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Project Acronym: **IDEAL-Cell**
Project Title: **Innovative Dual mEmbrAne fueL-Cell**

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For the RTD and Management activities on the

IDEAL-Cell project

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Logo of the project:

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1. Publishable summary

The IDEAL-Cell project is funded by the European Community within the Seventh Framework Programme (FP7; 2008-2012). Among the 328 projects proposed in the topic Energy, only 2 on high temperature fuel cell were accepted including the IDEAL-Cell project. This innovative concept was patented in 2005 by ARMINES with an international extension in 2007 for Europe, US and Japan. Considering the highly increasing activities of other Asian countries in the field of fuel cells, it is envisioned to extend the original IDEAL-Cell patent to China and Korea. The project federates a consortium of 9 European partners, both academics and industrials, in Italy, Germany, Bulgaria, Poland and France. Subsequently to ventilation and transfer of resources (conjoined withdrawal and entry of TURBOCARE and VISIMBEL respectively) since the amendment of the Description of Work in July 2009 (DoW – see annex A – 11th of July, 2009), 483 person-months (against 475 with respect to the 1st version – 23th of November, 2007) are engaged at constant volume funding to work on this project, being equivalent to 11 persons working full-time for 4 years.

The breakdown structure of the IDEAL-Cell project is composed of six Work Packages (WPs), five of them being directly involved in the first two years before a Go/No Go decision takes place. Each WP is divided into six interlocked tasks except WP1 (four tasks) which is dedicated to management activities and is under the responsibilty of ARMINES, the coordinator. The IDEAL-Cell project proposes to give an impetus to the high temperature oxide fuel cell technology for stationary applications (industries, residential flats, dwelling houses, hospitals…). The project aims at ***fabricating a dual membrane cell short-stack, with optimized properties and operating conditions in the 600-700 °C range of temperature under hydrogen and air, via low cost forming processes***. The final short-stack will consist of two full dual IDEAL-Cells integrated in an appropriate interconnect architecture that will be specifically designed to take advantage of the concept of three independent chambers.

As the first part of the project aims at proving the IDEAL-Cell concept, the consortium mainly focuses its technical and modelling activities in WP2 (Oxygen Electrode Assembly development), WP3 (Proton Electrode Assembly Development) and WP4 (Dual Cell Realization), the latter being obviously critical for the Go/No Go decision. Indeed, WP4 is devoted to the core of the concept, in other words, the mixed O^{2-}/H^{+} conducting and porous central membrane (fabrication and optimization). Since during the negotiation of the contract, it had been asked to the consortium to occurred very early to the partners that the Proof of Concept should be approached unambiguously through dedicated samples, with well controlled simple geometry, via criteria, as defined under the supervision of our independent advisory board (Prof. Paolo SPINELLI and Dr. Nikolaos BONANOS); this will be extensively explained in this report. Dedicated Proof of Concept (PoC) samples have allowed concentrating more effort in views of the Go/No Go decision rather than dilute resources on shaping directly 5 layers samples, and have given immediate relevant, well calibrated and exploitable data for kinetic, electrochemical and morphology modelling. Therefore, even if a “Proof of Concept” activity as such was not formally planned in the original DoW, one has found of uttermost importance to consider that it should be fully integrated to WP4. It can be mentioned that both BCY10-NiO/dense BCY10/porous BCY10/dense BCY10/BCY10-NiO (see DoW) and LSCF48/dense YDC15/porous YDC15/dense YDC15/LSCF48 (see Deliverable 1.1) pseudo-complete IDEAL-Cells were fabricated during the first year by tape casting and then proved the achievability to realize such a system. Moreover, during the second year, full IDEAL-Cells were obtained directly by a combination of cold pressing and tape casting (one electrochemically tested), and also by depositing electrodes on PoC samples via either tape casting or screen printing.

In addition, since the concept will clearly allow for innovative cell and stack architecture designs, it seemed reasonable to anticipate the work on interconnects within WP5, which requires on the one hand long term testing regarding ageing and reactivity and which, on the other hand, must be thoroughly associated with any research on the architecture design of the central membrane. We have found that the final architecture of the cell could not be approached separately from the shaping of each of the compartments. Therefore, substantial part of WP5 has already started during this first period. These scientific and technical activities have been continuously enriched with management actions in WP1 and communication tools as well as knowledge dissemination within WP6.

This periodic consortium yearly report (YR N°2 – Deliverable 1.2) presents the main advances in the IDEAL-Cell project for the second year (period m13-m24) with respect to the work plan in addition to the implementation of experimental and modelling activities dedicated to the Proof of Concept within WP4, not planned but nevertheless requisite to overstep the Go/No Go decision. This report establishes a quantitative account of the progresses made by the consortium in the diverse WPs activities, which are summarized below:

- Concerning WP1, administrative as well as monitoring tasks were carried out such as the amendment of the DoW (withdrawal of TURBOCARE, entry of VISIMBEL as a full partner, re-allocation of PM and budgets, transfer of the screen printing activities from AGH to CNR), the approval of the annual consortium report (YPR N°1) by the Project Officer, the creation of a monthly news report (suggested during the first year consortium meeting in Krakow and starting-up from the 5th of March, 2009) and the day-to-day supervision of the project. All scientific, technical, legal and administrative issues were discussed and recovery actions were taken in the case of work plan deviations. For the first 21 months of the IDEAL-Cell project, the Management Team drawn up a balance sheet of experimental activities carried out by partners. This action aims to ensure that person efforts follow the DoW requirements. Moreover, the Scientific Coordinator with the assistance of the Direction of European Affairs (DEA) of ARMINES, took the responsibility for communication actions such as the presentation of the IDEAL-Cell project on the occasion of congresses or symposia, the writing of publications or articles in international reviews, some with a large European audience (50,000 issues), the diffusion of the IDEAL-Cell leaflet within and outside the consortium… The implementation of a strategy in view of industrialisation of IDEAL-Cell was already discussed (first year consortium meeting in Krakow) with Véronique CHAPUIS (Head of the Legal Council at ARMINES) and first contacts with an industrial as SAINT-GOBAIN were get up to speed by the project Coordinator. Negotiations with SAINT-GOBAIN to join the consortium as a “full” partner for the phase II (Optimization and Integration of the Dual Cell) are under progress. This potential partner would be responsible for benchmarking activities within task 6.6 (2 PMs), the latter being frozen at the present time. As a conclusion, even if some important decisions had to be taken when unexpected problems occurred, activities of management are unanimously considered as having been excellent;

- Activities in WP2 and WP3 were mainly focused on the synthesis of powders, shaping and testing of the oxygen and the hydrogen compartments. Spray-dried spherical-shaped particles containing LSCF40(48) (and La-deficient LSCF40(48)) powders (tasks 2.1 [start month: m1]) for plasma spraying activities were fabricated. “Standard” YDC15, LSCF40, LSCF48 and BCY15 powders (tasks 2.1 and 3.1 [start month: m1]) are continuously produced and adjusted by MT to supply the stock of partners involved in tape casting and screen printing activities. Symmetrical cells were shaped via tape casting, screen printing and plasma spraying (the latter only for the oxygen compartment) (tasks 2.3 and 3.3 [start month: m6]). These symmetrical cells were electrochemically tested (tasks 2.5 and 3.5 [start month: 8]). Tasks 2.4 and 3.4 devoted to the fabrication of pseudo-symmetrical cells have been arbitrarily set back by the consortium insofar as they are of less pertinence with respect to the ones dedicated to the Proof of Concept, even if one of them was fabricated and being tested in month 25. The role of pseudo-symmetrical cells was to independently evaluate on the one hand the proton conductivity in porous BCY15, and on the other hand the oxygen conductivity in porous YDC15. It seemed to the consortium much more realistic to measure such parameters by feeding successively and independently a central membrane on the one hand with hydrogen, and on the other hand with oxygen. These electrochemical measurements are advantageously coupled to X-ray microtomography experiments made this summer (16th-19th of July, 2009) at ESRF in Grenoble on the central membrane. These extremely interesting and fruitful experiments were not planned in the DoW. Therefore, it seems reasonable to postpone tasks 2.4 and 3.4 to the second phase of the project

if they are still necessary (Optimization and Integration of the Dual Cell). Within tasks 2.6 and 3.6 [start month: m2] some convincing work was carried out to increase the chemical and mechanical adhesion between each layer by improving the quality of interfaces (modifying slurries or inks composition for tape casting or screen printing processes respectively, abrasion or sandblasting of the surface of substrates, optimizing the powders quality as well as process parameters in spray drying). As a conclusion, all types of powders were successfully fabricated after adjustements, all samples were produced successfully by tape casting, screen printing and plasma spraying; all samples were tested except the pseudo-symmetrical cells. Electrochemical results show that the conductivities of YDC15 and BCY15 are excellent, that the couple YDC15/LSCF48 is excellent; but it shows also that some works have still to be done on the anode material, which exhibit deceiving performances, that are currently under investigation;

- Regarding WP4, experimental (tasks 4.4 [start month: m12], 4.5 [start month: m14] and 4.6 [start month: m18] and modelling (tasks 4.1 [start month: m1]) activities were carried out to fabricate, test and model a full non optimized IDEAL-Cell. On this occasion, a simplified design of the dual cell (PoC samples) (task 4.4 [start month: m12]) was proposed, which consists in a central membrane (CM) sandwiched between both dense YDC15 and BCY15 electrolytes on the surface of which standard platinum electrodes were deposited: they were fabricated via several processes (task 4.5 [start month: m14]), some not planned in the original DoW such as spark plasma sintering (SPS) and hot pressing (HP) and electrochemically tested (task 4.6 [start month: m18]) at 600 °C using H_2 and O_2 respectively on the anode and on the cathode sides of the cell, via a dedicated three independent chambers set-up developed to detect and measure the water produced within the central membrane during operation. Electrical measurements established that the simplified PoC samples operate as a high temperature fuel cell with a behaviour characteristic of the device configuration itself. Proof of Concept criteria were defined, and PoC samples have successfully verified them. Lately, a full IDEAL-Cell obtained by cold pressing and tape casting showed the same electrochemical behaviour. On the other hand, an electrochemical macrokinetic model (tasks 4.1 [start month: m1]) was developed to precisely describe the electrical behaviour of the simplified PoC samples and simulation results show that the resulting polarization curve was mainly driven by the central membrane, not by the electrodes which showed very little overpotential losses, as it was expected when the concept was invented in order to eliminate the presence of water at electrodes. Activities regarding PoC samples were not focused on the geometry (layers thickness ranged between centimetres for the HP PoC samples, and millimetres for the SPS samples) and microstructure optimization; therefore the measured performances are evidently low. Modelling tells us which are the pertinent geometrical, morphological and microstructural parameters to play with in order to optimize the electrical performances (thickness of components, tortuosity and percolation pathways of both porosity and BCY15, YDC15 active phases, the active triple phase boundary (TPB) segments length or volume density, the permeability…). Activities on the central membrane fabrication (task 4.3 [start month: m3]) gave rise to promising results: several central membrane samples were prepared by tape casting with varying porosity (shape, size, amount) and proportion (in vol.%) of active phases (BCY15 and YDC15). The morphological parameters could be successfully extracted from X-ray microtomography 3D images analyses. The data were collected at the ESRF (European Synchrotron Radiation Facility) and obtained by scanning the sample in rotation with a high energetic X-ray beam. Results showed that a good control of the porosity over a wide range was easily obtained by adding dedicated pore formers to the starting slurries. The effective properties of the central membranes were effectively predicted from the morphological data and the resulting electrical behaviour was validated by injecting the appropriate morphological parameters into the electrochemical model developed in parallel. A complementary modelling approach by CFD was implemented to optimize the microstructure of the central membrane (CM) for an efficient removal of the water from the cell: results revealed that a channelled or patterned type structure of the central membrane should significantly increase the efficiency of water removal, hence diminish strongly the concentration overpotential in the central membrane. Experimentally, this objective should be easily realized in phase II of the project by adding an organic template/grid, having the shape of the desired channelled configuration, to a well-calibrated CM powder. A new strategy to prepare the composite CM powders in one step through a mixed starting precursor, that is to say without mixing both BCY15 and YDC15 electrolyte powders, was attempted within task 4.3 by the decomposition of a Ba-deficient BCY15 phase. This strategy is though to allow attenuating the difference of sintering behaviour between both BCY15 and YDC15 phases and highly increasing the density of triple phase boundary segment

length per unit volume. This approach is being under way and the consortium considers that this work is an anticipated part of task 5.1 dedicated to the central membrane optimization and forming of the optimized dual cell. Activities on reactivity studies (task 4.2 [start month: m3]) are completed and will allow defining precise thermodynamic sintering and operating conditions within task 5.3 (optimization of operating conditions). As a conclusion, simplified PoC samples and full IDEAL-Cells were obtained and electrochemically characterized; they all verified the PoC criteria defined in agreement with our Advisory Board (i/ stable OCV; ii/ stable polarization curve; iii/ complex impedance signature of water formation; iv/ detection and quantification of water formation in the central membrane). The polarization curve fits well our electrochemical modelling when experimental data are introduced in the model; owing to millimetre to centimetre thicknesses, the measured external current is low, in the range of 1.0 to 10 µA, but the possibilities of optimizing the central membrane morphology and microstructure are under control, especially via the highly relevant outcomes from the high resolution X-ray microtomography measurements and the modelling. **In other words, IDEAL-Cell is a real operating fuel cell**;

- The activities in WP5 have unquestionably begun insofar as first results have been obtained on the central membrane and dual cell optimization (task 5.1 [start month: m25]) (see results in task 4.3), as well as interconnects design (task 5.3 [start month: m25]). A set-up for ASR measurements (Real Life Tester) and some elements for their integration into a short-stack (task 5.4 [start month: m25]) came out during this second year. Modelling activities within tasks 4.1 and 4.3 have already allowed defining which experimental conditions should be the best for an optimal functioning of the dual cell that will be fine-tuned in WP5. Moreover, a new interconnect design for an IDEAL-Cell stack is taking shape (proposed during the “Cell Testing & Design and Interconnect” meeting in Stuttgart, the 10th of December, 2009): it will be more efficient for water evacuation and should limit the surface of metallic components facing aggressive atmospheres. The consortium had considered that it was essential to anticipate these long term tasks, and especially all those dedicated to the ageing and testing of the interconnects, in order to start the second phase of the project in the most efficient possible way. As a conclusion, WP5 was not supposed to start before month 25, but some of its long term activities needed to be anticipated, *i.e.* the fabrication of an original interconnect tester (Real Life Tester) that will evaluate the interconnect behaviour in its real environment (respectively oxidizing and reducing atmospheres on one side and on the other), the onset of the central membrane optimization, elements of integration design and modelling;

- In WP6, the design and the implementation of a public IDEAL-Cell website (task 6.1 [start month: m1] (address: www.ideal-cell.eu/), of an internal one for the management (task 6.2 [start month: m1]) (address: www.ideal-cell-team.eu/), of the organization of the "Advances and Innovations in SOFCs" workshop in Katarino (12th-19th September, 2009) (task 6.3 [start month: m1]) and of the dissemination of internal knowledge (task 6.4 [start month: m1]) correspond to the most important results obtained and actions implemented in WP6. A dozen papers were published in an international frame, and a series of talks in international conferences and meetings were given. As a conclusion, activities in WP6 have been made as efficient as possible and exactly followed the roadmap described in the DoW.

To consolidate the structure and the monitoring of the project, several crucial transversal activities were put under the supervision of experts in the consortium. During the kick-off meeting (Paris – the 19th-20th of February, 2008), the Scientific Coordinator therefore took the decision to appoint 4 “Specific Manager” positions which are:

⇨ Powders Manager (Jean-François HOCHEPIED – investigator from ARMINES);
⇨ Testing Manager (Antonio BARBUCCI – investigator from CNR);
⇨ Modelling Manager (Cristiano NICOLELLA – investigator from CNR);
⇨ Interconnect Manager (Paolo PICCARDO – investigator from CNR).

The role of these “Specific Managers” as well as the main objectives defined by their activities are clearly explained in a dedicated part (see part 5). Indeed, implementation of such Managers made clearer the day-to-day supervision of these different activities and made lighter the monitoring tasks under the responsibility of the Scientific and Technical Manager.