//EU HYDROGEN RESEARCH DAYS 15-16 NOVEMBER

PROJECT RUBY
Robust and reliable general management tool for performance and dUraBility improvement of fuel cell stationarY unit

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RUBY

Clean Hydrogen Partnership

European Hydrogen Week

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Project Overview

- Call year: 2019
- Call topic: FCH-02-8-2019: Enhancement of durability and reliability of stationary PEM and SOFC systems by implementation and integration of advanced diagnostic and control tools
- Project dates: 01/01/2020 – 31/12/2024
- % stage of implementation 01/11/2023: 80 %
- Total project budget: 2 999 715.00 €
- Clean Hydrogen Partnership max. contribution: 2 999 715.00 €
- Other financial contribution: 0 €
- Partners: (11 Partners 7 Countries) University of Salerno | Commissariat à l'énergie atomique et aux énergies alternatives | Ballard Power Systems Europe A/S | Bitron SPA; Institut Jozef Stefan | Teknologian tutkimuskeskus VTT Oy I Europäisches Institut für Energieforschung EDF-KIT EWIV | Université Bourgogne Franche-Comté | École Polytechnique Fédérale de Lausanne | Fondazione Bruno Kessler | Sunfire Fuel Cells GmbH

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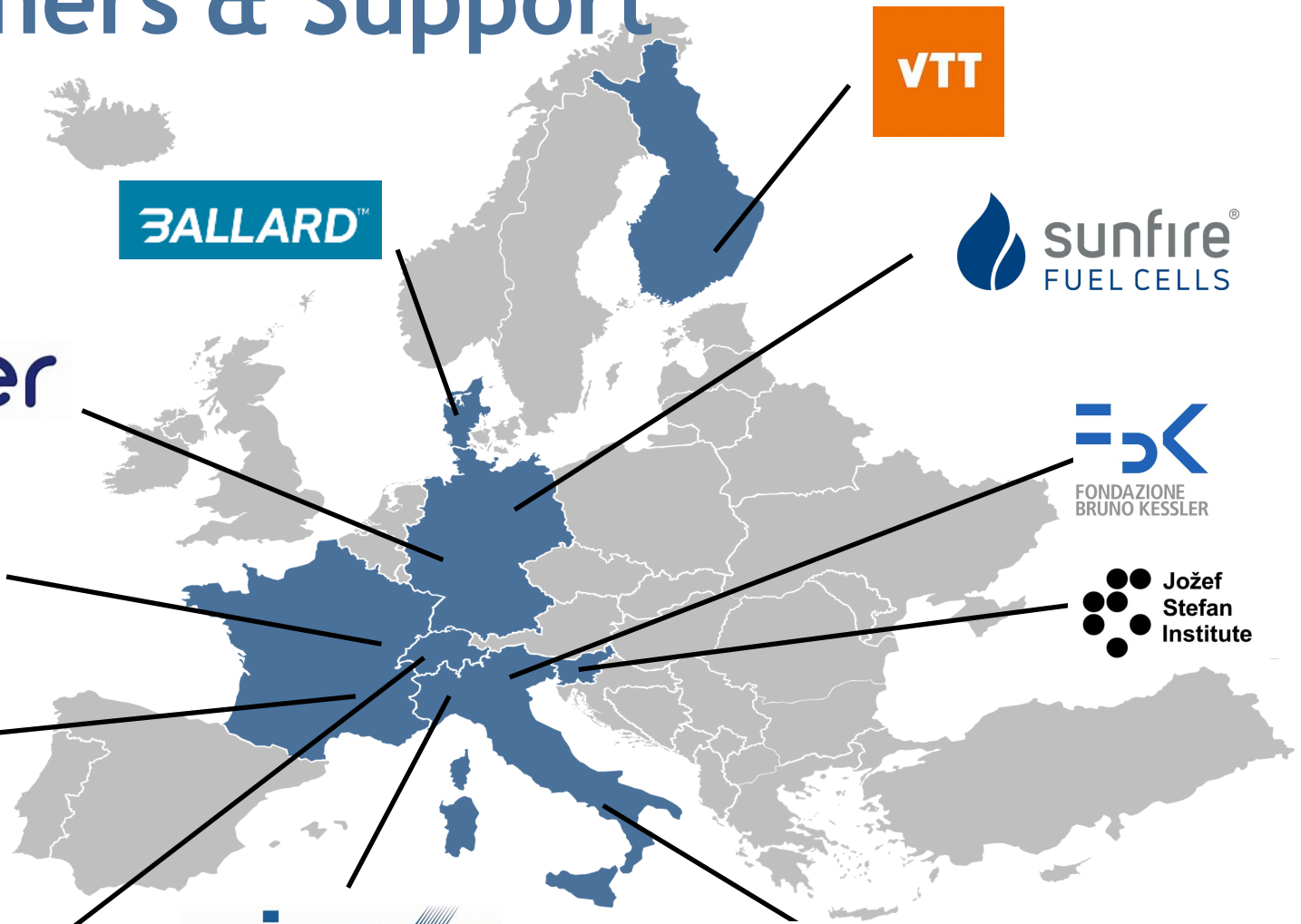
Partners & Support



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Main Objectives

Improve FCS performance and durability

Advanced algorithm combining monitoring, diagnosis, prognosis, control and mitigation actions

Design & engineer the MDPC HW

HW for algorithms application on PEM & SOFC technologies towards industrial scalability

Experimental campaigns for characterization and testing

Perform dedicated experiments for stacks and system & MDPC tool prototype in environment

Advanced management (smart-grid/ maintenance)

Supervisory for remote monitoring towards smart-grid interaction & predictive maintenance

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Project Summary

Main Objectives

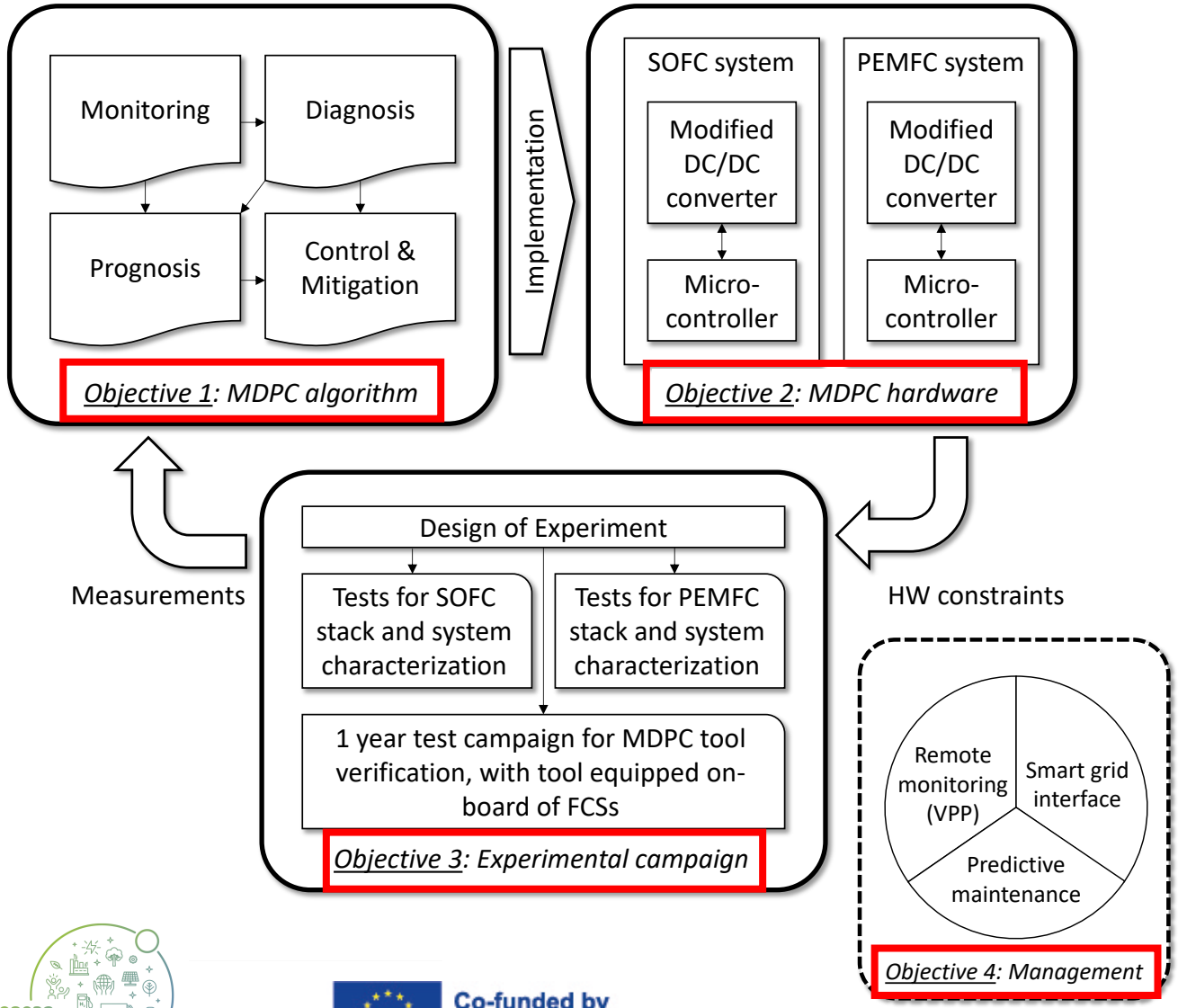
- Monitoring Diagnostic Prognostic Control (MDPC) Tool (HW & SW)
- 4 Objectives

SOA

- Advanced algorithms/tool
- Use of **EIS & RTO** on systems (on-field)
- Know How on advanced HW (Power Electronics) for FC

Application and market area

- Stationary FC & electrochemical device
- Potential use for automotive & batteries



Key concept: on-field EIS & RTO

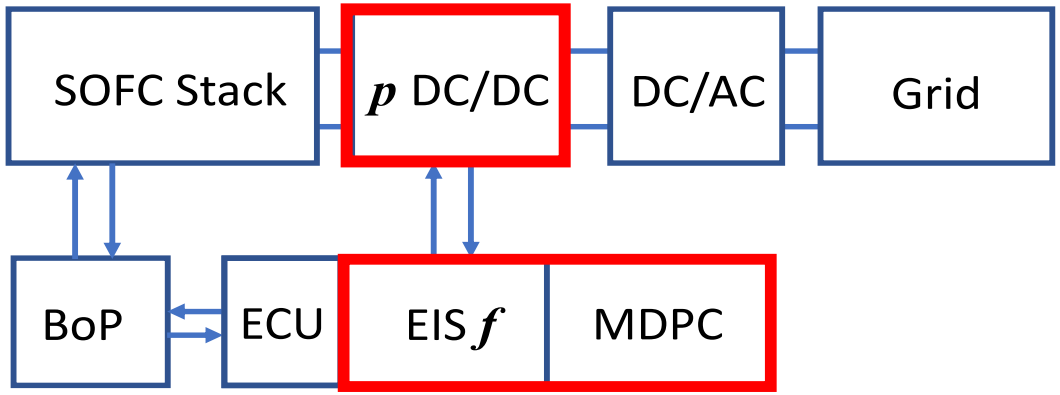
RUBY MDPC tool will improve FCS

1. Performance and durability.
2. Management for Remote monitoring in smart-grid & Predictive maintenance.

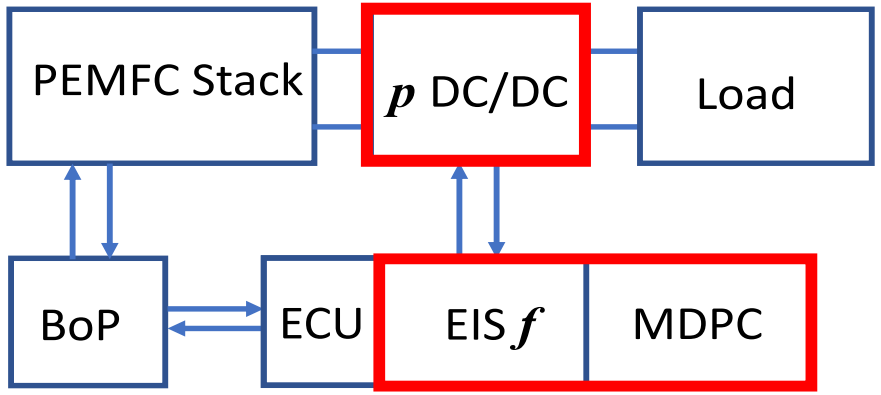
Key functions implemented on board:

1. Advanced stack Monitoring via EIS.
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.

Sunfire μ-CHP System



Ballard Backup System



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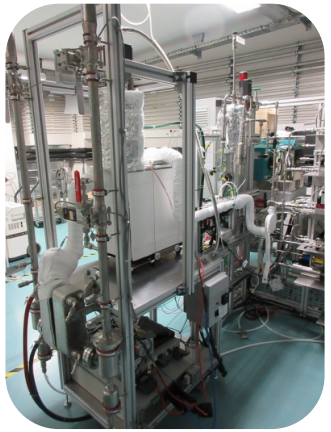
Main Achievements 1/4

Testing activity

SOFC Stack & System: 10000+ h in nominal & faulty

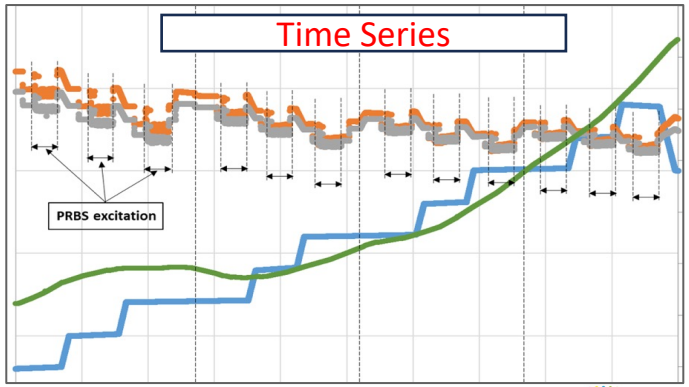
- 32 EIS spectra measured on stack in hot module and system
- 700+ hours of hot module operations with 74 EIS spectra

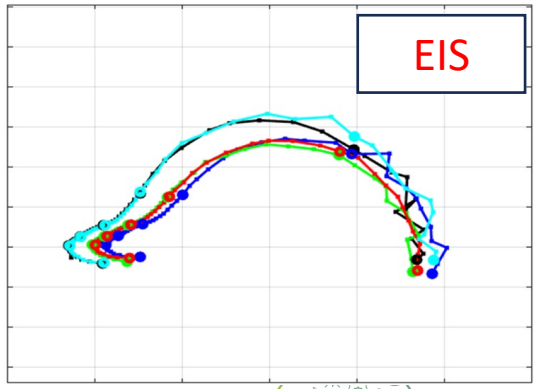


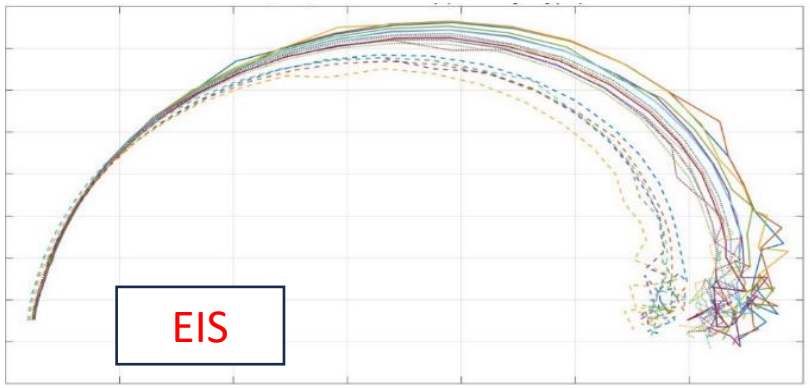
PEMFC: Stack (3800 h) System (1000 h) in nominal & faulty

- 100+ EIS spectra measured

Database of features for monitoring & diagnosis from EIS spectra







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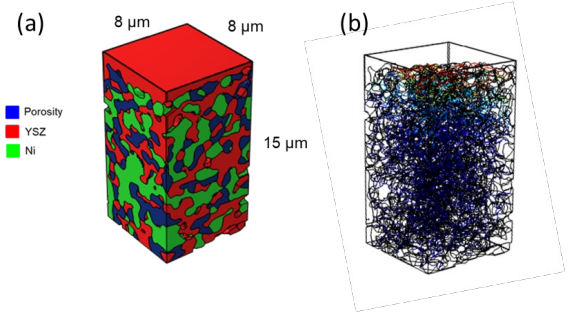
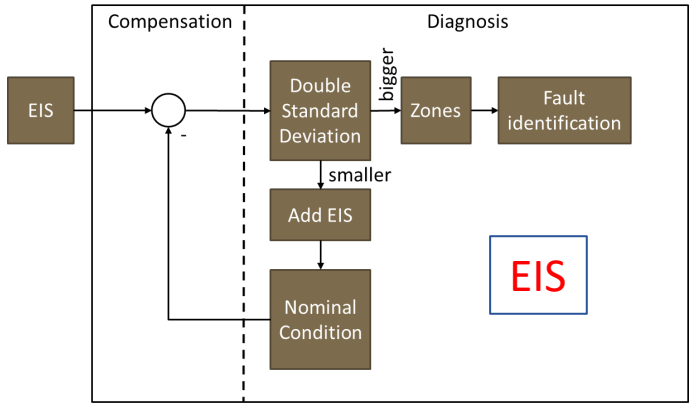
Main Achievements 2/4

Algorithms ready for on-field testing

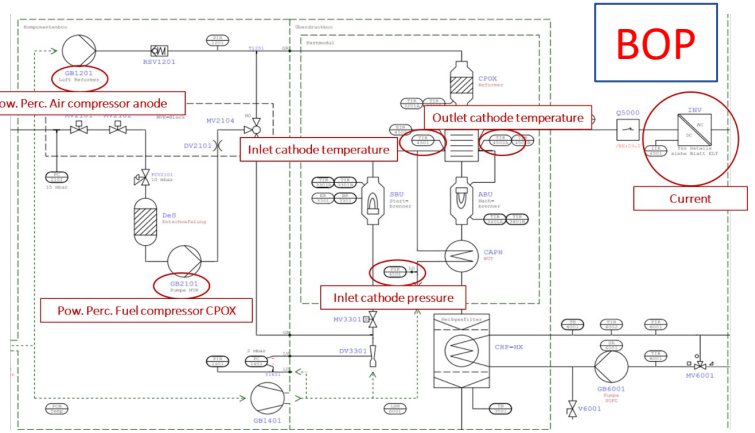
All algorithms & SW tested for RUBY-box implementation

Multi-Scale

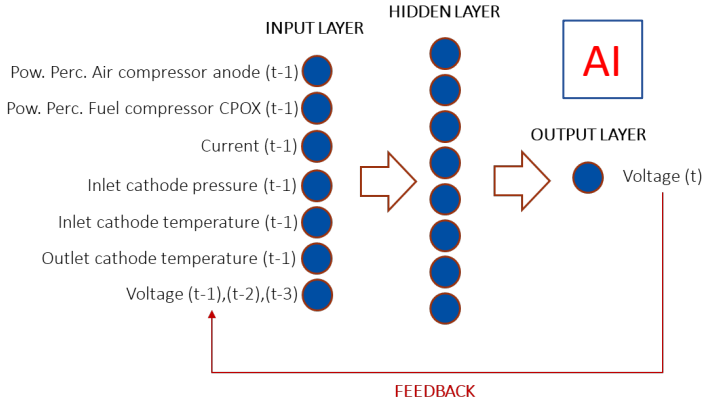


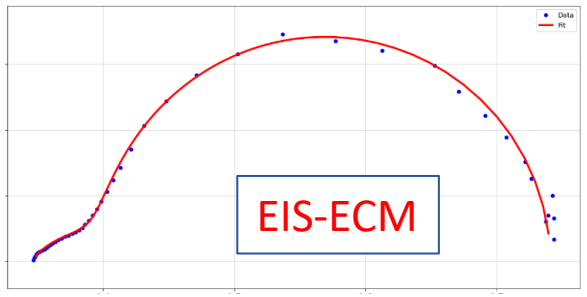


BOP

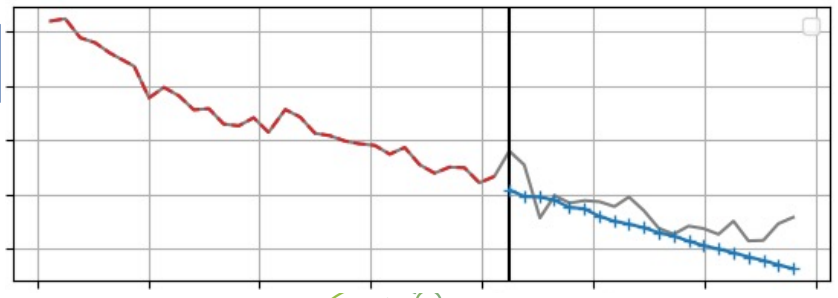


AI

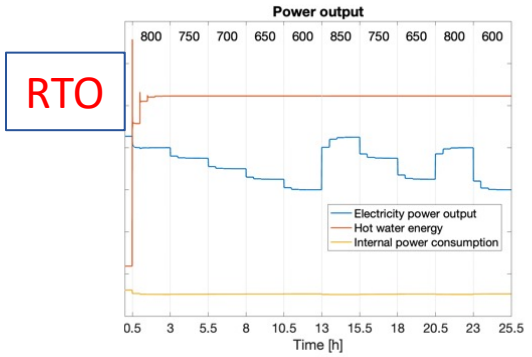




SOH



RTO



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Main Achievements 3/4

MDPC Tool tested and ready for implementation

RUBY-Box (HW tool) & Advanced Power Electronics (converter)

Algorithms/Software Developed in

python™

GNU Octave

EIS*, RTO**, Diagnostics, RUL

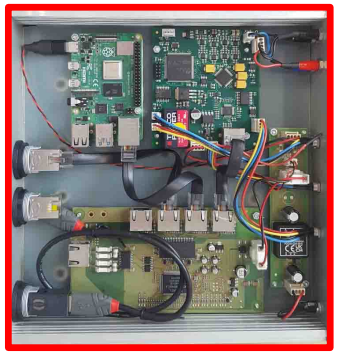
HW

Raspberry Pi

BITRON

RUBY

RUBY-Box



KOSTAL

BALLARD™

sunfire FUEL CELLS

External contributions:
*MinervaS S.r.l. licensee of UNISA patent
**HESSO support to EPFL

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Main Achievements 4/4

One-Year validation in real condition

µ-CHP & Backup installed and operational on sites, ready for MDPC

µ-CHP units installed at VTT and at GAZNAT in Aigle (CH)

PEMFC system running at EIFER in emulated environment

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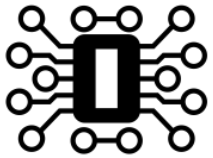
RISKS

RISKS

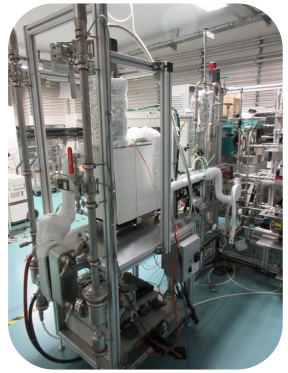
1. Pandemics limited the interaction among the partners and delayed the experimental activity.
2. One industrial partner withdrew.
3. Electronic components shortage (pandemics).



SOLUTIONS

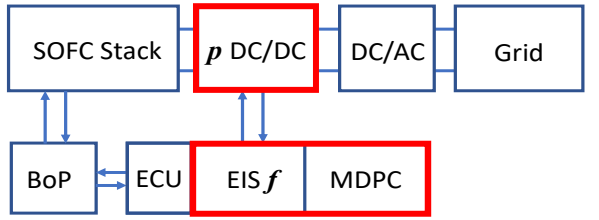
1. Remote interactions were strengthen, the databases of experiments (EIS, long run, other projects) and models were used to sketch the new algorithms.
2. The termination & accession of the new partner was successfully managed in 5 months thanks to the support of the JU.
3. Luckily, the problem was recovered, otherwise it would have cost more.

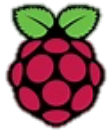
Main Challenges

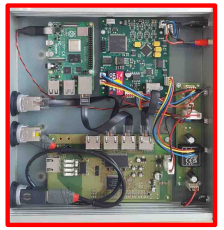


CHALLENGES

1. Adapt experimental activity to the new μ-CHP of SUNFIRE.
2. New scheme based on a single DC/DC converter with EIS features, which can be installed on μ-CHP & Backup.
3. Re-configure the Power Electronics to perform Stack EIS.
4. Final decision led to the outsourcing of a low-cost DC/DC converter compatible with different stacks/technologies.
5. Re-design the FW of the RUBY-Box with a new full ethernet layer for communication among RUBY-Box, power electronics and μ-CHP controller.







Exploitation Plan

Exploitation

- SUNFIRE will explore the integration of the converter and implement the MDPC tool.
- BITRON can exploit RUBY-Box as monitoring unit; the high-quality signal treatment circuits, may find applications in future products (e.g., energy meters, EV charging stations, electrochemical device).
- EPFL & HESSO will start an exploitation process for the RTO algorithm to be used on FC controller (Innovation Radar).
- UNISA, BITRON & MinervaS* will explore the integration of the EIS-based monitoring and diagnostic functions within the RUBY-Box. UNISA is applying a patented algorithm for EIS parameter identification, the patent is licensed to the Start-up MinervaS (Innovation Radar, IP Booster).

Intellectual Property Booster (IP Booster) is a professional IP service for public research organizations. Fully supported by EC.

Expected Impact

Impact of MDPC tool (HW & SW)

Improve performance & reliability:

- reduce TCO
- help market penetration

Better management W/ EIS & RTO functions:

- improve **RUL by 25%**
- keep **average efficiency at 35% until EoL**
- **availability ≥98% & MTBF > 45,000 h**
- reach **15 years of operations**
- low unit cost

MDPC paves the way towards advanced remote monitoring:

- help predictive maintenance
- easy integration in smart grids

Lean Business Canvas

PROBLEM	SOLUTION	UNIQUE VALUE PROPOSITION	UNFAIR ADVANTAGE	CUSTOMER SEGMENTS
Today PEM and SOFC systems **costs are too high** compared to conventional stationary solutions (μ-CHP and BUP), which prevents addressing large parts of the potential market. In addition, **performance needs to be increased** in terms of efficiency, durability and lifetime.	• Advanced monitoring (EIS via sine/PRBS stimuli) not available on large scale manufactured products. • Integrated approach of MDPC; • Link BOP to stacks for better lifetime; • General/flexible hardware & algorithms.	• RUBY will enhance the durability and reliability of stationary **SOFC and PEMFC systems** by developing an **MDPC tool** for monitoring, diagnosis, prognosis, control and mitigation. • FC manufacturers will **market best performing and most cost-competitive systems** to be compatible against conventional stationary systems. • **European manufacturer** and their suppliers may create new high-skilled jobs.	• Team with more than 10 years of experience on the topics for fuel cells; • Multidisciplinary group; • High development costs for newcomers; • Reduce TCO by: - Improving efficiency; - Maximize efficiency; - Increase durability.	**Prime target:** • μ-CHP commercial • BUP systems **Secondary target:** • Residential • Industrial • Energy storage • Automotive • Recharging station
EXISTING ALTERNATIVES • diagnosis and control by conventional measurements • Large amount of costly sensors	**KEY METRICS** • Electric efficiency: 35% (μ-CHP) 45% (Backup) • Lifetime expectation: 12 years (μ-CHP) 15 years (Backup) • Availability: 99% (μ-CHP) 99.999% (Backup)	**HIGH-LEVEL CONCEPT** MDPC tool > OBD-II for vehicles.	**CHANNELS** • Established network of SUN and BPSE; • Enhanced by RUBY Consortium efforts in WP8. • BITRON will spread the technology out of fuel cell sector	**EARLY ADOPTERS** • Involved project industries
COST STRUCTURE			**REVENUE STREAMS**	
• MDPC tool prototype: **> 2000€** • MDPC tool on the market: **< 3% of TCO** • MDPC licenses for manufacturer: **< 1000€/year**			• **SUN**: sales of complete μ-CHP SOFC systems; • **BPSE**: sales of complete Backup PEM systems; • **BITRON**: sales of EIS board for converters or external EIS box.	

Communications & Dissemination 1/3

Internet & Social Media

Web: www.rubyproject.eu | X (Twitter): @RUBYprojectEU | Linkedin: company/RUBYprojectEU

Newsletters: 3 issues; 700+ recipients

Workshops (50+ Pax, 28 Presentations, 10+ Countries, 6 Companies, 10 Research/Universities)

1. From Basic to Applied Research Towards Durable and Reliable FC
   - Workshop jointly organized with H2020 Project AD ASTRA
   - 5 July 2022 – Lucerne (CH) – KKL – European Fuel Cell Forum 2022
2. Pushing the Limits of Performance and Durability of Fuel Cells & Electrolysers Systems
   - Workshop jointly organized with H2020 Projects REACTT
   - 15 Sept. 2023 – Capri (Italy)– European Fuel Cells & Hydrogen 2023

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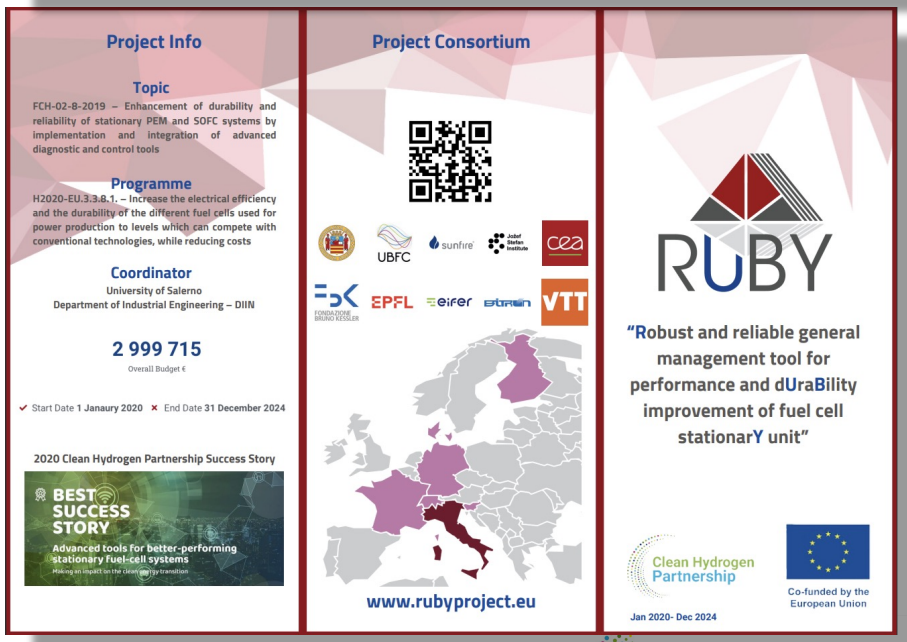
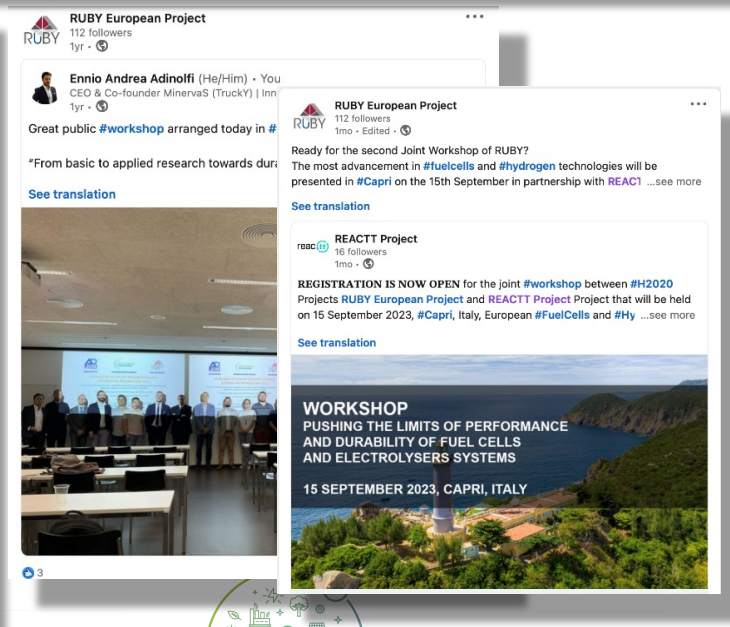
Communications & Dissemination 2/3





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Communications & Dissemination 3/3

Scientific Pubblications & Presentations

12 Papers on Applied Energy, ECS Transactions, Journal of Power Sources, IEEE Transactions
5 Presentations and **6** Conferences

Deliverables available on the web site

55 Deliverables have a public version (one page)
9 Public Deliverables
2 Extended Periodic Report publicly available on the web (@M23, @M43)

Students and Theses

18 - 4 PhD; **8** MSc; **6** BSc

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THANK YOU

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