Clean Hydrogen Partnership

WORKSHOP

PUSHING THE LIMITS OF PERFORMANCE AND DURABILITY OF FUEL CELLS AND ELECTROLYSERS SYSTEMS

15 SEPTEMBER 2023, CAPRI, ITALY

Grand Hotel Quisisana Room: Rotonda

RUBY

reac tt

RUBY AND REACTT - the twin projects

Presenters: Pierpaolo Polverino (University of Salerno), Dani Juricic (Istitute Jozef Stefan)

Project RUBY

Robust and reliable general management tool for performance and durability improvement of fuel cell stationary units

Grant Agreement No. 875047

Starting date: 01/01/2020

Duration: 60 months

Funding: 2 999 715.00 €

Co-funded by the European Union

Consortium

P01 – UNISA: Università degli Studi di Salerno (IT)
COORDINATOR

P02 – CEA: Commisariat a l'energie atomique et aux energies alternatives (FR)

P03 – SP: SolidPower S.p.A. (IT) (TERMINATED)

P04 – BPSE: Ballard Power Systems Europe AS (DK)

P05 – BITRON: Bitron S.p.A. (IT)

P06 – IJS: Institut Jozef Stefan (SI)

P07 – VTT: Teknologian Tutkimuskeskus VTT Oy (FI)

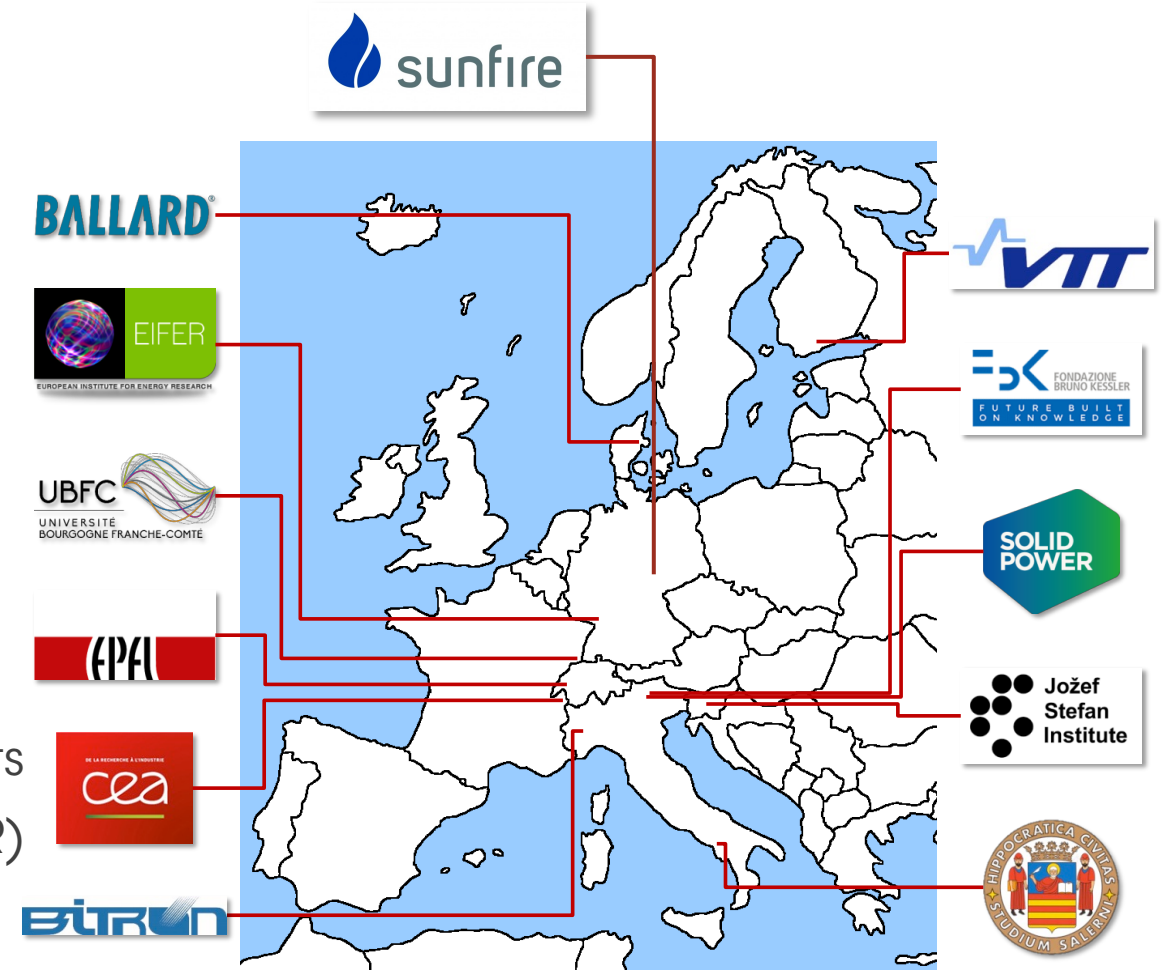
P08 – EIFER: EIFER Europaisches Institut fur Energ. (DE)

P09 – UBFC: Communaute d'universites et etablissements Université Bourgogne - Franche - Comte (FR)

P10 – EPFL: Ecole Polyt. Federale de Lausanne (CH)

P11 – FBK: Fondazione Bruno Kessler (IT)

P12 – SUN: Sunfire GmbH (DE)



Funded by the EU Fuel Cell and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) - H2020 Programme Grant Agreement Number 875047

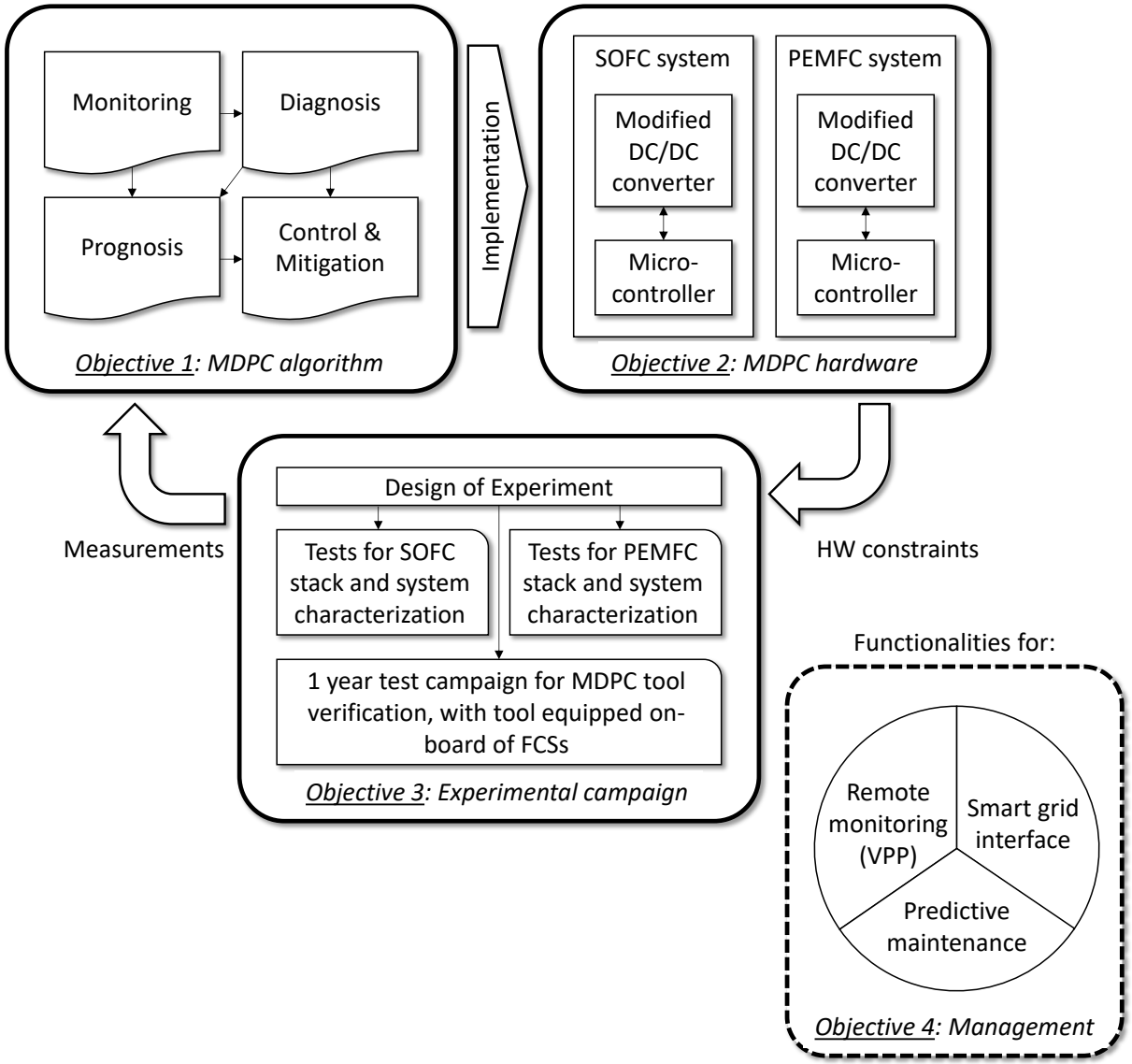
Objectives

Objective 1: Improve FCS performance and durability by implementing an advanced algorithm that combines monitoring, diagnosis, prognosis, control and mitigation actions for both SOFC and PEMFC systems.

Objective 2: Design and engineer the hardware required for MDPC algorithms application, with attention to sensors reduction issues and the specific constraints imposed by stack technologies and systems applications towards industrial scalability.

Objective 3: Perform dedicated experimental campaigns for stacks and system characterization and MDPC tool prototype validation embedded on FCSs running in operational environment.

Objective 4: Develop an advanced FCS management strategy (supervisory level), with functionalities integrated with remote monitoring, for future smart-grid interaction and predictive maintenance application.



Co-funded by the European Union

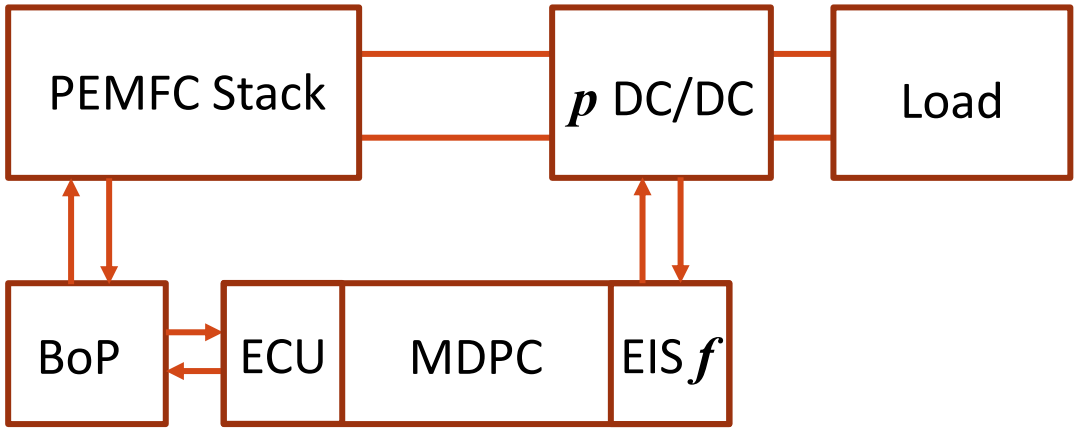
Funded by the EU Fuel Cell and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) - H2020 Programme Grant Agreement Number 875047

Key concept: on-field EIS

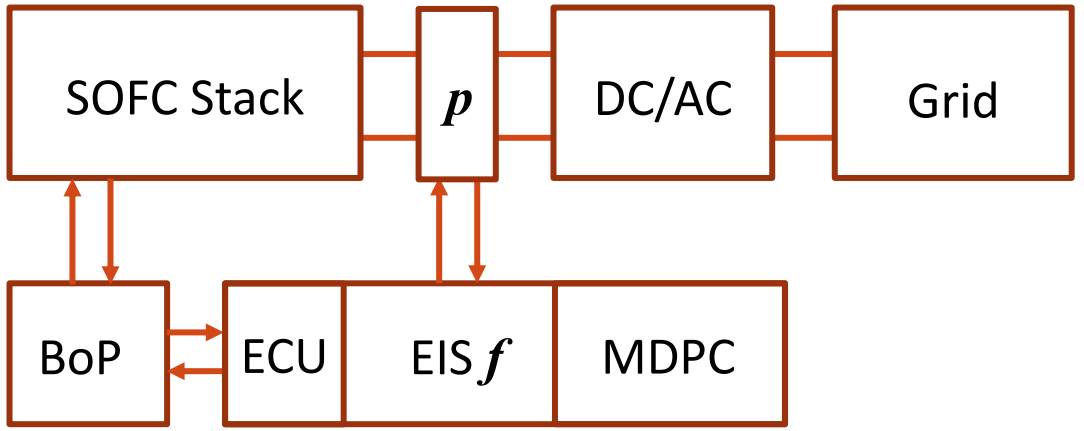
EIS on field has been conceptualized in previous projects and tested before by HEALTH-CODE and INSIGHT consortia leading to a Monitoring & Diagnostic Tool.

RUBY continues the development of EIS Stack monitoring for Prognostics and Control (MDPC tool) and includes mitigation functions as well as BoP diagnostics.

Ballard Backup System



Sunfire µ-CHP System



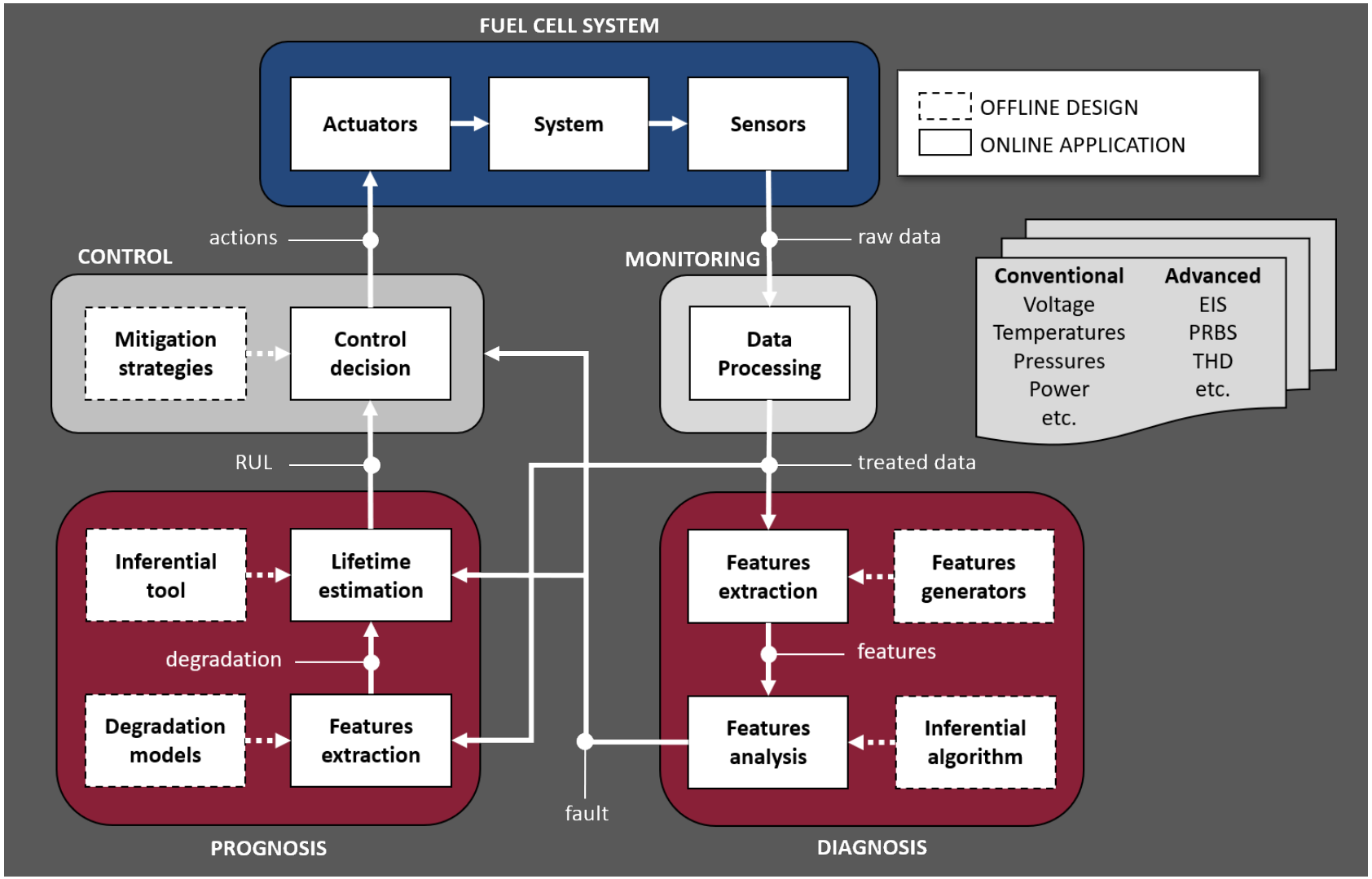
Main schemes of Ballard Backup System (left) and Sunfire µ-CHP System (right) with the EIS perturbation (p) and control functions (f).

Funded by the EU Fuel Cell and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) - H2020 Programme Grant Agreement Number 875047

Unique Value Proposition

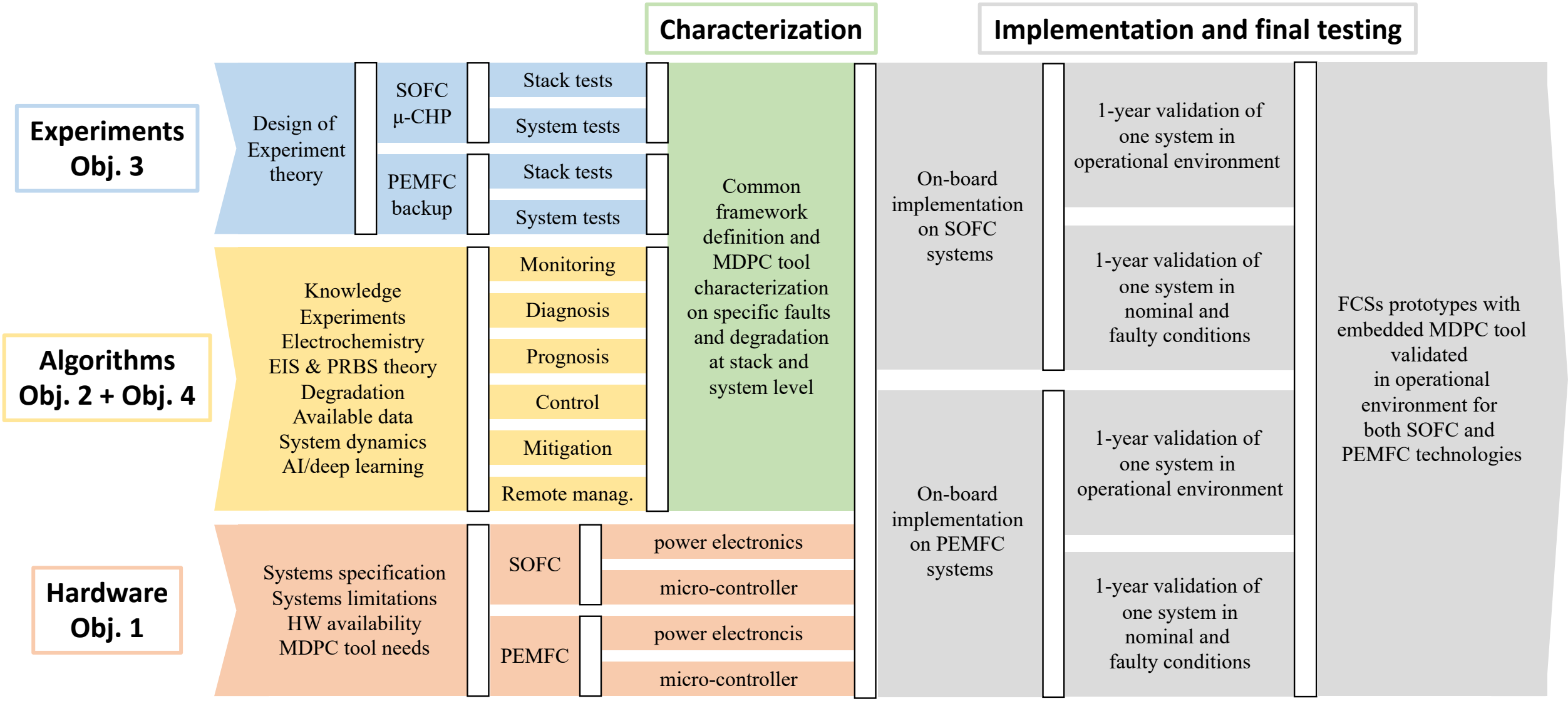
RUBY MDPC Tool main concepts:

1. Advanced stack Monitoring via Electrochemical Impedance Spectroscopy.
2. Stack diagnostics via EIS.
3. BoP component Condition Monitoring.
4. BoP Fault Detection and Isolation.
5. Prognostics of stack for Remaining Useful Life.
6. Real Time Optimization control.
7. Mitigation.



Funded by the EU Fuel Cell and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) - H2020 Programme Grant Agreement Number 875047

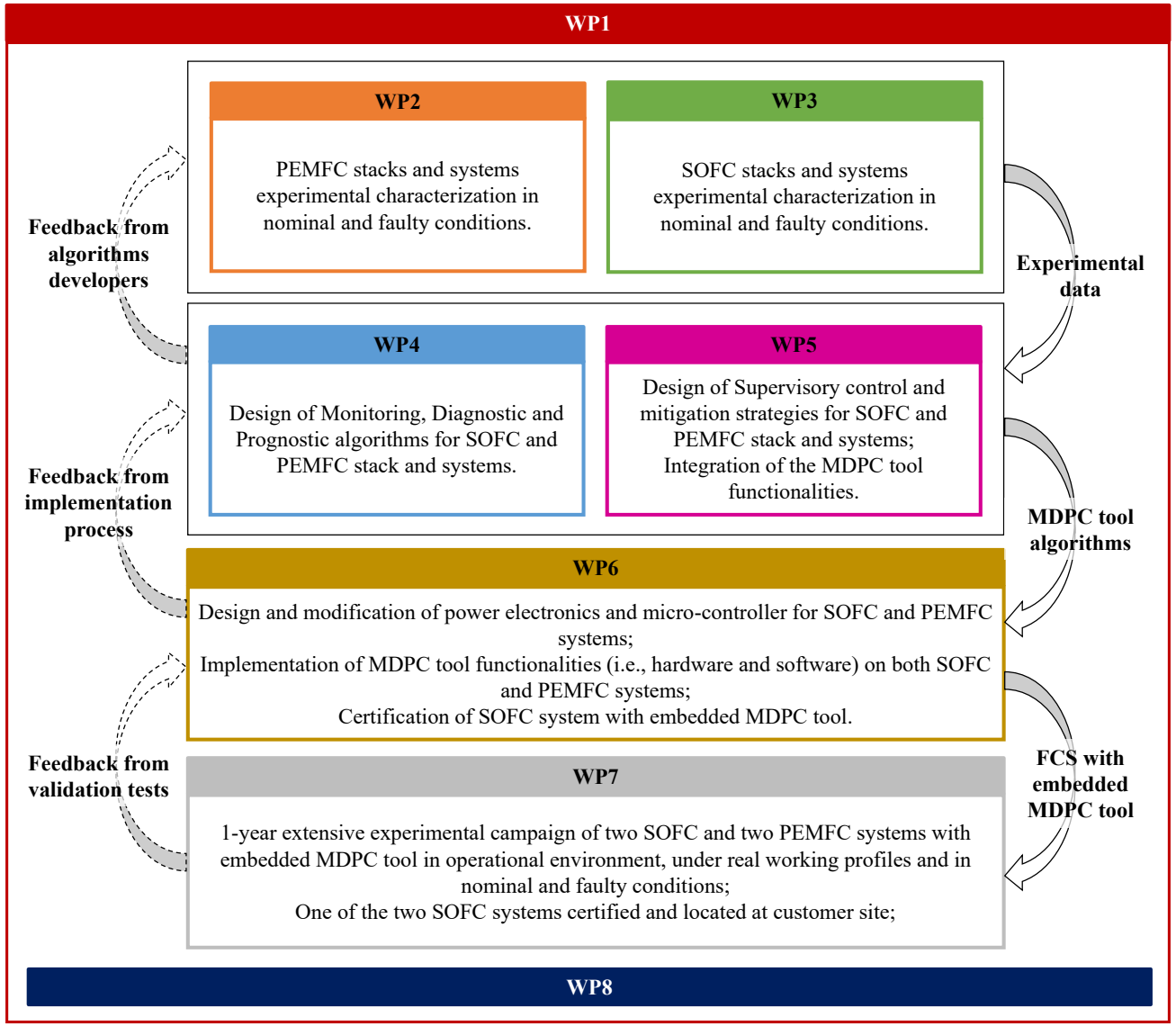
Activity workflow



Co-funded by the European Union

Funded by the EU Fuel Cell and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) - H2020 Programme Grant Agreement Number 875047

WPs activity breakdown

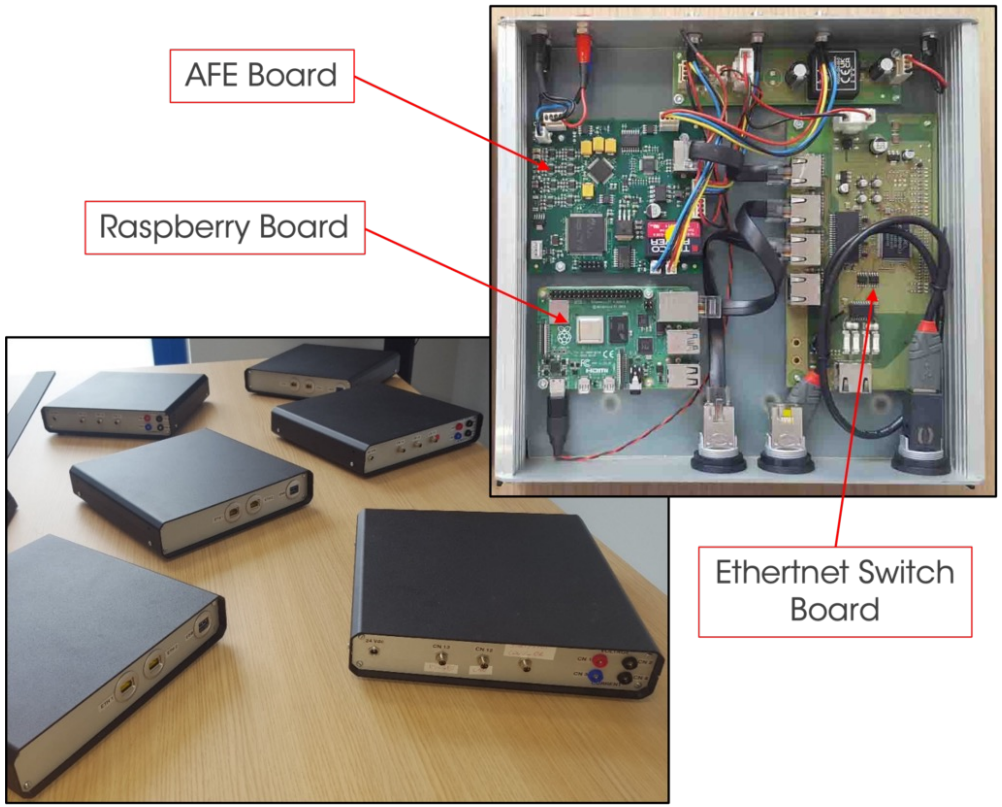


WP	Related workflow activity
2	Experiments
	Characterization
3	Experiments
	Characterization
4	Algorithms
	Characterization
5	Algorithms
	Characterization
6	Hardware
	Implementation
7	Final testing

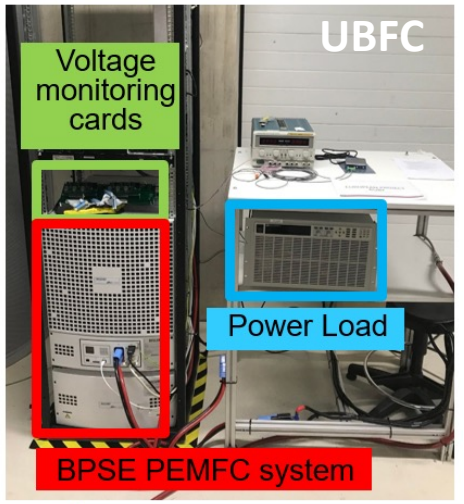
Funded by the EU Fuel Cell and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) - H2020 Programme Grant Agreement Number 875047

Main results

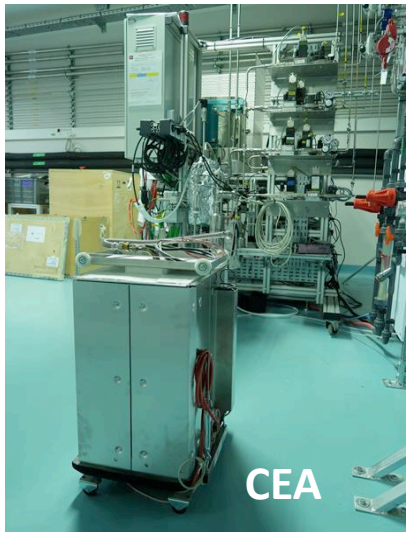
RUBY BOX HW



BPSE PEMFC STACK & SYSTEM



SUNFIRE SOFC STACK & SYSTEM



Funded by the EU Fuel Cell and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) - H2020 Programme Grant Agreement Number 875047

Main results

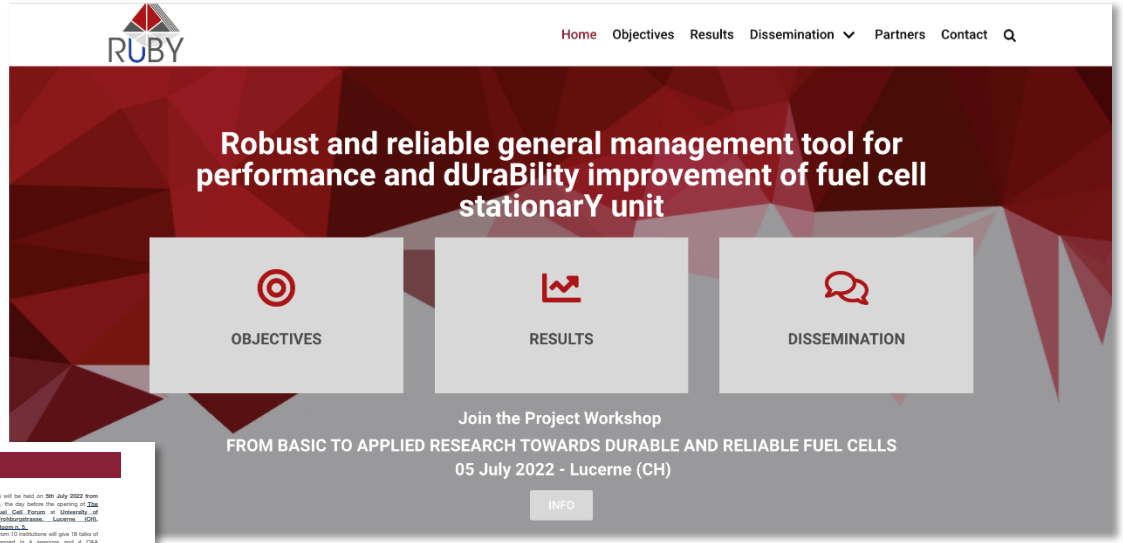
1. BPSE PEMFC stack fully characterized during >100 h of operation and >3700 h during drying in stand-by mode.
2. More than 100 EIS spectra of PEMFC stack measured in nominal and faulty operations.
3. BPSE PEMFC backup system fully characterized during >1000 hours of operation, self test and stand-by modes
4. SOFC stack module for SUN μ-CHP system under testing for EIS characterization in faulty operations.
5. SOFC system installed and tested under nominal and faulty operations.
6. EIS spectra available for the SOFC stack in nominal and fuel starvation operation .
7. Database of features for monitoring and diagnosis extracted from EIS spectra achieved.
8. SOFC stack monitoring algorithms based on Machine Learning ready.
9. Algorithms for stack and BoP diagnosis ready and under finalization.
10. Real Time Optimization (RTO) algorithm developed and tested in simulation environment.
11. Fully Ethernet based interaction between MDPC board and DC/DC converter
12. Firmware ready for MDPC board algorithms hosting.
13. MDPC board (RUBY Box) fully developed and ready for installation.
14. Specifications of converter for on-board EIS implementation ready for third party contracting.

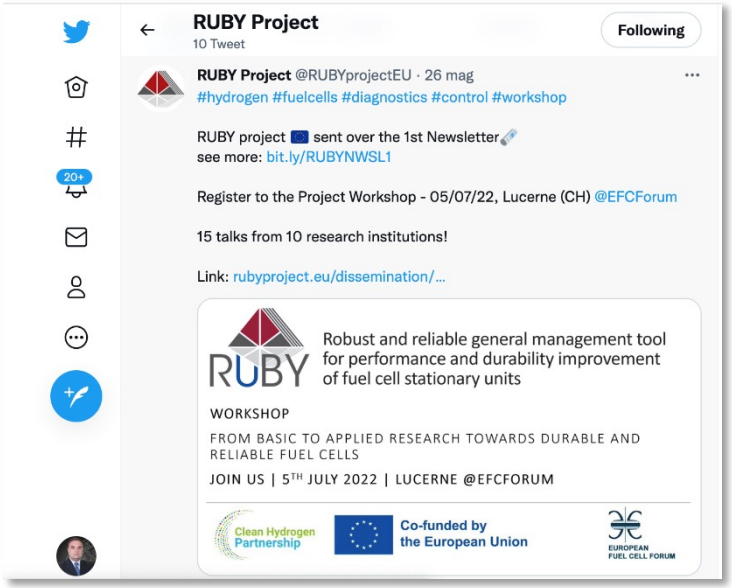
Co-funded by the European Union

Funded by the EU Fuel Cell and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) - H2020 Programme Grant Agreement Number 875047

Communication

1. Website www.rubyproject.eu
2. Newsletter (audience of about 700 people)
3. EMAIL: info@rubyproject.eu
4. TWITTER: @RUBYprojectEU
5. LINKEDIN: company/RUBYprojectEU





Funded by the EU Fuel Cell and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) - H2020 Programme Grant Agreement Number 875047

THANK YOU FOR YOUR KIND ATTENTION!

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) under Grant Agreement No 875047. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation programme, Hydrogen Europe and Hydrogen Europe Research.

Presentation of the REACTT project

Presenter: Đani Juričić (IJS)

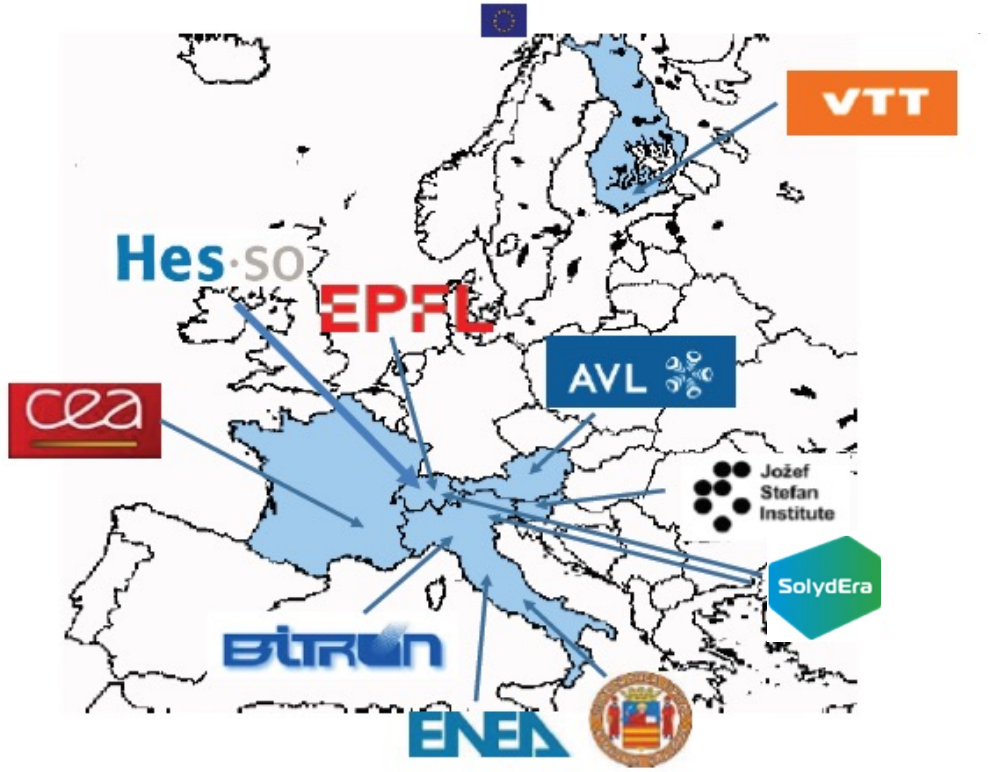
Co-funded by the European Union

Project in a nutshell

Project number	101007175
Acronym	REACTT
Project title	REliable Advanced Diagnostics and Control Tools for increased lifetime of solid oxide cell Technology
Start	1-JAN-2021
End	31-DEC-2023
Budget	2.712.322,50 €
Duration	36 months
Call identifier	H2020-JTI-FCH-2020-1
Topic	FCH-02-3-2020 Diagnostics and Control of SOE

Consortium

No.	Name	Short name	Country
1	Institute Jožef Stefan (Coordinator)	IJS	Slovenia
2	Commissariat à l'énergie atomique et aux énergies alternatives	CEA	France
3	Università degli Studi di Salerno (Coordinator)	UNISA	Italy
4	Ecole Polytechnique Fédérale de Lausanne	EPFL	Switzerland
5	Bitron S.p.A.	BITRON	Italy
6	SOLIDpower S.p.A.	SP	Italy
7	Teknologian tutkimuskeskus VTT Oy	VTT	Finland
8	AVL LIST GMBH	AVL	Austria
9	AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE	ENEA	Italy
10	Haute Ecole Spécialisée de Suisse occidentale	HES-SO	Switzerland



Co-funded by the European Union

Rationale, aims, objectives

- Rationale:
  - need for improved reliability, durability, operational performance, economized maintenance
- Aims:
  - to design a platform that integrates monitoring, diagnostics, prognostics and control (MDPC) for the emerging generation of solid oxide electrolysis systems for massive production of hydrogen at low cost from renewable energy sources
  - target TRL 5-6
- Objectives
  - Improved durability, reliability and maintainability of SOE and rSOC stacks by developing innovative algorithms for diagnostics and prognostics of their remaining useful life.
  - Advanced control strategy with self-optimizing and fault-tolerant features
  - Hardware module for implementation of the monitoring, diagnostics, prognostics and control
  - Characterization of stacks and systems in SOE and rSOC nominal and faulty conditions and validation of the product prototype

The idea

REACTT project

TRL 4

TRL 5

TRL 6

Objective 4: Experimental testing campaigns
- Protocols design
- Tests on short stacks and stackboxes

Data for design

Objective 1: Improve durability and reliability of SOE and rSOC
- Prognostics
- Diagnostics
- Monitoring

Objective 2: Advanced control strategy
- Supervisory control
- Real-time optimizer
- Tracking control
- Mitigation decision support

Algorithms for implementation

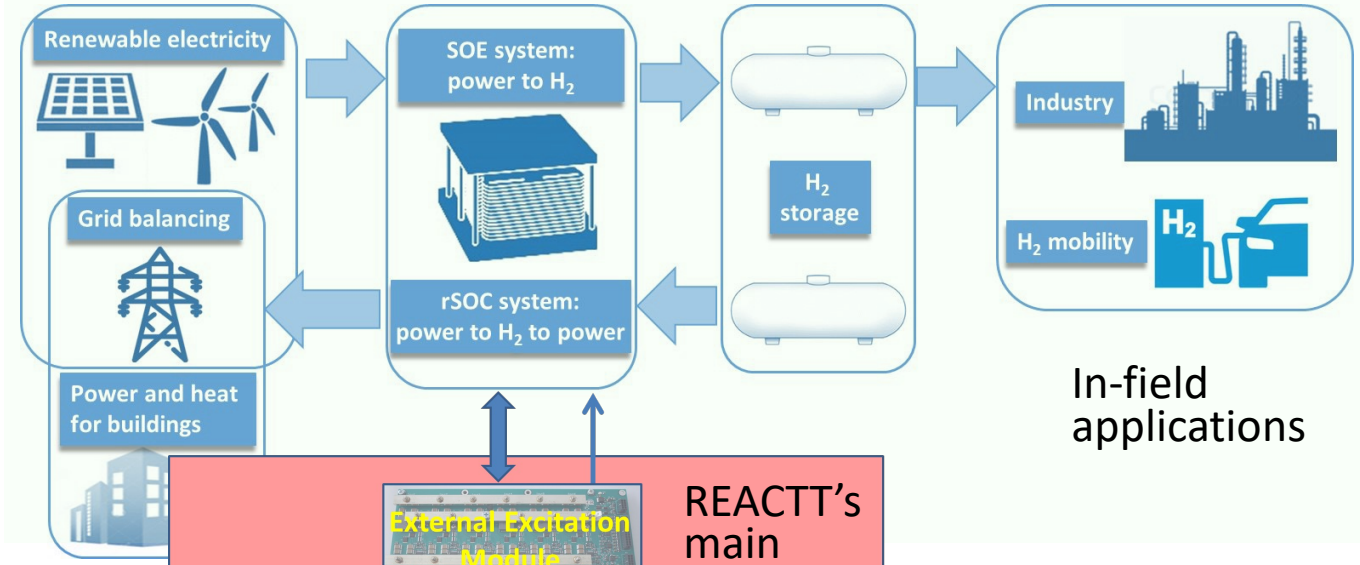
Objective 3: HW&SW modules for implementation
- Control board
- Firmware
- Stack excitation module
- Algorithms codes

MDPC tool for lab validation

MDPC tool for integration into system and proof-of-concept

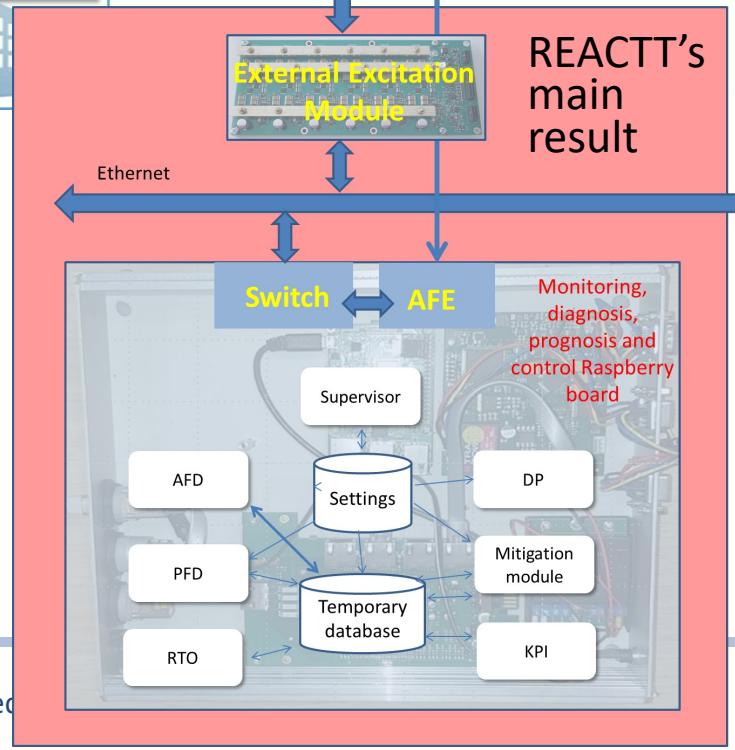
Demonstration on real SOE and rSOC systems

Objective 4: Experimental testing campaigns



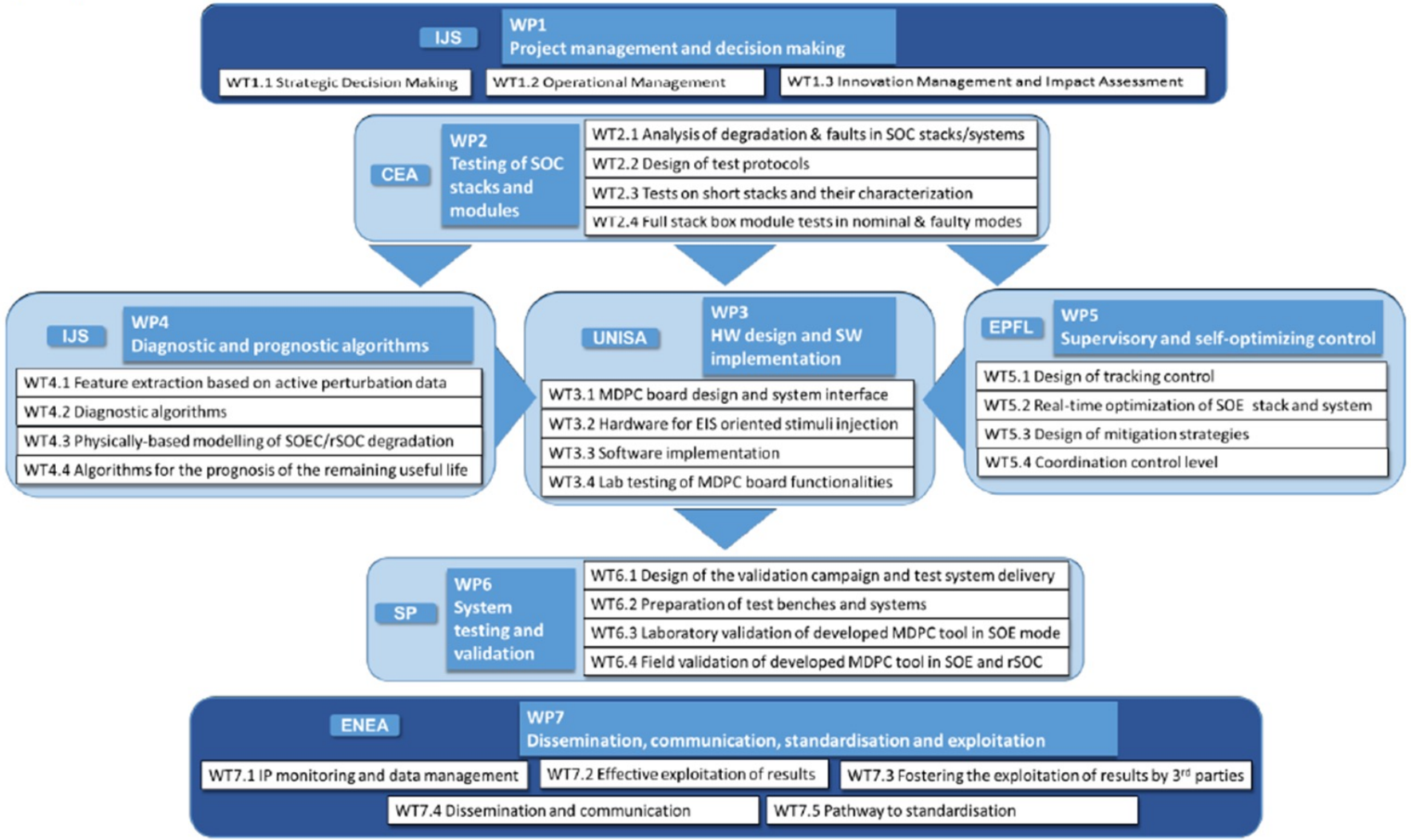
In-field applications

REACTT's main result



AFD – active fault detection
PFD – passive fault detection
DP - diagnosis and prognosis

Work breakdown



Co-funded by the European Union

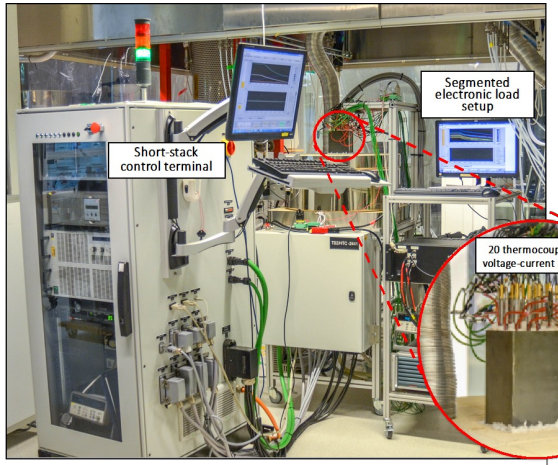
WP2: Testing of SOC stacks and modules

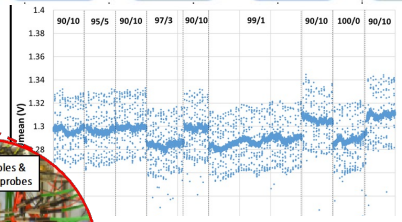
Objectives:

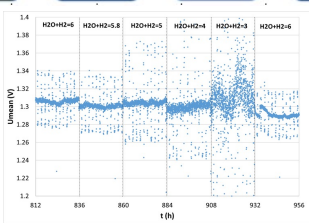
- Analyse degradation and fault modes in SOC stacks and systems;
- Define the faults/failures to be considered and tested;
- Define the test plan and protocol to meet the algorithm design requirements in WP4 and WP5;
- Use sinusoidal and PRBS stimuli for EIS measurements

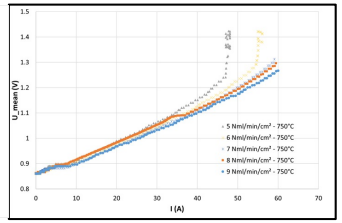
Accomplishments:

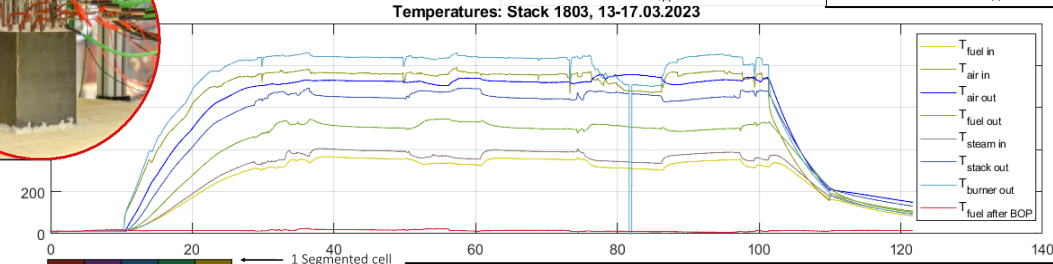
- Tests performed @ CEA and EPFL:
  - SP 20-segments cell in a 4-cells short-stack
  - 4 SP 6-cells Short Stack
  - 2 SP full stack (70 cells)

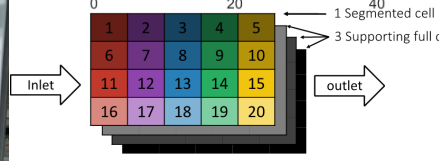




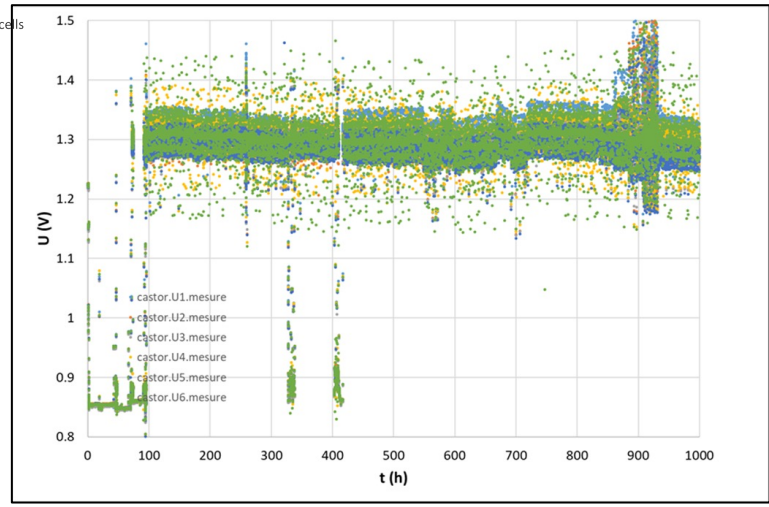








layout of the 4-cells segmented short stack



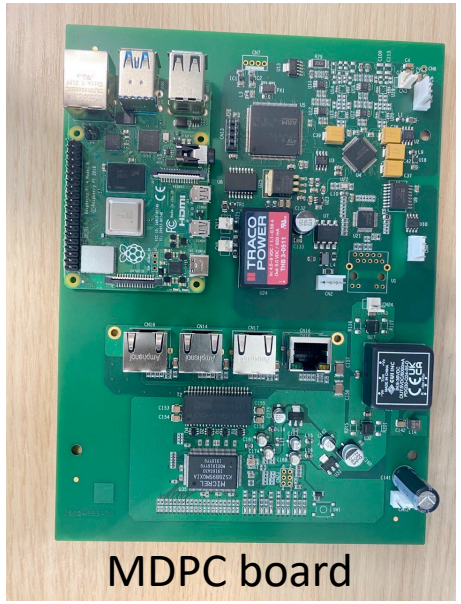
WP3: HW design and SW implementation

Objectives:

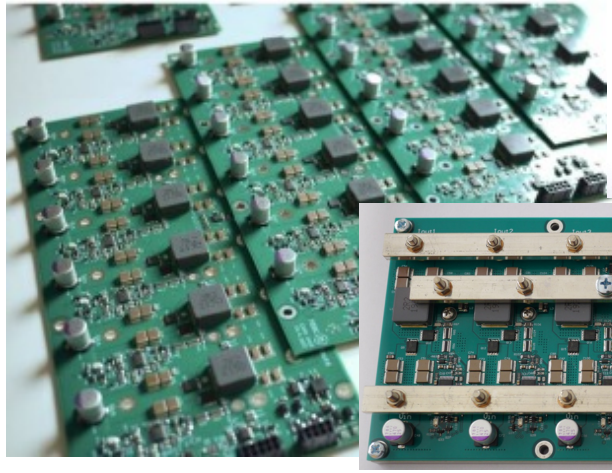
- Design and interface the HW and the SW for EIS measurements, with sinusoidal and PRBS stimuli;
- Design of the HW module for external excitation of the stack;
- Design the SW for the Analog Front-End (AFE) control and for the hardware used for EIS oriented control.
- Engineer the MDPC board with all functionalities embedded.
- Algorithms implementation

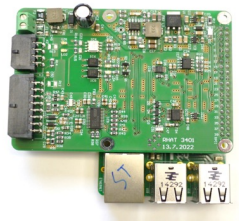
Accomplishments:

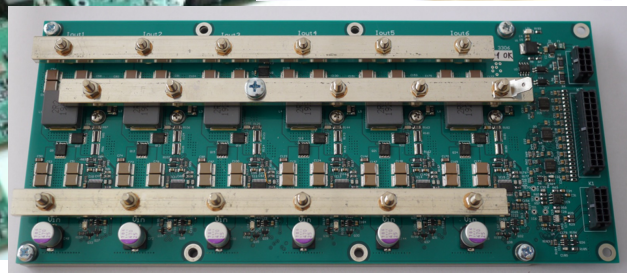
- prototype versions of the low-cost, computationally versatile HW platform
- reachable target: ≤ 3% of the overall manufacturing costs
- realization of the excitation HW module and integration with the MDPC tool
- first integration of the MDPC SW modules

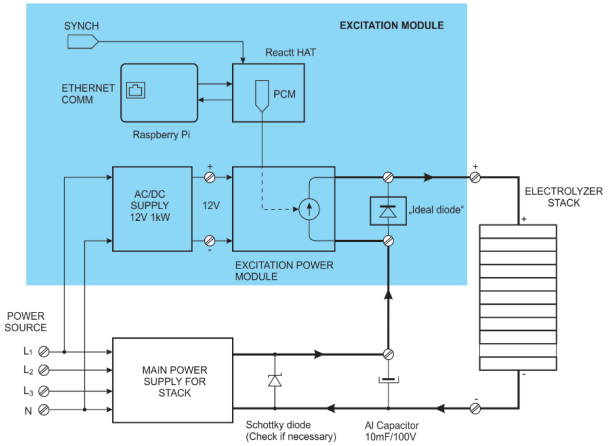


MDPC board









The Excitation Module

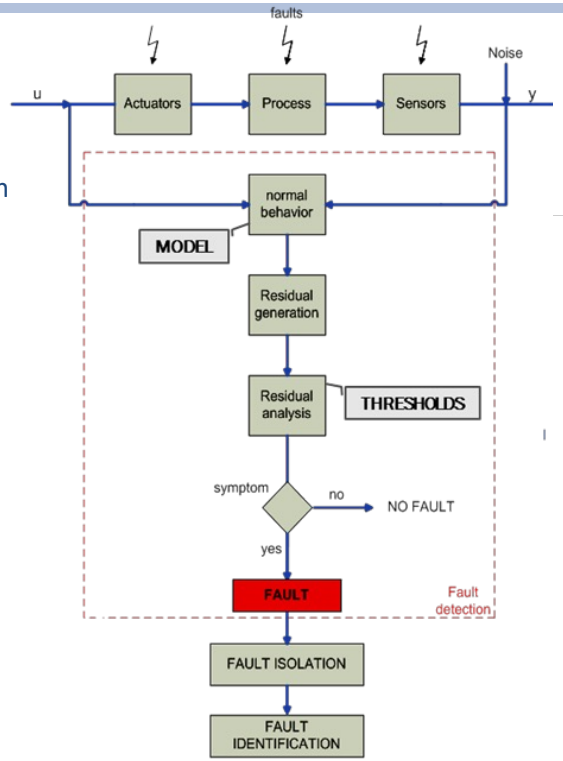
WP4: Diagnostic and prognostic algorithms

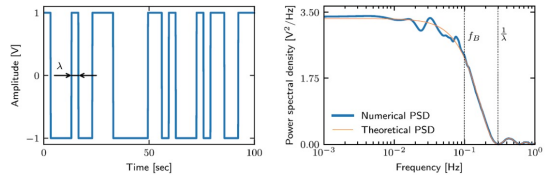
Objectives:

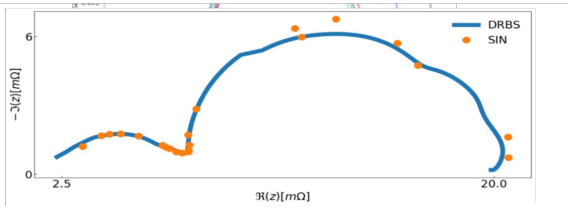
- Extract significant features for active diagnosis by stack perturbation via sine and PRBS stimuli and EIS evaluation;
- Derive features for passive diagnosis from the records taken from previous system operation data;
- Develop diagnostic algorithms with the highest possible degree of diagnostic sensitivity, stability and robustness, as well as capability to discriminate among different fault modes;
- Prepare computationally tractable code for the implementation of diagnostic and prognostic functionalities on the EIS board towards system on-board integration;
- Derive simplified semi-empirical models for SOE and rSOC cells operating under selected degradation modes;
- Design the algorithms for on-line prediction of stack remaining useful life (RUL)

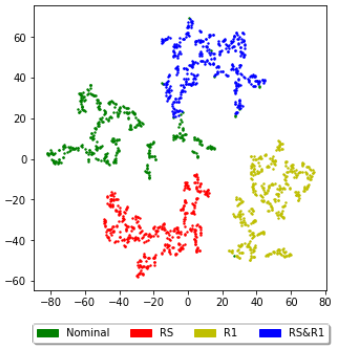
Accomplishments:

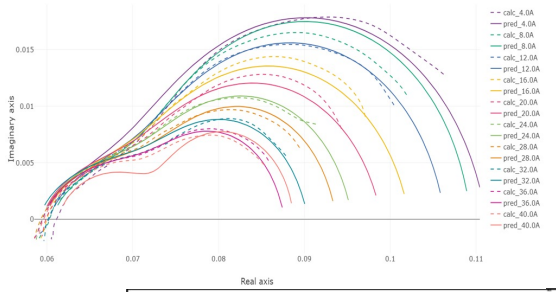
- a framework for combined active and passive feature extraction
- fast EIS for SOECs based on switching perturbation
- partly tested set of diagnostic algorithms → limited diagnostic resolution under existing instrumentation
- feature extraction under nonstationary operating conditions
- a framework for SOEC data-driven prognosis

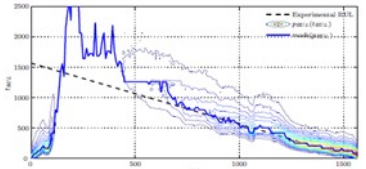


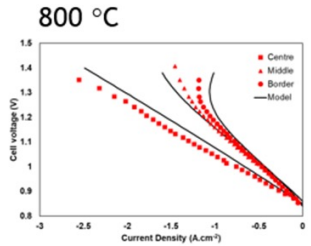


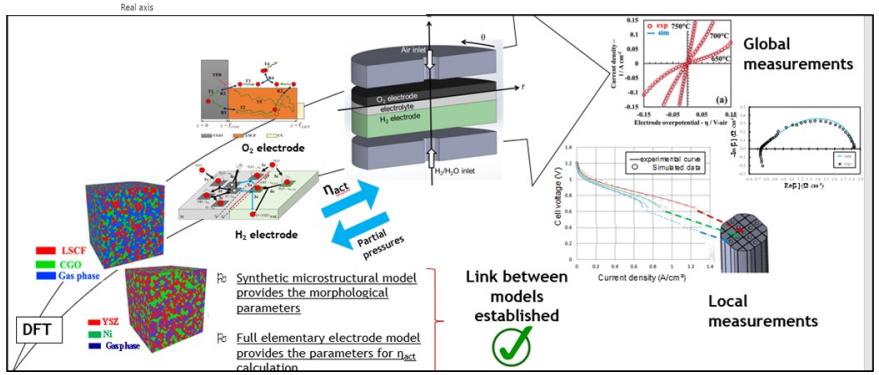












WP5: Supervisory and self-optimizing control

Objectives:

- low-level controller with fast tracking and efficient operating performance;
- Design a real-time optimization (RTO) approach for SOEC systems (obtaining a compromise between high efficiency of electrolysis and low degradation);
- Identify and propose mitigation strategies to recover the stack and system in case of reversible degradation;
- Design the coordination control level that orchestrates the MDPC aiming at fruitfully integrating the proposed RTO approach and degradation models developed in WP4;
- Validation of the control structure on the simulation level, as well as the actual SOE system

Accomplishments:

- first algorithms and results in real-time optimization of SOECs
- realization of the supervision module

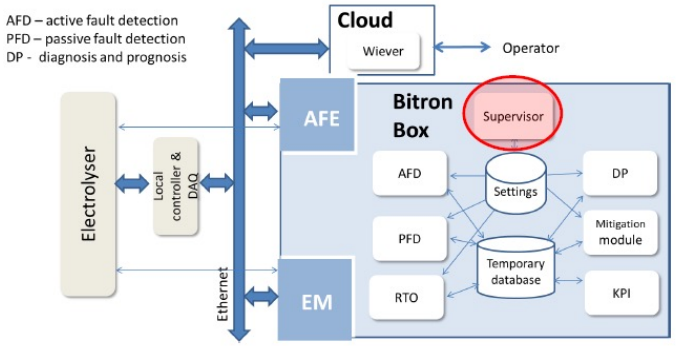
$$\mathbf{u} = \arg\max_{\mathbf{u}} \ \eta_{el} = \frac{q_{H_2} LV H_{H_2}}{P_{el}} + \vartheta_{\eta_{el}}$$

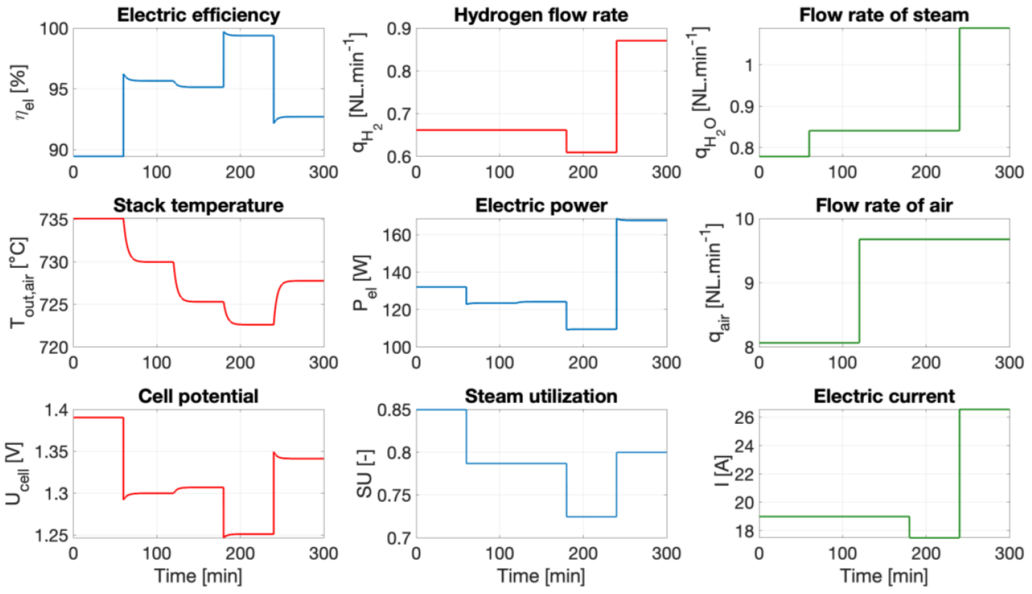
$$\text{s.t} \quad q_{H_2} = q^S_{H_2} + \vartheta_{q_{H_2}} \ \ \text{NL.min}^{-1}$$

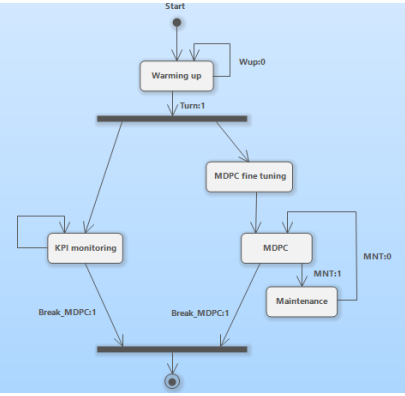
$$720 \leq T_{out,air} + \vartheta_{T_{out,air}} \leq 780 \ ^\circ\text{C}$$

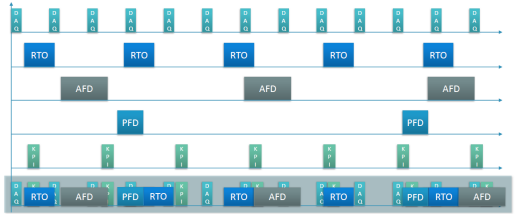
$$1.3 \leq U_{cell} + \vartheta_{U_{cell}} \leq 1.6 \ \text{V}$$

$$SU = 0.85$$





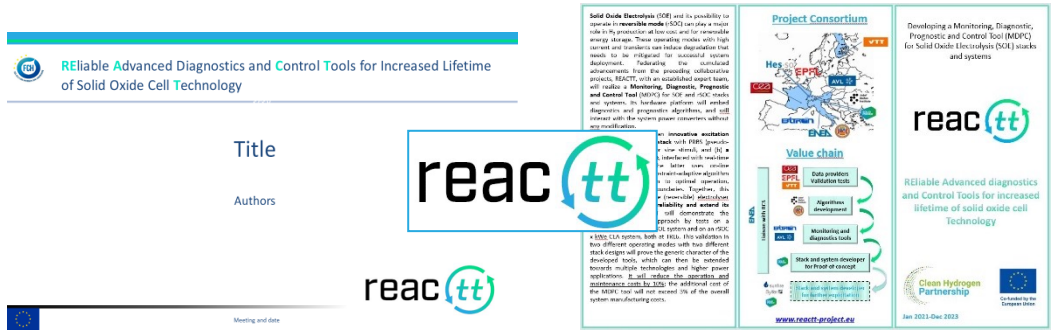


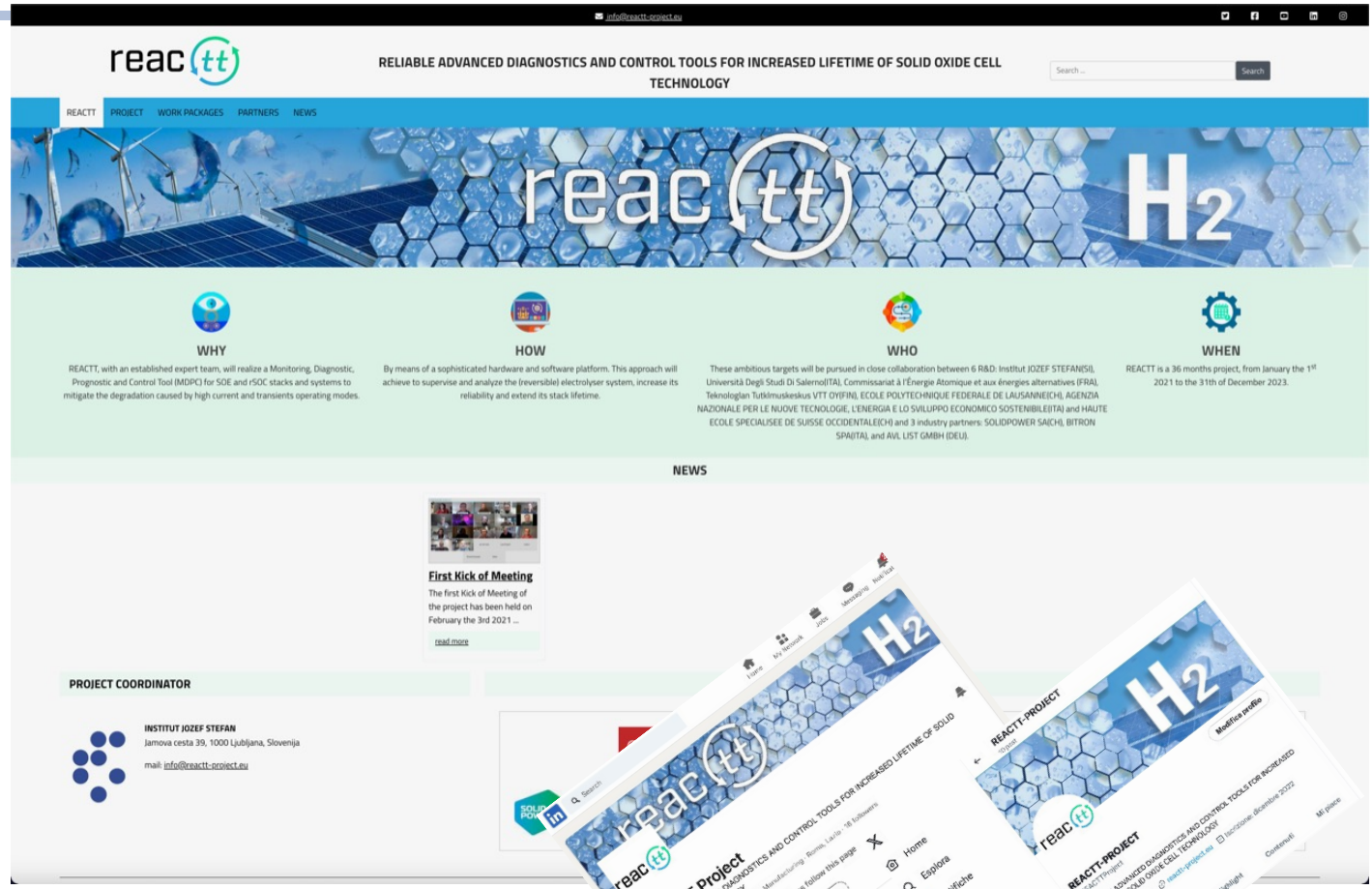


Final steps

- Laboratory and in-field experimental campaigns with SP stack boxes and a CEA stavk
- Arrangement of the HW and SW components of MDPC (performed in major part successfully) and integration with the 3 different local control systems
- Functionality testing, performance mapping
- Validation diagnostic algorithms for different fault scenarios (e.g. mass transport related issues)
- Validation of prognostic algorithms, under non-steady-state conditions

Dissemination and communication





Project website: *https://www.reactt-project.eu/*

LinkedIn: https://www.linkedin.com/company/reactt-project/).

Twitter: https://twitter.com/REACTTProject

- Project description, promotional and educational material, news, links to related projects;
- Internal pages (knowledge exchange, documents download).
- Workshops and brokerage events.

Let's get in touch!

Acknowledgement

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking (now Clean Hydrogen Partnership) under Grant Agreement No 101007175. This Joint Undertaking receives support from the European Union's Horizon 2020 Research and Innovation programme, Hydrogen Europe and Hydrogen Europe Research.

www.reactt-project.eu