

Enhancing Electrolyzer Durability Through a Multiscale Strategy: The ELECTROLIFE Approach

Alessandro Monteverde
Politecnico di Torino



Webinar: Advancing Online Diagnostics and Building Durable Electrolysis Systems for Europe's Hydrogen Future



Co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the Clean Hydrogen Partnership. Neither the European Union nor the granting authority can be held responsible for them.



Outline



- **About ELECTROLIFE**
- **Objectives and Concept**
- **Partners**
- **Approach**
- **Results**



Co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the Clean Hydrogen Partnership. Neither the European Union nor the granting authority can be held responsible for them.



ELECTROLIFE

- Electrolife: Enhance knowledge on comprehensive electrolyser technology degradation through modelling, testing, and lifetime prediction, toward industrial implementation.
- ELECTROLIFE aims to advance the understanding of electrolyzer degradation mechanisms and improve cell performance to boost efficiency, reduce critical material use, and extend system lifetime.
- How?
 - Through a combination of experimental testing, multiphysics modelling, and prototyping, the project supports the industrial implementation of durable, scalable, and recyclable green hydrogen technologies.
- Ultimately, ELECTROLIFE seeks to accelerate the decarbonization of European industry by overcoming current limitations in electrolysis technologies.



Acronym: ELECTROLIFE

Duration: 60 months

Start date: 01 January 2024

End date: 31 December 2028



Co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the Clean Hydrogen Partnership. Neither the European Union nor the granting authority can be held responsible for them.



Approach

The ELECTROLIFE concept and architecture is unique because focus its research activities on all **the 5 today classified electrolysis technologies**, in order to approach with the same structured methodology all the paths to understanding and modeling the degradation mechanisms of different electrochemical systems, to develop and assess improved electrochemical cells and stacks (especially under dynamic use and operational stress) and to validate technologies and diagnostic tools (SoH).

Keystones

The ELECTROLIFE concept consist of 8 keystones (KS):

- KS1: Identification and comprehension of degradation phenomena that affect the 5 (AEL, AEMEL, PEMEL, SOEL, and PCCEL) technologies involved
- KS2: Development of degradation and lifetime prediction models
- KS3: Development of testing procedures for degradation assessment
- KS4: Development of ad-hoc testing and diagnostic tools
- KS5: Technologies development and optimization
- KS6: Execution of test campaigns on the 5 electrolysis technologies
- KS7: Validation of the degradation models and diagnostic tools
- KS8: Guidelines for next generation robust stacks, diagnostic tools and optimized strategies of operation, for electrolyzers lifetime extension

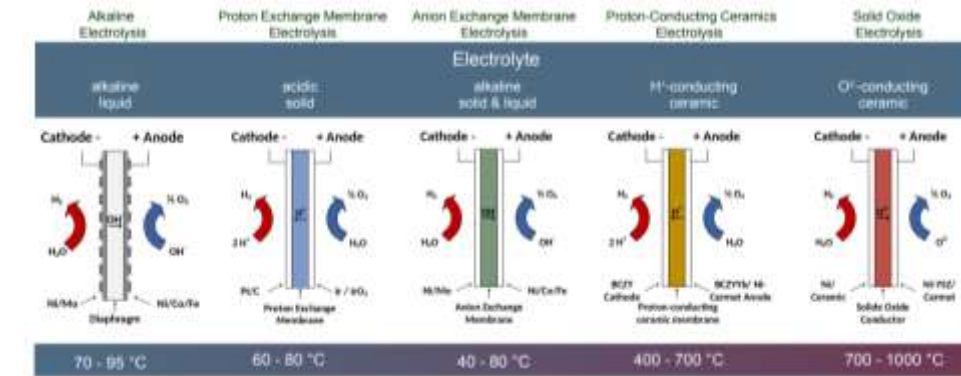


Figure. Overview of the five electrolysis technologies studied in ELECTROLIFE



Co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the Clean Hydrogen Partnership. Neither the European Union nor the granting authority can be held responsible for them.



ELECTROLIFE in figures



ELECTROLIFE in figures

40% progress

of the total project.

ELECTROLIFE started at January 2024
and will run for 60 months.

9.995.705,00 €

funding from the European Commission
in Horizon Europe program.

17 partners

from 9 different countries.

<https://electrolife-project.eu/>

<https://cordis.europa.eu/project/id/101137802>



Duration: 60 months

Start date: 01 January 2024

End date: 31 December 2028

Total budget: €9.995.705,00



Co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the Clean Hydrogen Partnership. Neither the European Union nor the granting authority can be held responsible for them.



ELECTROLIFE Partners



Co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the Clean Hydrogen Partnership. Neither the European Union nor the granting authority can be held responsible for them.



General assemblies and partners



Third General Assembly (#GA03) of ELECTROLIFE in Erlangen, Germany



Second General Assembly (#GA02) of ELECTROLIFE in Ancona, Italy



Four General Assembly (#GA04) of ELECTROLIFE in Tallin, Estonia



Kick-off meeting (#GA01) of ELECTROLIFE in Torino, Italy

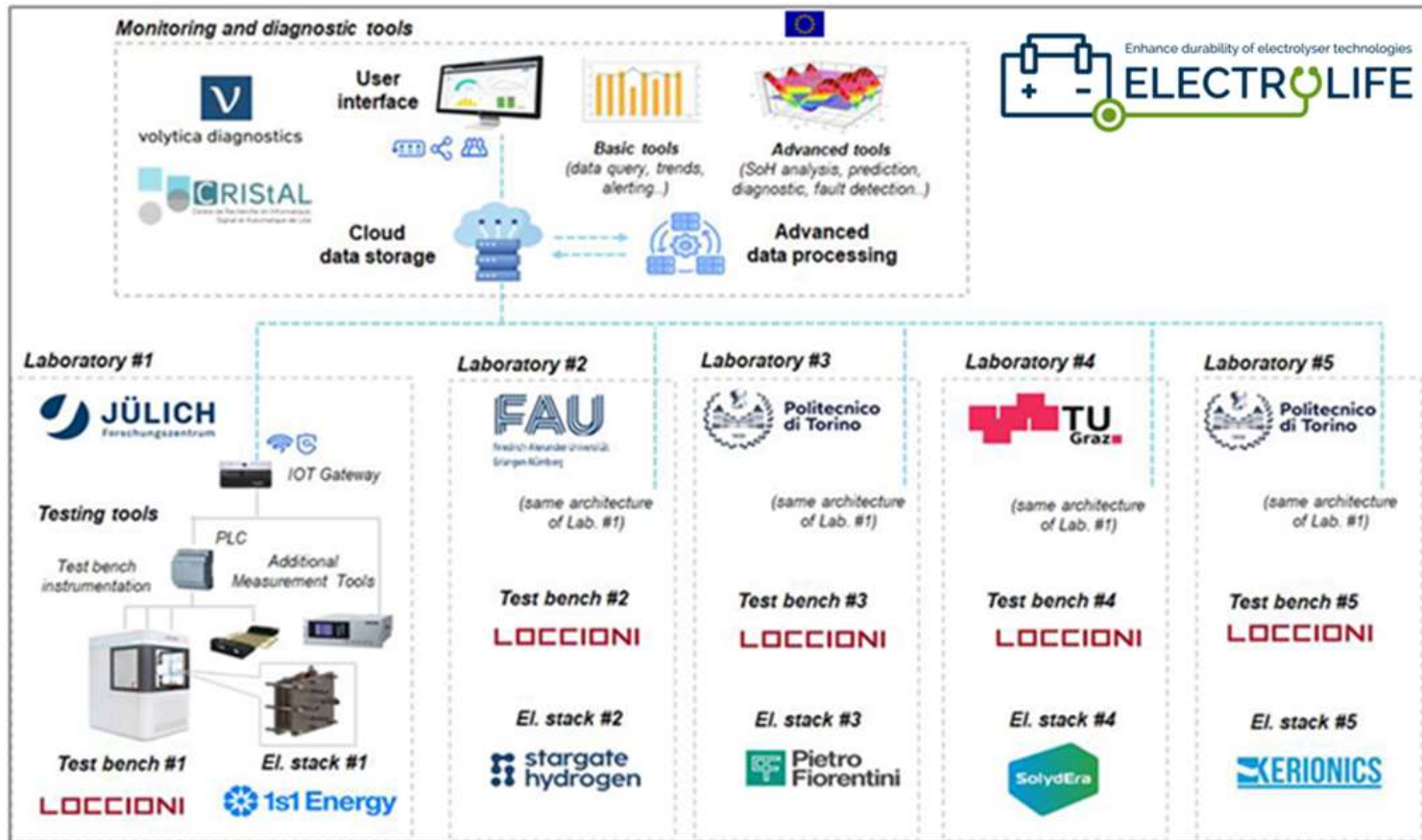
**Typical meetings: big crowd,
bigger ideas**



Co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the Clean Hydrogen Partnership. Neither the European Union nor the granting authority can be held responsible for them.



Overall Approach and Key Activities



Key Activities

Testing of all Electrolyzer Types

- Testing of AEL, AEMEL, PEMEL, SOEL, and PCCEL at the stack level (TRL 5).

Durability Testing:

- Conducting durability tests for 10,000 hours.
- Applying RES profiles to assess durability.

Degradation Modeling:

- Developing and validating degradation models at both single-cell and stack levels.

Economic Evaluation:

- Evaluating the Levelized Cost of Hydrogen (LCOH) for specific scenarios.



Co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the Clean Hydrogen Partnership. Neither the European Union nor the granting authority can be held responsible for them.



Results: Degradation factors, degradation mechanisms and degradation effects

HORIZON EUROPE PROGRAMME
TOPIC HORIZON-JTI-CLEANH2-2023-1
GA No. 101137802

ELECTROLIFE

Enhance knowledge on comprehensive electrolyser technologies
degradation through modeling, testing and lifetime prevision,
toward industrial implementation



Deliverable report
D2.1 – Degradation phenomena compendium

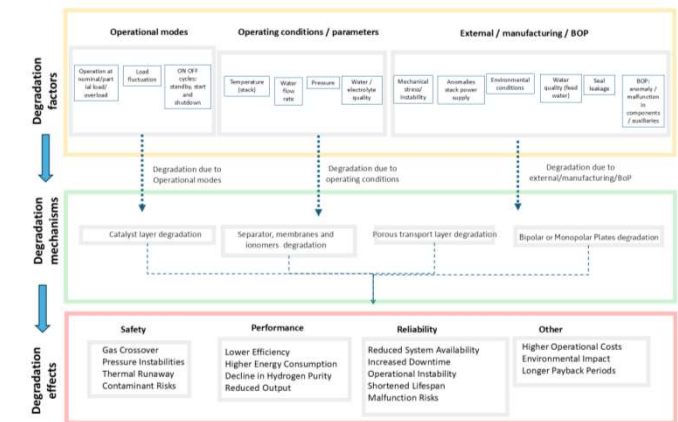
Co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the Clean Hydrogen Partnership. Neither the European Union nor the granting authority can be held responsible for them.

GA No. 101137802

Summary

1	Introduction, main goals, how to use this document and terminology	10
1.1	Introduction	10
1.2	Electrolysis Technologies Overview	10
1.3	Structure and Accessibility of the Document	11
1.4	Terminology	12
2	Degradation mechanisms	15
2.1	Degradation mechanism related to catalyst instability	15
2.2	Degradation mechanisms related to the instability of the separator, membranes and ionomers	36
2.3	Degradation mechanisms related to the instability of the porous transport layer	51
2.4	Degradation mechanisms related to the instability of the bipolar or monopolar plates	57
2.5	Degradation mechanisms related to the instability of components due to contaminants	64
2.6	Degradation mechanisms related to electrolyte variables: including composition, concentration and flow configuration	71
2.7	Summary of all technologies	75
3	Relation between Operational Modes and Degradation	76
3.1	Load Fluctuation	79
3.2	Partial Load	85
3.3	Dry/Off cycles	86
3.4	Synergistic Effects	87
3.5	Temperature	89
3.6	Pressure	91
3.7	Water Flow rate and quality	94
3.8	Anomalies stack power supply	94
3.9	Environmental conditions, Mechanical stress, seal leakage, BOP	95
3.10	Stressors (summarized degradation factor on performance...)	97
3.11	Impact of Degradation factors on Performance and Reliability	99
4	Industrial and partners experience of this topic	101
5	EU funded project analysis	105
6	Characterization techniques	112
7	Exploring interconnections between Technologies	116
8	Conclusions	118

D2.1 – « Degradation phenomena compendium » (PU)



See next slide

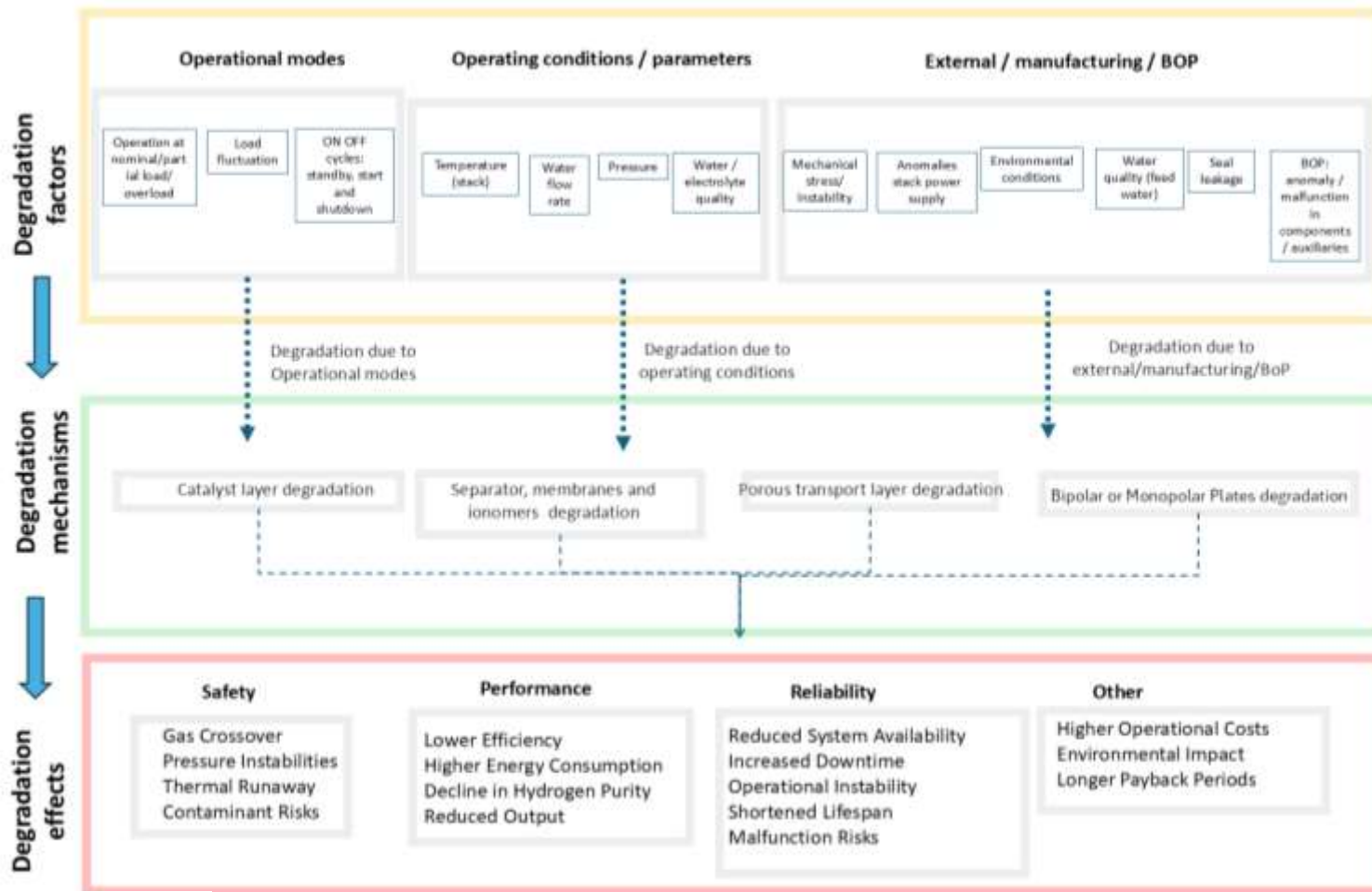
https://electrolife-project.eu/wp-content/uploads/sites/24/2025/02/ELECTROLIFE_D2.1-Degradation-phenomena-compendium_PUB_final.pdf



Co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the Clean Hydrogen Partnership. Neither the European Union nor the granting authority can be held responsible for them.



Results: Degradation factors, degradation mechanisms and degradation effects



Electrolyser operational modes and various degradation factors (e.g., operating conditions, manufacturing, BoP) trigger specific degradation mechanisms—chemical or physical—based on their frequency and intensity. These mechanisms lead to performance loss, safety issues, and reduced reliability.

Figure illustrates the degradation process in three layers:

Top (yellow): Main degradation factors, including operational, environmental, and manufacturing-related stressors.

Middle (green): Resulting degradation mechanisms affecting key components (e.g., membranes, catalysts, BPPs).

Bottom (red): Effects on system-level performance, safety, and economic viability.

The figure highlights how factors lead to mechanisms, which in turn cause measurable degradation effects.

https://electrolife-project.eu/wp-content/uploads/sites/24/2025/02/ELECTROLIFE_D2.1-Degradation-phenomena-compendium_PUB_final.pdf



Co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the Clean Hydrogen Partnership. Neither the European Union nor the granting authority can be held responsible for them.



Results: Harmonised protocols for LTEL

GA No. 101137802

Content

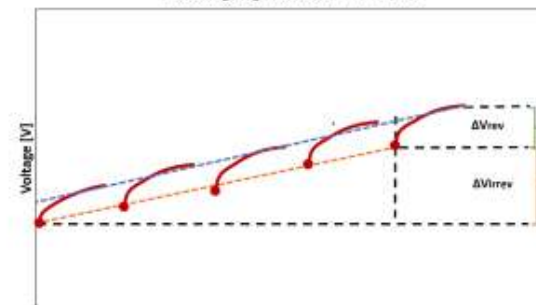
1	Introduction.....	8
2	Methods and core part of the report.....	10
2.1	Background.....	10
2.1.1	Studying Degradation in PEMEL, AEMEL, and AEL Electrolysers Under Steady State Conditions.....	10
2.1.2	Studying Degradation in PEMEL, AEMEL, and AEL Electrolysers Under Dynamic Operating Conditions.....	11
2.2	Protocols.....	11
2.3	Data Analysis.....	12
2.3.1	Main electrochemical parameters.....	12
2.3.1.1	Tafel equation.....	12
2.3.1.2	Electrochemical Impedance Spectroscopy.....	14
2.3.1.3	Determination of the degradation rate.....	16
2.3.1.4	Calculation of efficiency.....	18
3	Results & Discussion.....	20
3.1	Single-cell and stack protocols.....	20
3.1.1	MEA performance evaluation.....	21
3.1.2	Polarization curve test procedure.....	22
3.1.3	Durability test under steady state condition.....	26
3.1.4	Durability test under dynamic profile.....	28
3.1.4.1	RW-derived profile for Power to Gas Application and Grid balance application.....	31
3.1.4.2	Wind and PV derived profiles for the Assessment of Degradation Phenomena under Dynamic Conditions.....	32
3.1.5	Accelerated Testing protocols and procedures.....	35
3.1.5.1	Dynamic Load profiles.....	37
3.1.5.2	High current and High voltage fluctuating profiles.....	38
3.1.5.3	Start-up / shut down profiles.....	40
3.1.5.4	Pressure Cycling test profiles.....	41
3.1.5.5	temperature Cycling test profiles.....	43
3.2	Contribution to project (linked) Objectives.....	44
3.3	Contribution to major project exploitable result.....	45
4	Conclusion and Recommendation.....	46
5	Risks and interconnections.....	47

D4.1 - Specification, terminology and Harmonised protocols for LTEL (PU)

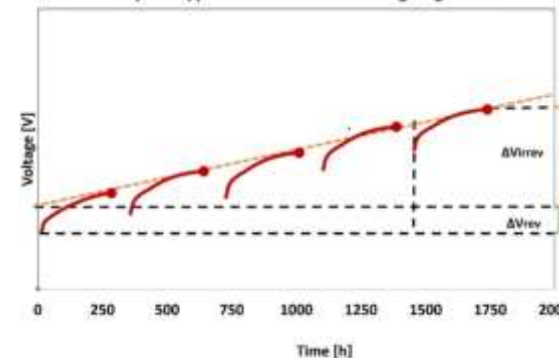
3 / 50



JRC's voltage degradation calculation method



Proposed approach for calculation of voltage degradation



<https://electrolife-project.eu/deliverable-4-1/>

HORIZON EUROPE PROGRAMME
TOPIC HORIZON-ET-CLEANH2-2023-1
GA No. 101137802

ELECTROLIFE

Enhance knowledge on comprehensive electrolyser technologies degradation through modelling, testing and lifetime prediction, toward industrial implementation



- Deliverable report

D4.1 - Specification, terminology and Harmonised protocols for LTEL

Co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the Clean Hydrogen Partnership. Neither the European Union nor the granting authority can be held responsible for them.

Reviewed by JRC ✓



Co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the Clean Hydrogen Partnership. Neither the European Union nor the granting authority can be held responsible for them.



Results: Specifications of the testing tools



Test bench Provider	LOCCIONI	LOCCIONI	LOCCIONI	LOCCIONI	LOCCIONI
Laboratory	JÜLICH Forschungszentrum	FAU	Politecnico di Torino	TU Graz	Politecnico di Torino
Stack manufacturer	1s1 Energy	stargate hydrogen	Pietro Fiorentini	Solydura	KERIONICS
	PEM	AEL	AEMEL	SOEL	PCCEL

Figure 1. ELECTROLIFE partners directly involved in stack testing



Detail engineering of stacks and test bench:

Specifications and requirements of the stacks to be tested were discussed between three actors (Test bench Provider, Laboratories and stack manufacturer):

- **Test Bench provider (Loccioni)**
- **Stack manufacturers (1s1, Stargate, PF/Hyter, Solydura, Kerionics)**
- **RTOs owners of labs (Polito, FAU, GRAZ, Julich)**
 - PEMEL, AEL, AEMEL, SOEL and PCCCEL
 - Stack specifications, requirements for stack manufacturers; Requirements For Laboratories and Rtos; Specifications of Testing Tools.

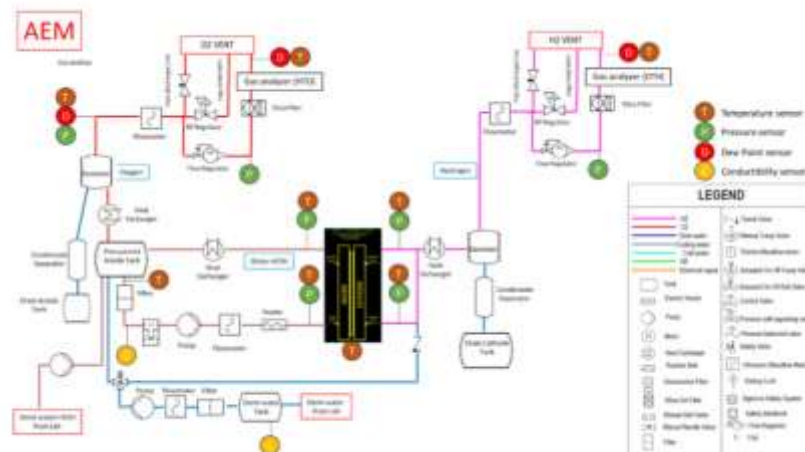


Figure 10: Process Flow Diagram of AEMEL test bench



Test bench design & construction (*indicative):

- Example of PI&D for AEMEL

[a] EU harmonised protocols for testing of low temperature water electrolysis. <https://op.europa.eu/en/publication-detail/-/publication/bbbbeba00-ee82-11eb-a71c-01aa75ed71a1>



Co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the Clean Hydrogen Partnership. Neither the European Union nor the granting authority can be held responsible for them.



Results: Test benches manufacturing



Frame of first two test benches (AEM, AEL) assembled



LOCCIONI

*Courtesy image: Loccioni



Co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the Clean Hydrogen Partnership. Neither the European Union nor the granting authority can be held responsible for them.





The project is supported by the Clean Hydrogen Partnership and its members.

The project has received funding from Clean Hydrogen Partnership Joint Undertaking under Grant Agreement No 101137802. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation programme, Hydrogen Europe and Hydrogen Europe Research.



Co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the Clean Hydrogen Partnership. Neither the European Union nor the granting authority can be held responsible for them.



Thanks for the Attention



Politecnico di Torino

DISAT

(Department of Applied Science and Technology)



Corso Duca Degli Abruzzi 24- 10124 Torino - IT

Alessandro Monteverde



T +39 011.0904720



E alessandro.monteverdevidela@polito.it



<https://www.polito.it/personale?p=alessandro.monteverdevidela>



Co-funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the Clean Hydrogen Partnership. Neither the European Union nor the granting authority can be held responsible for them.

