International perspective – FCH JU supported High temperature Electrolysis in the EU

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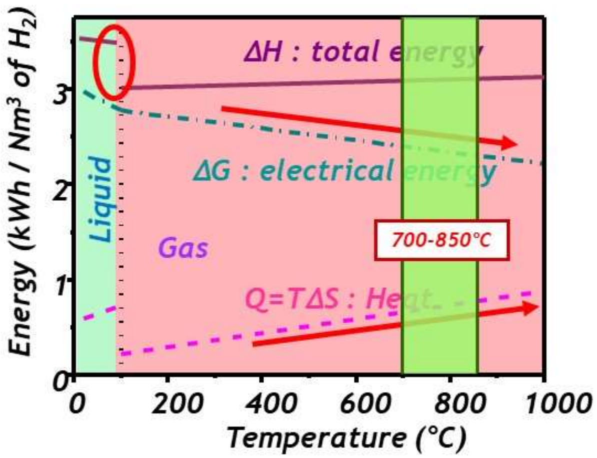
Outline

- Introduction
  - Interest of High Temperature Electrolysis (HTE) – Solid Oxide Cell (SOC) technology
- Current status of HTE deployment in EU
- HTE Technology Key Performance Indicators
- HTE harmonized terminology
- Cells and stacks testing protocols
- Accelerated stress testing
- Testing in faulty operating conditions
- EU contribution to normative work
- Conclusions

Introduction: interest of High temperature Electrolysis (HTE)



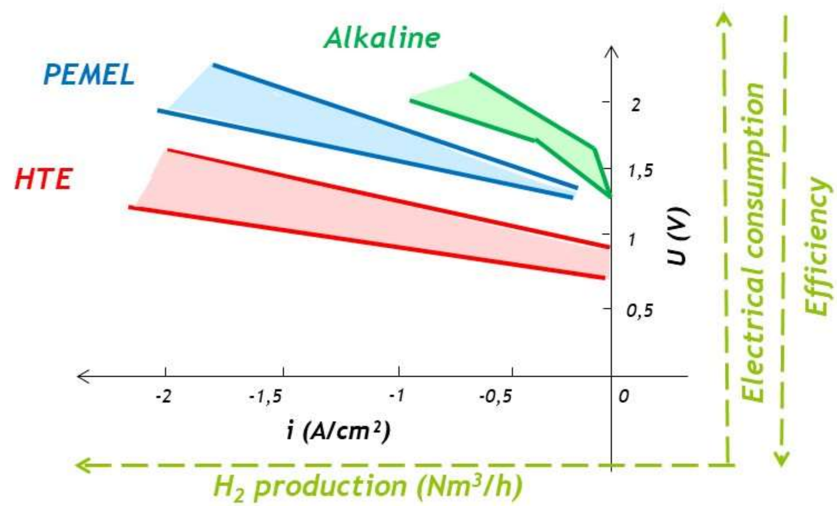
H_2O (g) → H_2 (g) + ½ O_2 (g)

ΔH = ΔG + TΔS ~ constant

The reaction **overall energy ΔH** to be provided is **lower** to split a **steam** molecule than a water one

- **ΔG is the minimum part of electric energy required for the electrolysis reaction,** the rest can be provided as heat
- ➡ The hotter the electrolysis operation, the lower the electricity demand:
  - High T: energy = 70% electricity, 30% heat
  - Low T: energy = 85% electricity / 15% heat
- ➡ **HTE Temperature range = 700-850°C**

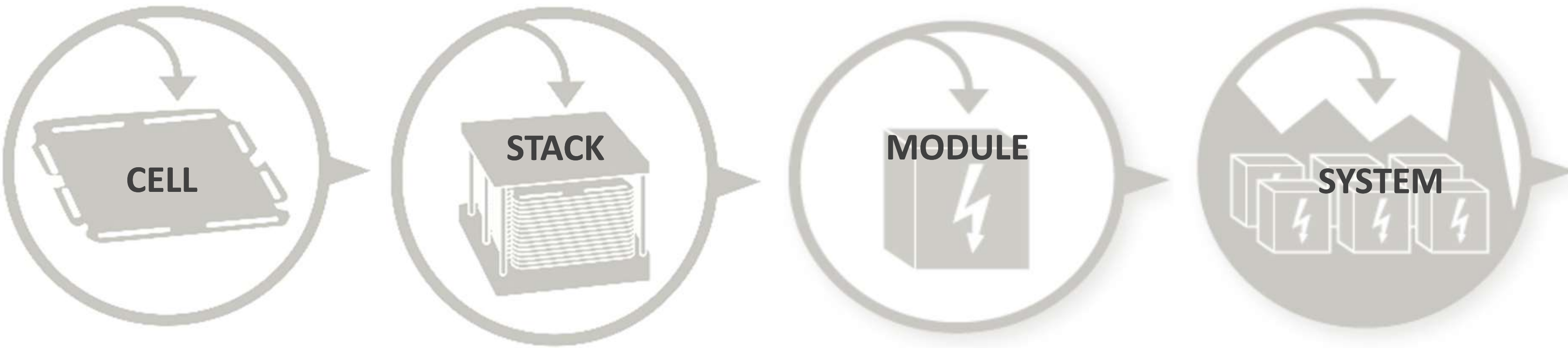
HIGH EFFICIENCY TECHNOLOGY



Efficiency:
LTE :
4 to 6 kWh/Nm³
HTE:
< 3,5 kWh/Nm³

Introduction: interest of High temperature Electrolysis (HTE)

MODULAR TECHNOLOGY



Electrolysis cell made of:
- 2 electrodes (anode and cathode)
- One electrolyte
- Need of electricity (and heat)

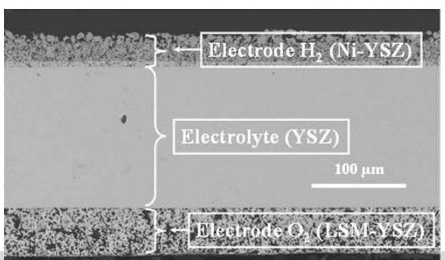
Stacking of several electrolysis cells to increase the power

Integration of stacks into a **module** including 1st level Balance of Plant components

Can/will include several stacks into a module

Integration of modules into an **electrolysis system/plant** including all Balance of Plant components = electrolyser

Can/will include several modules into the electrolysis system/plant

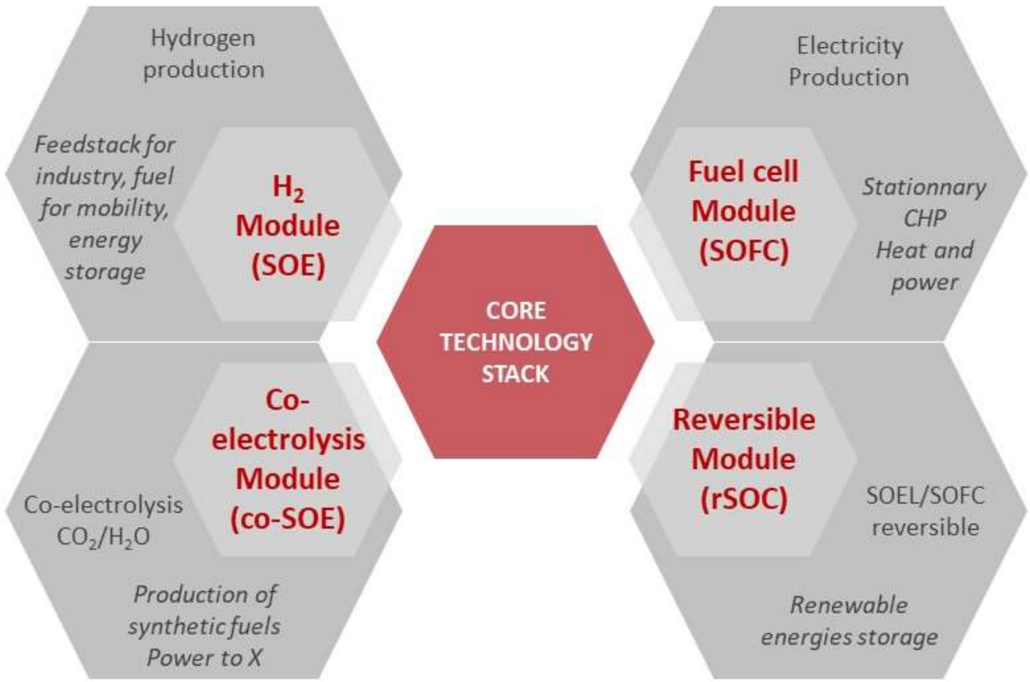


Technology with no expensive noble catalysts

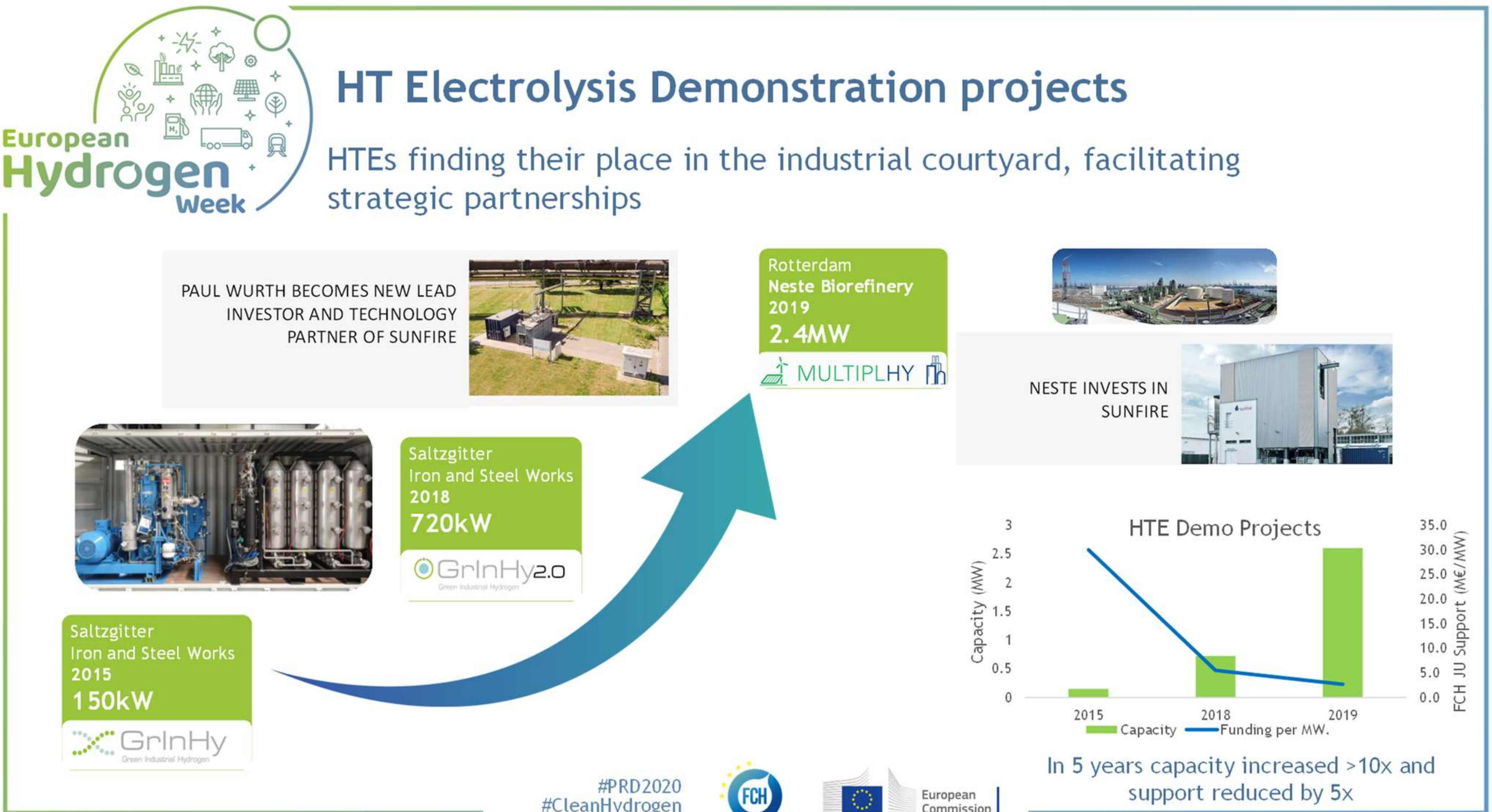
Introduction: interest of High temperature Electrolysis (HTE)

FLEXIBILITY OF USE

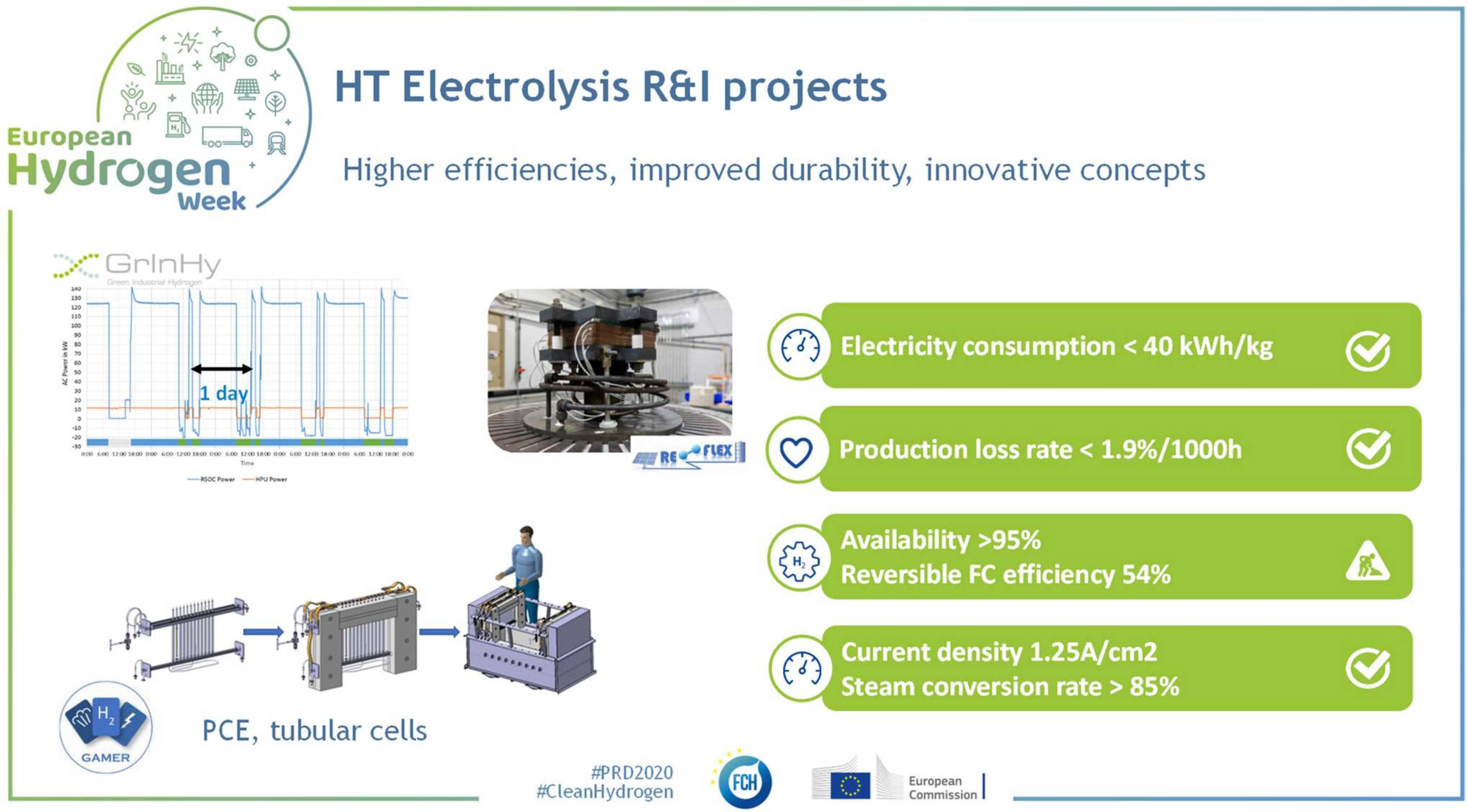
Same core technology for several applications



Current status of HTE deployment in Europe



Current status of HTE deployment in Europe



HTE Technology Key Performance Indicators

STATUS

Cells and Stacks

- High performances: current density of 0.6 A/cm² and above at the thermoneutral voltage (1.3V)
- Durability : degradation < 2%/1000h

Modules and Systems

- First demonstration systems installed
- Upscaling and in-field deployment for various use cases

TARGETS

Ambitious improvement of key parameters

Source: Strategic Research and Innovation Agenda, Final Draft, Hydrogen Europe, 07/2020

No	Parameter	Unit	SoA	Targets		
			2020	2024	2027	2030
System*						
1.	Electricity consumption @ nominal capacity	kWh/kg	40	39	38	37
	Heat demand @ nominal capacity	kWh/kg	9.9	9.0	8.5	8
2.	Capital cost	€/(kg/d) (€/kW)	3,550 (2,130)	2,000 (1,250)	1,200 (760)	800 (520)
3.	O&M cost	€/(kg/d)/yr	180	100	60	40
4.	Hot idle ramp time	sec	600	300	250	180
5.	Cold start ramp time	h	12	8	6	4
6.	Footprint	m^2/MW	--	150	75	50
Stack						
7.	Degradation @ U_{TN}	%/1,000hrs	1.9	1.0	0.7	0.5
8.	Current density	A/cm^2	0.6	0.85	1.0	1.5
9.	Use of critical raw materials as catalysts	mg/W	n/a	n/a	n/a	n/a
Technology related KPIs						
10.	Roundtrip electrical efficiency	%	46%	52%	55%	59%
11.	Reversible capacity	%	25%	30%	35%	40%

HTE Harmonized terminology

- **Work for a EU harmonised terminology for hydrogen generated by electrolysis**
- Draft document prepared end of 2020 by JRC with the support of academia, R&D and industrial experts from different countries participating to FCH2JU funded HTE R&D projects
- Includes a part on HTE (SOEC)

European Commission

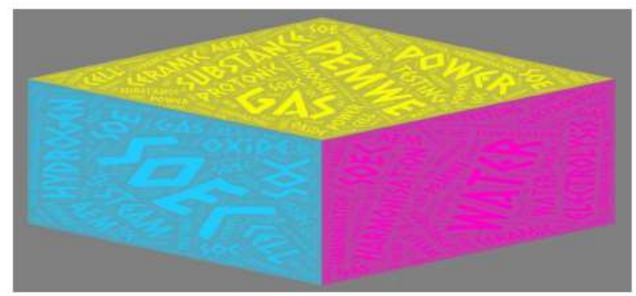
JRC VALIDATED METHODS, REFERENCE METHODS AND MEASUREMENTS REPORT

EU harmonised terminology for hydrogen generated by electrolysis

An open and comprehensive compendium

Malkow, K T, Pilenga, A , Blagoeva, D

2020



Joint Research Centre

EUR 30324 EN

HTE Harmonized terminology

- **Objective of this pre-normative research (PNR) document**
  - To present an open and comprehensive compendium of harmonised terminology which are encountered in electrolysis applications.
  - Terms and definitions cover many aspects : materials, modelling, design & engineering, analysis, characterisation, measurements, laboratory testing, prototype development and field tests including demonstration as well as quality assurance (QA).
  - may be used in RD&D project documents, test and measurement methods, test procedures and test protocols, scientific publications, and technical documentation.
  - information useful for others, e. g. auditors, manufacturer, designers, system integrators, testing centres, service providers and educators.
  - it is expandable to account for future power-to-hydrogen (P2H2) developments in energy storage (ES) particularly electrical energy storage (EES), hydrogen-to-power (H2P), hydrogen-to-industry (H2I) and hydrogen-to-substance (H2X) applications
- **Next steps:**
  - approval by ISO, IEC and IUPAC for use of their terms & definitions as used in this document
  - public stakeholder consultation

Contents

Cells and stacks testing protocols

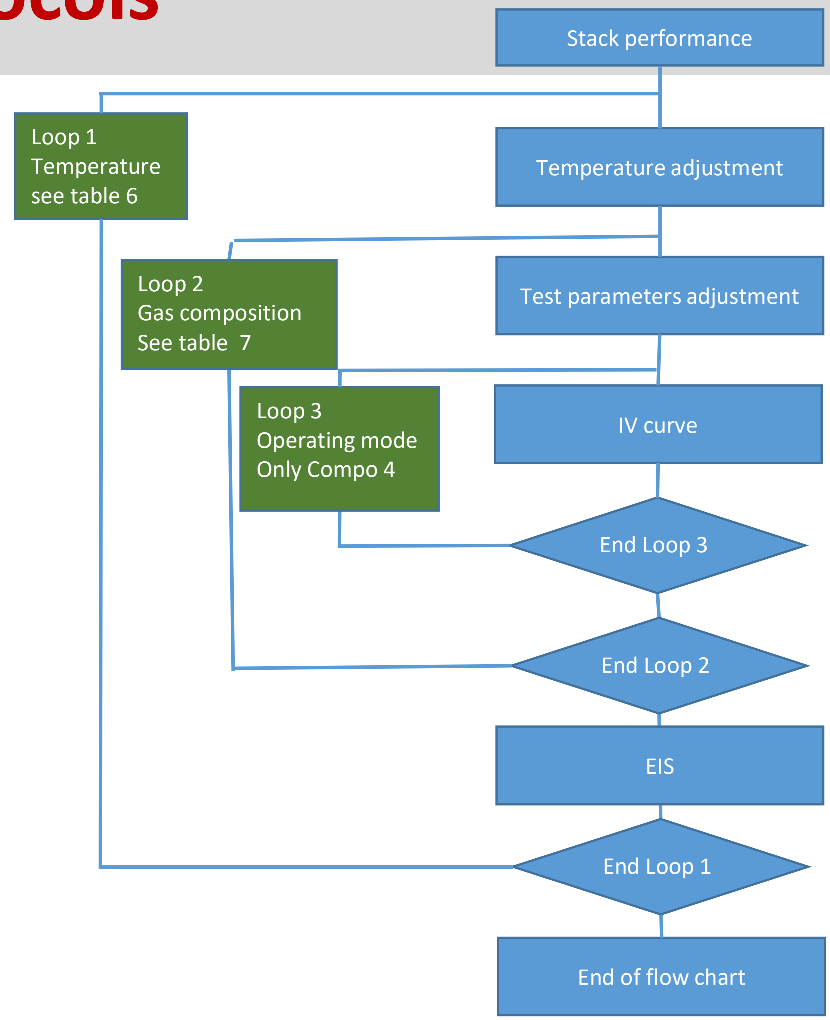
- **In several EU projects, testing protocols have been proposed / defined**
- **Covering SOFC, SOEC and/or rSOC**
- **Projects that can particularly be quoted:**
  - SOCTESQA: Development of industry wide uniform performance test schemes for SOFC/SOEC cells & stacks (2014-2016):
    - Taking advantage for the methodology on previous SOFC and/or PEMFC projects (FCTESQA)
    - Output = Basis for SOFC and SOEC testing protocols
      - D2.1 List of existent SOC test procedures
      - D3.1 Test matrix document
      - D3.6 Final document of test protocols
      - All publically available
      - *See M. Lang et al., Quality Assurance of Solid Oxide Fuel Cell (SOFC) and Electrolyser (SOEC) Stacks, ECS Transactions, 78 (1) 2077-2086 (2017)*
  - REFLEX: Reversible solid oxide Electrolyzer and Fuel cell for optimized Local Energy miX (2018-2021)
    - Cells and Stacks testing protocol, Deliverable D2.1, publically available on http://reflex-energy.eu
  - MULTIPLHY: Multimegawatt high-temperature electrolyser to generate green hydrogen for production of high-quality biofuels (2020-2024)
    - Definition of Testing Protocols, Deliverable D2.1, publically available on www.multiplhy-project.eu

Cells and stacks testing protocols

- **Highlight of content from REFLEX project**
- **Performance**

ID	Temperature levels °C
ST-1	800
ST-2	750
ST-3	700

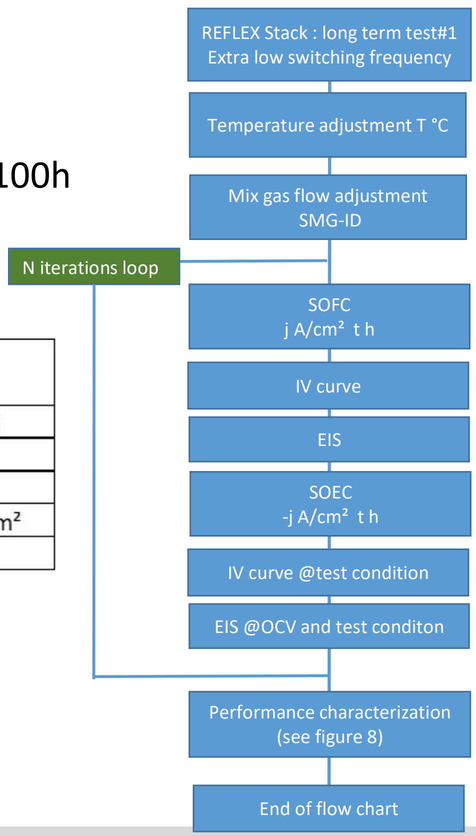
ID	Operating Mode		H2 Side Total flow rate	Mix gaz molar ratio				
				H2 side			O2 side	
	SOFC	SOEC	Ncm3/min/cm²	H2 %	H2O %	N2 %	N2 %	O2 %
SMG-1		x	12	10	90	0	80	20
SMG-2		x	6					
SMG-3		x	18					
SMG-4	x	x	12	50	50	0		
SMG-5	x			50	0	50		
SMG-6	x		3	100		0		



Cells and stacks testing protocols

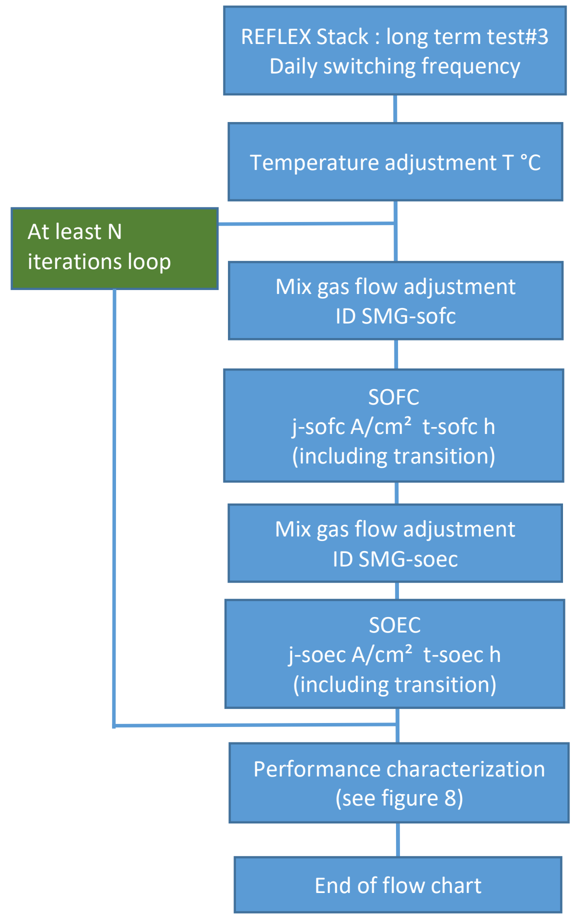
- **Highlight of content from REFLEX project**
- **Durability: 2 types of switching in rSOC mode**

Long switching ~ 100h



Parameters		
T	700	°C
SMG-ID	SMG-4	
N	4	
j	0.5	A/cm²
t	100	h

Daily switching



Parameters		
T	700	°C
SMG-sofc	SMG-6	-
SMG-soec	SMG-1	-
N	20	-
j-sofc	0.6	A/cm²
j-soec	-1.2	A/cm²
t-sofc	16	h
t-soec	8	h

Accelerated stress testing

- **One ongoing project: AD ASTRA (2019-2021)**
- **Objective:** development of Accelerated Stress Test (AST) protocols that allow **quantitative identification and prediction of critical degradation mechanisms,** correlating them with overall performance variables in selected solid oxide fuel cell/electrolyser (SOFC/SOEC, or SOC) stack components (fuel electrode, oxygen electrode and interconnect).
- Target AST durations should be **under 3000 hours** and **represent** real-world stack operations of up to **40,000h** through defined acceleration factors, with identification of transfer functions of degradation measured in AST to real-world behaviour within a **±15% uncertainty margin**, and **publication of downloadable documents at project end**.
- Public Deliverable D2.4 Accelerated Stress Test protocols for specific SOC components in CHP and P2X application areas due in December 2021
- *See S. McPhail et al, Developing Accelerated Stress Test Protocols for Solid Oxide Fuel Cells and Electrolysers: the European project AD ASTRA, ECS Transactions, 91 (1) 563-570 (2019)*
- *And/or www.ad-astra.eu*

Testing in faulty operating conditions

- **One ongoing project: REACTT (2021-2023)**
- **Objectives:** develop a Monitoring, Diagnostic, Prognostic and Control Tool (MDPC) for stacks and systems for SOE and rSOC operation
- Includes:
  - thorough and critical literature analysis of the **degradation phenomena** and **faults** that may affect SOC stacks and systems
  - focus will be put on the **SOE** operation, thus complementing the existing review on the fuel cell mode (INSIGHT project).
  - additional constraints arising from alternatively operating the same stack or system in both modes (**reversible SOC**) addressed.
  - For each degradation process and faulty condition, **severity, frequency of occurrence, detectability** and **potential for mitigation or recovery measures** assessed and listed.
  - risk assessment done to rank (i) the faults/failures and (ii) degradation processes based on their relevance to the stack or system lifetime
  - the most important will be investigated in the frame of the project.
  - **testing protocol and test matrix** will be defined.
  - In order to optimize the time needed for the experimental campaigns and to define an accurate and feasible test plan, the **stack operating range** (in terms of, e.g., current, voltage, steam conversion (SOE mode), fuel utilization (SOFC mode), cycle duration, dynamic of switching between fuel cell and electrolysis modes in rSOC operation, temperature, best-worst cell maximum allowed difference, etc.) is carefully **defined** with the help of the **manufacturer**.
- Public document will be made available end of 2022

EU contribution to Normative work

- **IEC TC105 Working group 13: focus on reverse mode**
- **IEC IS 62282-8-101:** Energy storage systems using fuel cell modules in **reverse mode** - Test procedures for solid oxide single cell and stack performance including reversing operation
- Mainly **based on SOCTESQA methodology and procedures**
- Content:
  - Test environment
  - Measurement instruments and measurement methods
  - Test procedures and computation of results
  - Current-voltage characteristics test
  - Effective reactant utilization test
  - Constant load durability test
  - Temperature sensitivity test
  - Separation of resistance components test via electrochemical impedance spectroscopy
  - Current cycling durability test
  - Thermal cycling test
  - Pressurised test
  - Test report

IEC

105/688/CDV

COMMITTEE DRAFT FOR VOTE (CDV)

PROJECT NUMBER: IEC 62282-8-101 ED1	
DATE OF CIRCULATION: 2018-06-29	CLOSING DATE FOR VOTING: 2018-09-21
SUPERSEDES DOCUMENTS: 105/653/CD, 105/667B/CC	

EU contribution to Normative work

- **IEC TC105 AD-HOC GROUP 11: Accelerated stress testing**
- In line with AD ASTRA project, the process for standardisation of AST procedures (when they will be finalised) initiated.
- A New Work Item Proposal (NWIP) needs to be submitted and accepted by the IEC TC105 on (reversible) fuel cells.
- an Ad Hoc Group (AHG11) was created to prepare this NWIP, planned to be submitted by the summer: SOC and PEMFC.
- To define what is in scope of the Standard, a questionnaire has been compiled, and circulated to several stakeholders
- Content of questionnaire (circulated in January 2021):
  - Generic issues:
    - List standards and protocols that should be a reference for this standard (also from other technologies, e.g. batteries), State of the art AST protocols that could be integrated in our work/standard as starting point
    - boundaries/interfaces of the NWIP compared to existing standards and IEC WGs
  - Technical issues
    - How should the test conditions and test stressors be defined?
    - What should be the system boundaries addressed by the procedures?
    - Should the procedures focus on in-situ/in-operando diagnostics only, or also consider post-test analyses?
    - How to quantify degradation acceleration?
    - How to correlate to real ageing?
    - What criteria for representativeness of the AST?
    - Can an ex-situ AST be representative for degradation in a stack?
    - Should prediction methods be considered?

Conclusions

- Several demonstration units installed or planned with exponentially growing sizes
- Roadmaps and KPI defined
- Harmonized terminology document prepared
- Several past and ongoing EU projects defined testing protocols for cells and stacks in HTE and rSOC modes
- Including accelarated stress testing and tests in faulty conditions
- Link with normative works in adequate committees

Acknowledgements

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