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

D1.4 – Annual Data Reporting (Year 3)

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.

Clean Hydrogen Partnership

Co-funded by the European Union

Deliverable No.	ANIONE D1.4	
Related WP	WP1	
Deliverable Title	Annual Data Reporting (Year 3)	
Deliverable Date	30-06-2023	
Deliverable Type	REPORT	
Diss level	Public (PU)	
Lead Beneficiary	CNR-ITAE	
Author(s)	S. C. Zignani, A. Carbone, G. Dispenza, M.G. Bottari, M. Giorgianni, G. Monforte, A.S. Aricò (CNR-ITAE) D. Jones, R. Gentile, J. Roziere, S. Cavaliere (CNRS) E. Tal Gutelmacher, A. Amel (HydroLite, formerly PoCellTech) D. Hodgenson, S. Nundy, F. Rafique (TFP Hydrogen, formerly PV3) M. Odgaard, H. Yilirim (IRD) L. Geerts, S. Herregods (Hydrogenics (part of Cummins)) A. Molinari (UNR)	May-2023
Checked by	n/a	
Reviewed by (if applicable)	n/a	
Approved by	Antonino Aricò (CNR-ITAE) - Coordinator	25-06-2023
Status	Final	

Disclaimer/ Acknowledgment

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. The information and views set out in this publication does not necessarily reflect the official opinion of the European Commission. Neither the European Union institutions and bodies nor any person acting on their behalf, may be held responsible for the use which may be made of the information contained therein.

Publishable summary

Deliverable D1.4 - Annual Data reporting (Year 3) provides concise information about the activities and project achievements in the third 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, for the year 01/01/2022-31/12/2022, 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.

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

Contents

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 D1.4 - Annual data reporting (Year 3) is requested by Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership).

ANIONE was asked, as each year, in March 2023 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 2023 (PRD) survey. A copy of the information provided is included in this deliverable.

Deliverable D1.4 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 third year of the ANIONE project (2022).

2.1 TRUST DATA - RESULTS

Parameter Display Name	Input type	Measurement Type	Value	Data Provider Comment
Achievement/Result_accomplished (1)	freeText		Anode catalysts	NiFe anode catalyst
Achievement/Result_Type (1)	list		Product	NiFe anode catalyst
Year_Accomplished (1)	quantity		2022	Results fully accomplished in the year 2022 in terms of upscaling
Market Maturity (1)	list		Emerging	Emerging market
Time to impact (1)	list		1-5 Years	5 years time to impact
IR (1)	list		Yes	Results provided
HRP (1)	list		No	Not yet
Achievement/Result_accomplished (2)	freeText		Cathode catalyst	NiMo/C cathode catalyst
Achievement/Result_Type (2)	list		Product	NiMo/C cathode catalyst
Year_Accomplished (2)	quantity		2022	Results fully accomplished in the year 2022 in terms of upscaling
Market Maturity (2)	list		Emerging	Emerging market
Time to impact (2)	list		1-5 Years	5 years time to impact
IR (2)	list		Yes	Results provided
HRP (2)	freeText			Not yet
Achievement/Result_accomplished (3)	freeText		AEM membrane	Hydrolite-ionomer based reinforced reinforced AEM hydrocarbon membrane
Achievement/Result_Type (3)	list		Product	Hydrolite-ionomer based reinforced reinforced AEM hydrocarbon membrane
Year_Accomplished (3)	quantity		2022	Validation in single cell in 2022. Upscaling still undergoing.
Market Maturity (3)	list		Market creating potential	Promising perspectives
Time to impact (3)	list		5-10 Years	5 years time to impact
IR (3)	list		Yes	Results provided
HRP (3)	list		No	No
Major difficulties or shortcomings(1)	freeText		Control of surface properties	Control of surface properties of anode catalyst
Major difficulties or shortcomings (2)	freeText		Complex manufacturing	Complex manufacturing for cathode catalyst
Major difficulties or shortcomings (3)	freeText		Upscaling	Reinforced membrane upscaling

2.2 TRUST DATA – ELECTROLYSIS STACK KPIs

Parameter Display Name	Input type	Measurement Type	Value	Data Provider Comment
Start date for reporting	date		01/01/2022	
End date for reporting	date		31/12/2022	
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	Planned capacity. Not yet in operation in 2022
Number of stacks	quantity		1	
Nominal system electrical power	quantity	kW		Not yet in operation
Overload capacity	quantity	%	100	Planned capacity. Not yet in operation in 2022
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 carried out in 2022.
Operating pressure	quantity	bar	30	Nominal
Operating temperature	quantity	°C	50	Nominal
Power usage of BoP	quantity	kW		Not yet in operation in 2022
Area occupied by unit	quantity	m^2/MW		Not yet in operation in 2022
KPI- Electricity consumption @ nominal capacity	quantity	kWh/kg	50	Estimated value for the stack from single cell results. No stack tests have been carried out in 2022.
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 in 2022
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 in 2022
KPI - Cold start ramp time	quantity	sec		Not yet in operation in 2022
KPI - Degradation	quantity	%/1,000 hrs	3	Estimated value for the stack from single cell results. No stack tests have been carried out in 2022.

KPI - Current Density	quantity	A/cm^2	1	Estimated value for the stack from single cell results. No stack tests have been carried out in 2022.
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	%		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		01/01/2022	
End date for reporting	date		31/12/2022	
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	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

2.4 TRUST DATA – DISSEMINATION and EXPLOITATION

Parameter Display Name	Input type	Measurement Type	Value	Data Provider Comment
Updated/revised D&E plan	list		Yes	Provided in the core report of the first period and in D7.3
Dissemination Activities in total	quantity		17	4 published paper in international journals and 13 presentations at conferences and workshops
Dissemination Activities within the timeframe of this data collection exercise	quantity		5	2 published paper in international journals in the year 2022 and 3 presentations at conferences and workshops in the year 2022
Presentation of results in conferences, events and workshops	quantity		13	13 presentations at conferences and workshops
Peer-Reviewed Scientific Publications	quantity		4	4 published paper in international journals
Peer-Reviewed Scientific Publications in Open Research Europe	quantity		0	No papers published yet through this specific platform
Education & Training Activities	quantity		3	3 young researchers trained in Anione
Meetings with stakeholders	quantity		3	Two web meetings organised in collaboration with the Clean Hydrogen JU and related AEM water electrolysis projects Channel and Newly. One presentation at the Clean Hydrogen JU Review Days
Other Dissemination Activities	quantity		10	1 Web site, 1 Flyer, 4 Newletters, 1 interview, 3 video
Scientific/Research Communities	quantity		5	2 published paper in international journals in the year 2022 and 3

				presentations at conferences and workshops in the year 2022
Industry/Business Partners	quantity		3	Two web meetings organised in collaboration with the Clean Hydrogen JU and related AEM water electrolysis projects Channel and Newly. One presentation at the Clean Hydrogen JU Review Days
EU Institutions / Policy Makers	quantity		3	Two web meetings organised in collaboration with the Clean Hydrogen JU and related AEM water electrolysis projects Channel and Newly. One presentation at the Clean Hydrogen JU Review Days
Standardisation Bodies	quantity		0	
Society / Specific End-Users Communities	quantity		10	1 Web site, 1 Flyer, 4 Newletters, 1 interview, 3 video
Other Target Audiences	quantity		0	
Delivered Dissemination Activities	quantity		12	12 Dissemination activities among publications, conferences, workshops, Newsletters, Videos etc.
On-going Dissemination Activities	quantity		2	1 Publication and 1 workshop
Postponed or Cancelled Dissemination Activities	quantity		0	
OpenAIRE_platform	list		Yes	3 Documents
Exploitation Activities performed within the timeframe of this data collection exercise	quantity		1	Update of the exploitation activities provided in the core report for the first phase
IPR Activities within the timeframe of this data collection exercise	list		No	Not yet
Business Model / Plan - Market Survey	list		No	Not yet
Potential Investors / Users	list		No	Not yet
Steps towards standardisation	list		No	Not yet
Patent Application	list		No	Not yet
Other Exploitation Activities	list		No	
Other Exploitation Activities_	freeText		0	
Industry/Business Partners	list		Yes	One collaboration activity with Solvay as Industry partner external to the Consortium
Research Communities	list		Yes	2 Collaborations with Channel and Newly consortia

Standardisation Bodies	list		No	
Innovators	list		No	
End Users	list		No	
Other Audience	list		No	
Other Audience_	freeText		0	
Lack of Regulation, Codes or Standards	list		No	
Lack of Financing	list		No	
Lack of Labor Skills	list		No	
Trade Issues	list		No	
IPR-related Issues	list		No	
Other	freeText		0	
Innovation Radar	list		Yes	4 Results
Horizon Results Platform	list		Yes	4 Results
Horizon Results Booster	list		No	
Standardisation Booster	list		No	
Dealflow	list		No	
Other	freeText		0	

3 Input for FCH JU Programme Review Days survey

3.1 ANIONE progress towards project targets and objectives M25-M36

ANIONE aims to develop a high-performance, cost-effective and durable anion-exchange membrane (AEM) water electrolysis technology. The approach involves using an AEM and ionomer dispersion in the catalytic layers for hydroxide ion conduction. The project aims to validate a 2 kW AEM electrolyser with a hydrogen production rate of about 0.4 Nm3/h (TRL 4). Advanced AEMs have been developed in conjunction with non-critical raw materials (CRMs) high-surface-area electrocatalysts and membrane electrode assemblies. These advanced AEMs have shown promising performance and stability.

The **major project achievements** in the third year of the project are:

- Highly conductive and chemically stable, hydrocarbon ionomer/membrane for AEM water electrolysis (IR,-).
- Reinforced and composite AEM hydrocarbon membranes for water electrolysis showing capability to operate at higher temperatures
- Highly performing and electrochemically stable NiFe oxide, oxygen evolution, anode electrocatalyst for AEM water electrolysis (IR,-).
- Enhanced catalyst coated electrodes-based membrane electrode assemblies for AEM water electrolysis (IR,-).
- Large-area membrane-electrode assemblies based on non-critical raw materials showing performance comparable to small area MEAs

The major **project difficulties** during implementation in 2022 (the third) year of the project are still linked to the after-effects of the COVID-19 pandemic:

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

Unforeseen Risks reported in 2022: Delays on project activities (and consequently dissemination activities) due to limited office/laboratory access to prevent the spread of Covid-19.

➔ State of Play: Request of 9-month project extension. Extension approved. Frequent evaluation of Covid-19 status at all partner organisations. Frequent monitoring of project activities. Specific delays concern the difficulty to carry a systematic work for components development, assessment of MEAs under pressurised conditions, development of stack and BoP components.

Activities related to **sustainability and circularity aspects** had not yet been started in 2022.

Contribution to new/additional activities and fields not originally foreseen or targeted:

- 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.

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	Full reference	Comments
1	Project's own objectives and AWP 2019	"Cell voltage at 1 A cm-2 (cell performance at 45 °C) "	V	2	1.75	1.67	2020	Adv. Energy Mater. 2020, 2002285	SoA performance is achieved using carbon paper as anodic diffusion layer which is unstable under OER.
2	Project's own objectives and AWP 2019	Degradation rate: voltage increase at 1 A cm-2	mV/h	<0.005	<0.005	2	2020	Adv. Energy Mater. 2020, 2002285 SoA	SoA performance is achieved using carbon paper as anodic diffusion layer which is unstable under OER.
3	Project's own objectives and AWP 2019	Membrane conductivity	mS cm-1	50 mS cm-1	105	80	2022	Sustainion® X37-50 Grade RT; https://www.fuelcellstore.com/sustainion-x37-50-gradertmembrane#:~:text=Sustainion%C2%AE%20X37%2D50%20Grade%20RT%20is%20an%20anion%20exchange,use%20with%20a%20supporting%20electrolyte.	SoA conductivity: Measured in 1 M KOH
4	Project's own objectives and AWP 2019	Maximum operating temperature	°C	90	90	60	2022	Electrochim. Acta 413 (2022) 140078.	
5	Project's own objectives and AWP 2019	Series resistance	Ohm cm2	<0.07	0,06	0,1	2022	Electrochim. Acta 413 (2022) 140078.	

The following **non-quantitative objectives** related to the project have been addressed in the third year of the project (starting already since year 2):

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 last project months:

- Large area stack assembling and testing.
- Full validation of functional materials at stack level.

Interactions with other projects, sectoral organization and initiatives

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.

The AEM-HUb met in February 2022 together with the Clean Hydrogen experts to discuss the progress and challenges of the projects in the first two years and identify synergies and solutions for the last phase of the projects. (Another meeting took place in March 2023).

3.2 ANIONE Scientific Publications

Type	Title	Authors	Title of the Journal/Proc. /Book	Number, date or freq. of the Journal/Proc./Book	Peer-reviewed?	Open Access?	DOI	Repository Link	Year
Publication in Conference proceedings/ Workshop	Green hydrogen production by innovative membrane electrolysis technologies	Antonino Salvatore Aricò, Stefania Siracusano, Sabrina Campagna Zignani, Alessandra Carbone	Electrolysers, Fuel Cells & H2 Processing, Proceedings of EFCF 2021 Conference,	EFCF-2021_PoC_Proceedings_A-Sessions_ConfVersion_s	Yes	Green	-	www.Zenodo.org	2021
Article in Journal	Performance and stability of a critical raw materials-free anion exchange membrane electrolysis cell	S. C. Zignani, M. L. Faro, A. Carbone, C. Italiano, S. Trocino, G. Monforte, A.S. Aricò	Electrochim. Acta 413 (2022) 140078.		Yes	Gold	10.1016/j.electacta.2022.140078	Elsevier Open Access Science Direct	2022
Article in Journal	Aquivion-based Anion Exchange Membranes: Synthesis Optimization and Physio-Chemical Investigation	A. Carbone, I. Gatto, R. Pedicini, S. C. Zignani, C. Oldani, A. Cattaneo, A. S. Aricò	Chemical Engineering Journal (2022) 140765.		Yes	Gold	10.1016/j.cej.2022.140765	Elsevier Science Direct	2022
Article in Journal	Design Strategies for Alkaline Exchange Membrane–Electrode Assemblies: Optimization for Fuel Cells and Electrolyzers	A. Ashdot, M. Katten, A. Kitayev, E. Tal-Gutelmacher, A. Amel, M. Page	Membranes	Membranes 2021, 11, 686. Membranes, 11090686	Yes	Gold	10.3390/membranes11090686	MDPI	2021
Article in Journal	Performance and stability of a critical raw materials-free anion exchange membrane electrolysis cell	S. C. Zignani, M. L. Faro, A. Carbone, C. Italiano, S. Trocino, G. Monforte, A.S. Aricò	Electrochimica Acta	Electrochim. Acta 413 (2022) 140078.	Yes	Gold	10.1016/j.electacta.2022.140078	Elsevier Open Access Science Direct	2022
Article in Journal	Aquivion-based Anion Exchange Membranes: Synthesis Optimization and Physio-Chemical Investigation	A. Carbone, I. Gatto, R. Pedicini, S. C. Zignani, C. Oldani, A. Cattaneo, A. S. Aricò	Chemical Engineering Journal	Chemical Engineering Journal (2022) 140765.	Yes	Gold	10.1016/j.cej.2022.140765	Elsevier Science Direct	2022

4 Conclusion

The activities carried out in the third year of the ANIONE project were summarised, 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.

During the period reported (01/01/2022-31/01/2023) the following deliverables have been submitted:

- **D4.3-**Publishable report on electrocatalysts and recombination catalyst developments (March 2022, CNRS)
- **D5.3**-Publishable report on MEA assessment (March 2022, IRD)
- **D1.3**-Annual Data Reporting year 2 (April 2022, CNR-ITAE)
- **D4.2-**Manufacturing of catalysts meeting the specification and provision for large area MEAs and stack (April 2022, TFP)
- **D3.3**-Data-set on membranes and ionomer dispersions. Supply of down-selected membranes and ionomer dispersion manufacturing large-area MEAs (August 2022, Hydrolite)
- **D5.2-** Optimised lareg-area MEAs supply for stack testing (October 2022, IRD)

The following milestones have been achieved:

- **MS3-Enhanced electrochemical and mechanical stability for the anionic exchange membranes (June 2022)**

➔ The reinforced PO-AEI membrane developed by Hydrolite and CNRS, initially selected for scale-up and further characterization in an AEMWE single cell, demonstrated improvement over the non-reinforced membrane in terms of hydrogen crossover and dimensional swelling, while other properties relevant for the application in AEMWE (ion conductivity, tensile strength, KOH uptake) were only slightly modified by the presence of the reinforcement. However, upscaling PO-AEI membranes and application in a stack was considered premature, and therefore the consortium decided to use the non-reinforced FAA-3 membrane in MEAs for the stack. The FAA-3 hydrocarbon membrane was thus selected for large area MEAs showing a decrease of series resistance between 0.17 and 0.14 Ohm cm2 during 2000 h durability test and good mechanical properties matching the requirements (D3.3, D4.1, Electrochim. Acta 413 (2022) 140078).

- **MS4-Membrane scaling-up and optimisation (August 2022)**

➔ FAAA-3 hydrocarbon membrane, activated according to an exchange procedure developed at CNR and validated in a 3000 h cumulative test showing series resistance of about 0.15 Ohm cm2, was provided to IRD for large area MEAs manufacturing. The results are documented in D5.2, D3.3, D4.1, Electrochim. Acta 413 (2022) 140078.

- **MS6-Catalysist scaling-up and optimisation (June 2022)**

➔ Non-PGM and non-CRM electrocatalysts based on Ni80Mo20/KB and Ni85Fe15 LDH, for cathode and anode, respectively have been synthesized at TFP Hydrogen (formerly PV3) and CNR-ITAE and upscaled to 100 g preparation batch. The catalysts were assessed in small MEAs prepared at CNR-ITAE and large MEAs prepared at IRD showing cell voltages close or lower than 2 V at 1 A cm-2 during 1000 h operation (D4.2, D5.2).

- **MS8-Improved MEA electrochemical durability (June 2022)**

➔ An MEA based on nanosised NiMo/C cathode and NiFe-oxide anode electrocatalysts and hydrocarbon FAA-3 membrane was assessed at 1 A cm-2 and 50°C for 2000 h under steady-state conditions and 1000 h under cycled (1-1.8 V) conditions. The MEA showed decrease of cell voltage from 2 V to 1.75 V during 2000 hrs operation and stable performance (no increase

of cell voltage) of 2 V at 1 A cm-2 under cycled operation for 1000 hrs (D4.1, D5.1) with total durability exceeding 3,000 hours cumulative and degradation rate lower than 5 µV/h under both conditions

- MS9-Large area engineered MEAs for stack integration (November 2022)

➔ Large area engineered MEAs for stack integration have been developed at IRD based on the electrocatalysts provided by TFP Hydrogen and CNR-ITAE as well as on the activated FAA-3 membrane and provided to Hydrogenics and ITAE for preliminary testing. A large area MEA was operated for 1000 h at 1 A cm-2 showing cell voltage close to 2 V/cell and sustained several BoP interruptions. The full set of large area MEA (25) delivered from IRD to Hydrogenics.

During the third project year a project extension of nine (9) months has been requested (and granted by the Clean Hydrogen). The delays on some project activities are due to the impact of covid19 that limited access to labs at some partners for a substantial part of 2021. The updated delivery dates of effected tasks, deliverables and milestones have been approved.

5 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

6 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

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.