FCH JU Review day 2012

Robust Advanced Materials for Metal Supported SOFC (Grant Agreement n° 256768)

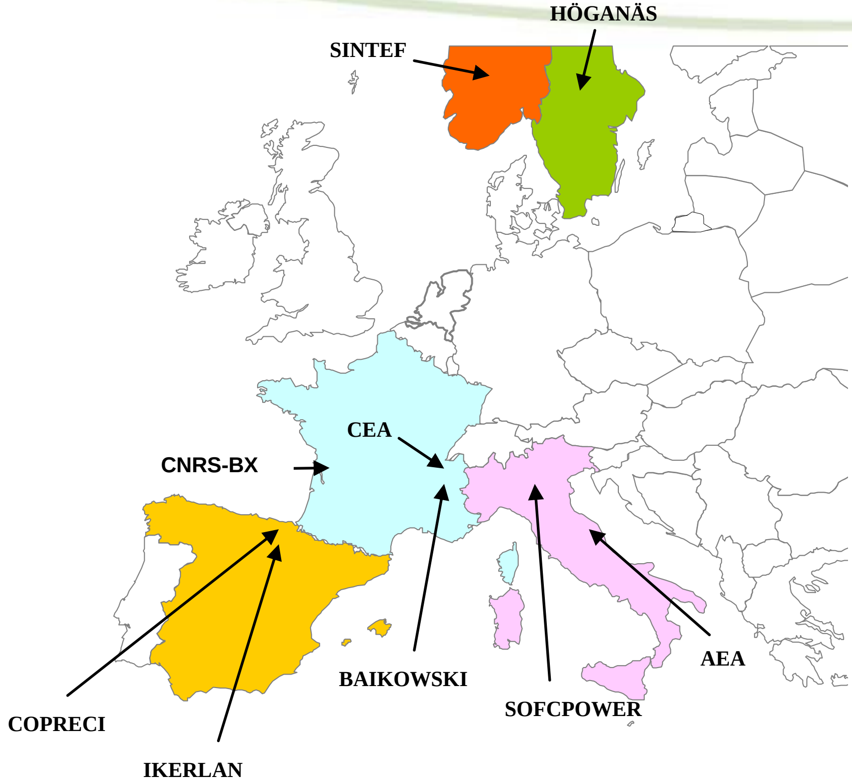
Julie MOUGIN
CEA-LITEN
Head of Hydrogen Technologies Laboratory

0. Project & Partnership description

RAMSES: Robust Advanced Materials for Metal Supported SOFC

- 3 years collaborative project: 01-01-2011 to 31-12-2013
- Total budget: 4'696 k€
- Total funding: 2'140 k€

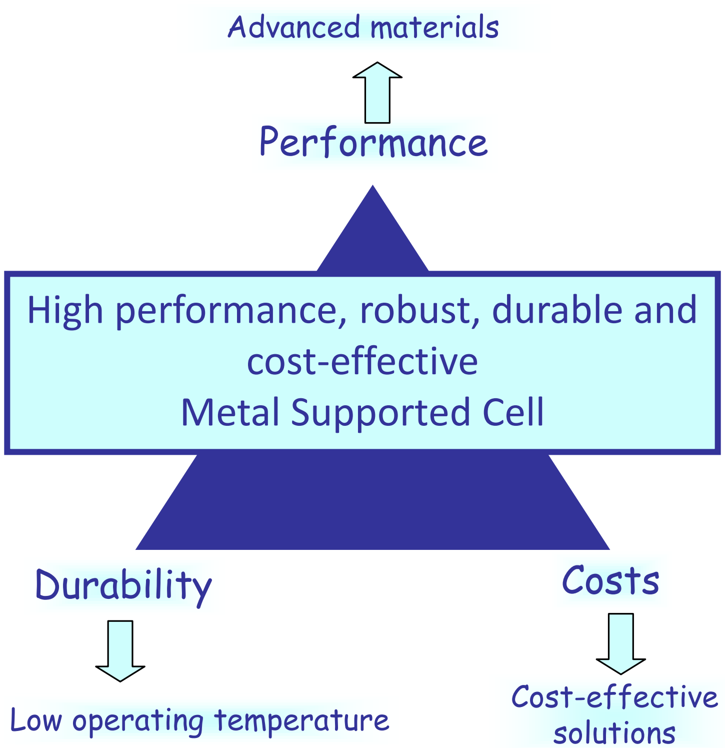
Partners	Type
Commissariat à l'Energie Atomique et aux Energies Alternatives	R&D
SOFCpower S.p.a.	SME
Centre National de la Recherche Scientifique	R&D
Höganäs AB	Industry
Baikowski	Industry
AEA S.r.l	Industry
Stiftelsen SINTEF	R&D
Ikerlan S. Coop.	R&D
Copreci S. Coop.	Industry
National Research Council Canada	R&D



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

www.ramses-project.org

1. Project achievements
Goals and Targets



- **Increase durability through operating at low T:**
  - decreased rate of thermally activated degradation mechanisms
    - cell components
    - interconnects
  - reduced problems due to CTE mismatch
    - within the cell
    - between cell and interconnect
  - simplify BoP components

- **Increase performance:**
  - selection of advanced materials (cell/interconnects/coatings)
  - selection of adapted cell design

- **Reduce costs:**
  - low T = use of cheaper materials, mainly metallic materials
  - cost-effective materials and processing routes

1. Project achievements
Targets and milestones

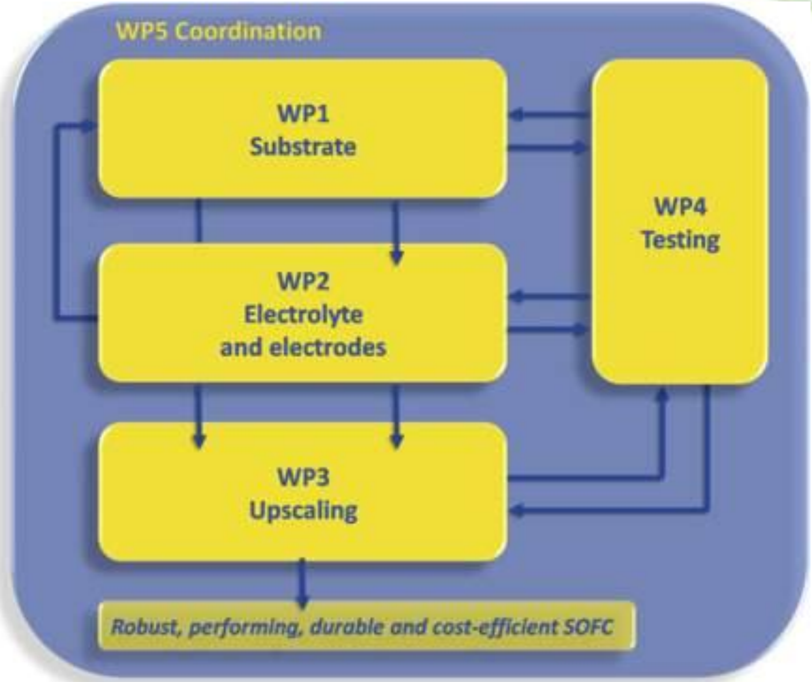
Milestones :

- M0
- M3
- M6
- M9 — MS material selection
- M12
- M15 — Optimised MS
  Gastight electrolyte
- M18 — **Proof of concept at button cell level**
  Selection of the best solution for upscaling
- M24
- M27
- Full-scale cells delivery
- M30
- M33 — Stack delivery, adapted to MSC
- M36 — Proof of concept of short stack operation

- **Technical objectives:**
- Operating at **600°C** with **H_2** or **internal methane steam reforming (ISR)**
- **Planar** and **tubular** MSCs
- **Performances:**
  - planar cells: ASR=0.6 $\Omega.cm^2$ with H_2, 0.8 $\Omega.cm^2$ with ISR
  - tubular cells: ASR=0.8 $\Omega.cm^2$ with H_2, 1 $\Omega.cm^2$ with ISR
- **Durability:**
  - H_2: ASR increase < 15 $m\Omega.cm^2$/kh
  - ISR: ASR increase < 30 $m\Omega.cm^2$/kh
- **Combines thermal and redox cycles**

1. Project achievements
Ramses approach

Approach in performing the activities:



Performance & Durability CRITERIA to follow project achievements

(progressive targets at component and cell levels)

CONTINGENCY PLAN
after Go No Go decision for upscaling in M18

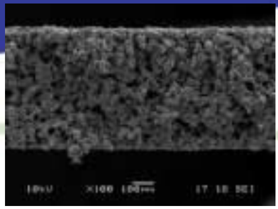
1. materials optimisations
2. development of the manufacturing processes
3. proof of concept at cell → short stack level
4. investigation of the performance, degradation and some specific failure mechanisms

Testing procedures:

- Common protocol defined for single cells
- Following as much as possible FCtestNet and MSC manufacturers recommendations
- Round robin test started

Technical Accomplishments

- **Metal support development:**
  - Several metal powders manufactured: ferritic stainless steels
  - Optimisation of the porous metal substrate manufacturing:
    - – Porosity target achieved: 30-50% vol
    - – Sintering conditions optimised for compatibility with subsequent cell processing
  - Granulometry adaptation to fit with planar and tubular process requirements
  - Suitable coating process developed for porous metal supports
  - Oxidation resistance target achieved both in air and in $H_2/80\%H_2O$: Oxide < 3 µm thick after 500h at 600°C



Milestone: MS material selection (M9) achieved

Milestone: development of MS resistant toward oxidation (M15) achieved

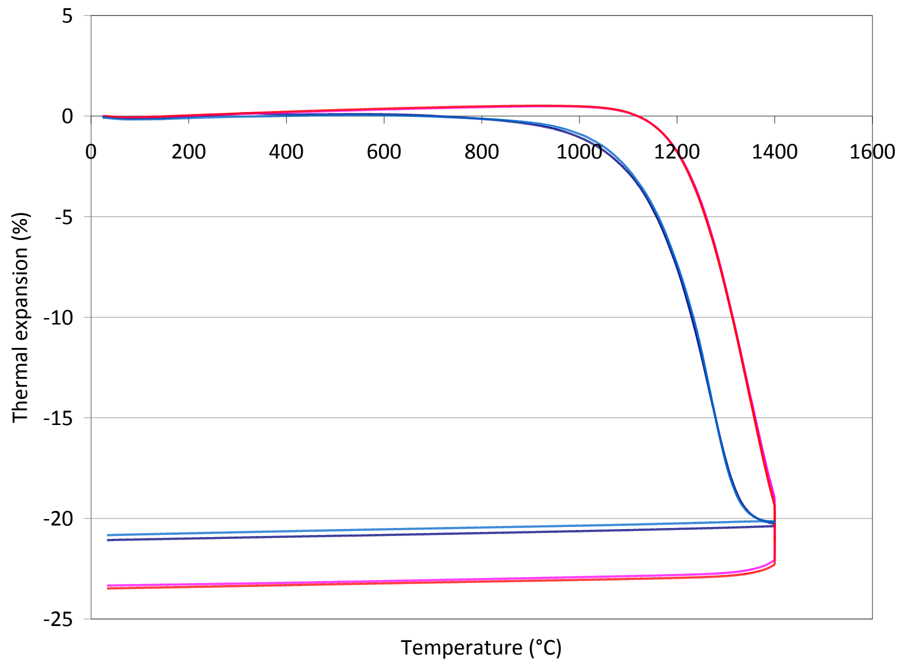
Technical Accomplishments

• Anode development:

- Modified Ni-YSZ allows reaching target of ASR (0.3 Ohm.cm² at 600°C) in specific sintering conditions
- However, integration in MSC not fully successful yet due to reactivity issues ⇒ standard Ni-YSZ kept

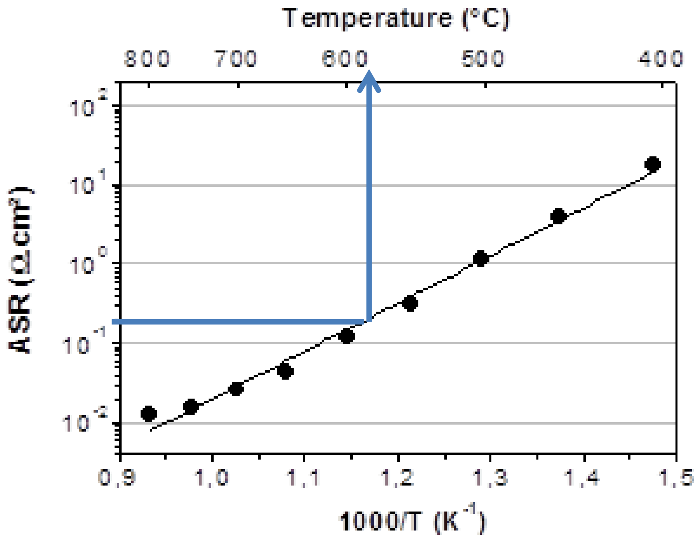
• Electrolyte development:

- 8YSZ
- improved sintering behavior compared to reference Tosoh 8YSZ: -100°C both in air and in reducing atmosphere
- Ionic conductivity and density similar as Tosoh



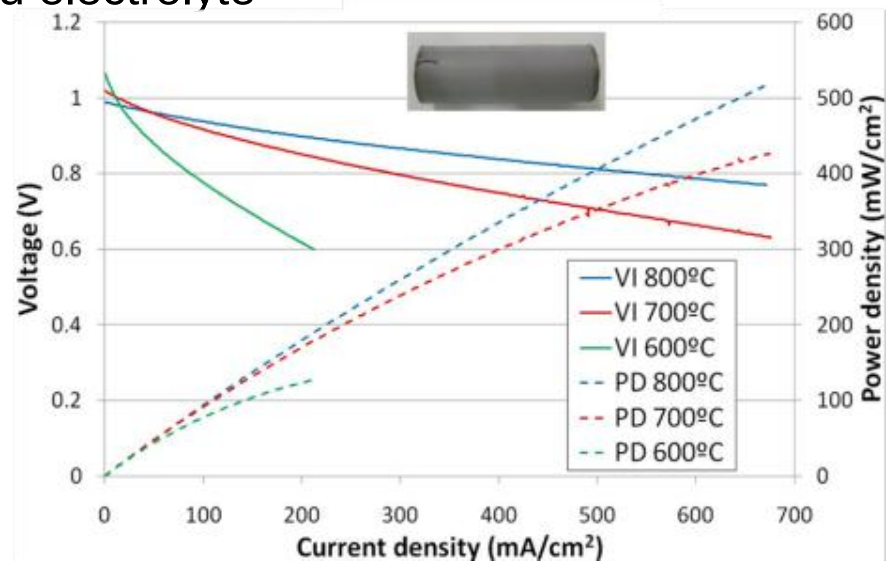
Milestone: gastight electrolyte (M16) achieved

- **Cathode development:**
  - LSC and nickelates Ln_2NiO_4 (Ln = La, Pr, Nd) investigated
  - Best results with nickelates and optimised barrier layer
  - Target of ASR (0.2 Ohm.cm² at 600°C) achieved
  - Thanks to optimised architecture and sintering conditions, low T sintering in low P_{O2} atmosphere possible and demonstrated
  - Material stability achieved in MSC manufacturing and operating conditions



Performance criteria met at the component level

- **Cell development:**
  - Both planar and tubular cells manufactured, including RAMSES materials and/or components
  - Planar cells:
    - Project target not yet achieved
  - Tubular cells:
    - Successful integration of MS and electrolyte
    - Performance target reached: 1.56 Ohm.cm² at 600°C
    - 12 partial thermal cycles and 2 full thermal cycles sucessfully performed
    - 1st durability tests promising: no degradation over 500 h



Proof-of-concept done for the tubular cells in M18 according to milestone

2. Alignment to MAIP- AA3
Stationnary Power Generation & CHP

Target of MAIP – AA3	Project objective	Status at 50% of project
Achievement of principal technical and economic specifications for stationary FC competitivness / other technologies	- Increase SOFC durability: low T operation and more robust MSC architecture - Cost reduction: low T, MSC concept with less expensive ceramic materials	- First durability and thermal cycling results promising - Forecast, gain to be evaluated in 2nd period
Use of multiple fuels	Targets to be reached in the project have been fixed both for H_2 and ISR.	Characterization in ISR pending
Lifetime increase to 40,000 h	low T operation and more robust MSC architecture Degradation target in agreement with such lifetime target	First durability and thermal cycling results promising, complete study during 2nd period
Novel architecture for cell and stacks → improvements of performance, endurance, robustness, durability and cost	Innovative MSC architecture developed in the RAMSES project to achieve these goals	as above

2. Alignment to AIP 2009 – Topic 3.2

Materials development for cells, stacks and BoP

Target of AIP 2009 – Topic 3.2	Project objective	Status at 50% of project
Novel and improved materials can increase performance, reduce statistically based failures, increase lifetime and reduce cost	- Low cost porous metal as cell support - Selected advanced materials, performing at low T, and advanced processes which contribute to the robustness and cost-effectiveness of the concept	- Improved performances obtained for materials, components and tubular cells so far - Planar cell still below target
Development and design of materials to improve performance of both cells and stack and BoP components. Mechanical, thermal and electro-chemical stability should be considered and lifetime and degradation issues relevant to production cost for single cells and stacks.	- Improvement in performance by material and manufacturing development at cell and stack level: WP3 dedicated to up-scaling and stack manufacturing - MSC concept, selected materials and low operating temperature to increase mechanical and thermal resistance and to reduce degradation: WP4 dedicated to test	- Id - 1st thermal cycling and durability results promising

2. Alignment to AIP 2009 – Topic 3.2

Materials development for cells, stacks and BoP

Target of AIP 2009 – Topic 3.2	Project objective	Status at 50% of project
Investigation on failure mechanisms (such as Cr poisoning, redox resistance in SOFCs)	- In MSC: thin anode layer → cell less sensitive to re-oxidation ; 1 task dedicated to redox resistance investigation - Selected cathode materials considered as good candidates regarding Cr poisoning: 1 task dedicated to Cr poisoning investigation	- Redox test not yet started - Tests performed: all materials however sensitive , more or less to Cr, protective coating required
New and improved material production techniques to ↓ cost, emissions	- Low cost processes considered for the metallic support and electrodes - Aqueous route promoted as much as possible	Cost and LCA analysis planned in WP3 during 2^{nd} period
Development of inspection techniques that can be used in manufacturing of materials and cells	Efforts to develop inspection techniques that are transferrable to manufacturing lines, in particular to evaluate the electrolyte gastightness in MSCs by direct or indirect methods: development of inspection technique for electrolyte gastightness will be assessed in 1 task	Task started ahead of schedule; preselection of one technique Task to be continued during 2^{nd} period

3. Cross-cutting issues

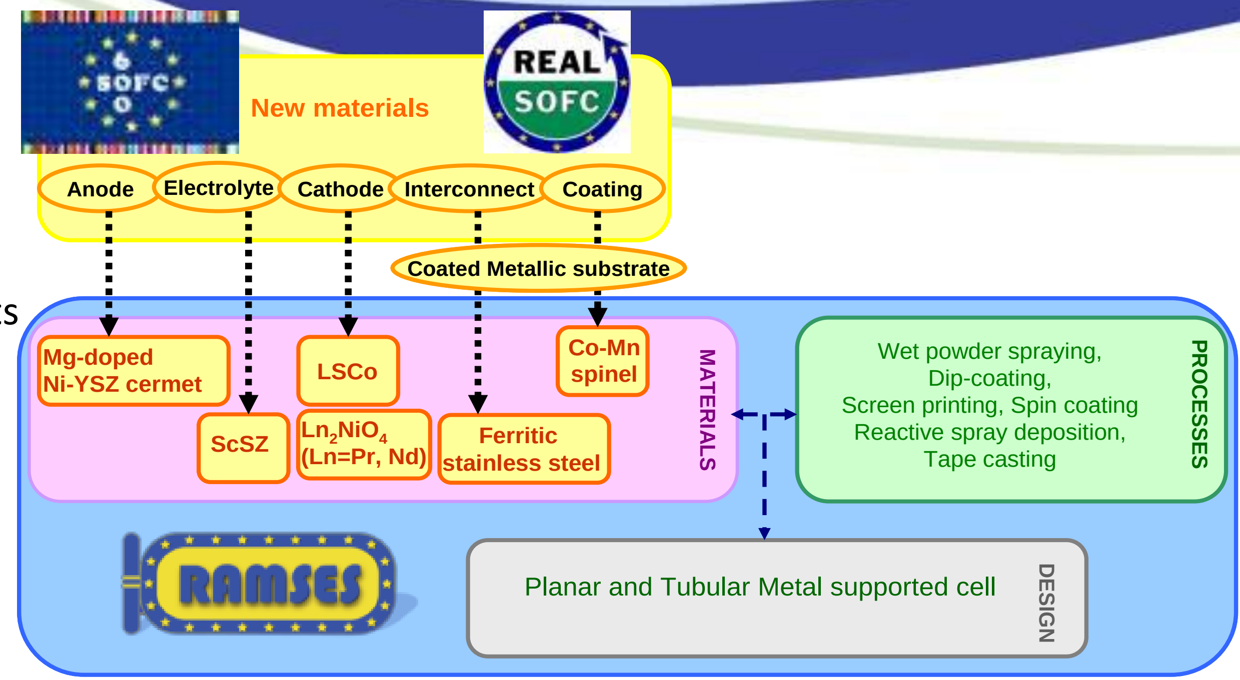
- Training and Education
  - post-doctorates and training engineers contributing to the RAMSES project at several partners
  - exchange of students during the project possible upon request by partners
- Safety, Regulations, Codes and Standards
  - water-based processes, reduction of hazardous materials are considered preferentially for manufacturing for safety/environmental issues, in addition to costs reduction
- Dissemination & public awareness
  - Public website available since M4: www.ramses-project.org
  - Promotion of publications and conference papers, with preliminary validation of the PCC
    - Peer review journals: J. of Power Sources, Fuel Cells, J. of the Electroch. Society, …
    - Conferences: EFCF, SOFC-x series, Fuel Cell Seminar,…
  - Publication to date: Lide Rodriguez, "Tubular metal supported solid oxide fuel cell resistant to high fuel utilization" given at the 10th European SOFC Forum 2012, 26 - 29 June 2012, Lucerne Switzerland: some RAMSES results included
  - Presentation to date: at Workshop "Materials Issues for fuel cells and hydrogen technologies", held in Grenoble on March 26th – 27th 2012
  - Organization of one Workshop on MSCs planned in M36
  - Membership in associations/technical committees (International Energy Agency Advanced Fuel Cells technical Annex XXIV, …)

4. Enhancing cooperation and future perspectives
Technology transfer and collaboration

- Main outputs taken from former FP6 projects:

SOFC600 (FP6-SUSTDEV IP, 2006-2010, ref. 20089, Coordinator: ECN, Common Partners: CEA, CNRS-BX, HTc/SP, NRC): materials developments

RealSOFC (FP6-SUSTDEV IP, 2004-2008, ref. 502612, Coordinator: Forschungszentrum Jülich, Common Partners: HTc/SP, CEA, SINTEF): materials development



- RAMSES also capitalize on previous EU-funded projects:

CEXICELL (FP5, ref. ENK5-CT-2002-00642, 2002-2005, Coordinator: INASMET): cost effective SOFC

FCTESTNET (FP5 ref. ENK5-CT-2002-20657, 2003-2005): testing procedures

FLAME-SOFC (FP6-SUSTDEV IP, 2005-2009, ref. 19875), Coordinator VDI, start-up time requirements and thermal cycle tolerance.

Technology transfer and collaboration

- RAMSES also capitalize on previous national-funded projects:
  - French ANR Fuel Cells and Hydrogen program (program Ceramet, Icare, Ciel, Oxygene) or ADEME program (Armanasol)
  - Italian, Norvegian, Spanish programs
- Complementarities with ongoing projects
  - other architectures and other concept considered compared to METSOFC/METSAPP project
- Participation in the consortium of a Canadian partner (NRC)
- Industrial partners involved in the project

- RAMSES coordinator (CEA) is chairing the N.ERGHY association *(50 European universities and research centres working in the field of hydrogen and fuel cells)*

Project Future Perspectives

In the future, RAMSES could interact with national, European or international projects on MSCs and/or SOFC/SOEC at reduced temperature :

- RAMSES-METSAPP joint workshop (both dealing with MSC)
- ADEL, dealing with 600°C operation in SOEC
- SOFC-Life for generic evaluation of the degradation mechanisms
- DESIGN for diagnostic tools development
- …