

ESF Exploratory Workshop on
**Proton Conducting Materials For Next-
Generation Solid Oxide Fuel Cells**

Scientific Report

Genova, Italy, 22 - 24 October 2007

Convened by:
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Executive summary

This EW have seen the participation of a total of 24 invited people, including 3 convenors and the ESF representative. Ten European Countries were represented and one participant was coming from the US. A proper balance among age groups was achieved, with most of participant in the range 35-55 but with significant presence of both younger and more experienced scientists. The event stimulated the publication of a few newspaper, web journal and TV articles.

Keynotes, oral and poster presentations focused on the state of the art, recent and possible future developments and perspectives of proton conducting solid oxide fuel cells (pSOFC).

The advantages offered by proton conducting fuel cells over traditional SOFC are multiple and make winning the pSOFC technology over the traditional oxide ion conduction SOFC.

Such advantages are of thermodynamic nature (higher Nernst voltages and efficiency) and technological (no dilution of fuel).

The chemical stability of best protonic conductors represents the main limitation although new, highly stable compounds are under development. Acceptor-doped perovskites are still the most performing materials and all laboratories dealing with high temperature pSOFC try to optimise them, increasing the stability without reducing the conductivity and water uptake. Not many studies have been devoted to electrodes for PCSOFCs yet and many expect that cathodes represent the largest challenge.

Several critical aspects well known for oxide ion conducting SOFC remain relevant for pSOFC. For instance the size effect on conduction needs to be explored. At the moment incomplete and contradictory information is available on the properties of nanosized proton conducting ceramics, both for the difficulty to get reliable samples and for the limited number of laboratories devoted to these aspects. Also mechanical stability issues are largely underestimated or neglected, but would require in depth analysis both through dedicated testing and modelling. Computational approach revealed a powerful tool for the design of SOFC materials (e.g. composite electrodes) and assemblies development.

A number of national projects address this lack of knowledge of SOFC based on proton conducting materials and now also one FP7 project will be dedicated to the development of a new cell concept partially based on the pSOFC approach. “*IDEAL-Cell*” gathers nine among research centres and industries around the Dual Cell concept, i.e. the realisation of a proton conducting anode compartment and an oxygen conducting cathode compartment

In conclusion, the Workshop was defined by participants “*necessary to clarify new directions for research*” on pSOFC and gave impulse to the formulation of some initiatives in form of RNP and COST actions, which are expected to be submitted in 2008.

Scientific content

Solid proton (H^+) conductors offer in principle considerable advantages as electrolytes in fuel cells over aqueous or polymer H_3O^+ conductors because of higher operating temperature and resulting cooling efficiency and higher heat value, less water management, less electrode poisoning, and overheat robustness. More important is that proton conductors – because the cell produces water at the cathode – give much easier fuel handling, less fuel dilution, higher fuel efficiency, higher Nernst voltages, and higher overall efficiencies than the traditional oxide ion conducting solid oxide fuel cells SOFCs. Equally important, since the oxygen activity on the fuel side remains more constant during load, an anode material like Ni remains stable over much more of the power curve, enabling one to draw peak loads without oxidising an anode and thereby ruining a whole stack. This gives a proton conducting SOFC (PCSOFC or PCFC) a “turbo” that the SOFCs don’t have and allows the use of a smaller stack for the same power range.

As an example of higher efficiency, a PCSOFC running on hydrogen with 3 % water vapour at as much as 97 % fuel efficiency, and at 2/3 of maximum power, operates at an overall efficiency (electrical power only) of 45 %, while an SOFC under the same conditions runs with 25 % overall efficiency. In this example the air flow was three times that needed (3 air stoichs). If running at more moderate 80 fuel utilisation the SOFC catches up a little, and the PCSOFC and SOFC run at 40 and 30 % overall electrical efficiency, respectively. Advantages are also achieved with highly reformed carbon-containing fossil fuels or bio-fuels.

Today, the purely proton conducting materials comprise solid acids like $CsHSO_4$ and CsH_2PO_4 , high temperature polymers like the polybenzimidazole (PBI) based films, and ceramic oxides. The two first operate around 200 ± 50 °C and have advantages and disadvantages. Proton conducting ceramics are oxides normally acceptor-doped and compensated by mobile protons in the presence of water vapour at high temperatures.

The state of the art materials are barium-containing perovskites. An empirical correlation indicates that those with small difference in electronegativity between B- and A-site cations are easiest to hydrate, so that high proton concentrations are maintained in e.g. acceptor-doped $BaCeO_3$, $BaThO_3$, and $BaZrO_3$. They also exhibit high proton mobilities and proton conductivities up to around 0.01 S/cm at intermediately high temperatures. However, they suffer from reactivity with CO_2 and – at ambient temperatures – H_2O .

Sr-based perovskites like $SrCeO_3$ exhibit half an order of magnitude lower conductivity, but equally poor stability.

The goal has thus been – and is – to identify chemically more stable – less basic - proton conductors. A couple of years ago, proton conductivity in rare earth niobates and tantalates was reported. The highest conductivity is found for $LaNbO_4$ with ca. 0.5 % Ca substituting for La. The tantalates exhibit lower conductivities than the niobates. The proton conductivity of $LaNbO_4$ is of the order of magnitude of 0.001 S/cm, requiring very thin electrolyte films, down to 1 μm . The materials are chemically and mechanically robust, the latter caused by their ferroelasticity.

The niobates are examples of materials with oxide ion tetrahedra, as opposed to the perovskite’s octahedra. Proton jumps must take place between polyhedra instead of within them, giving lower mobilities. Moreover, the stability of the tetrahedra makes defects like oxygen vacancies and protons have large formation energies, limiting the solubility of acceptor dopants. Nevertheless, the higher stability and robustness is

attractive and leads to continued search for suitable fabrication of thin membranes and better materials candidates.

Amphoteric or basic hydroxides – that is, oxides with structural protons – are potentially excellent proton conductors for intermediate temperatures. All candidate hydroxides decompose before the protons become mobile but several groups are intensively studying such class of materials. A number of natively oxygen deficient oxides can be hydrated into oxyhydroxides, and these are being investigated with respect to conductivity and thermal disorder. Examples comprise $\text{Ba}_2\text{In}_2\text{O}_4(\text{OH})_2$, $\text{Sr}_4(\text{Sr}_2\text{Nb}_2)\text{O}_{10}(\text{OH})_2$, and $\text{La}_{26}\text{O}_{26}(\text{OH}_2)(\text{BO}_3)_8$. Many of these are very basic and thus merely model materials at this stage. Since the materials tend to decompose at elevated temperatures, high water vapour pressure cells are being employed to stabilise the hydroxides to high enough temperatures that proton disorder can be observed. Future work should also comprise aliovalent doping of hydroxides.

Not many studies have been devoted to electrodes for PCSOFCs yet. Electrode materials have comprised the noble metals, notably Pt and Pd, and Ni for anodes and traditional perovskite SOFC cathode materials. One might expect that in particular Ni would function well for hydrogen/proton exchange at the anode, and that Ni cermets with the electrolyte could be applied like for SOFCs. But the chemical and thermal compatibility with the new electrolytes must be checked.

Many expect that cathodes represent the largest challenge. Metals are out of the question, and mixed proton electron conductors are not easily at hand. It remains to be seen whether such mixed conduction is necessary or whether a suitable “cercer” composite (one ceramic proton conductor and one ceramic electron conductor) can be developed.

The rising interest in nanotechnology has led to a series of questions about the properties and usefulness of ionic conductors on the nanoscale. Thanks to the efforts of the pioneers in this subject, it has been shown that electronic conduction can also appear in non-doped ceria when the grain size is below 100 nm. The nature of the electrical conductivity in nanograin-sized heavily doped ceria is not yet thoroughly understood although great progress has been made with the space charge theory. Electrons, ions and protons are the most likely charge carriers and bulk or grain boundary are the likely migration paths. Results on nanocrystalline bulk materials, however, are limited because of the difficulty in maintaining the nanostructure during densification of the nanopowders. The interaction between water and electrical properties of Ln-doped ceria has not been properly addressed to give a definitive answer. It is a known fact that the surface of cerium oxide is catalytically very active and that a variety of molecules can be trapped in the surface of the nanoparticles. It has been suggested that water has a high solubility in ceria. The suggestion has been followed by strong indications that this is correlated to the basic nature of the rare earth dopants. These rare earth oxides have been proved to be proton conductors. These results have led to a series of questions that will need to be answered if the material is going to be used as a solid electrolyte in fuel cells. Can water be readily dissolved in doped ceria? To what levels? What happens to that water when the material is sintered? Can protons move freely in the interfaces of nanoceramics? Can this amount of water be responsible for the variety of results observed in the literature? Can the segregation of dopants lead to a Ln^{3+} enriched regions where proton conduction can take place? How can we detect protons in these oxides?

Interesting results might come from quasi-elastic neutron scattering (QENS), carried out in large-scale facilities. Proton diffusion is believed to be a two-step process, where at moderate temperatures protons rotate locally around a lattice anion with very low activation energy in the order of few meV. At higher temperature, the proton may overcome the activation barrier of 0.1 to 1.0 eV to leave this site and jump to another anion. This is coherent with results obtained on acceptor-doped BaZrO₃, particularly with high yttrium substitution. Proton motion in solids with diffusion constant D causes an inelastic neutron peak broadening. The full-width-at-half-maximum (FWHM) of the Lorentzian fit of scattering curves shows a linear trend vs. Q^2 , leading to the conclusion that the protons move by successive jumps, probably along oxygen ions in the lattice. The slope of either linear curve corresponds to the diffusion constant D, confirming that D increases with increasing temperature. The Arrhenius representation of D(T) from QENS shows that the proton diffusion between 700 K and 900 K is thermally activated with an energy of $E_a=0.13$ eV, whereas below 700 K, the activation energy is only 0.04 eV. Two ranges with different activation energy at around 700 K are observed in other systems as well. For instance, the corresponding activation energies for SrCe_{0.95}Yb_{0.05}O_{2.925} with 3-10 micrometer grain size are 0.61 eV and below 100 meV, respectively.

Current trend in SOFC research is to lower the operating temperature in order to benefit from reduced costs, increased durability, easier design and engineering, affordable portability. The decrease of the operating temperature of HTFCs in the next years most rely on the improvement of existing materials and/or in the development of new microstructures and architectures. Limitations to temperature decrease basically come from the reduced conductivity of the active materials. The application of thin electrolyte layers (about 5-10 μm) is a problem solving approach which, however, makes critical the contribution of the electrodes.

Requirements for electrodes with high electrochemical activity are:

- high ionic conductivity and efficient oxygen transport;
- high electronic conductivity;
- efficient transport in the gas phase (pores);
- high density of electrochemically active zones.

In addition, for anodes supporting the cell, mechanical resistance is also a basic requirement. The key factor to find a good compromise among the different requirements is to design and realise the proper connectivity among different phases avoiding tortuous and/or resistive paths. It is possible to identify a few architectures with different complexities which satisfy, at least in part, the different requirements, by taking into account size, shape and reciprocal orientation of all the three phases. Some examples are:

- composites with controlled microstructure and porosity obtained by using templating agents or pore formers (e.g. graphite, corn starch, latex spheres) and by modification of size, shape and orientation of the solid component particles. The relative volume fraction of the components is a further microstructure parameter which has a strong impact on electrochemical activity.
- ordered macroporous materials of the ionic conducting phase decorated on the inner surfaces or admixed with particles of the electronic/mixed conductor.

- arrays of micro/nanorods of the ionic conducting phase where the empty space between the rods is filled with a porous matrix of the mixed conductor. A less sophisticated version of this architecture is a porous film with columnar structure where porosity is located around the “pillars”.

More generally, the major issues to be addressed to control the PCFC’s behaviour are:

- Controlled manufacturing process of proton conducting electrolyte as a thin film
- Development of porous electrodes that also exhibit good conducting properties, either electronic or preferably mixed electronic-ionic, at these intermediate temperatures,
- Quality of the interfaces between electrodes and p-electrolyte that correspond to the location of i) the proton defect creation controlling the proton conductivity in the electrolyte and ii) the charge transfer reactions responsible for the activation polarisation,
- Influence of the surrounding atmosphere and temperature on the nature of the charge carrier (proton, hole or anion) and consequences on the electrolyte conductivity,
- Stability of p-electrolyte towards CO₂ as far as direct hydrocarbon fuelling is concerned

Modelling is a recognised powerful approach to study and optimise complex electrochemical devices like Fuel Cells. Accurate models are necessary to investigate different phenomena occurring in the electrochemical core, to define proper operating conditions, to guide experiments, and to optimise conduction, technological development and system design. For this purpose, a micro-model description was developed in order to obtain the local kinetic behaviour of the cell that allowed to determine the local consumption rate of reactants and local electrical current per unit electrode area. Then, the local micro-model was introduced into a two-dimensional macroscopic model that allowed to evaluate significant variables on the cell plane. Some specific results obtained from this approach, together with comparison with experimental data, will be presented and discussed.

The models developed for traditional SOFCs can be extended, with suitable modifications, to p-SOFCs

Advanced electrochemical data analysis is also required in order for investigation and identification of the effect of different components of PCFC devices. Since the precision of the identification depends on the quality of the impedance data, the preliminary estimation and correction of potential errors is very important. Although often underestimated, this procedure, known as data pre-processing, is very essential. One of the common and highly desirable properties of fuel cells is the low internal resistance, which is in the range of mΩ. For SOFC this requirement is fulfilled at elevated temperatures. Thus their precise and reliable analysis needs knowledge and procedures for evaluation and elimination of the parasitic inductance errors. The main sources of inductance errors are the self-inductances of the connecting cables, of the electrochemical cell, of the investigated object and of the shunt. Although more pronounced at higher frequencies, those errors have significant effect in the middle and even in the low frequency range for objects with very low impedance, such as fuel cells. Fuel cells are typical fuzzy objects – their electrodes are porous and have a large developed surface. Thus from one hand the resulting impedance corresponds to a system with unknown distribution of the parameters and from another the knowledge-

based theoretical models necessary for data analysis are rather an exception, than a rule. This basic problem of the parametric identification, which needs preliminary working hypothesis, can be bypassed by applying the technique of the Differential Impedance Analysis (DIA). It provides both structural and parametric identification without initial construction of a hypothetical model, i.e. the model structure is extracted directly from the experimental data. In addition this method for “soft computing” has high selectivity, good noise immunity and recognizes easily distribution of the parameters.

Current status and future trends of planar solid oxide fuel cell (SOFC) interconnect (IC) materials have been also discussed, with special attention to research and development efforts for protective coatings on ferritic stainless steel (FSS) and considerations for proton conducting SOFC systems.

FSS are promising candidates for SOFC-IC materials operating $<800^{\circ}\text{C}$. Protective and functional coatings can significantly improve SOFC-IC performance and durability.

Coatings on FSS for the SOFC-IC application range in composition and architecture, with those most common being various oxides with perovskite, spinel or corundum crystalline structures. Examples of common SOFC-IC coatings include: 1) perovskites with similar composition to SOFC cathode materials (e.g., $\text{La}_{1-x}\text{Sr}_x\text{MnO}_3$); 2) spinels with different mixtures of cations (e.g., $(\text{Co},\text{Mn})_3\text{O}_4$ or $(\text{Cu},\text{Mn})_3\text{O}_4$); and, 3) corundum-type oxides with different cation ratios (e.g., $(\text{Cr},\text{Al})_2\text{O}_3$). These coatings vary in thickness from submicron to over $20\mu\text{m}$ and are applied using different solution and vapour-based techniques.

Proton-conducting SOFCs may introduce additional challenges for FSS interconnects. Since steam is produced at the cathode side, the additional moisture may affect air-side corrosion behaviour. Furthermore, hydrogen transport through FSS may be affected by absence of water vapour in the anode gas phase (as is the case for oxygen ion conducting SOFCs).

Future research should focus on characterizing fundamental corrosion/protection processes for coated and uncoated FSS in conditions relevant to proton-conducting SOFCs. In addition, attention should be directed toward the technical and economical aspects involved with industrial scale-up of coating technologies

The realization of PCFC structures was presented. Tape-casting and co-sintering of $\text{BaCe}_{0.9}\text{Y}_{0.1}\text{O}_{3-\delta}$ (BCY10) – based layers was successfully prepared by the use of organic solvent/binders like Ethanol-Poly(vinylbutyral)/Poly(ethylenglycole). Excellent interface adhesion and mechanical integrity were observed as well as appropriate microstructures for all the components.

Such results supported the ideas that support the FP7 Project “Innovative dual membrane fuel cell” – (IDEAL-Cell).

IDEAL-Cell proposes to develop a new innovative and competitive concept of a high temperature Fuel Cell, operated in the range $600-700^{\circ}\text{C}$, based on the junction between a PCFC anode/electrolyte part and a SOFC electrolyte/cathode, through a mixed H^+ and O^{2-} conducting porous ceramic membrane. Protons created at the anode progress toward the central membrane to meet with Oxygen ions created at the cathode, to form water, which is evacuated through the interconnected porosity network. Therefore, Hydrogen, Oxygen and water are located in 3 independent chambers, which allows avoiding all the detrimental consequences linked to the presence of water at electrodes (low fuel and

electrical efficiency, interconnect corrosion, need for a gas counter-flow...). The IDEAL-Cell concept brings a considerable enhancement of the overall system efficiency (fine-tuning of the catalytic properties of the electrode, possibility of applying a pressure on both the electrode sides, simpler and more compact stack-design with less sophisticated interconnects, more efficient pre-heating of gas, simplified heat exchange system for co-generation, availability of high quality pure water for vaporeforming ...).

European research opportunities on Fuel Cells were presented by the Commission. The European Commission has naturally followed the state-of-the-art and one can say that there is a clear increasing trend in EU funding to Fuel Cell research over successive FPs. Just during last FP6, more than 150M€ of EU funding was awarded to research and demonstration projects for Fuel Cells in FP6, not just funded by the Sustainable Energy Systems but also from many other Thematic Priorities as research cuts across a number of different areas and the existing funding instruments. Europe and the rest of the World share the common objectives of providing abundant, clean, secure and affordable energy, whilst simultaneously achieving substantial reductions in greenhouse gas emissions to mitigate the potentially serious consequences of climate change. As described in the Commission's Green Paper on a European strategy for sustainable, competitive and secure energy, Europe has entered into a new energy era. Today's FWP recognizes its importance and particular attention is paid to stimulating research, development and demonstration and promoting capacity building in this area. Ten activities have been considered in the Energy Theme, being Hydrogen and Fuel Cells one of them.

The topics under this Activity were selected under the assumption that the Commission will propose a Joint Technology Initiative (JTI) on hydrogen and fuel cells, on the basis of Article 171 of the Treaty, to become fully operational by 2008. This strategically managed, goal oriented programme, will cover industrial applied research, demonstration activities and relevant cross-cutting activities.

Being EC-funded research under the Cooperation programme, projects will involve multinational partnership, often from different scientific disciplines and/or different technological sectors, in order to work across traditional boundaries. But there should be no "superfluous" partners who will hinder effective management and research flexibility.

On the other hand, it will not be considered for funding any research that does not involve significant and clearly identifiable novel aspects, any research that constitutes a technology demonstration or a combination of existing technologies, any open-ended blue-sky research and finally, any research directed towards hypothetical phenomena, with no plausible or convincing evidence as to their real or potential existence or inconsistent with the most basic laws of science.

In short the idea is to provide rewards for "high risk/high impact" science and to vigorously promote multidisciplinary on a European collaborative basis. The research activities should go beyond conventional approaches, be highly novel, very ambitious and of long-term nature.

These topics are expected to attract projects that will contribute to the establishment of strong strategic positions for Europe in emerging materials science areas of

technological relevance and to explore new paths leading to highly innovative novel technologies for energy applications.

Considering that the business as-usual scenario will not solve the increasing energy demand, it is essential to encourage a shift from incremental progress towards more radical changes. At a time when emerging areas of science and technology often embrace substantial elements of both 'basic' and 'applied', when the classical distinctions between them have lost much of their relevance not just the wording but also the mentality need to change. Basic research findings feed technology progress and, conversely, technology demands predefine basic research and priorities. But, above all scientists should be ready to think "out-of-the-box". Despite considerable demand by scientists, research funding agencies set aside, if at all, a miniscule share of their overall budgets to directly support non-conventional or high-risk research projects. More widely recognized European high-risk frontier research programs should be established to attract and fund multidisciplinary, unconventional and non-hypothesis based research proposals.

From 2008 onwards it is expected that most of the R&D on hydrogen and fuel cell technologies will be implemented by the Joint Technology Initiative (JTI), a Joint Undertaking funded 50/50 by the EC and the industry. This Joint Technology Initiative will be a new way of realising public-private research partnerships at European level to jointly manage an EU research programme. Industry will be in the driving seat on management and implementation and the EC will ensure the necessary alignment with public policy and protect the public interest.

Europe's energy economy is currently on a pathway that is not sustainable. This must change. The research and demonstration actions during the next years will have for sure an important role to play.

From an energy science policy point of view creativity should be encouraged as the only way to tackle the challenges. Technologies like H₂/FC might become key technologies if non-incremental novel research discoveries are pursued. The creation of an environment in which to encourage breakthroughs is needed.

Assessment of the results, contribution to the future direction of the field, outcome

The last part of the Workshop was dedicated to a general discussion on the themes introduced by presentations. A list of points fully agreed was composed. It may represent a roadmap for the near-future research in the field of materials for p-SOFC:

- This workshop was necessary to clarify new directions for research
- The p-SOFC possesses long-term advantages
- The temperature of operation is likely to be lower than 600°C
- p-SOFC can be powered by hydrogen
- p-SOFC can be powered by hydrocarbon reformed in same unit
- New high temperature proton conducting systems are required
- Grain boundary and interfacial phenomena need priority
- Electrolyte supported architecture are mainly interesting for demo (1st-generation)
- Nickel cermet anode support is a possibility (2nd-generation)
- Thin electrolyte & metallic support are recommended (3rd-generation)
- Thermo-mechanical properties of electrolytes need to be addressed
- Oxide based cathodes are advantageous in the longer term
- HTPC compatibility of anode systems are worthy of attention
- Sealant issues are basically same as for SOFC TFA
- Current collection issues are same as for SOFC TFA
- Single chamber fuel cell needs to be explored
- Other states of solvated hydrogen in solids to be explored
- Mixed oxide ion/proton conduction advantageous for HC operation
- Ba and Sr to be minimised to reduce CO₂ degradation

Future common activities at European scale were also envisaged, that might be implemented through COST actions or Research Networking Programmes. In particular, one initiative will be devoted to the development of Hydrogen Energy culture with a special attention to the dissemination of the result of the research and of the possibilities of the technologies based on the use of Hydrogen as energy vector.

Another action is planned about the study of effect of Hydrogen incorporation or solvation in materials. There a lot of effects, some already known but most never investigated, that has to be considered when materials interact with protons. In fact mechanical, electrical and chemical properties of materials may change considerably, especially when they are operated at high temperature. Specific exempla can be found among materials to be used in Fuel Cells, both ceramic and metals, materials for hydrogen sensors and pumps, for storage.

Publicity to the event was given through the press agency of CNR (Dr. Marco Ferrazzoli, marco.ferrazzoli@cnr.it). A number of Italian newspapers published news about the Workshop on October 22nd, the website Le Scienze Web News published an article about the topic (http://www.lswn.it/comunicati/stampa/2007/la_ceramica_per_le_celle_a_combustibile_di_nuova_generazione) and the Italian Radio-Television Company (RAI) broadcasted a video news in the regional channel (RAI3-Liguria) on October 23rd.

Presenters also agreed to submit to convenors papers to be published in a special issue of the Journal of Applied Electrochemistry in 2008.

FINAL PROGRAMME

Day 1 - Monday 22 October

14:00 – 15:00 registration
15:00 – 15:30 introduction

Di Trapani — ESF
Marchi, — University of Genova
Passerone, — CNR-IENI
Barbucci, — Convenor

Session: Synthesis and sintering of protonic electrolytes

chair: F. Lefebvre-Joude

15:30 – 16:15 keynote – K1 **Norby** State of the art of proton conducting SOFCs
16:15 – 17:00 keynote – K2 **Bonanos** Materials for p-SOFCs (“to be or not to be protonic”)
17:00 – 17:15 *coffe break*
17:15 – 17:45 oral – O1 **Thorel** Tape casting of proton conducting ceramic materials
17:45 – 18:15 oral – O2 **Caboche/Estourne** $\text{BaCe}_{0.9-x}\text{Zr}_x\text{Y}_{0.1}\text{O}_{3-\delta}$ Ceramic Oxide for PCFC Application Synthesis, Sintering, Reactivity, Improvement of SPS Elaboration
18:15 – 18:45 oral – O3 **Ruiz-Trejo** Searching for protons in nanoceramics of Ln-doped cerium oxide
20:45 dinner at the Restaurant “*Sul fronte del Porto*”- Porto Antico, Metro San Giorgio

Day 2 – Tuesday 23 October

Session: Cell design, testing and analysis

chair: Z. Stoynov

- 09:00 – 09:45 keynote – K3 **Lefebvre-Joud** Cell design and testing on p-SOFC
- 09:45 – 10:15 oral – O4 **Braun** Advanced characterisation of yttrium substituted barium zirconate
- 10:15 – 10:45 and Stacks oral – O5 **Lang** Activities of DLR for future SOFC Cells
- 10:45 – 11:00 *coffee break*
- 11:00 – 11:30 oral – O6 **Vladikova** Impedance Analysis of Solid Oxide Fuel Cells
- 11:30 – 12:00 oral – O7 **Costamagna** SOFC Modelling

Session: Electrocatalysis

chair: A. Thorel

- 12:00 – 12:45 performance keynote – K4 **La Rosa** Electrode effects on cell
- 12:45 – 14:15 *lunch*
- 14:15 – 14:45 oral – O8 **Ragnoli** A low-temperature catalyst design
- 14:45 – 15:15 oral – O9 **Viviani** Innovative materials architectures

Session: Interconnects

chair: N. Bonanos

- 15:15 – 16:00 keynote – K5 **Gannon** Interconnect materials for next-generation solid oxide fuel cells
- 16:00 – 16:30 oral – O10 **Piccardo/Chevalier** History and perspectives of metallic interconnects in FC design
- 16:30 – 16:45 *coffee break*
- 17:00 *visit to the Aquarium*
- 19:00 **posters & buffet**

Day 3 – Wednesday 24 October

Session: Cooperative research

chair: M. Viviani

- 09:30 – 11:00 European projects opportunities: EU-FP7 calls (**Saraiva-Martins**), the FP7 project “IDEAL-Cell” (**Thorel**), other instruments (**Baraldi, Mantegazza**)
- 11:00 – 11:15 *coffe break*
- 11:15 – 12:30 **Round table:** plans for follow-up research activities and collaborative actions
- 12:30 *lunch & farewell*

Final List of Participants

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Statistical information on participants

(ESF Representative not included)

The participation to the Workshop was geographically broad, with scientists coming from 10 different European countries and one from the US. Number of participants coming from each Country is indicated in the table below.

BE	2	FR	5
BG	2	IT	5
CH	1	NO	1
DE	1	UK	3
DK	1	US	1
ES	1		

Age distribution is also equilibrated: 70% of participants were in the 35-55 range, 17% in the range 25-35 and 13% were over 55. The majority (62%) of participants were below 45 and male gender (75%).

