was necessary to evaluate the electrochemical performance of the cathode and anode catalysts reported from CNR-ITAE. Results found anode materials exhibited small crystallite size, a good metal ratio as expected and a well-defined structure. The cathode materials on the other hand exhibited larger crystallite sizes, NiCuMo in particular proved a poor NiCuMo ratio, with a dominantly MoO_2 structure. A second synthesised sample received from CNR-ITAE showed an improved metal ratio.

Deviations from Annex I → No deviations, the progress of the activities in WP4 are in line with the DoA.
Non achievement of objectives → No
Corrective actions → No

3.5 WP5 - MEA engineering and cell testing

Summary of progress and activities per partner

CNR-ITAE
CNR carried out electrocatalysts' assessment in MEAs. The main results are summarised below.



The observed results are in line with the expected project targets for the period.

CNRS
No work done in the reporting period.

IRD
CENmat catalysts for benchmark MEAs has been purchased.

IRD has worked with ink optimization as part of an ionic percolation study (Table 1). IRD has for this reason received NiCu and Fe Ni catalyst developed within WP4 by CNR-ITAE. The electrodes for the percolation study will be made as 5 cm^2 GDEs with the composition as outlined in Table 1. A cold in situ membrane-electrode assembly will be made at CNR-ITAE for the test. The Fumatech AEM membrane in the Cl-form has been chosen for the study.

IRD has started the ink optimization. The catalyst dispersion degree obtained is very satisfactory (Fig. 1) with an average agglomerate size below 6 µm and no particles above 40 µm. However, the high loadings aimed has raised some drying challenges, where even gentle drying schemes has resulted in pronounced mud cracks formation in the CL (catalyst layer).

Table 1 CL (catalyst layer) composition for the ionic percolation study.

Cathode Catalyst	FAA-3 ionomer content wt%	GDL Sigracet	Target NiCu loading mg/cm²	Anode Catalyst	FAA-3 ionomer content wt%	GDL	Target FeNi loading mg/cm²
NiCu	33%	39 BC	5.0	NiFe	33%	Ni-felt	2.5
NiCu	25%	39 BC	5.0	NiFe	25%	Ni-felt	2.5
NiCu	20%	39 BC	5.0	NiFe	20%	Ni-felt	2.5

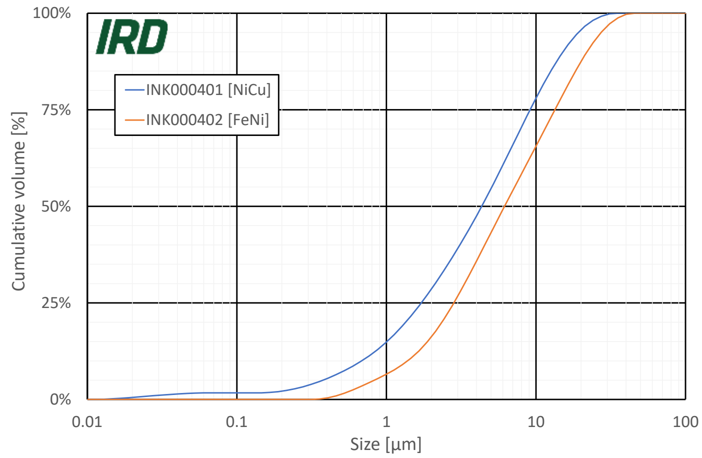


Fig. 1 Agglomerate size distribution of the developed Cathode (INK000401) and anode ink (INK000402).

Covid19 impact:

- Delay from other WPs will affect WP5. Currently also at IRD limited access to labs

Deviations from Annex I → No deviations, the progress of the activities in WP5 are in line with the DoA.
Non achievement of objectives → No
Corrective actions → No

3.6 WP6 - Stack engineering, BoP design, prototyping and testing

Summary of progress and activities per partner

TFP Hydrogen (formerly PV3)
TFP hydrogen have looked at various coatings for corrosion protection. However, finding a test these has proven difficult. Initial results have suggested that electroplated samples have shown much better corrosion resistance than electroless plated samples.

HYDROGENICS
WP6 starts at M7. Hydrogenics has started working on the stack design and has mainly been involved in discussions with component suppliers, for gas diffusion layers, structural rings, flanges, and gaskets. Several samples of gas diffusion layers have been acquired.

Deviations from Annex I → No deviations, the progress of the activities in WP6 are in line with the DoA.
Non achievement of objectives → No
Corrective actions → No

3.7 WP7 - Dissemination, Communication and Exploitation

Summary of progress and activities per partner

CNR-ITAE
The following activities have been carried out:
- Input/review of website (logo, statement for posting).
- Providing video material for project video: Video #2 | Synthesis of catalyst explained
- Participated in online conferences:
    - 9th World Hydrogen Technologies Convention (WHTC 2021): Sabrina Zignani, oral presentation
    - 12th edition of the International Conference on Hydrogen Production (ICH2P-2021): Antonino Aricò, invited keynote lecture

CNRS, TFP Hydrogen (formerly PV3), IRD, HYDROGENICS
The following activities have been carried out:
- Input/review of website (logo, statement for posting).

HydroLite (formerly PoCellTech)
The following activities have been carried out:
- Input/review of website (logo, statement for posting)
- Providing video material for project video: Video #1 | Membrane development explained

UNIRESEARCH
The following activities have been carried out:
- Definition of a project visual identity including logo and colour schemes.
- Setting up for the project website; www.anione.eu
- Regular updates to project website (news items, events, project reports)
- Preparation and distribution of project flyer (project introduction)
- Preparation of interactive project overview (distributed via the project website)
- Preparation of newsletter (distribution in M7 and M14)
- Preparation of templates for project dissemination activities; presentation, poster, letterhead
- Setting up a dissemination activity database
- Setting up a dissemination distribution database (ensuring compliance with privacy regulations)
- Preparation and submission of D7.1 (visual identity) and D7.2 (website and dissemination database)
- Preparation of the first draft of D7.3 (dissemination plan and knowledge management protocol)
- Created two videos from the lab at HydroLite (formerly PoCellTech) and CNR-ITAE. These were distributed in M11 and M12.

In addition, a collaboration with the FCH JU projects NEWELY and CHANNEL has been established in the framework of the Horizon Results Booster (HRB). UNR as represented ANIONE in the HRB collaboration and has participated in Model A of the HRB services between 07/10/2020 and 10/11/2020. The HRB Module B is planned to take place between March 2021 and June 2021.

Deviations from Annex I → No deviations, the progress of the activities in WP7 are in line with the DoA.
Non achievement of objectives → No
Corrective actions → No

4 Deliverables

All deliverables related to the period (M1-M12) have been submitted on time apart from D4.1 (Dataset on catalytic activity, electrochemical performance and stability of enhanced catalysts) and D8.1 (NEC – Requirement No 1) which were submitted in M13 and M14, respectively. The deliverables related to the period are listed in Table 4.1. The present deliverable, D1.2, is expected in M18. This deliverable is completed after the submission of the TRUST questionnaire (March 2021).

Table 4.1 ANIONE Deliverables M1-M12

Del. No	Deliverable title	Lead Beneficiary	Submission Date
D1.1	Project management plan including shared workspace implemented and operational	UNIRESEARCH	25/02/2020
D2.1	Harmonised test protocols for assessing AEM electrolysis components, cells and stacks in a wide range of operating temperature and pressure	CNR-ITAE	24/06/2020
D3.1	Supply of 1st generation ionomer dispersions, reinforcements, and additives for manufacturing AEM electrolysis membranes	CNR- ITAE	04/02/2021
D4.1	Dataset on catalytic activity, electrochemical performance and stability of enhanced catalysts	CNR- ITAE	27/01/2021
D7.1	Design of a project visual identity set and provision of project templates (presentations, minutes, logo etc.)	UNIRESEARCH	30/01/2020
D7.2	Project website and database for dissemination (stakeholders, interest groups, contact details)	UNIRESEARCH	28/03/2020
D8.1	NEC - Requirement No.1	CNR- ITAE	18/02/2021

5 Milestones

One milestone is expected in the M1-M12 period. The milestone details are listed below:

MS No	Milestone title	Related WP	Lead	Due Date	Means of verification	Status
MS5	Advanced nanostructured anode and cathode catalysts for AEM electrolysis	WP4	CNR-ITAE	M12	Reduced oxygen and hydrogen evolution overpotentials under AEM electrolysis conditions (<150mV IR-free at 1 A cm-2) and low degradation rate (<5% increase in overpotential in a 2000 h durability test at 1 A cm-2)	Achieved (1200 h test)

6 Participation at meetings/conferences/events

In the period M1-M12, all partners have participated in the following meetings:

- 1st Consortium Meeting/Steering Committee - Project Kick-off (M1), 22/01/2020, Brussels, host: CNR-ITAE
- 2nd Consortium Meeting/Steering Committee (M6), 04/06/2020, online (due to covid19)
- Steering Committee (M10), 01/10/2020, online (due to covid19)

In addition, partners have participated in:

CNR-ITAE

- Management team teleconference (M4), 16/04/2020, online
- Management team teleconference (M9), 17/09/2020, online
- Partner meeting (name change at PV3), 06/10/2020, online
- Technical Meeting, 03/12/2020, online

Planned conferences:

- 9th World Hydrogen Technologies Convention (WHTC 2021): Sabrina Zignani, oral presentation
- 12th edition of the International Conference on Hydrogen Production (ICH2P-2021): Antonino Aricò, invited keynote lecture

CNRS

- Technical Meeting, 03/12/2020, online

HydroLite (formerly PoCellTech)

- Technical Meeting, 03/12/2020, online

TFP Hydrogen (formerly PV3)

- Partner meeting (name change at PV3), 06/10/2020, online
- Technical Meeting, 03/12/2020, online

IRD

- Technical Meetings all online, 04/06/2020, 09/07/2020, 26/08/2020, 01/10/2020, 27/01/2021 & 15/04/2021

HYDROGENICS

UNIRESEARCH

- Management team teleconference (M4), 16/04/2020, online
- Management team teleconference (M9), 17/09/2020, online
- Partner meeting (name change at PV3), 06/10/2020, online
- Horizon Results Booster (completion of Module A), 25/11/2020, online
- Technical Meeting, 03/12/2020, online

7 Conclusion

The activities carried out in the first year of the ANIONE project were discussed in relation to the specific tasks in the Work Packages by providing details about the activities carried out by each partner. The aim is to provide a concise overview and monitoring of the general activities carried out in the first 12 months of the project, of the submitted deliverable, and achieved milestones. Also, the data requested by the FCH JU via the TRUST system and PRD surveys are presented.

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

- Development of advanced non-CRM, Fe-Ni-based catalyst for oxygen evolution reaction showing reduced overpotential of 170 mV at 1 A cm^{-2};
- Development of advanced non-CRM, Ni-based catalyst for the hydrogen evolution reaction showing reduced overpotential of 120 mV at 1 A cm^{-2};
- Development of cost-effective advanced anion exchange membranes with hydroxide ion conductivity higher than 50 mS cm^{-1}.

The major project challenges in the first year of the project are:

- The pandemic has delayed significantly project activities in terms of materials screening and catalyst/membrane/MEAs development;
- Restrictions due to the pandemic have not allowed organizing progress meeting and join meeting with other projects in-person;
- The pandemic has impeded participation to conventional dissemination events in-person.

All deliverable related to the first year have been submitted. Deliverables D4.1 and D8.1 were submitted with a delay of 1 and 2 months, respectively.

8 Risk Register

No risks linked to D1.2 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

9 Acknowledgement

The author(s) would like to thank the partners in the project for their valuable comments on previous drafts and for performing the review.

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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