Overview of ID-FAST

Investigations on degradation mechanisms and Definition of protocols for PEM Fuel cells Accelerated Stress Testing

Content

Overview of ID-FAST & status at mid-term

- Objectives
- Approach
- Organisation
- Overview of technical progress *(survey 2020)*
- Development of ASTs & Approach towards standardization

Introduction

Start date 01/01/2018
3-year project

The objective of this project is to **support and promote the deployment of fuel cell vehicles,** through the development of **Accelerated Stress Tests (AST)** of Proton Exchange Membrane Fuel Cells (PEMFC) components and associated **transfer functions** allowing to **predict the performance degradation during real world operation,** and accelerating the **introduction of innovative materials in next generation designs.**

ID-FAST

Objectives & concept

1. **Identification of real ageing degradation mechanisms and quantification of their impact,** *as the basis for the identification of stressors and the development of relevant ASTs*
2. **Development and application of performance degradation models integrating several degradation mechanisms, for the simulation of accelerated ageing***, as a tool for the development and validation of combined ASTs*
3. **Development and validation of ID-FAST methodology: AST protocols and transfer functions correlating accelerated degradation to real world degradation**.

From real ageing data to real ageing prediction

Identification and analysis of real ageing degradation data: performance decay & mechanisms

Definition and simulation of stressors effects and accelerating protocols

Proposal of ASTs & transfer functions

Validation of developed AST by correlation with real life ageing

Relevance & lifetime prediction capability

Objectives & concept

TRANSFER FUNCTIONS

$\mu V/h_{REAL} = TF(\mu V/h_{ID\text{-}FAST})$

"Real world" ageing: components & data from systems → **Component single mechanisms AST SoA & New** → **ID-FAST combined AST protocols** ↔ **Real ageing on stack**

Analyses of degradation phenomena & mechanisms

Investigations of stressors impact (acceleration) & coupling

Validation of relevance *(mechanisms & acceleration)* at single cell level
Validation of correlation to Real World *via* Specific Stressing Tests on Stack

Two major items for demonstrating the validity

1/ Verification that the same mechanisms are involved qualitatively but also quantitatively

Representativeness (same alteration of components along with quantitatively consistent degradation of functional properties)

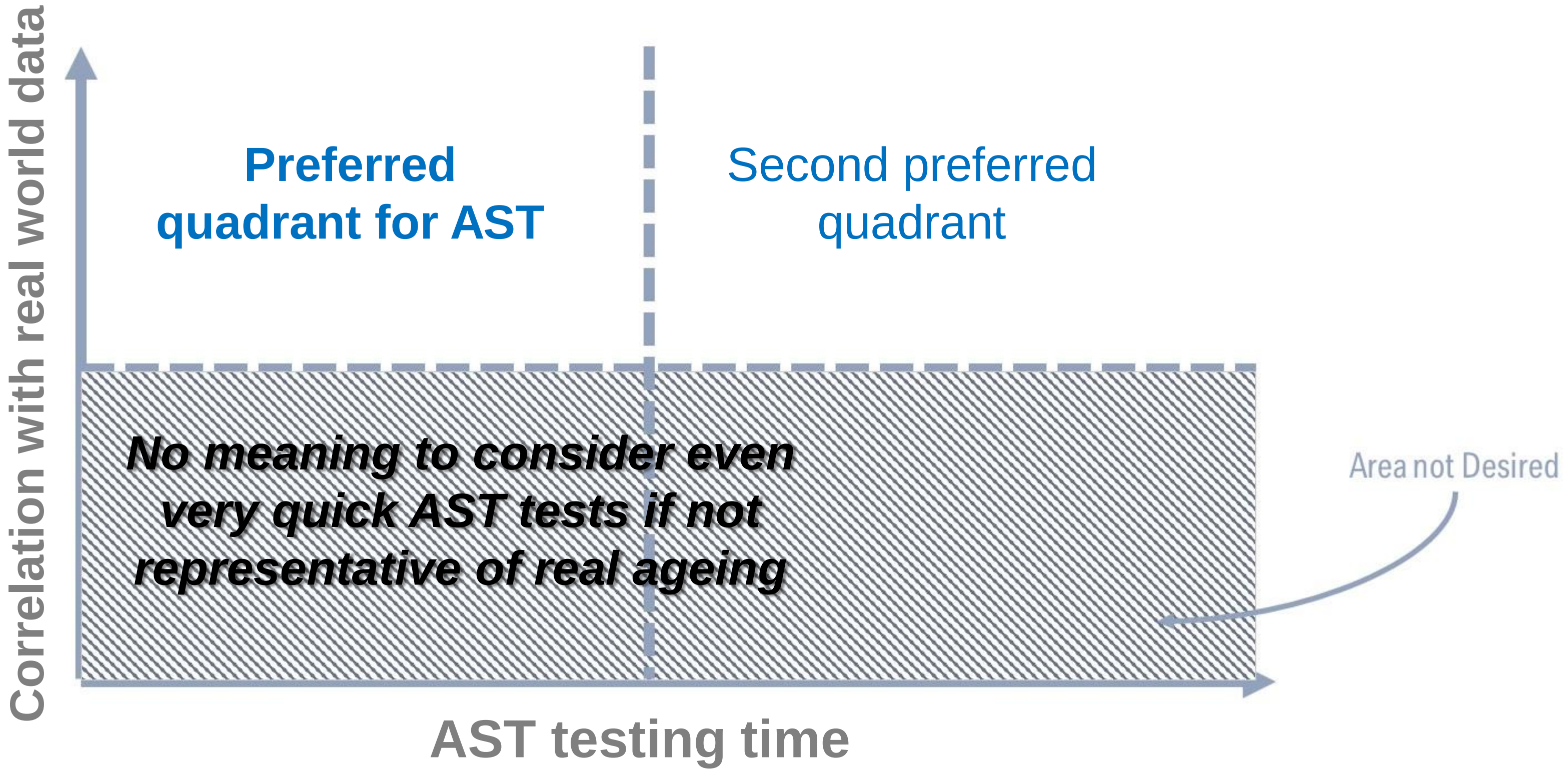
2/ Confirmation that real performance losses can actually be accelerated and also predicted

Outcomes allowing suitable prediction of stack lifetime is expected as valuable exploitation

Issues for automotive application

How to address representativeness

Most important is accuracy of correlation with real-world data



PEMFC studies

How to address representativeness

<u>Starting point</u> ➡ **Gather aged components from stacks with known operational history and related ageing data**

Ageing investigations

(In situ, ex situ experiments & simulation)

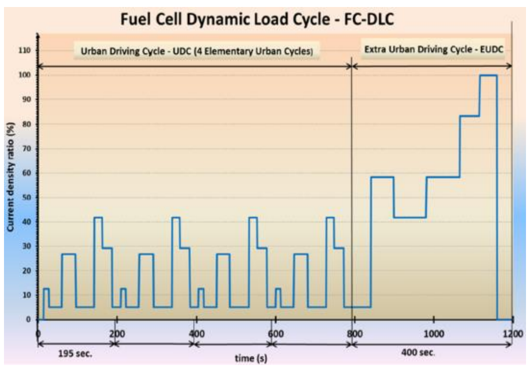
Samples from previous projects + **SoA stack and components**

Johnson Matthey Fuel Cells
the power within

DANA

99 kW max cont
114 kW peak (30sec)
(30% N_2 in H_2, 335

5 kW FC system + 44 kW battery (+ 200 bars hydrogen storage)



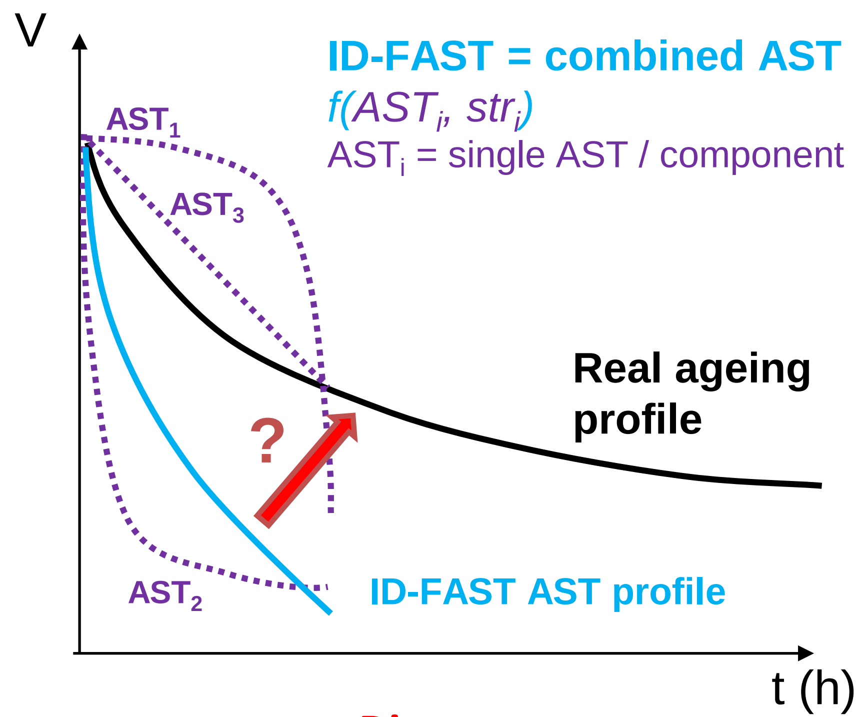
Realistic Protocols
Load cycles
+ events

AST Protocols
Load cycles +
events

Planned method

How to address prediction

Fuel Cell performance evolution / degradation rate during real ageing?



Increased performance losses	Direct	Nominal performance losses
Higher degradation rate *µV/h* $_{ID\text{-}FAST}$	link	Nominal degradation rate *µV/h* $_{REAL}$

Planned outcomes & validation

From real world aged samples of cells from stacks aged in real systems,

→ AST to **reproduce** ageing mechanisms inducing **faster** performance decrease

(superposition or combination of degradation modes and actual acceleration)

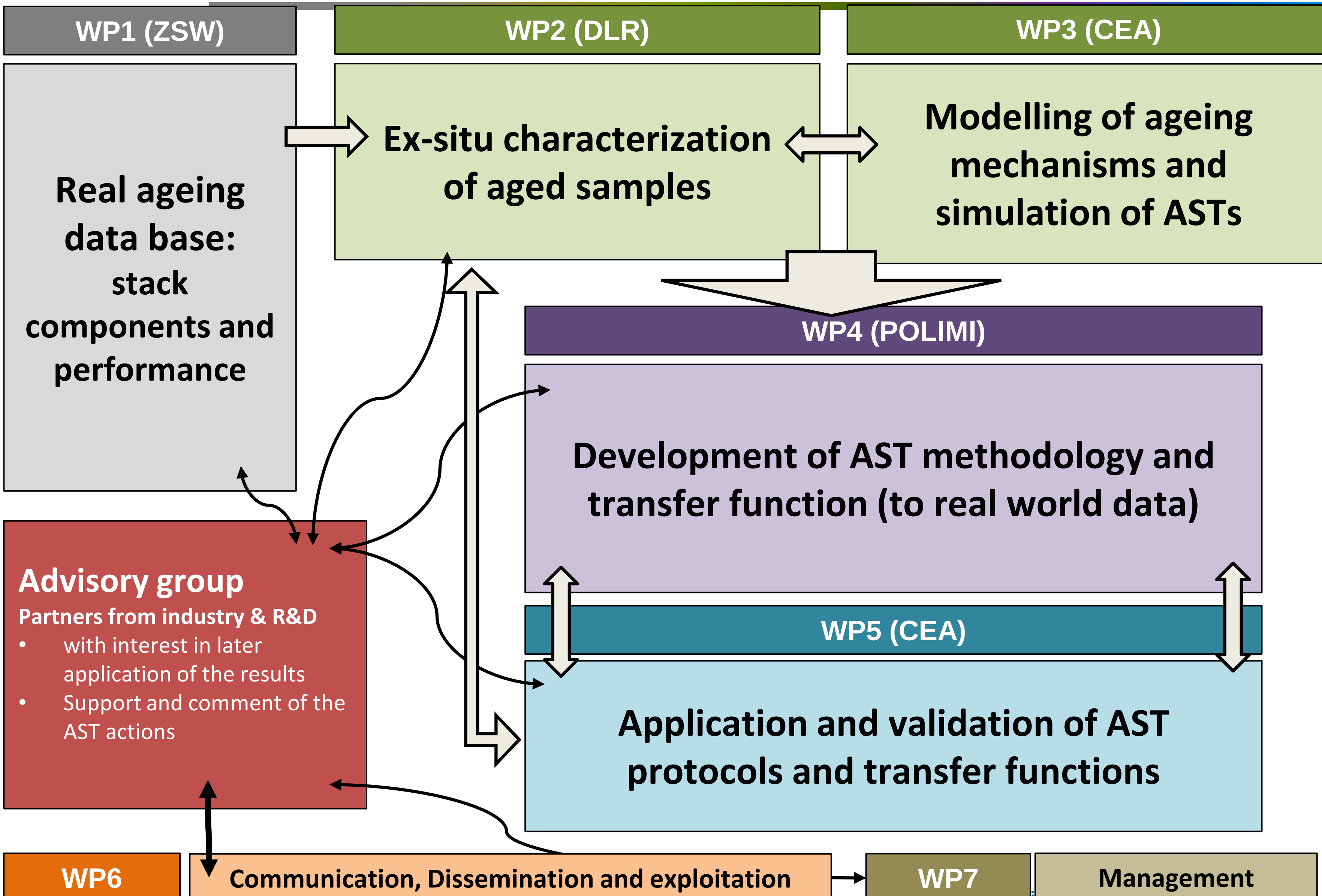
- ✓ **1st step: validation at single cell level by comparison of AST & real ageing**
  - → ***Transfer function (F) with generic validity*** *[public outcome]*
- ✓ **2nd step: validation at stack level of Specific Stressing Test (SST) vs. AST in SC**
  - → ***Heterogeneities taken into account / design related*** *[thus non-public outcome]*
  - → ***Methodology to define the associated transfer function (G)*** *[public outcome]*

Technical Plan & WPs

Focusing on scientific and technological R&D activities

4 Main steps	Aim	WPs
Identification or confirmation and quantification of degradation phenomena (morphology, composition and properties of components) involved in real ageing	Determination of major causes of components degradation for real aging case in correlation with operating conditions	WP1 and WP2 mainly
Analysis of stressors and of their accelerating factor for each single mechanism AST	Identification of stressors and quantification of their impact on degradation	WP2, WP3 and WP4
Analysis and development of combined AST protocols (superposition of degradation modes and acceleration through coupling)	Definition of combined AST with regard to their relative impact	WP2, WP3, WP4 and WP5
Validation of combined ASTs and development of transfer functions to link AST ageing in single cell to real ageing in stack, with realistic lifetime estimation	Validation of correlation to real world ageing and definition of a methodology to predict stack lifetime	WP1, WP2, WP3, WP4 and WP5

WP organisation



ID-FAST

WP organisation

WP1

Real ageing data base: stack components and performance

- Selection and supply of samples aged in real systems (incl. ageing conditions and profile)
- Definition of i) the SoA stack and components for ageing investigations and ii) SoA ageing tests representative of real systems
- Ageing test on SoA components in real conditions

WP2

Ex-situ characterization of aged samples

- Definition of the methods (electrochemical & physico-chemical) and of samples
- Characterization of non aged samples
- Characterization of samples from real ageing in cells and stacks
- Characterization of aged samples from AST

WP3

Modelling of ageing mechanisms and simulation of ASTs

- Modeling of ageing mechanisms
- Analysis and simulation of multi-mechanisms degradation modes
- Simulation of AST including main observed degradation mechanisms

WP4

Development of AST methodology and transfer function* (to real world data)

- Specific single cell hardware definition
- SoA and Development of single cell components AST
- Investigation of stressors and coupling effects
- Analysis of coupling between degradation mechanisms in single cell
- Identification of transfer function from AST to real aging in single cell
- Method to identify the transfer function from aging in single cell to stack

WP5

Application and validation of AST protocols and transfer functions

- Application of combined AST protocols in single cells
- Validation of AST and transfer function from AST to real aging in single cell
- Application of combined stressing protocols in stacks
- Proposal and validation of specific transfer function from AST ageing in single cell to real ageing stack

Advisory group

Partners from industry & R&D

- with interest in later application of the results
- Support and comment of the AST actions

Ind: JMFC (GB) – DANA (GE)

Lab: LANL (US) JARI (JP) UCONN (US)

More R&D or industry groups to be contacted (e.g. JRC)

WP6

Communication, Dissemination and exploitation

WP7

Management

Achievements (survey 2020)

	Objective name *70 character(s) maximum*	Status and short comments *150 character(s) maximum*
1	Identification of real ageing mechanisms and impact of conditions	Post-mortem analyses available from real stacks. Tests and stressors defined for stack ageing and for single cells to mimic local ageing in stack.
2	Development of models and coupling of mechanisms for ASTs' simulation	GDL degraded properties and impact of catalyst degradations simulated. Coupling of several models achieved. Bases for simulations of ASTs available.
3	Development and validation of specific and combined AST protocols	Analyses done on new AST proposed for start-up and protocols developed for GDL ageing - Combined tests with different conditions and profiles applied.
4	Proposal of transfer functions relating accelerated to real degradation	Comparison between real ageing conditions and accelerated conditions started for some mechanism – Further analyses needed on combined protocols.
5	Support to standardization efforts on Fuel Cell testing related to ASTs	First exchanges with IEC TC105 started in 2019, with a preliminary presentation of the AST approach, in collaboration with the SOFC project Ad-ASTRA.

3 major project achievements

- ➔ **Post-mortem** determination of **local degradations** and **impact** of ageing conditions, profiles or specific stressors applied **in real stacks or single cells**
- ➔ Advances in **methods to mimic real** states in stack and in diagnostics of catalyst layer-related reversible and irreversible electrochemical losses.
- ➔ Assessment of **new protocols** defined for ageing gas diffusion layers operando and for simulating start-up, by coupling modelling and experiments.

In addition

- ➔ **Good progress in the support to standardization bodies: active participation to a new working group within IEC TC105 dedicated to ASTs** (in collaboration with SOFC project Ad ASTRA) – **NWIP** to be proposed before end of the project.

3 Major difficulties (survey 2020)

- Delays in getting and setting-up the single cell hardwares originally planned for specific tests to assess and validate ASTs - Some delay induced on models validation, particularly for coupling aspects and definition of combined ASTs. Back-up solutions identified, other single cells selected and project extended by 1 year to recover.

- Difficulties in getting MEAs for stack testing to establish the real ageing data base with the selected reference components. Back-up solutions: MEA assembling with reference components taken in charge by a partner and other supplier identified particularly for the validation process with different MEAs - Tests of stack re-scheduled in line with project extension of 1 year.

- From the first period, less time, technical objects and information available to work on the analyses and AST development of metallic bipolar plates, apart from post-mortem analyses obtained about mid-term - some dedicated tests planned in a metallic single cell during the extension of 1 year.

Future plans and main expected steps (survey 2020)

- Getting **more controlled real ageing data** on reference stacks. **Improving diagnostics for quantification of losses** due to multi-mechanism degradation.

- Proposal of **combined ASTs based on experiments/models** – Check in **single cells** their **impact** on degradation rates and define transfer functions.

- Achievement of **all couplings (>two mechanisms)**. Integration of simplified models in the macroscopic code. Long time simulations of all mechanisms

- Applying the **validation process**: post-mortem comparison of data between AST and real ageing for **different MEAs, cells & stacks** and AST refinement.

- **Extend the approach to metallic bipolar plates** as far as possible with specific analyses and tests to be defined/applied in a dedicated single cell.

- Go-on with the contribution to **standardization of ASTs for PEMFC** with ID-FAST outcomes and involved partners

Technical progress by WP - Selected items

- From MTR presentation

Ageing and degradation characterizations

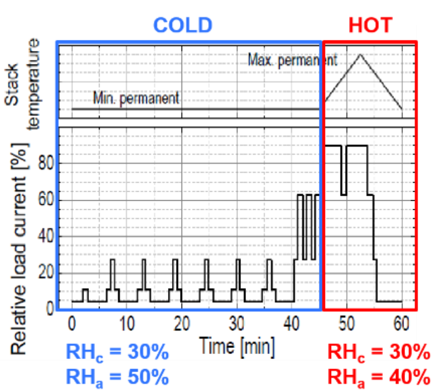
❑ Selection of aged samples from stacks of previous projects

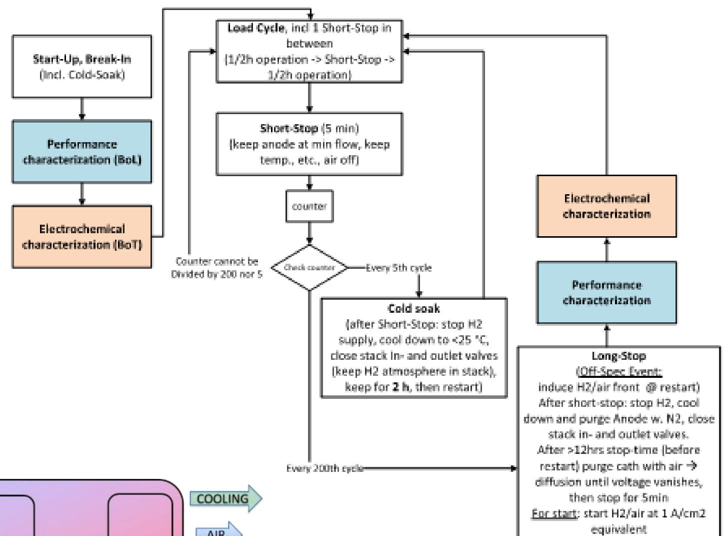
Cf. WP1 & 2

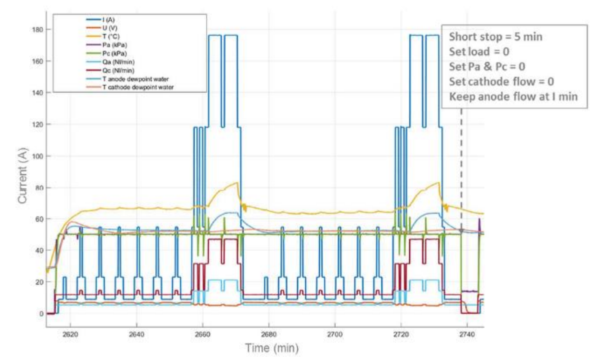
COBRA autostack core IMPACT IMPALA HyWAY

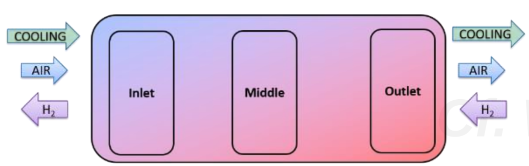
❑ Specification and application of endurance test protocols reproducing real ageing in controlled conditions

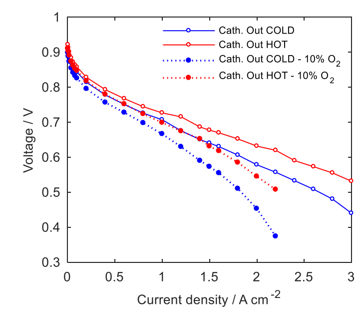
Single cells & stacks











→ Assessment of phenomena to support modelling and empirical AST developments

Ageing and degradation characterizations

- Selection of aged samples from stacks of previous projects

Cf. WP1 & 2

COBRA autostack core IMPACT IMPALA HYWAY

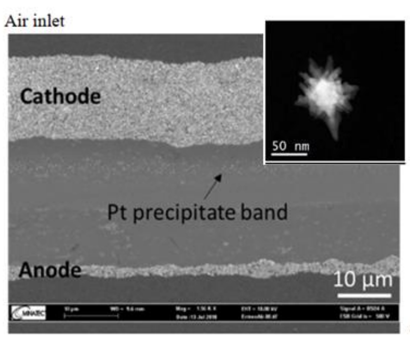
- Post-mortem specific analyses on each stack component

CL, GDL, Membrane, BPP samples

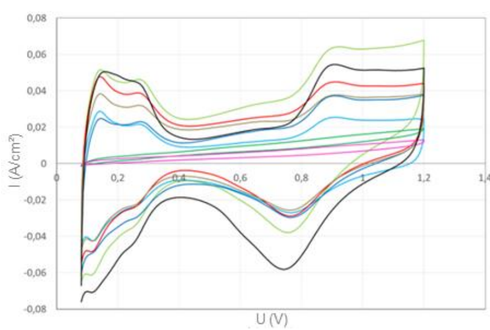
Spatially & vertically resolved distributions

Cf. WP2

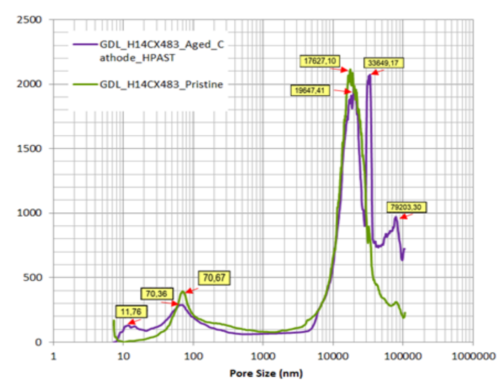
Elemental compositions / Morphology changes / Properties changes



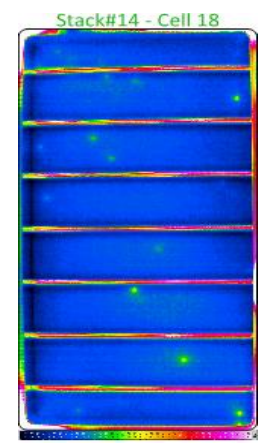
Electron microscopy on the CCM and Pt catalyst



Electrochemical measurements on aged MEA samples from stacks



Pore Size Distribution of GDLs

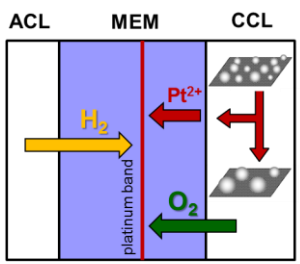


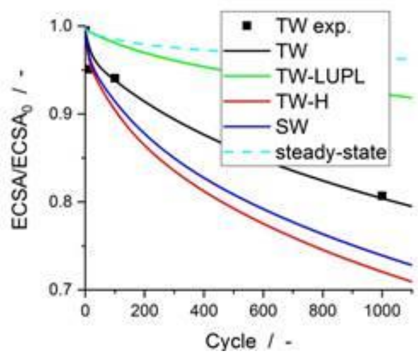
IR thermography on BiPolarPlates

→ Assessment of phenomena to support modelling and empirical AST developments

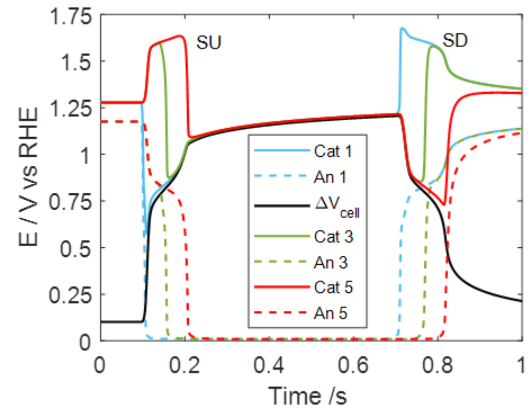
Modeling of MEA components

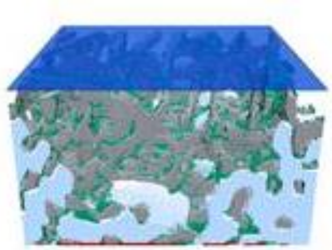
- Modelling of MEA material degradation mechanisms
  - **Pt nanoparticles degradation**





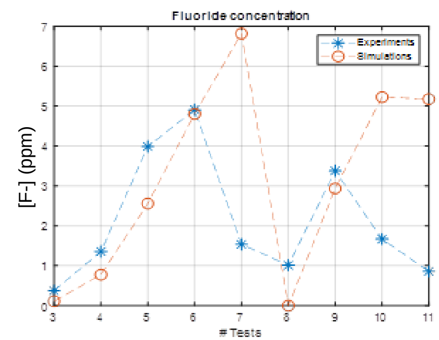
  - **Corrosion of carbon support related to Start-Up / Shutdown**





  - **GDL material degradation impact on properties**

Cf. WP3



  - **Membrane degradation implemented in cell model**

- First coupling of single mechanisms
  - **Effect of catalyst degradation onto membrane chemical degradation**
  - **Effect of catalyst layer degradation (ECSA) on SU impact (C corrosion)**

→ Assessment of stressors impact / Support to AST development and validation

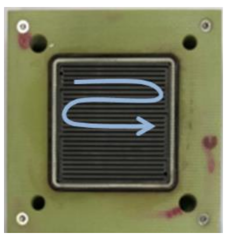
Development of new ASTs

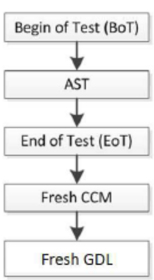
❑ GDL AST

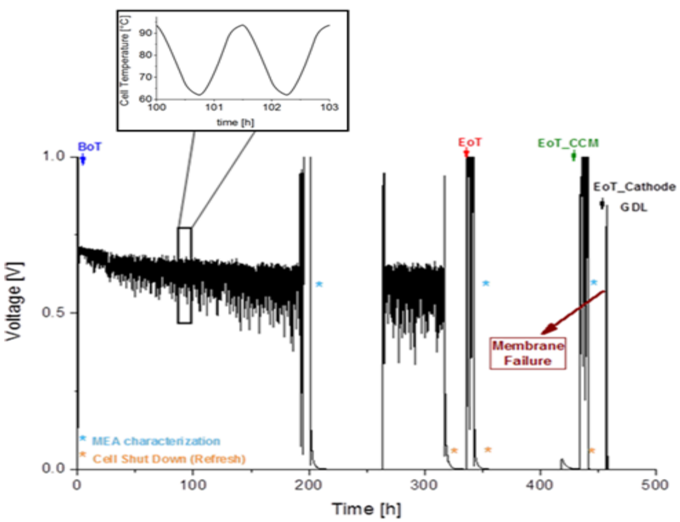
SoA data about impact
& ex-situ tests

New in-situ tests & method
to assess impact of identified
stressors

Cf. WP4

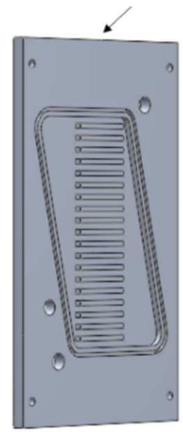


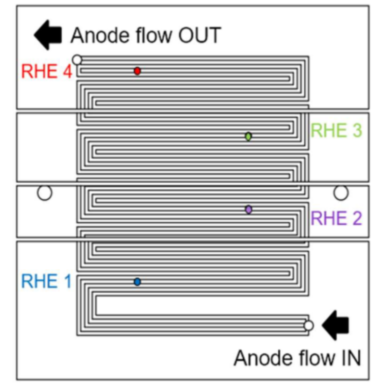




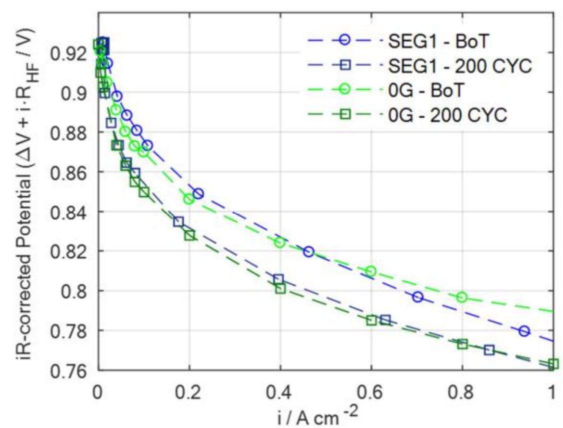
Particle erosion
Mechanical stress
High electrode potential
High temperature
F/T cycling**
Constant load operation

❑ Start-up AST





→ Similar impact confirmed by comparison to real start-up



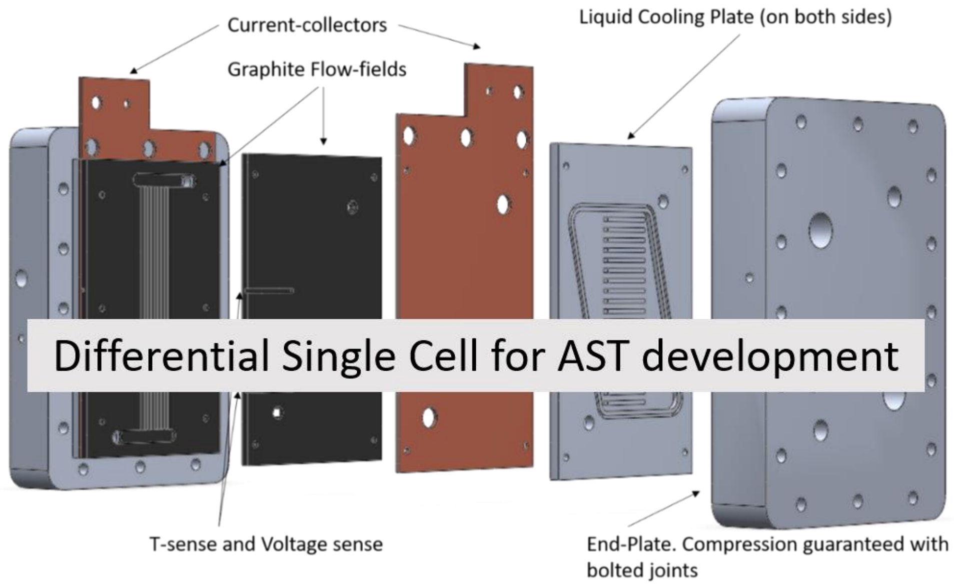
➔ AST development before further combination and validation

Technical achievements - Selected items

- From material supplied for PRD2020

Development of specific single cell hardware for protocols validation

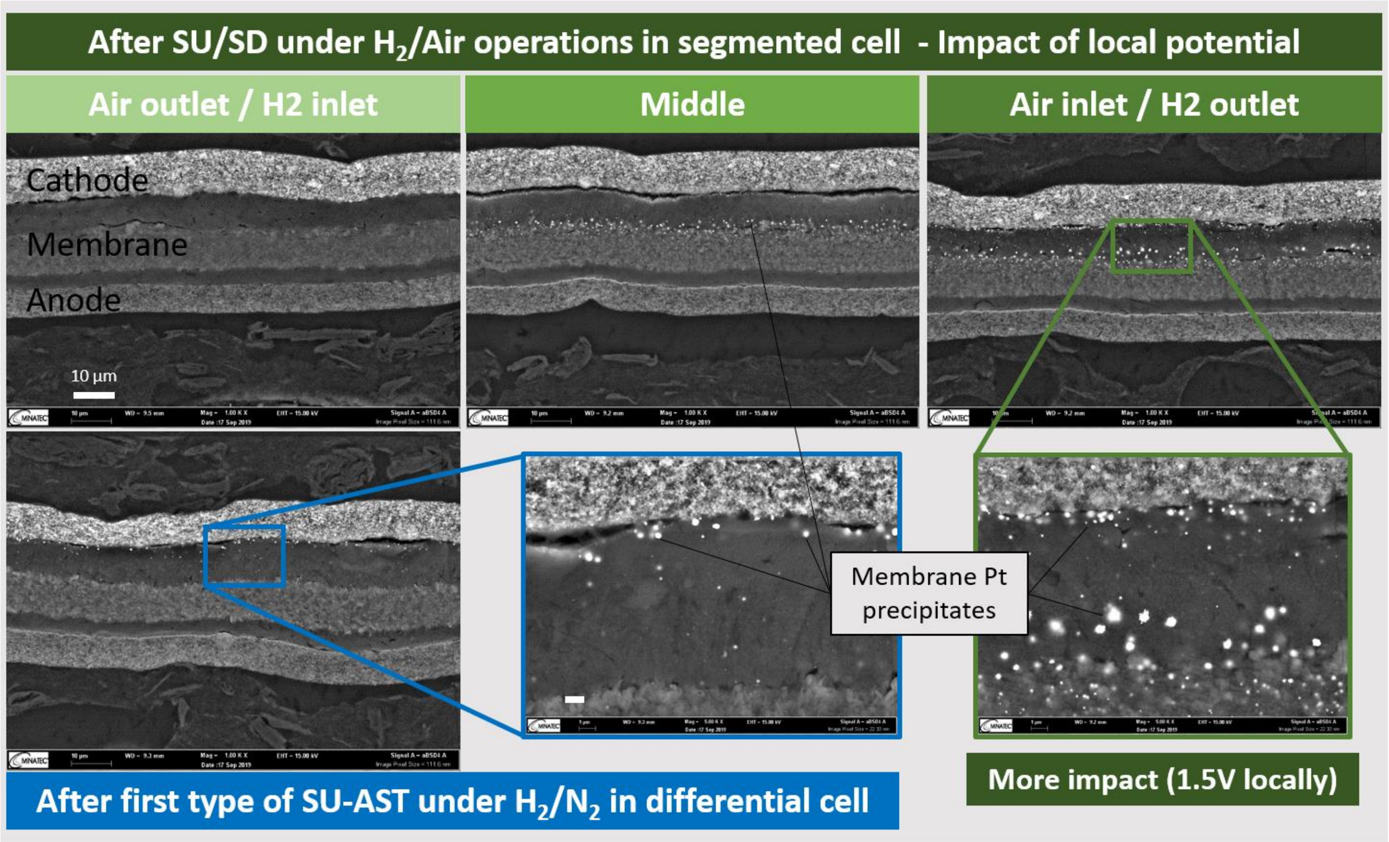
Images for PRD poster



<u>Legend</u>: Differential Single Cell drawing

AST development and ex-situ characterization

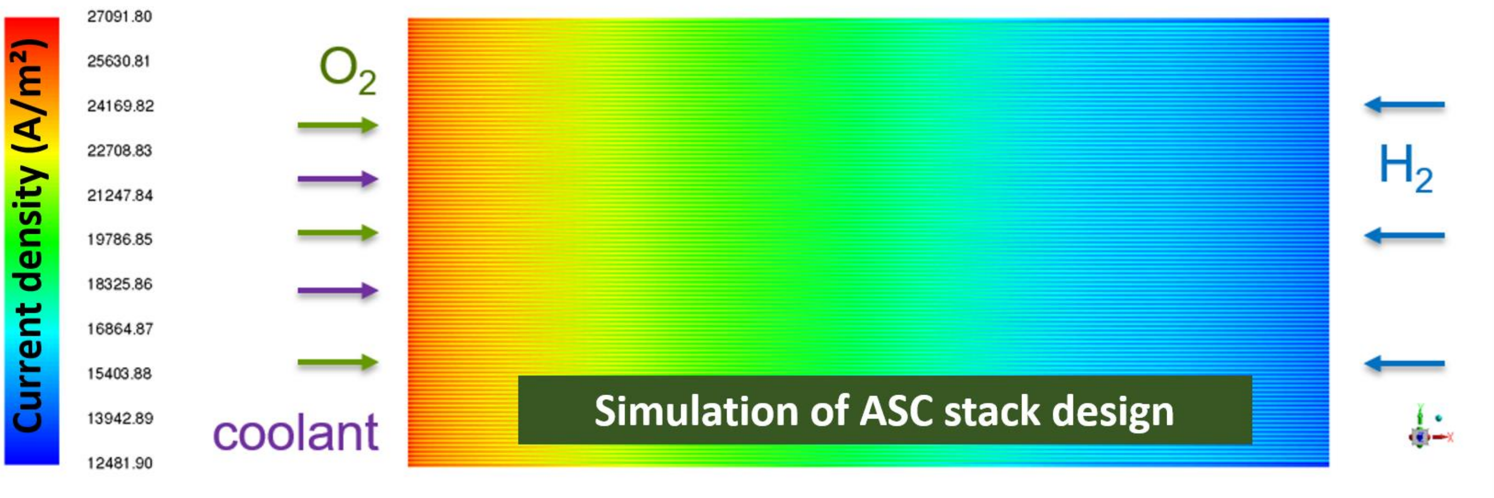
Images for PRD poster



Legend: "ID-FAST post-mortem analyses by Electron Microscopy – Effect of SU/SD "

Modelling and validation of local conditions in a selected cell design

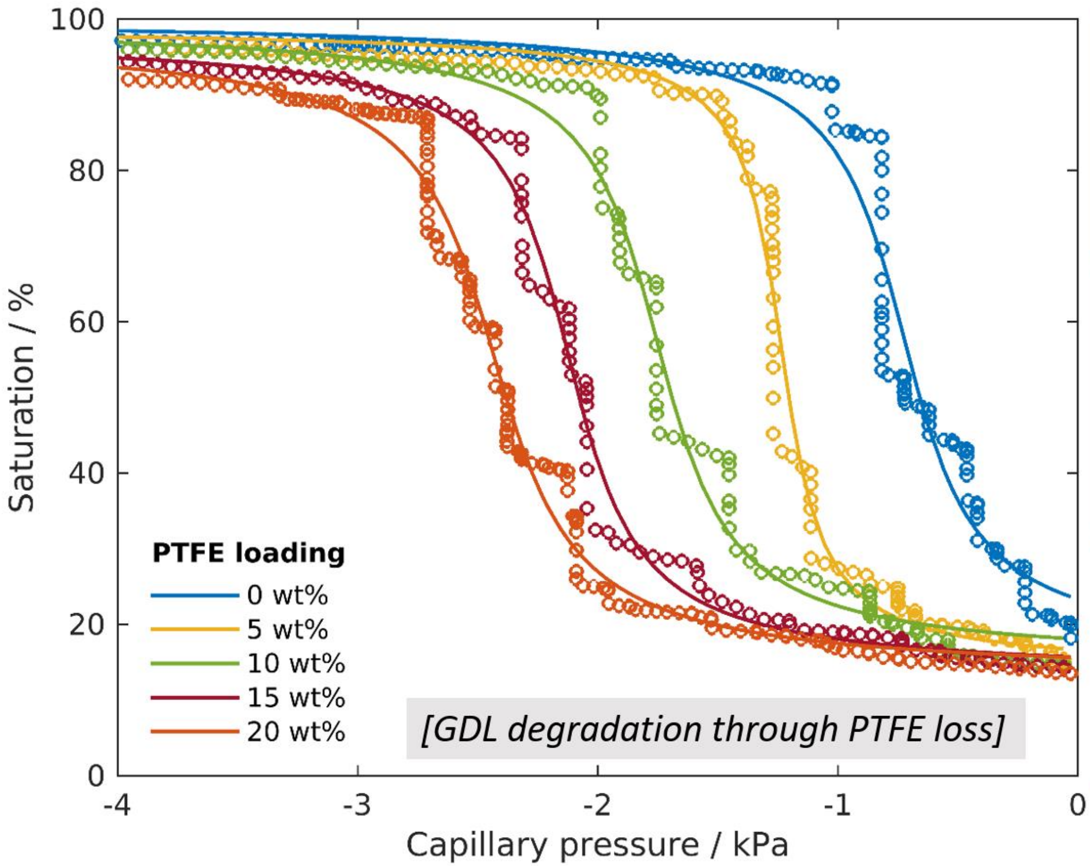
Images for PRD poster

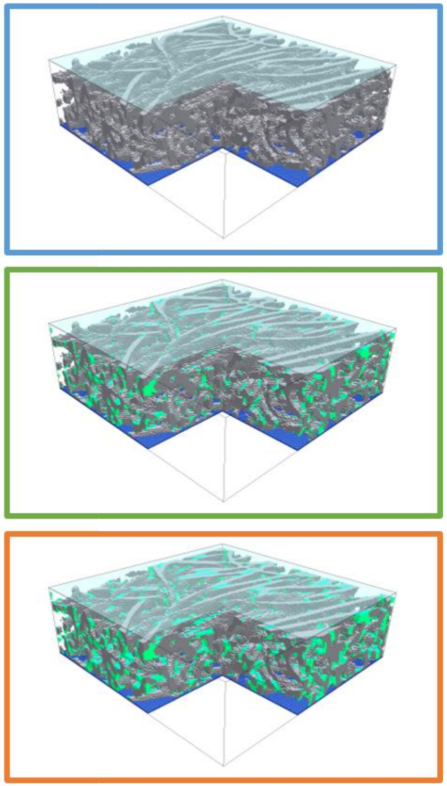


Legend: ID-FAST simulation of ASC cell design - Current density distribution

Development and validation of models for components properties simulation

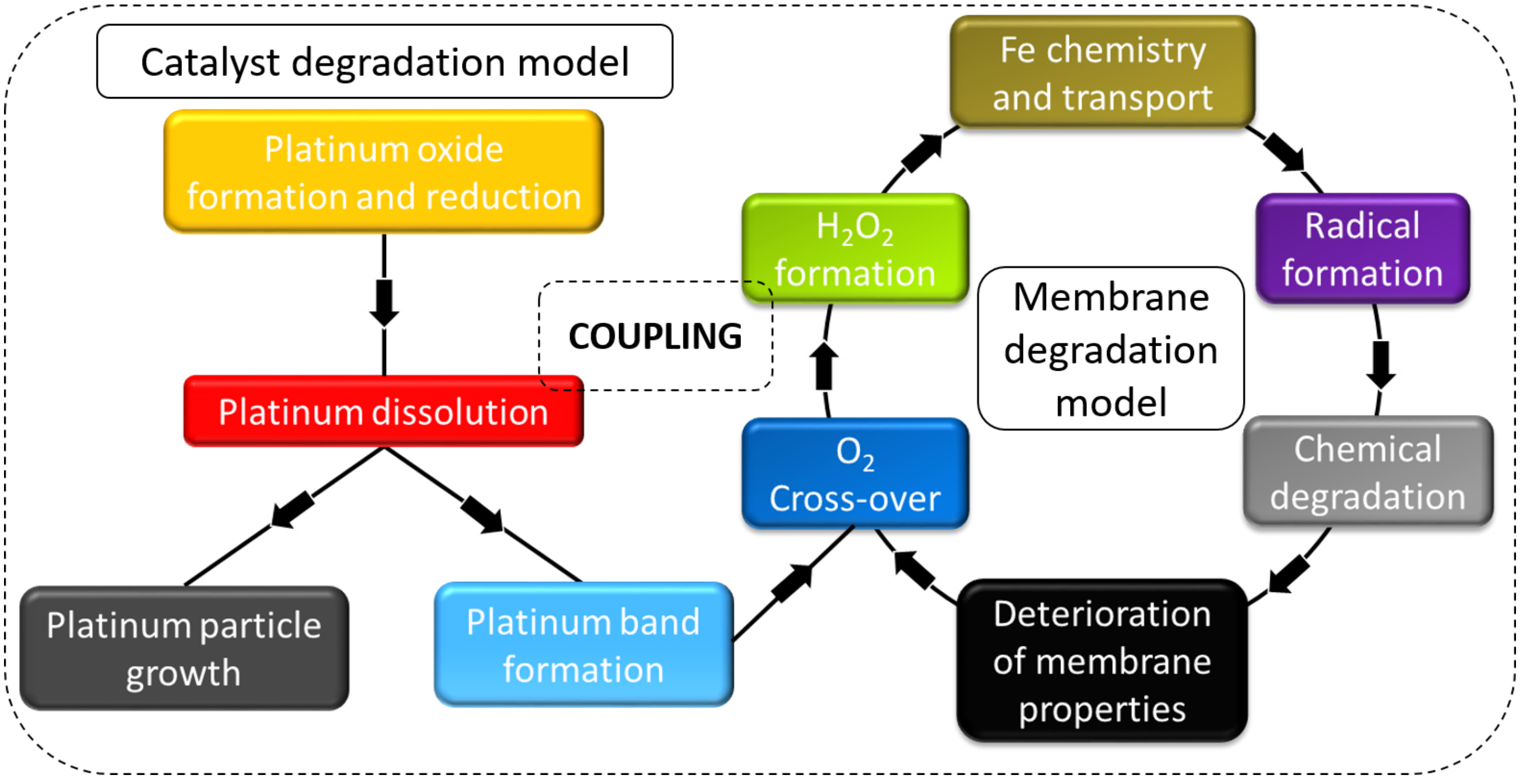
Images for PRD poster





Legend: modelling and simulation of GDL properties

Coupling of models for the simulation of multi-mechanisms degradation



Legend: Scheme of the coupled catalyst and membrane degradation model

Development of new ASTs & Approach towards standardization

❑ Analysis of SoA mechanisms and AST

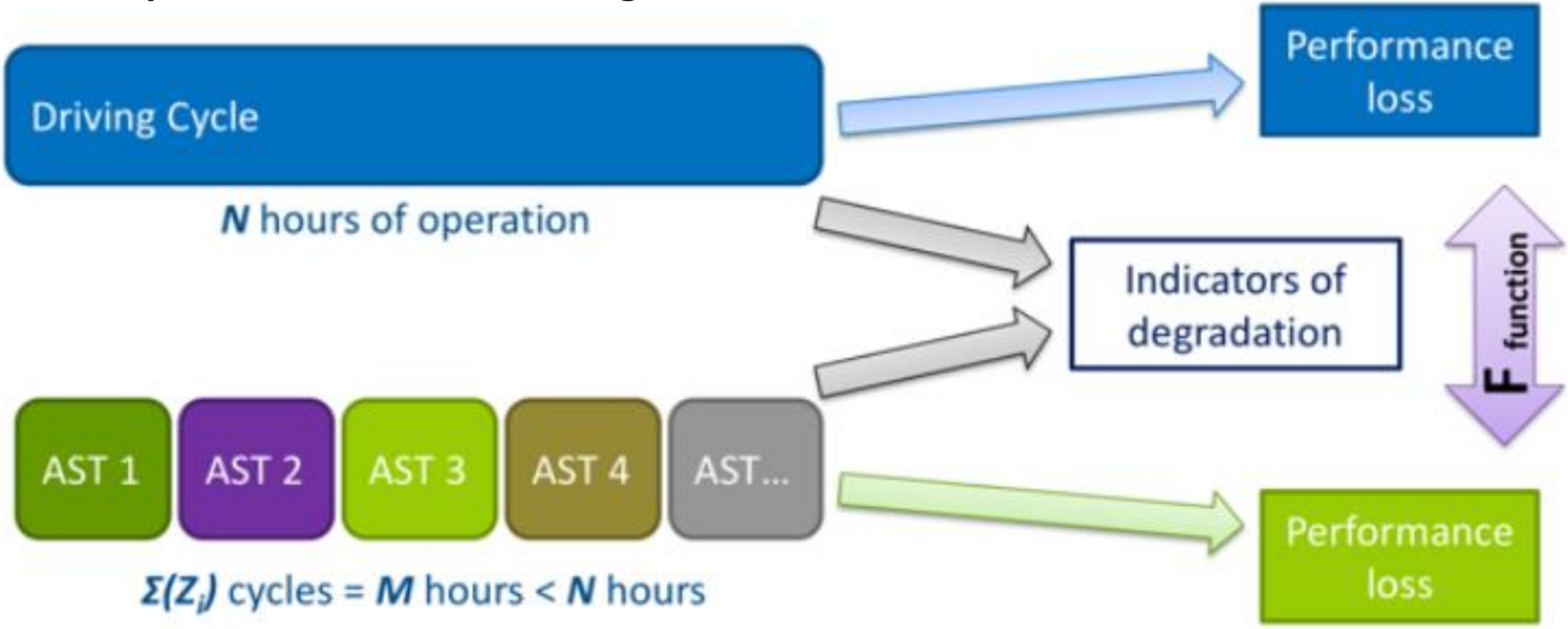
Aim: to propose new conditions and/or new protocols applicable for in-situ operando tests

AST	Mechanisms	Reference AST	Improvement	Indexes (Measurement technique)
Cathode activity loss	PGM dissolution and ripening	DOE, IEC, JARI Based on potential cycling,	potential limits, slew rate, wave form and flow rate	• Mass activity • ECSA loss (CV) • mass transport R (lim. I) • ionomer conductivity (EIS)
Cathode Catalyst support degradation	Carbon corrosion	DOE, IEC, JARI Consolidated for cathode, but stressors not fully understood	Based on potential cycling or simulated start-up	• Mass activity • ECSA loss (CV) • mass transport R (lim. I) • ionomer conductivity (EIS)
Membrane	Chemical and mechanical degradation	DOE, IEC, JARI Consolidated, based on OCV and humidity cycling	Not a priority	• Hydrogen crossover • Ion conductivity • Electric resistance
Porous layers degradation	Hydrophobicity loss, mechanical ageing	Ex-situ not harmonised	in-situ AST	Not defined
Bi-polar plates degradation	Corrosion	Ex-situ not harmonised	Ex-situ and in-situ	Not defined

Development of ASTs & Approach towards standardization

- Approach to link « real » life and ASTs : definition of a transfer function

Aim: to enable reproducing but faster cells performance degradation and predicting losses expected when ageing the cells in conditions representative of real usage.



AST protocols & Standardization approach?

To be considered within IEC TC 105 AHG11 Working Group

- Mechanisms
  - **Single mechanim / single component → SoA ok**
  - **Coupling of mechanisms → less knowledge**

- Conditions or stressors
  - **Generic**
  - Specific ?

- Procedure
  - **Single / Multiple profiles / Combination?**
  - **In-situ / operando ... ?**
  - **Included diagnostics: electrochemical / post-mortem ex-situ ?**

- Validation process included ?
  - **Criteria for representativeness?**
  - **Boundaries for materials and components ?**
  - **Boundaries for the hardwares ?**
  - **Prediction considered ?**

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THANK YOU FOR YOUR ATTENTION