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AD ASTRA

FROM BASIC TO APPLIED RESEARCH TOWARDS DURABLE AND RELIABLE FUEL CELLS

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5th July 2022 – Lucerne (CH)

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PROJECT ID

Released by: FCH-JU **Topic:** FCH-04-3-2018: Accelerated Stress Testing (AST) protocols for Solid Oxide Fuel Cells (SOFC). 1st of 4 proposals

First name: AD ASTRA
Last name: HArnessing Degradation mechanisms to prescribe Accelerated Stress Tests for the Realization of SOC lifetime prediction Algorithms
Start of the project: 1 January 2019
End of the project: 31 August 2022
Grant Agreement number: 825027
Costs declared: € 3,008,426.25 → **100% funded**

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PROJECT HIGH-LEVEL OBJECTIVES

- Enhanced, multidimensional **Failure Mode and Effects Analysis** (FMEA) matrix for SOC stacks tested in the field:
  stack operation → performance monitoring → post-mortem analysis
  WP2 & WP4
- **Prioritization of dependent and independent variables** causing observed degradation
  WP2, WP3 & WP5
- AST protocols that address realistic failure modes of **fuel electrode, oxygen electrode** and **interconnect** in power-to-X (**P2X**) and combined heat and power (**CHP**)
  WP2, WP3 & WP5
- Target **AST durations < 3000 hours** ←→ real-world stack < 40,000 h identifying transfer functions of degradation measured in AST to real-world behaviour within a ±15% uncertainty margin
  WP3
- **Remaining Useful Life** (RUL) **prediction** models based on operating profile (including accelerated stress conditions) ***in real-time***
  WP5
- A *generalized methodology* for the definition of ASTs **submitted for standardization** to the International Electrotechnical Commission (IEC)
  WP2& WP6

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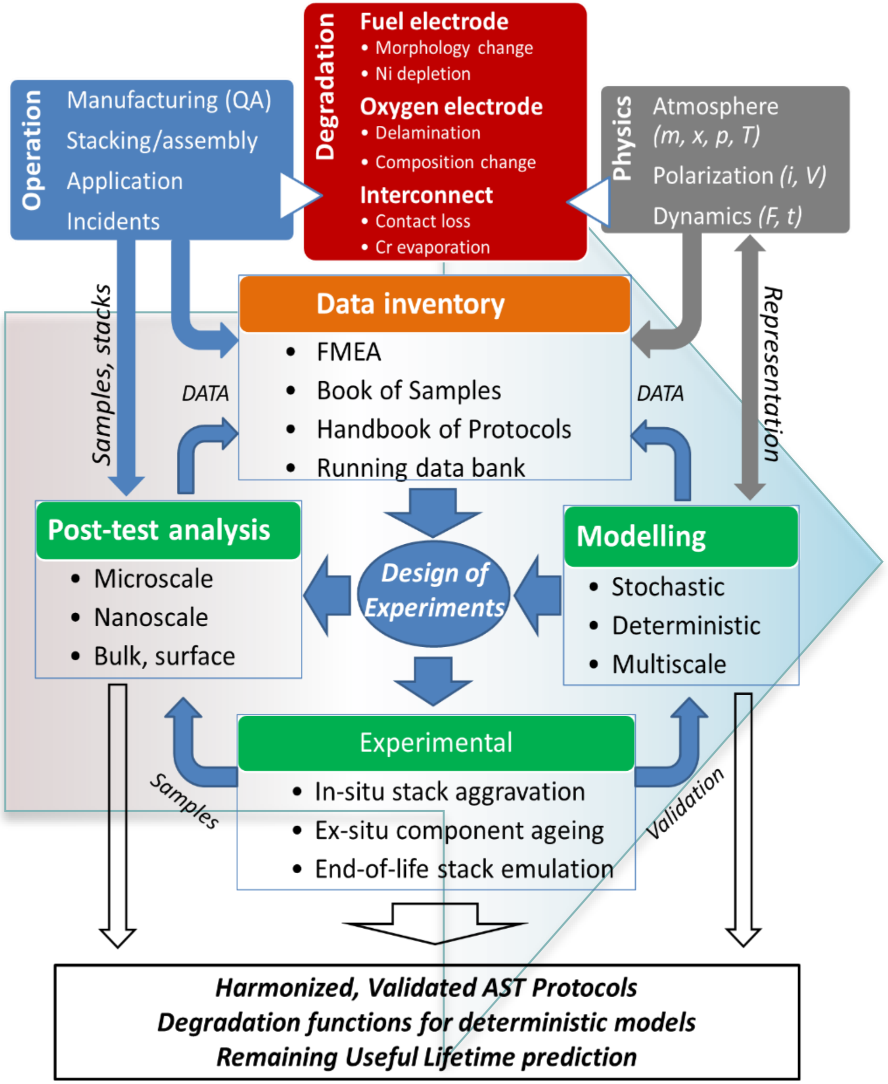
PROJECT APPROACH

PER ASPERA:

- Durability targets of SOC stacks 80,000 h
- Failure modes governed by:
  - variance in component manufacturing or stack assembly
  - operating conditions
  - potential incidents
- Lack of correlation between intrinsic degradation phenomena and failure modes



AD ASTRA:

- **Understanding of most critical failure modes in the critical components of the stack**
- **Formulation of mechanistic and fast stochastic models for lifetime prediction**
- **Develop AST protocols able to control and steer (& accelerate) degradation mechanisms**

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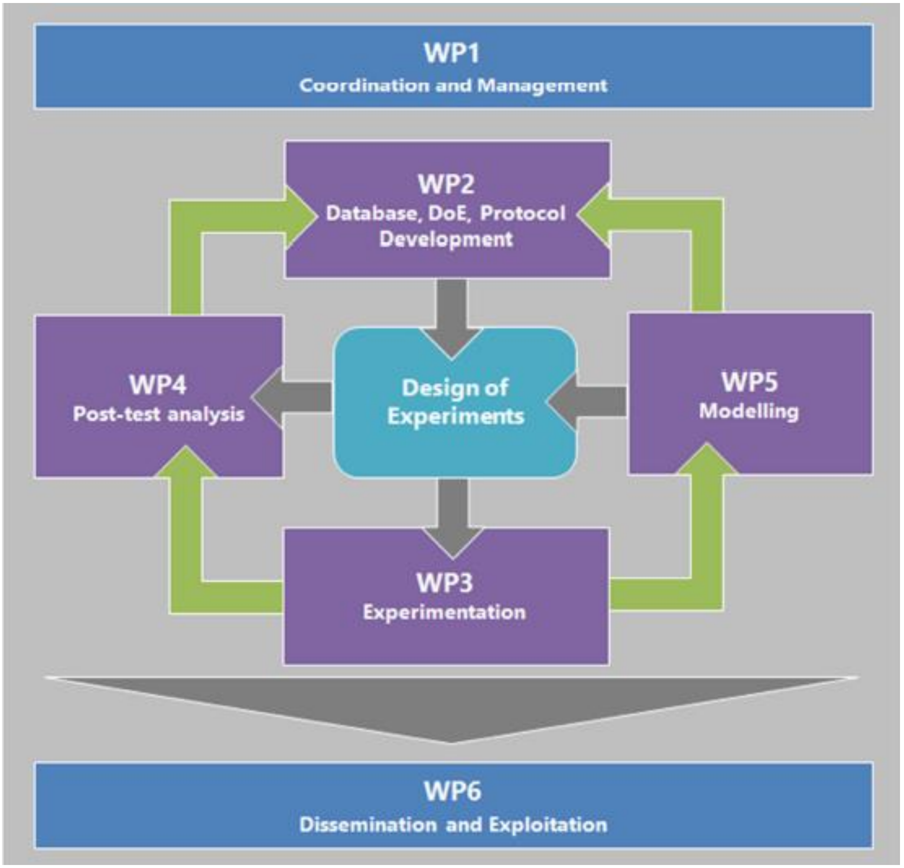
IMPLEMENTATION

WP2:
Database, Design of Experiments and Protocol Development

WP4:
investigate and characterize macro- and micro-samples after the experimental sessions and correlate changes in materials or degradation effects to real-life events observed during the experiment



WP5:
Identification of the main degradation parameters, Development of grey-box degradation models and Definition of proper stack performance and lifetime models

WP3:
identify and develop relevant test samples to study specific degradation mechanisms

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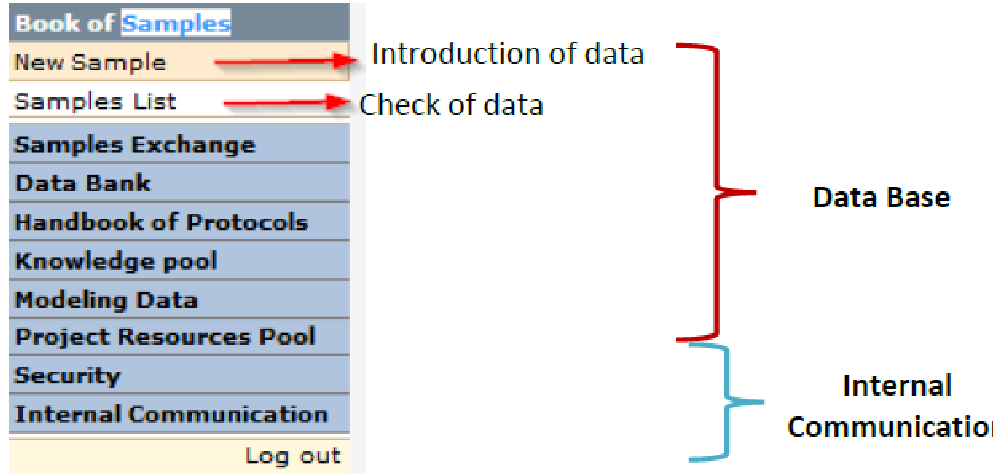
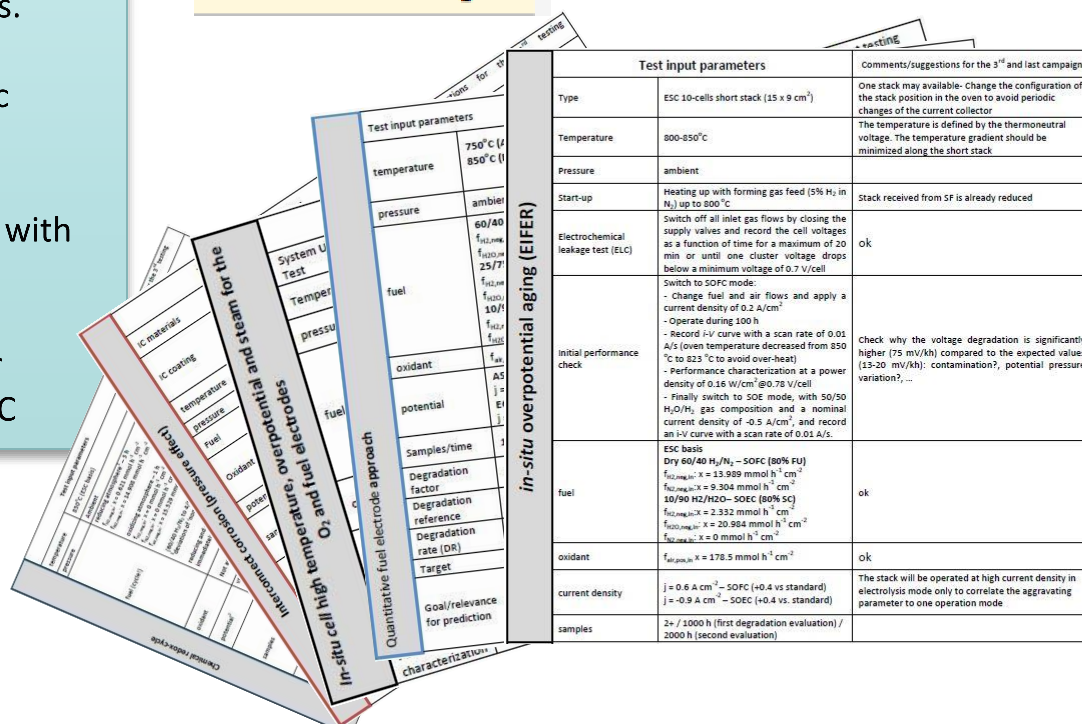
WP2: DATABASE, DOE AND PROTOCOL DEVELOPMENT

- To gather, organize and safely store: (i) project input data/information; (ii) data/results generated during the implementation of the project; (iii) project output data/results.
- To provide a framework ensuring efficient data exchange between partners.
- To analyse all relevant input data/information from previous projects.
- To programme experiments in a cyclic approach.
- To formulate replicable AST protocols, with definition of the accelerating factors.
- To describe a generic methodology for the definition of AST protocols for SOC





in-situ overpotential aging (EIFER)

Test input parameters		Comments/suggestions for the 3rd and last campaign
Type	ESC 10-cells short stack (15 x 9 cm^2)	One stack may available- Change the configuration of the stack position in the oven to avoid periodic changes of the current collector
Temperature	800-850°C	The temperature is defined by the thermoneutral voltage. The temperature gradient should be minimized along the short stack
Pressure	ambient	
Start-up	Heating up with forming gas feed (5% H_2 in N_2) up to 800 °C	Stack received from SF is already reduced
Electrochemical leakage test (ELC)	Switch off all inlet gas flows by closing the supply valves and record the cell voltages as a function of time for a maximum of 20 min or until one cluster voltage drops below a minimum voltage of 0.7 V/cell	ok
Initial performance check	Switch to SOFC mode: - Change fuel and air flows and apply a current density of 0.2 A/cm^2 - Operate during 100 h - Record *i-V* curve with a scan rate of 0.01 A/s (oven temperature decreased from 850 °C to 823 °C to avoid over-heat) - Performance characterization at a power density of 0.16 W/cm^2@0.78 V/cell - Finally switch to SOE mode, with 50/50 H_2O/H_2 gas composition and a nominal current density of -0.5 A/cm^2, and record an i-V curve with a scan rate of 0.01 A/s.	Check why the voltage degradation is significantly higher (75 mV/kh) compared to the expected values (13-20 mV/kh): contamination?, potential pressure variation?, ...
fuel	**ESC basis** **Dry 60/40 H_2/N_2 – SOFC (80% FU)** $f_{H2,neg,in}$: x = 13.989 mmol h^{-1} cm^{-2} $f_{N2,neg,in}$: x = 9.304 mmol h^{-1} cm^{-2} **10/90 H2/H2O– SOEC (80% SC)** $f_{H2,neg,in}$: x = 2.332 mmol h^{-1} cm^{-2} $f_{H2O,neg,in}$: x = 20.984 mmol h^{-1} cm^{-2} $f_{N2,neg,in}$: x = 0 mmol h^{-1} cm^{-2}	ok
oxidant	$f_{air,pos,in}$ x = 178.5 mmol h^{-1} cm^{-2}	ok
current density	j = 0.6 A cm^{-2} – SOFC (+0.4 vs standard) j = -0.9 A cm^{-2} – SOEC (+0.4 vs. standard)	The stack will be operated at high current density in electrolysis mode only to correlate the aggravating parameter to one operation mode
samples	2+ / 1000 h (first degradation evaluation) / 2000 h (second evaluation)	

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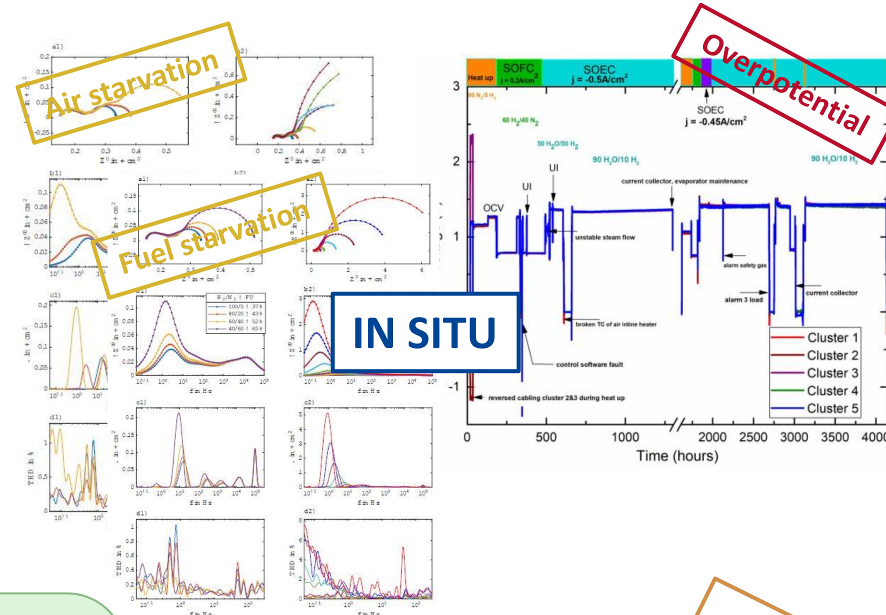
WP3: EXPERIMENTATION

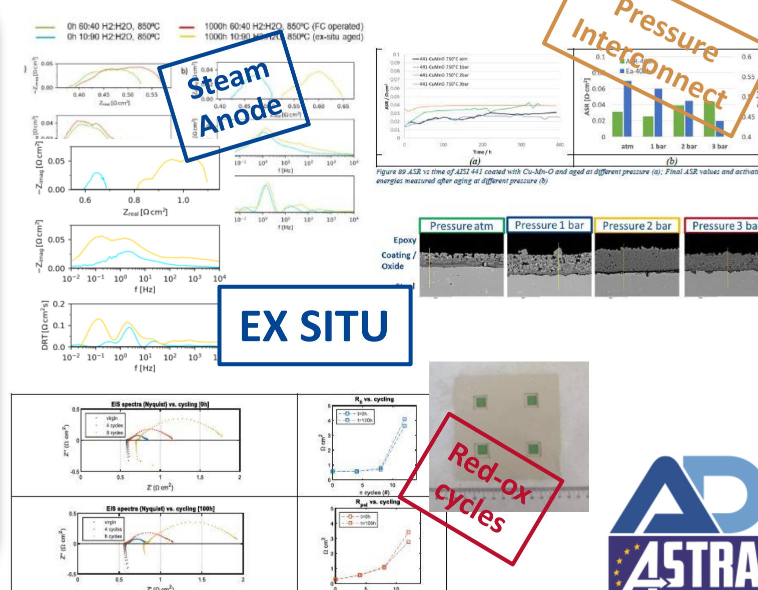
- To supply test samples to study specific degradation mechanisms.
- To design and develop systematic tests, both *ex situ* and *in situ*, on components and short stacks based on WP2 analysis.
- To supply WP4 (Post-test analysis) with well-documented, tested samples for further microstructural and physico-chemical analysis.
- To generate measurement data for WP5 (Modelling) and WP2

2 Different approaches

Ex Situ
SOC components are aged out of the cell frame environment and reassembled in a SRU or Stack to check the degradation occurred in the ageing process

In Situ
Ageing strategies of single SOC components are implemented directly in SRUs or stacks





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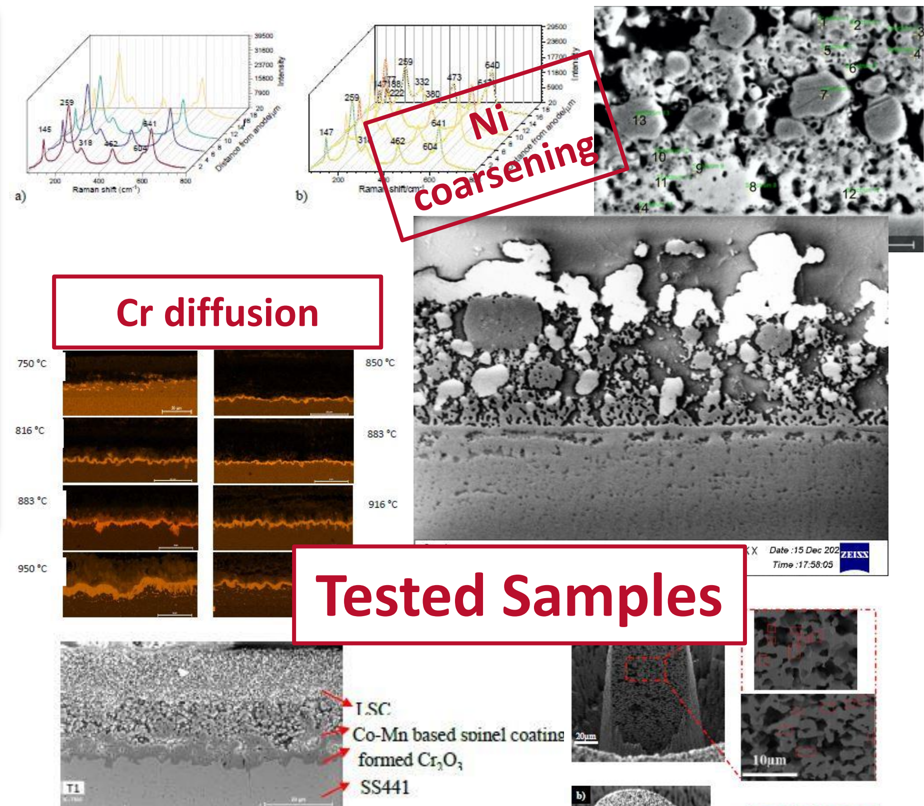
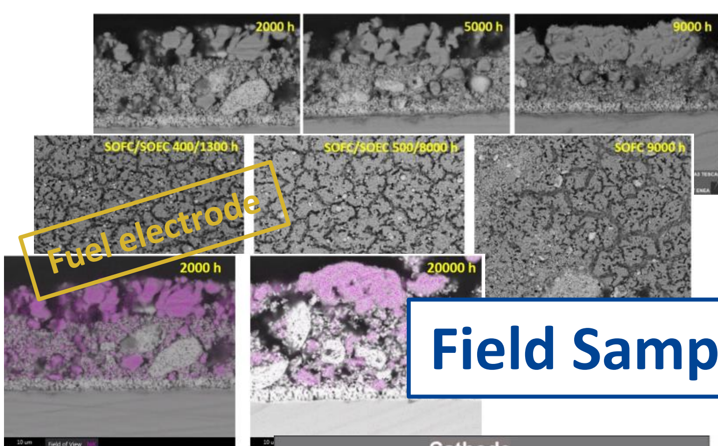
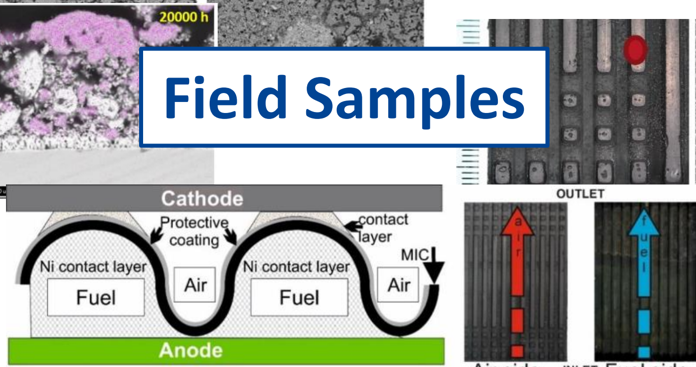
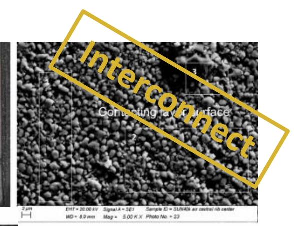
WP4: POST-TEST ANALYSIS

- To investigate and characterize macro- and micro-samples after experiments.
- To identify weak spots in the stack components (i.e. fuel and oxygen electrodes, interconnect, and their interfaces).
- To correlate changes in materials or degradation effects to real-life events observed during the experiment.
- To transfer morphological, microstructural and chemical data to WP5 for the refining of the modelling process.

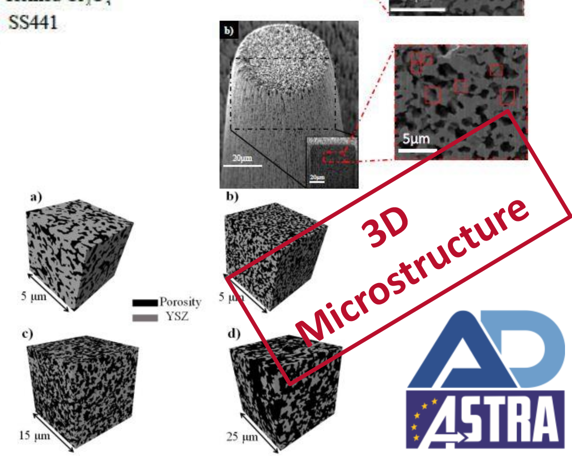








Elements	Area 1 At%	Area 2 At%	Area 3 At%
O	63.0 ± 0.5	63.9 ± 0.6	71.5 ± 0.5
Mn	16.4 ± 0.4	15.8 ± 0.4	14.3 ± 0.3
Co	1.5 ± 0.2	1.5 ± 0.2	11.9 ± 0.4
Sr	3.3 ± 0.3	3.3 ± 0.3	-
La	15.8 ± 0.6	15.5 ± 0.6	1.8 ± 0.3
Cr	-	-	0.6 ± 0.1



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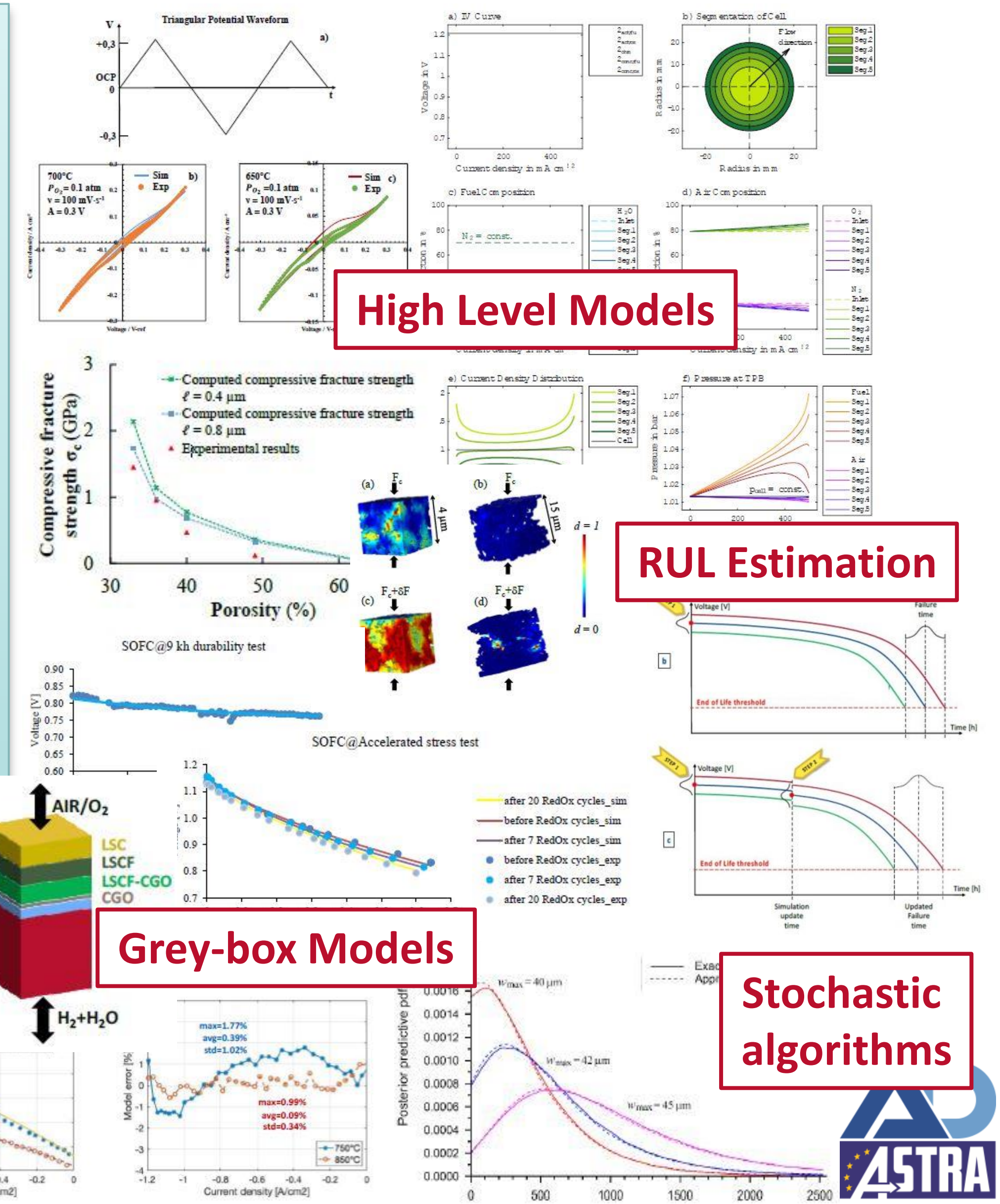
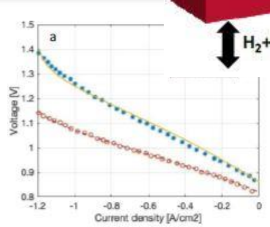
WP5: MODELLING

- Identification of the main degradation parameters from available data and high-level physical models.
- Development of grey-box (i.e. simplified) degradation models, describing the time evolution of degradation parameters.
- Feed into WP2 as necessary for experimental parameter estimation.
- Stack performance and lifetime models, with embedded degradation mechanisms, simulated through parameter-based and statistical approaches.
- Association of suitable stochastic and signal treatment based algorithms to define uncertainties in high and low-level physical models in order to.
- Identification of statistical approaches allowing extrapolation of accelerated variables from high to low acceleration levels.





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FINAL STEPS…

Results from in situ and ex situ final campaigns...

...characterization results of accelerated stress-tested samples and stacks...

Harmonized AST protocols

&

Final version of models

incl. degradation functions

validated accelerating factors

RUL estimation

A *generalized methodology* for the definition of ASTs **submitted for standardization** to the International Electrotechnical Commission (IEC)

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