Degradation Signature Identification for Stack Operation Diagnostic (256693)

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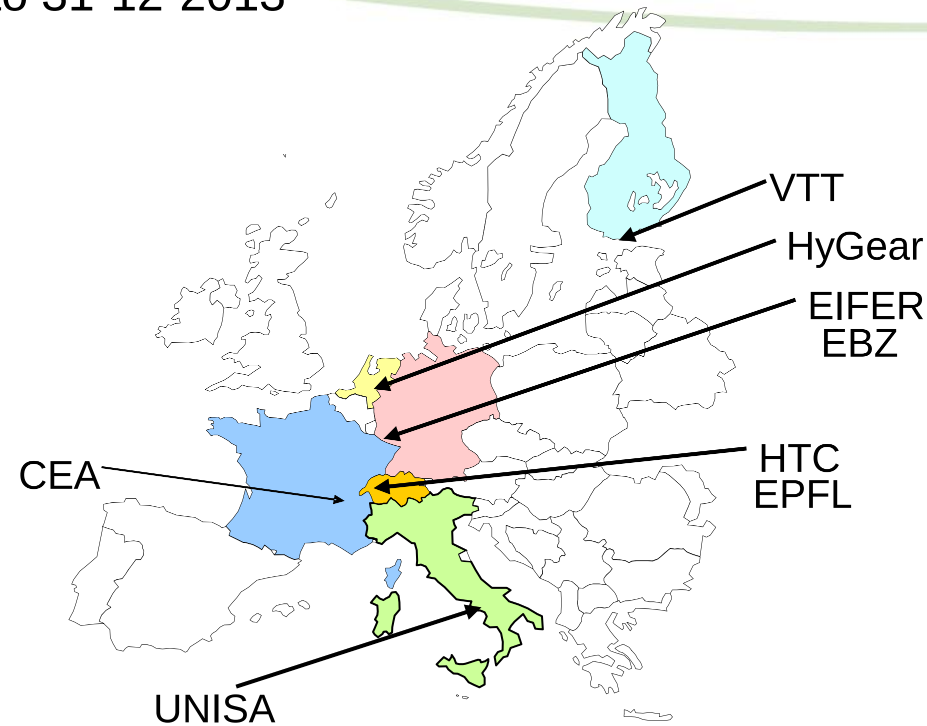
Design Partnership & Budget

3 years collaboration project: 01-01-2011 to 31-12-2013

Total budget: 3’266 k€

Total funding: 1’746 k€

Participant	Country	Type
CEA	France	R&D
VTT	Finland	R&D
Eifer	Germany	R&D
UNISA	Italy	University
EPFL	Switzerland	University
HFCS	Netherlands	Industry/SME
HTc	Switzerland	Industry/SME
EBZ	Germany	Industry/SME



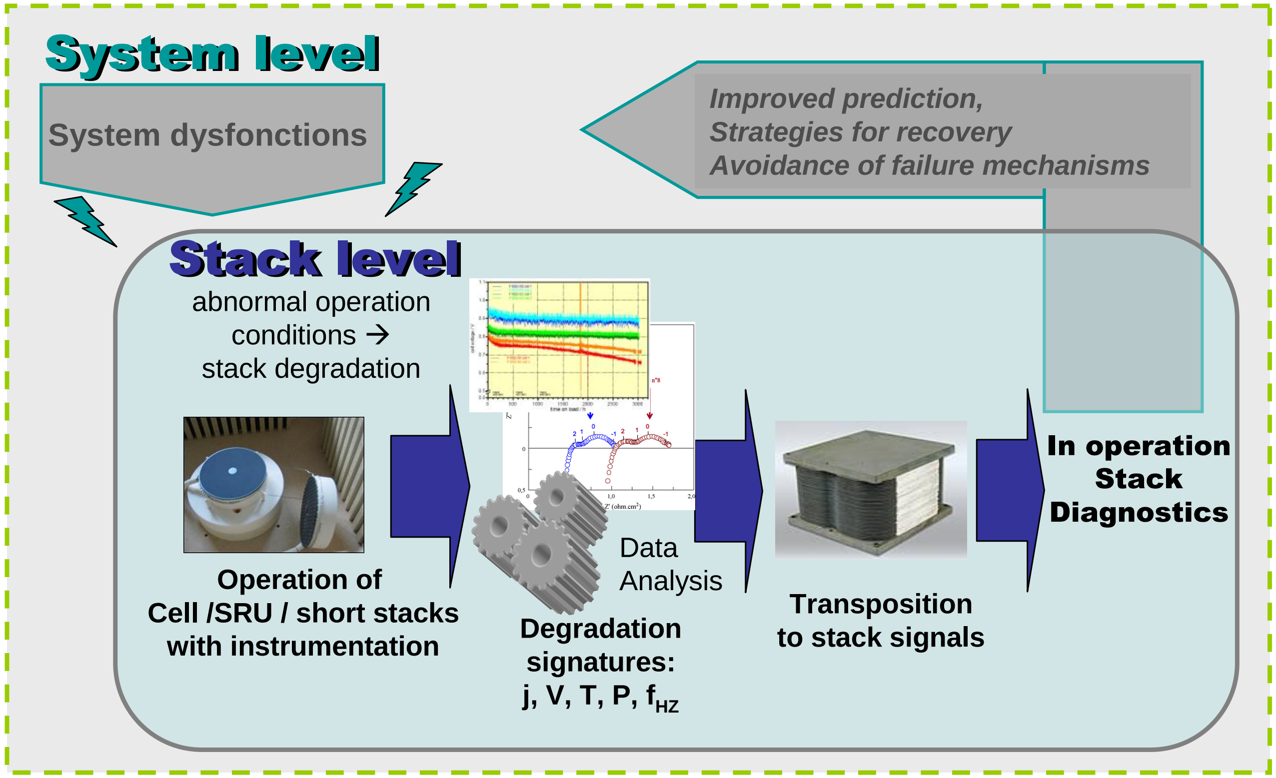
A European dimension with a good balance between academics, R&D centres and industries

Design Goal & Targets

- The overall objective of the DESIGN project is to provide **a sound diagnostic method for insidious phenomena** that slowly accelerate the degradation at the commercial stack level, through the understanding of the local responses of sub-stack elements.

1-Identification of **specific signatures at the local** cell /SRU / small stack level

2-**Transposition** from local signatures to **full stack** with limited instrumentation

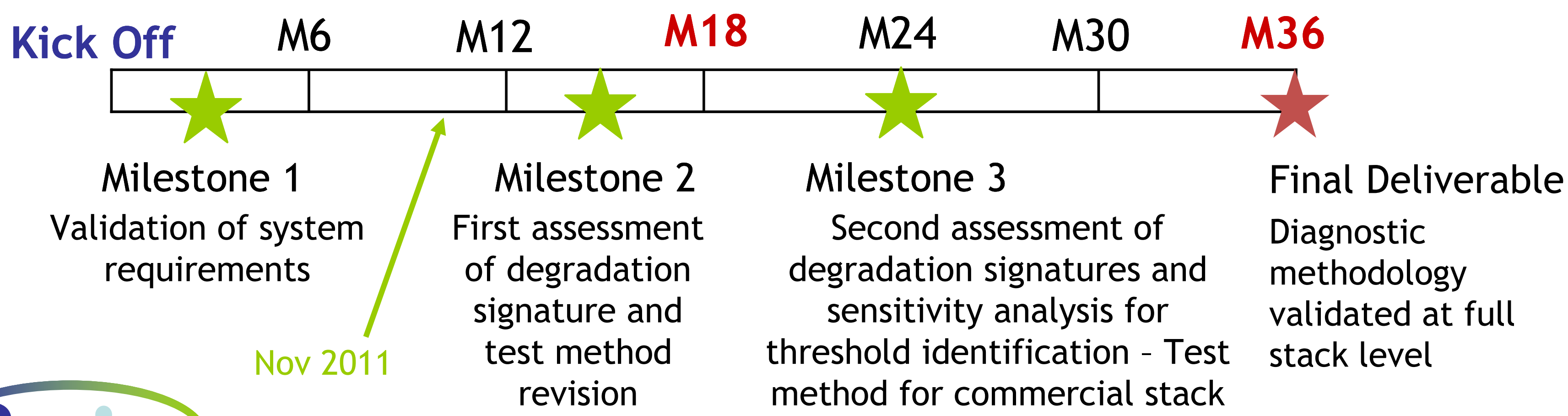


Design Outcomes & Milestones

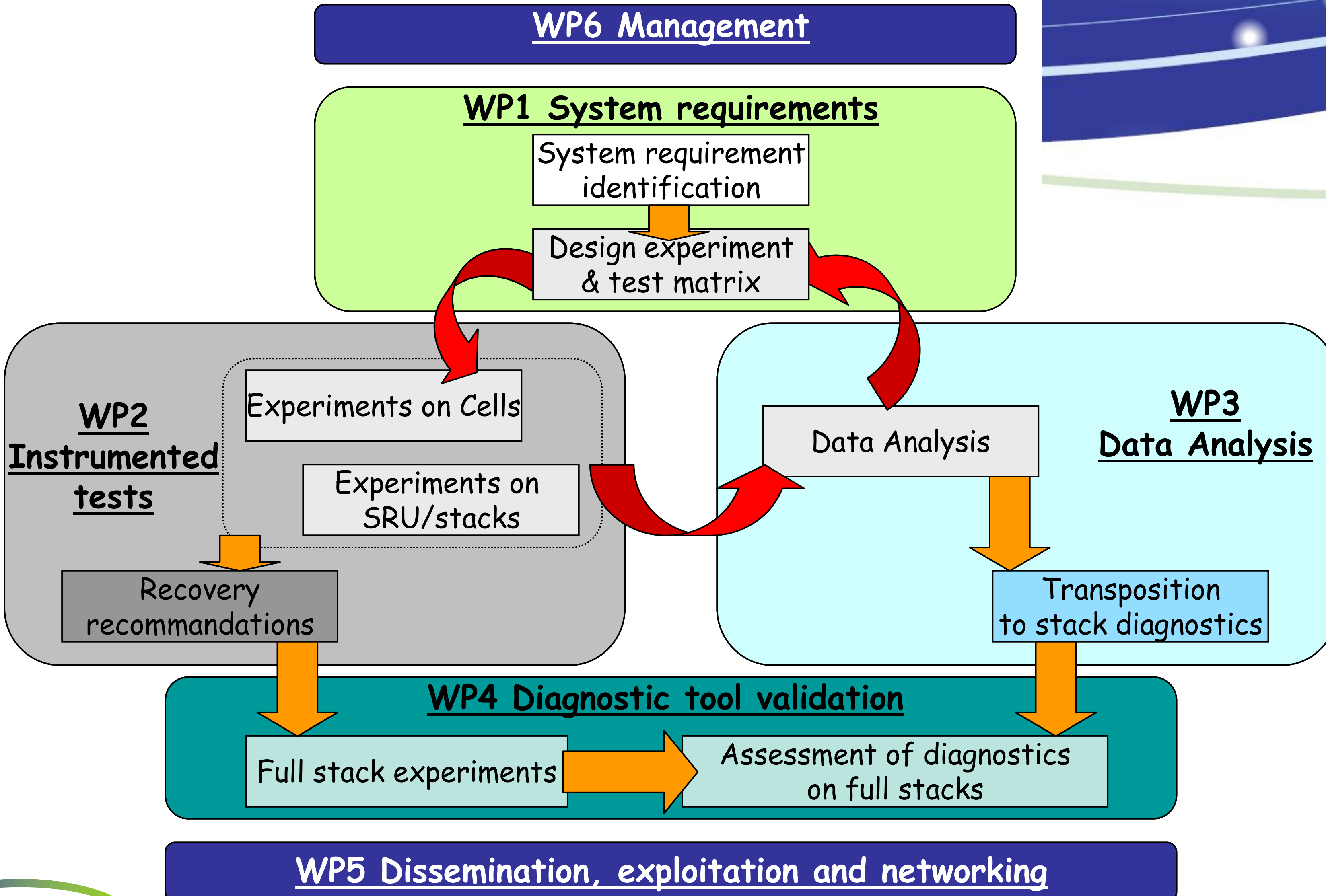
Design Outcomes

1. Identification of **relevant sensors and signals** to be monitored to diagnose full stack degradation phenomena;
2. A **data analysis methodology** to be applied to measured signals;
3. A set of **characteristic signatures** for the different degradation phenomena at the local and stack level, to be extracted from the actual sensor signal to diagnose long-term degradation conditions;
4. **Recommendations for operation recovery**, once a degradation condition is identified at the cell, SRU or stack level.

Design Milestones



Design Approach



Degradation Mechanism Selection

Main degradation phenomena occurring nowadays in SOFC technology upon continuous operation have been listed and analysed on the basis of 10 criteria :

- Assignment to main stack parts (*anode, electrolyte, interconnector, sealing*)
- Collection of degradation phenomena *(anode deactivation, anode oxidation, electrolyte, resistance increase, cathode deactivation, contact loss, channel blocking, leakages…..)*
- Assignment of degradation mechanism *(sulphur poisoning, carbon deposition, nickel agglomerations, material interdiffusion…)*
- Identification of sources and events *(desulphurizer breakthrough, thermal gradients, reformer dysfunction, air humidity, chromium evaporation in BoP components, …)*
- Mitigation and prevention *(monitoring of S/C ratios, temperature monitoring, protective layers…)*
- Potential for recovery *(fatal failure, irreversible loss with stabilization, partial and total recovery)*
- Recovery strategies *(decrease of fuel utilization, increase of CPOX lambda, increase of S/C resp. O/C ratio, exchange of desulphurizer, catalyst exchange / regeneration)*
- Degradation signatures *(voltage drop, impedance spectroscopy, temperature increase, voltage fluctuations, OCV drop)*
- Time scale *(immediately, medium-term, long-term)*
- Risk level *(probability of occurrence x severity of damage)*

Degradation Mechanism Selection

Degradation phenomena interesting for DESIGN:

- have a clear signature
- can be distinguished from other degradations
- have a potential of at least partial recovery

Some like cathode contamination by chromium, contact loss or oxide scale growth on the interconnector cannot be recovered → not considered.

Those related to transient operation → not considered

→ Degradation mechanism analysis (D1.11) led to the selection of the following mechanisms to be investigated:

1) Anode re-oxidation by locally increased fuel utilizations

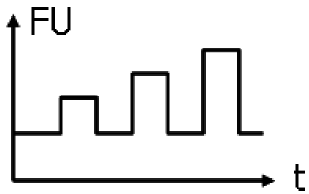
2) Carbon deposition

3) Small leakage at anode side

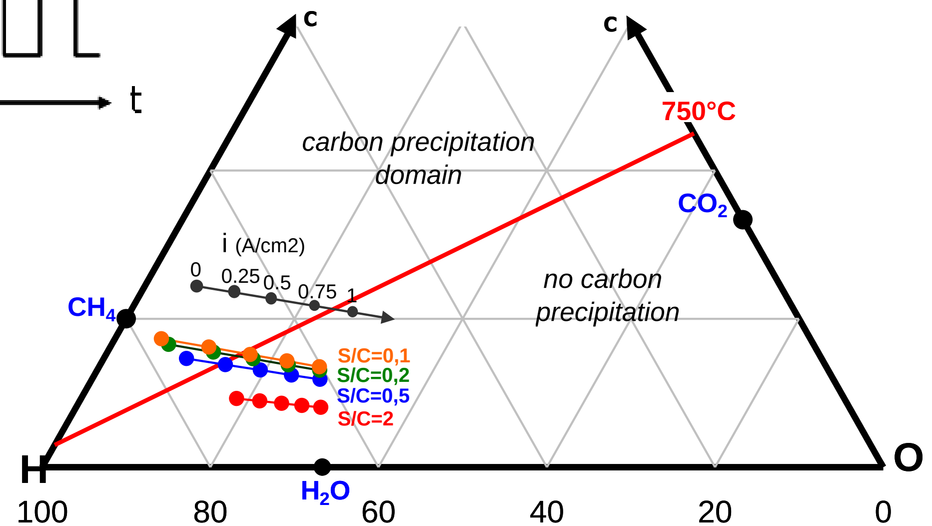
Test matrix Elaboration

- **Nominal testing conditions identified:**
  - Fuel composition as recommended in FCtestQA for internally steam pre-reformed methane at 10% (14% CH_4, 6% H_2, 28% H_2O, 1,8%CO_2,50% N_2 …)
  - Initial furnace temperature 750° C
  - Current density 0.5 A.cm^{-2} for ASC and 0.3 A.cm^{-2} for ESC
  - Gas Flow to target FU of 60%

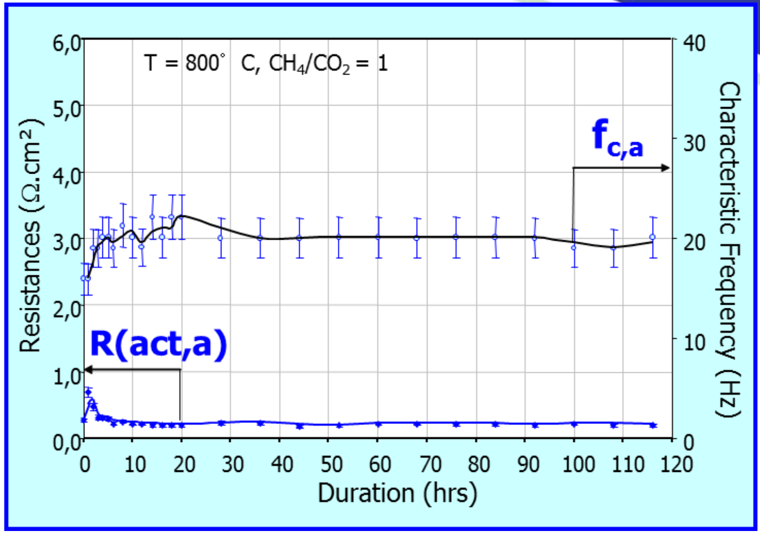
- **Excursion to emphasize degradation mechanisms** (first on single cell and SRU, then on instrumented short stacks)
  - **For High fuel utilization:** progressive increase of current density or decrease of fuel inlet up flow to reach 90% FU



  - **For carbon deposition:** progressive decrease of S/C ratio and/or decrease of current density
  - **For leakage:** technological study on going to implement a controlled, and reproducible leakage



Example of carbon precipitation signature

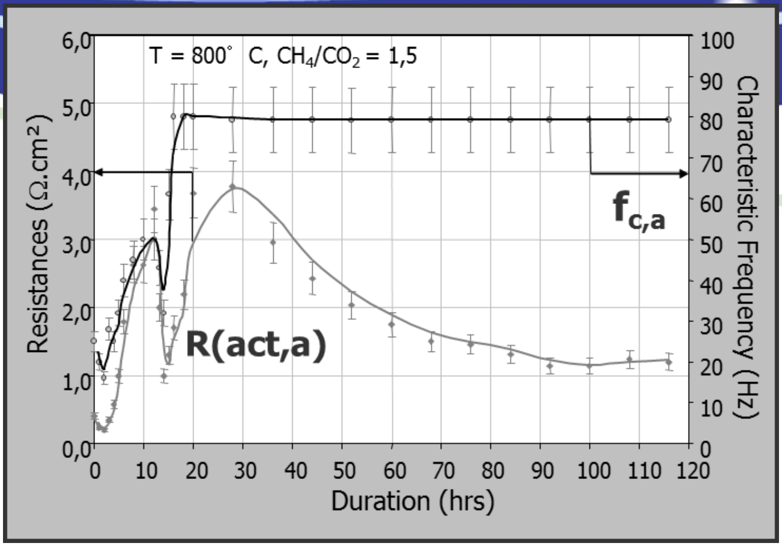


CH_4/CO_2 = 1

- no carbon precipitation expected nor observed on post test analysis

- simultaneous limited variations of R(act,a) and f(c,a) before stabilisation:

→ the anode reaction mechanism does not seem to be modified



CH_4/CO_2 = 1.5

- carbon precipitation expected and observed on post test analysis

- major and simultaneous variations of R(act,a) and f(c,a) : after 20 h **the anode reaction mechanism is modified**

→ R(act,a) and f(c,a) can be used to detect early carbon precipitation

K. Girona, et al ECT Transactions, 25(2), 2009, p. 1041.

Alignment to MAIP- AA3 Stationnary Power Generation & Combined Heat and Power

"The aim will be to achieve the principal technical and economic specifications necessary for stationary fuel cell systems to compete with existing and future energy conversion technologies"

→ Adapted diagnostic tool for **in situ fine tuning of cell/stack operation conditions** will pave the way to SOFC stack reliability and durability

"This aim includes the use of multiple fuels"

→ A **fuel composition** as recommended in **FCtestQA** for internally steam pre-reformed methane will be tested within the project, **varying S/C ratios**

"This aim includes a lifetime increase up to 40,000h "

→ **Early detection** of identified degradation mechanisms, will allow avoiding failure by modifying operation parameters thereby **increasing substantially cell/stack lifetime**.

→ Recommendations will be provided for **recovery strategies** for later detection

"The aim will be to deliver reliable control and diagnostics tools both at a component and at system level "

→ The main target of the project is to deliver a diagnostic methodology liable to serve as the basis for a diagnostic tool as the stack level

Alignment to AIP 2009 – Topic 3.3 Operation Diagnostics and Control for Stationary Power Application

"Novel diagnostics to identify potential failures, including in-operation diagnostic tools for cell/stack"

→ Project direct output: **set of characteristic signatures** monitored **during operation** and related to selected degradation phenomena.

"Improved prediction and avoidance of failure mechanisms"

→ Signatures of selected failure mechanisms will be experimentally evaluated and suitable data analysis methods developed in order to **separate the effect of each failure mechanism** from normal base-line stack degradation at an early stage. This **early detection** will allow **minimizing degradation** by **optimizing system operating parameters**.

"Development of strategies for recovery of cell and stack performance"

→ One main target of the project is to provide **recommendations for recovery strategies**.

"Tools for improved diagnostics and services"

→ Signatures of different degradation or failure mechanisms, when assessed both experimentally and through data analysis methods, will be **implemented at the stack level** with most suitable **sensors**.

Education, Training & Dissemination

Education & Training:

1 PhD student funded at UNISA, who will spend time at partners laboratories

Organisation of workshops:

☺ *Workshop 1, M3: to determine the most probable and the most critical events for the stack operation to be studied in the project with industry partners (SOFC system & cells and stack providers)*

• Workshop 2, M12-M18: with sensor producers or integrators to collect knowledge of State of the Art sensors that are easy to integrate and cost effective, applicable to SOFC diagnostics. Linked with industrial event.

• Workshop 3, M30-36: Dissemination and exploitation workshop (SOFC system & stack providers)

A minimum of 1-2 coordination events (meetings) will be proposed between GENIUS and DESIGN in agreement with both consortia to ensure cross dissemination.

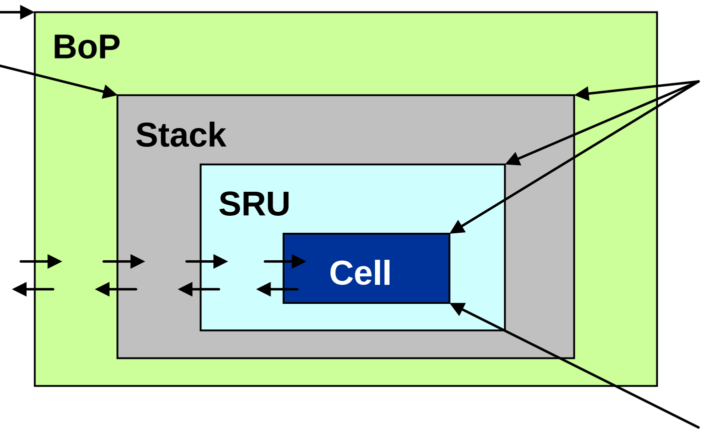
Public website: www.design-sofc-diagnostic.eu

Technology transfer and collaboration

- **Collaborations**

GENIUS
Subject: System
Sensor: Stack
Outcome: diagnostic tool

ASSENT ?
Subject: Anode Recirculation
Outcome: Degradation source Specification?



DESIGN
Subject: Stack
Sensors: Various levels
Outcome: Method & signatures as inputs to a diagnostic tool + recovery strategies recommandations

SOFC Life
Subject: Cell degradation mechanisms
Outcome: mechanism understanding and modelling

- **Technology Interfaces**

➨Enhanced interface between SOFC manufacturers and signal treatment specialists and sensors producers

Design Future perspectives

- **Project Future Perspectives**
  - Need/opportunities for international collaboration
    - High: Sharing fundamental approaches and understanding can accelerate the identification of relevant signals and the development of adapted sensors for diagnostic
  - Possible contribution to the future FCH JU Programme
    - Signal analysis and transposition from cell to stack to build a reliable signature may require deeper analysis and more basic approach
    - Design is focused on 3 degradation mechanisms when some 15 ones have been listed (including transients ones)
      → Understanding of the parameters controlling these 15 degradation mechanisms and identifying their signatures from cells to stack and to system remain challenging and deserves more effort
    - An integration between the results of e.g. SOFC Life (understanding of cell continuous degradation mechanisms), DESIGN and GENIUS (analysis of stack signals upon transients for system monitoring) in order to have a multi-scale diagnostic tool