



D2.1 Quasi-harmonized testing protocol for low and high temperature electrolysis



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Abstract

This document provides experimental testing protocols for assessing critical factors driving performance degradation of water electrolysis cells and stacks that will be used in the framework of the **funded project DELYCIOUS** (*Project number: 101192075*). It corresponds to the **deliverable D2.1 of WP 2 Lab scale testing**.

The protocol will be applied to three different electrolysis technologies: Proton Exchange Membrane Electrolysis (PEMEL), Alkaline Electrolysis (AEL), Solid Oxide Electrolysis (SOEL). Albeit the net chemical reaction remains the same in the three encompassed technologies, the nature of the materials and conditions employed differs. This translates in differences in the experimental conditions and protocols required to assess the performance degradation mechanisms affecting the three technologies. Nevertheless, based on the similarity of the type of key degradation effects under examination, their outcomes and their means of determination, this document is defined as "quasi-harmonized testing protocol".

These protocols are intended for use in the framework of the project to highlight key degradation mechanisms and their operational causes using advanced monitoring and diagnostic tools developed in the framework of DELYCIOUS, ultimately allowing to develop, within the duration of the project, operational scenarios to improve cell/stack lifetime.

Their use in other contexts by both the research community and industry, for research and development (R&D) purposes as benchmarking aid is welcomed.

A review of the three technologies, in terms of a detailed description of their functionality, materials employed at stack and cell level as well as the current developments, is outside the scope of this document and only definitions deemed necessary for understanding the protocol will be recalled in text.

Contributors

The document is produced under the collaboration framework within the project DELYCIOUS (*Project number: 101192075*). The document is the result of the joint contributions from academia and industry partners part of the project consortium, combining the expertise of researchers from research and technology public institutions, university, original equipment manufacturer of stacks, original equipment manufacturer of advanced hardware as well as from major gas industry.

This document is also shared with the Joint Research Center (JRC) in the framework of their testing harmonization activities. The testing protocols herein included capitalize from the work already published by the JRC.

The list of the organizations involved in the creation of the document is provided below in alphabetic order:



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List of Acronyms

WE	Water Electrolysis
PEMEL	Proton Exchange Membrane Electrolysis
AEL	Alkaline Electrolysis
SOEL	Solid Oxide Electrolysis
LTWE	Low Temperature Water Electrolysis
HTWE	High Temperature Water Electrolysis
DC	Direct Current
AC	Alternating Current
TIP	Testing Input Parameter
ТОР	Testing Output Parameter
FIS	Electrochemical Impedance Spectros-
LIJ	сору
SoH	State of Health of a cell/stack
SoH BoT	State of Health of a cell/stack Beginning of Time
SoH BoT MoT	State of Health of a cell/stack Beginning of Time Middle of Time
SoH BoT MoT EoT	State of Health of a cell/stack Beginning of Time Middle of Time End of Time
SoH BoT MoT EoT OER	State of Health of a cell/stack Beginning of Time Middle of Time End of Time Oxygen Evolution Reaction
SoH BoT MoT EoT OER HER	State of Health of a cell/stack Beginning of Time Middle of Time End of Time Oxygen Evolution Reaction Hydrogen Evolution Reaction
SoH BoT MoT EoT OER HER SPx	State of Health of a cell/stackBeginning of TimeMiddle of TimeEnd of TimeOxygen Evolution ReactionHydrogen Evolution ReactionSet-point x
SoH BoT MoT EoT OER HER SPx SPTx	State of Health of a cell/stackBeginning of TimeMiddle of TimeEnd of TimeOxygen Evolution ReactionHydrogen Evolution ReactionSet-point xSet-point time x
SoH BoT MoT EoT OER HER SPx SPTx HTx	State of Health of a cell/stackBeginning of TimeMiddle of TimeEnd of TimeOxygen Evolution ReactionHydrogen Evolution ReactionSet-point xSet-point time xHolding Time (of setpoint) x



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1. Introduction

1.1. Reactions and Technologies

Water electrolysis (WE) cells/stacks are at the core of electrochemically generating hydrogen (H_2) in bulk amounts in addition to oxygen (O_2) and heat by the electrolysis of water (H_2O) using electricity (Direct current, DC) to drive the generalized net reaction (**Eq. 1**):

Eq. 1 $H_2O_{(l/g)} \rightarrow \frac{1}{2}O_{2(g)} + H_{2(g)}$

Most industrial commercial electrolysers currently use low-temperature (60-100 °C) water electrolysis (LTWE) technologies, namely alkaline water electrolysis (AEL) and proton exchange membrane water electrolysis (PEMEL). The interest is rising also toward high temperature (650-850 °C) water electrolysis (HTWE) technologies, namely solid oxide electrolysis (SOEL) as of today industrially deployed only at smaller hydrogen production capacities.

- In **PEMEL** two electrodes anode and cathode are sandwiched onto a proton conducting polymeric membrane. The reaction occurring at the electrodes are the following:

Anode, oxygen evolution reaction (OER):

Cathode, hydrogen evolution reaction (HER):

 $\begin{array}{c} H_{2}O_{(l)} \xrightarrow{OER} 2 H_{(aq)}^{+} + \frac{1}{2} O_{2 (g)} + 2 e_{(el)}^{-} \\ 2 H_{(aq)}^{+} + 2 e_{(el)}^{-} \xrightarrow{HER} H_{2 (g)} \end{array}$

Protons are transported from anode to cathode through the membrane via vehicular and Grotthuss mechanism. Water can also reach the cathode via electro-osmotic drag.

- In **AEL** two electrodes immersed in an alkaline solution (lye, typically KOH or NaOH at 20-40 wt%) are separated by a diaphragm. During the project a zero-gap AEL design will be used. The reactions at the electrodes are:

Anode, oxygen evolution reaction (OER): Cathode, hydrogen evolution reaction $2 \operatorname{OH}_{(aq)}^{-} \xrightarrow{\operatorname{OER}} \operatorname{H}_2 \operatorname{O}_{(l)} + \frac{1}{2} \operatorname{O}_{2 (g)} + 2 \operatorname{e}_{(el)}^{-}$ $\operatorname{H}_2 \operatorname{O}_{(l)} + 2 \operatorname{e}_{(el)}^{-} \xrightarrow{HER} \operatorname{H}_{2 (g)} + 2 \operatorname{OH}_{(aq)}^{-}$

The hydroxide ions are transported from cathode to anode through the diaphragm with the concentration gradient and applied potential being the main driving force.

- In **SOEL** two electrodes are typically deposited onto an oxygen-ion conducting solid electrolyte (this configuration is called electrolyte supported cell, other designs are also possible). The electrodes reactions are:

Anode, oxygen evolution reaction (OER): $0^{2-}_{(el)} \xrightarrow{\text{OER}} \frac{1}{2} O_{2(g)} + 2 e^{-}_{(el)}$ Cathode, hydrogen evolution reaction
(HER): $H_2O_{(g)} + 2 e^{-}_{(el)} \xrightarrow{\text{HER}} H_{2(g)} + O^{2-}_{(el)}$

The oxygen ions are transported from cathode to anode via diffusion and migration through the solid electrolyte, either along the grain boundaries or inside the grains thanks to the presence of oxygen vacancies in the crystal.

(*HER*):

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1.2. Classical and advanced experimental techniques exploited during the tests

In the course of the tests, several classical and advanced experimental techniques will be employed to track changes in the cell/stack performances. Apart from classical outputs from usual sensors (*e.g.,* voltmeter, flow meters, temperature controllers, pressure sensors, conductivity sensors for H_2O/lye and online μ GC), other measurement techniques and methodologies that will be employed are reported below.

POLARIZATION CURVES

The measurement of current- voltage curves $(I_{DC}-U_{DC})$ will be executed according to the standards for $LTWE^1$ and $HTWE^2$.

Polarization curves can be measured at stack and/or cell level (if a Cell Voltage Module, CVM is equipped). It is often the case that $U_{stack} \neq N_{cells} \overline{U_{cells}}$ (where U_{stack} is the measured stack voltage, N_{cells} is the numbers of cell in the stack, $\overline{U_{cells}}$ is the average single cells voltage). The reasons behind stem from stack internal resistances transcending cell level (*e.g.*, in-stack interfaces) and/or the position of the terminals at which the stack and cells voltages are measured. These differences will be taken into account during the processing of the test data.

ELECTROCHEMICAL IMPEDANCE SPECTROSCOPY

Electrochemical impedance spectroscopy (EIS) is a powerful diagnostic method to characterize WE cells and stacks as it is a non-destructive technique that can be used *in-operando* to assess degradation effects on cell components.

EIS measures the frequency (*f*) dependence of the impedance (*Z*) by applying a small AC current perturbation (galvanostatic mode) or a small alternating voltage (potentiostatic mode) and recording the voltage (or current) response. A broad frequency range usually ensure to capture effects ranging from ohmic resistances (arising from Ohm's law abiding phenomena) to transport processes but, a trade-off between measurement time and number of parameters to be determined is necessary. The ohmic phenomena will dominate the *Z* response at high frequencies, while transport processes occur in the lowfrequency range. At middle-low frequency electrode polarization phenomena are dominant.

For recording the impedance spectra, the standards contained in [3] will be followed as closely as possible, with acquisitions at least once every 24 h or 12 h when the stack/cells are in steady-state condition.

RAMAN SPECTROSCOPY

Raman Spectroscopy is a non-destructive chemical analysis technique which provides detailed information about chemical structure, phase, crystallinity and molecular interactions. It is based upon the interaction of light with the chemical bonds within a material. Raman is a light scattering technique, whereby a molecule scatters incident light from a high intensity laser light source. Most of the scattered light is at the same wavelength as the laser source and does not provide useful information (this is called Rayleigh Scatter). However, a small amount of light ($\approx 0.0000001\%$) is scattered at different wavelengths, which depend on the chemical structure of the analyte (this is called Raman Scatter).

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A Raman spectrum features a number of peaks, showing the intensity and wavelength position of the Raman scattered light. Each peak corresponds to a specific molecular bond vibration which allows the identification of the analyte (usually using Raman libraries). Raman can be used as both quantitative and qualitative technique. In the case of DELYCIOUS, Raman spectroscopy will be used to detect (in-line) in two measurement points the following KPIs:

(*i*) concentrations < 2% of H₂ in O₂ (HTO). This is relevant for PEMEL and AEL, where gas crossover is an indicator of the cell/stack degradation (due to *e.g.*, thinning and corrosion effects) as well as a hindering effect for safe operation due to the low explosivity limit of H₂/O₂ mixtures (when a threshold is reached, the plant will trip interrupting the operation). Two big advantages of Raman probes compared to classical HTO sensors (*e.g.*, thermal conductivity detectors) are that they (*a*) can be mounted before the oxygen separator allowing a prompt HTO detection due to its inherent less sensitivity to humidity, as well as (*b*) their selectivity toward the analyte.

(*ii*) concentrations of up to 30% H_2 and <1% N_2 (usually arising from sealant degradation pathways) at the outlet streams. This is relevant mainly for SOEL, where the presence of a solid electrolyte will intrinsically prevent gas crossover. These concentrations can be used for tracking changes in the faradaic efficiency towards H_2 production.

The adaptation of a Horiba proprietary online Raman probe is one of the objectives of the funded project DELYCIOUS, therefore no testing parameters (*e.g.*, laser wavelength, acquisition time, etc.,) can be provided at this stage.

1.3. Degradation evaluation

During the operation, a WE cell or stack will undergo a more or less severe degree of degradation of its performance. This is usually reflected into an increase of the cell/stack voltage (due to overpotentials), overall leading to higher energy input required to obtain the same amount of Hydrogen/Oxygen as at Beginning-of-Time (BoT).

A compendium on degradation phenomena for all the water electrolysis technologies was recently published in the framework of the ELECTROLIFE project (GA 1011137802), and the interested reader can find the relevant section for AEL, PEMEL and SOEL in Sections 2.1.1, 2.1.3 and 2.1.4 of the report, moreover, Section 7 highlights specifically the similarities in degradation mechanisms for the three technologies ⁴.

One can divide the overall cell/stack voltage in its individual terms 5,6,7 (Eq. 2) independently from the type of WE technology under examination:

Eq. 2
$$U_{cell/stack} = U_{OCV} + U_{act} + I_{DC} R_{\Omega} + U_{conc}$$

Where:

- **U**ocv is the open circuit voltage.
- **U**_{act} is the activation overpotential due to the kinetics of the OER and HER and takes the form in **Eq. 3**:

Eq. 3
$$U_{act}(T) = \frac{RT}{zF} \log \left[\left(\frac{I_{0,a}(T)}{I_{a}} \right)^{\alpha_{a}} \cdot \left(\frac{I_{0,c}(T)}{I_{c}} \right)^{\alpha_{c}} \right]$$

With: R gas constant (Jmol⁻¹K⁻¹), *T* temperature in K, F is the Faraday constant (Cmol⁻¹), I_0 is the exchange current density and α is the charge transfer coefficient. The subscripts "a" and "c" indicate anode and cathode. To discriminate between the anodic and cathodic share of the activation overpotential is not always possible, a common approximation is to assume that the anodic term is predominant due to the more sluggish kinetic of the OER. The I_0 can be related to the polarization resistance (R_p) via the relation in Eq. 4:

Eq. 4
$$R_p I = \frac{RT}{\alpha n F} \ln(\frac{I}{I_0})$$

The polarization resistance can be extracted at middle-low frequencies from an EIS spectrum.

- $I_{DC} R_{\Omega}$ is the ohmic resistance, where R_{Ω} is the high frequency resistance in the EIS spectrum. Ohmic resistive contributions stem essentially from contacts, material interface and electrolyte resistances to electronic or ionic transport. The main contributor is generally the electrolyte/membrane/diaphragm.
- **U**_{conc} is the concentration overvoltage due to mass transfer limitations in the electrodes of the cell/stack including hindrances caused by gas bubbles. It is expressed as **Eq. 5**:

Eq. 5
$$U_{conc}(T) = \frac{\mathbf{R}T}{\mathbf{z}\mathbf{F}} \log\left[\left(\frac{c_{O_2}}{c_{O_2}^0}\right) \cdot \left(\frac{c_{H_2}}{c_{H_2}^0}\right)\right]$$

EXPRESSION OF DEGRADATION RATES

In the evaluation of the test results the degradation rates will be expressed as:

- Total rate of change of the area-specific resistance ($\Delta_k^{tot} R_{ASR}$, Eq. 6 and Eq. 7) in which :

Eq. 6
$$R_{ASR}(m\Omega cm^2) = R_{TOT}(\Omega) A_{act}(cm^2) \cdot 1000$$

Eq. 7
$$\Delta_k^{tot} R_{ASR} (\%) = \frac{R_{ASR} (t_k) - R_{ASR} (t_0)}{R_{ASR} (t_0)} \cdot 100$$

 A_{act} is the electrodes active area, R_{TOT} is the sum of the high frequency, middle frequency and low frequency (if taken into account) resistances, t_0 is the beginning of test or the reference point, t_k is the last point in time acquired at the same operational condition as the reference.

- In the case of AEL and PEMEL, the change in electrical energy $(\Delta_{q_{m,H2}}^{tot} E_{el})$ expressed in Wh/kg H₂ will also be used, Eq. 8:

Eq. 8
$$\Delta_{q_{m,H_2}}^{tot} E_{el} \left(Whkg H_2^{-1} \right) = \frac{P_{el} \left(t_k \right)}{q_{m,H_2} \left(t_k \right)} - \frac{P_{el} \left(t_0 \right)}{q_{m,H_2} \left(t_0 \right)}$$

Where q_{m,H_2} is the mass flow rate of hydrogen (in kgh⁻¹) and $P_{el} = U_{cell/stack} I_{DC}$ (in W) For SOEL, the change in current density will be instead considered between t_0 and t_k .

2. Definition of the test protocol

2.1. Scope of the test plan and its structure

The test plan has the primary scope to generate experimental data for the development and validation of advanced diagnostic tools (able to assess and predict stack/cell state of health) while integrating in the test setups advanced monitoring tools (Raman Spectroscopy and Electrochemical Impedance Spectroscopy, EIS). Given the major focus on degradation parameters, the protocol will be designed in the form of accelerated stress tests.

In the following test plan will be provided: (i) the testing input parameters (TIPs), (ii) testing procedure and their duration.

The test plan is divided in two main phases:

- Data generation (time on stream \ge 1000 h): composed by an initial phase (baseline) of operation at nominal load and a second phase where variable loads are used, they are defined in **3.1**.
- Validation (time on stream \geq 500 h): operation at the condition specified in **3.2**.

In the case of the AEL demonstration at large scale (> 100 kW) the test duration is reduced as only the baseline and validation are required.

2.2. Devices under test for the three technologies

For the three technologies under examination different type of cells/stack are used:

- 1. PEMEL: a short stack of five commercial catalyst coated membranes will be used (the cells will have the same material compositions). The short stacks used for the data generation and validation will not be previously treated and are pristine. The cells conditioning will be executed according to the manufacturer specifications.
- 2. SOEL: a single commercial cell (fuel electrode- or electrolyte-supported) will be tested. The cell won't be aged beforehand. The conditioning will be executed according to the manufacturer specifications.
- 3. AEL (lab-scale): five different single cells (proprietary) will be tested for 200 h each to reach a total testing time of 1000 h. One of the cells will be pristine for the baseline acquisition, while the other four will contain selected defects each. The aim is to understand the impact on performance due to degradation events such as anode oxidation, cathode leaching, membrane blocking.
- **4. AEL (large scale):** A proprietary stack of > 100 kW will be supplied by Stargate Hydrogen to Fraunhofer IWES and tested in their facility. The conditioning will follow Stargate specifications.

2.3. Terminology and Unit of Measures

Terms and definitions used in this document are consistent with what used in Refs. ^{8,9}, and ISO and IEC terminological databases maintained at the following websites:

- ISO Online browsing platform available at https://www.iso.org/obp.
- IEC Electropedia available at http://www.electropedia.org.



Regarding units we reference to the Système International d'Unités (SI). Decimal fractions are denoted by comma. Alongside SI units, non-SI units may be used as customary *e.g.,* we use degree Celsius (°C) as unit of temperature (T) alongside Kelvin (K) and kilo Watt hours (kWh) as unit of energy (E) instead of kilo Joule (kJ).

3. Test protocol

3.1. Data generation Protocol

BASELINE

Baseline data are acquired at nominal load. The following TIPs, coherent with the experimental boundaries of the three test benches (PEMEL, AEL, SOEL), will be utilized for the baseline acquisition and are summarized in **Table 1**. These conditions are referred in the rest of the text as **SPO** (setpoint 0)

Table 1 TIPs to be used for the baseline acquisition for each technology and scale.

TIPs	PEMEL (lab-scale)	AEL (lab- scale)	AEL (large- scale)	SOEL (lab- scale)
Current density J / A cm ⁻²	1,5	0,55	0,55	-
Voltage U / V	-	-	-	1,29
Temperature inlet / °C	60±4	70 ± 0,5	70	-
Water / KOH inlet flow / mLmin ⁻¹ cm ⁻²	2,5±0,5	44,4	15 NL/min - 750 NL/min	50
Conductivity of water / µScm ⁻¹	≤0,1 @ 25 °C	< 0,5	< 0,5	-
Conductivity of electrolyte / mScm ⁻¹	-	-	-	30 @ 800 °C
Electrolyte concentration / wt%	-	30 ± 0,2	30 ± 0,2	-
Actively applied p / bar	-	-	10-32	1
Duration / h	150	150	150	150

DATA GENERATION TEST PROTOCOL

For the data generation test protocol we foresee a total duration of at least 1000 h including 150 h of baseline acquisition according to the TIPs reported in **Table 1**. The test protocol is designed for the three technologies as an accelerated stress test based on load cycling (in the case of SOEL voltage cycling will be used as degradation driver). The choice of using load cycling profiles is dictated by the leading role that this type of operation will have in the near future due to the increasing integration of electrolysers with renewable and intermittent energy sources.

Before and after an *n* number of cycles (herein defined as NC) three set points are held for a certain amount of time during which EIS spectra are acquired after the voltage (or current in case of SOEL) stabilizes (at least one spectrum every 24 h).

Polarization curves will be acquired at least at beginning-of-time (BoT), middle-of-time (MoT) and endof-time (EoT). Additional acquisitions are not excluded (especially based on voltage trends) but not fixed beforehand.

CYCLING PROFILE

The cycling profile is defined in **Figure 1** and it is composed by three set-points (SP1, SP2, SP3) with durations (SPT1, SPT2 and SPT3) detailed in **Table 2** for each technology and scale.



Figure 1 Cycling profile that will be used in the current protocol. SP1, SP2 and SP3 are the three set-points of the current density (or voltage in the case of SOEL). SPT1, SPT2, SPT3 reflect their duration.

SET-POINT HOLDING

After the baseline acquisition the SP1, SP2, SP3 are held for a holding time HT1, HT2, HT3 (**Table 2**). After each *n* cycles (NC) the holding times will be repeated.

HTx is much longer than SPTx (therefore expressed in hours rather than minutes, **Figure 2**). Therefore, during the holding times the voltage (or current in case of SOEL) will equilibrate, generating a comparable point basis along the experimental test. The holding times allow also the acquisition of EIS spectra and polarization curves in the course of the test.



Figure 2 Holding times HT1, HT2 and HT3 at SP1, SP2 and SP3. The start (or restart) of a cycling procedure is also shown (not in scale).

TEST PROCEDURE STEPS

The data generation procedure is composed by the following steps, with relevant parameters detailed in **Table 1** and **Table 2**:

- 1. Cell conditioning according to manufacturer specifications (this time is not accounted in the test duration).
- 2. Setting of SPO according to TIPs in **Table 1**. Immediately after, a polarization curve and EIS spectra are acquired. During this phase EIS spectra can be acquired every 12 h during the 150 h of baseline acquisition. An additional polarization curve has to be acquired before step 3.
- 3. The procedure detailed in the section **SET-POINT HOLDING** is initiated. Also, during this time EIS spectra are acquired every 12 or 24 hours. A polarization curve can be acquired after HT3, before starting the step 4.
- 4. The procedure described in **CYCLING PROFILE** is followed for *n* cycles (NC). For SOEL, the cycling profile is slightly modified (as shown in Figure 4) to minimize large voltage jumps and prevent excessive strain on the cell.
- 5. Steps 3 and 4 are repeated to reach a test duration of 975 h.
- 6. The condition of SPO is set for a duration of 24 h. At the end of the test, EIS spectra and the last polarization curve are acquired.

A visual representation of the test plan above is presented in **Figure 3** for PEMEL, **Figure 4** for SOEL, in **Figure 5** for AEL (lab scale) and in **Figure 6** AEL (large scale).



PEM Data generation Protocol

Figure 3 Visual representation of the data generation test plan, example for PEMEL.



Figure 4 Visual representation of the data generation test plan, example for SOEL. Here, V_{tn} is the thermoneutral voltage = 1,29 V at 800 °C and 1 bar.



Figure 5 Visual representation of the data generation test plan, example for AEL.



Figure 6 Visual representation of the test plan for AEL at a large scale. The holding times may vary due to the current lack of knowledge regarding the required duration to execute an EIS measurement at the test rig. The test protocol has been developed in close alignment with the test protocol for AEL lab-scale testing. Any modifications by Stargate may lead to slight adjustments in the number of cycles and the holding times of individual set-points. Moreover, at large scale a step response to changing loads is not ensured as this depends on the ramp-rate limitations, but nevertheless this factor will not have a big impact in the test scope.

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Table 2 List of relevant parameters for the data generation test protocol.

parameter	PEMEL (lab-scale)	AEL (lab-scale)	SOEL (lab-scale)
SP1	1,5 Acm ⁻²	0,55 Acm ⁻²	1,5 V
SP2	0,6 Acm ⁻²	0,22 Acm ⁻²	1,29 V
SP3	0 Acm ⁻²	0 Acm ⁻²	0,98 V
SPT1 / min	30	30	30
SPT2 / min	30	30	30
SPT3 / min	30	30	30
Number of consec- utive cycles (NC)	14	32-48	11
Number of total cy- cling periods	16	1	16
HT1/h	10	0,5	10
HT2 / h	10	0,5	10
HT3 / h	10	0,5	10



3.2. Validation Test Protocol

The test validation protocol follows the same structure of the data generation one (section **3.1**), but its duration is shorter (about 500 h). This phase is used to validate the hybrid modelling approach developed within DELYCIOUS. The relevant parameters are listed in **Table 3**. In this case the SPO duration (step 2 in **TEST PROCEDURE STEPS**) is shortened to 70 h and step 6 is shortened to 12 h.

parameter	PEMEL (lab-scale)	AEL (lab- scale)	AEL (large- scale)	SOEL (lab- scale)
SP1	1,5 Acm ⁻²	0,55 Acm ⁻²	0,55 Acm ⁻²	1,5 V
SP2	0,6 Acm ⁻²	0,22 Acm ⁻²	0,22 Acm ⁻²	1,29 V
SP3	0 Acm ⁻²	0 Acm ⁻²	0 Acm ⁻²	0,98 V
SPT1 / min	15	15	15	15
SPT2 / min	15	15	15	15
SPT3 / min	15	15	15	15
Number of con- secutive cycles (NC)	28	32-48	32-48	22
Number of total cycling periods	8	1	5	8
HT1/h	10	1	1	10
HT2 / h	10	1	1	10
HT3 / h	10	1	1	10

 Table 3
 List of relevant parameters for the data validation test protocol.

4. Conclusion

This report proposes a quasi-harmonized test experimental protocol for low and high temperature major electrolysis technologies with the scope of assessing critical degradation pathways within WE cells/stacks using a common definition of the degradation expression (*e.g.,* as variation of the ASR or electrical energy).

The common ground among the different technologies in the experimental procedure is dictated by the use of a cycling profile based on three main set-points. These are defined differently due to the difference in operation modes of PEMEL, AEL and SOEL. The choice of using load cycling profiles is dictated by the leading role that this type of operation will have in the near future.

These protocols are intended for use in the framework of the project to highlight key degradation mechanisms using advanced monitoring and diagnostic tools developed in the framework of DELYCIOUS, ultimately allowing to develop, within the duration of the project, operational scenarios to improve cell/stack lifetime. Their use in other contexts by both the research community and industry, for research and development (R&D) purposes as benchmarking aid is welcomed.

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