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SOCTESQA - Solid Oxide Cell and Stack Testing, Safety and Quality Assurance

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Abstract

Many research facilities and industrial companies worldwide are engaged in the development and the improvement of solid oxide fuel cells/stacks (SOFC) and also of solid oxide electrolysis cells/stacks (SOEC). However, the successful application of fuel and electrolysis cells/stacks in real world conditions requires reliable assessment, testing and prediction of performance and durability. Therefore the EU-project "SOCTESQA" has started at the beginning of May 2014 with the aim to develop uniform and industry wide test procedures and protocols for SOC cell/stack assembly. The paper presents the main objectives, the consortium, the structure, the work packages and the workflow plan of the project. The project builds on experiences gained in the "FCTESTNET", "FCTESQA" series of projects taking up the methodology developed there. It will address new application fields which are based on the operation of the SOFC cell/stack assembly in the fuel cell and in the electrolysis mode, e.g. stationary SOFC µ-CHP, mobile SOFC APU and SOFC/SOEC "power to gas" systems. The test procedures will include current-voltage curves, electrochemical impedance spectroscopy and long term tests both under steady state and dynamic operating conditions. The project partners are from different countries in Europe: German Aerospace Center (DLR), French Alternative Energies and Atomic Energy Commission (CEA), Technical University of Denmark (DTU), Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Joint Research Centre – European Commission (JRC) from Belgium and European Institute for Energy Research (EIFER) from Germany. All of them have long-term experience in the development, testing and harmonization of solid oxide cells/stacks. The project will have a clear structure based on an initial definition and specification phase, the development of generic test modules, the corresponding experimental validation phases, the review of the test procedures and finally the definition of the corresponding test protocols. Moreover, the project will address safety aspects, liaise with standards developing organizations (SDO) and establish contact with industrial practice. This collaborative project will essentially help to accelerate the development and the market penetration of hydrogen and fuel cell (H2&FC) energy systems in Europe.

1. Motivation

Test systems for high temperature solid oxide assembly units are very complex in structure and processing. There are a lot of parameters which have to be considered. Especially the temperature and gas control subsystems are important for the test output results. Figure 1 shows a schematic graph which gives an overview of important test inputs and operational conditions in order to obtain the object test results. Due to the complexity of the complete system, it is clear that detailed test schemes, procedures and protocols are essentially necessary for the development of SOC cell/stack assembly units - even more when the operation mode is transferred from steady state operation to dynamic operating conditions. In consideration of reproducibility beyond different research facilities, laboratories and developer it is also reasonable to establish uniform and industry wide test procedures and protocols.

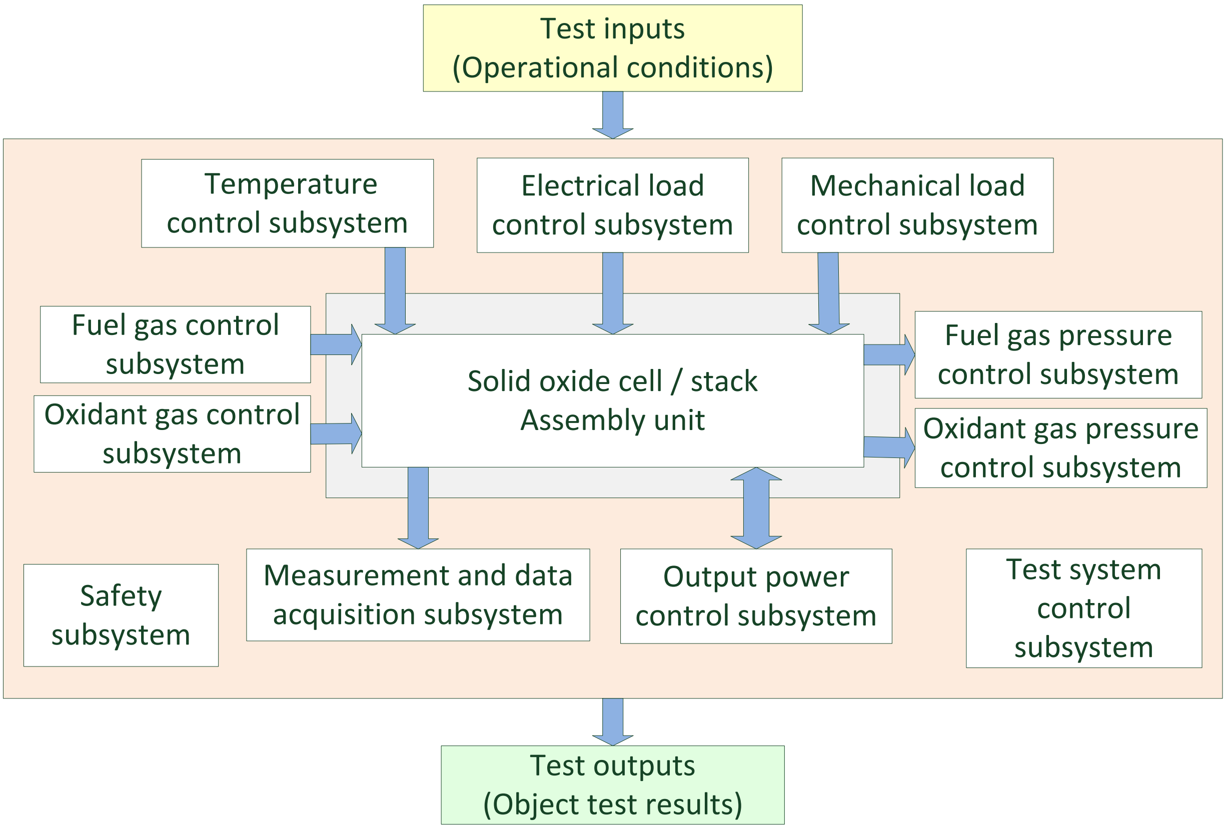

Figure 1: Schematic graph of a test system for high temperature solid oxide assembly unit

2. Progress beyond the state-of-the-art

As there are only a few specifications of test procedures for SOCs, the project builds on the experience and the methodology gained in previous European projects such as “FCTESTNET” [1] and “FCTESQA” [2]. These projects focused mainly on single cell tests and system level tests under steady state conditions for fuel cells in general. Test modules for steady state current-voltage curves, galvanostatic long-term steady state operation, electrical load cycling operation and steady state durability tests were established. Concerning the electrolysis operation, procedures for performance and steady state durability tests were defined and validated in the European "RELHY" project [3]. A first protocol of transient operation (load cycling) in SOEC mode was defined and tested from single cell to short stack level through single repeat unit level in the European project "ADEL" [4]. However, none of these documents include detailed specifications of SOC cell/stack assembly units, e.g. for dynamic thermal cycling operation or for the combined fuel cell/electrolysis mode. Moreover established advanced characterization techniques, e.g. the electrochemical impedance spectroscopy (EIS) have not yet been integrated thoroughly in the test protocols. Additionally, though reasonably consistent experimental results were achieved in the previous projects, several issues related to statistical data analysis and data presentation could not be resolved. Only few results were validated by round robin tests.

Therefore in "SOCTESQA" it is intended to develop a full set of application specific testing procedures addressing function, performance, durability and degradation. Moreover, advanced characterization techniques like electrochemical impedance spectroscopy (EIS) will be integrated in the test protocols. It is aimed to cover a wide range of application fields, e.g. stationary and mobile applications for both fuel cell as well as electrolysis modes.

3. Applications

Covering the whole range of operation modes like SOFC, SOEC and combined SOFC/SOEC as well as steady state and dynamic operations will gain many potential fields of application. A good example for the stationary SOFC operation are the micro-combined heat and power generation systems (μ-CHP) which are already commercial available, e.g. from companies like Hexis AG (Switzerland) [5] or Ceramic Fuel Cells Ltd. (Australia) [6]. Moreover, for the stationary decentralized power generation bigger systems, e.g. from Mitsubishy Heavy Industries, are under development [7]. Dynamic SOFC operation is applied in auxiliary power units (APU) to create electricity for mobile applications, for example in trucks or vans [8]. In the field of renewable energies SOEC and combined SOFC/SOEC are used as energy conversion systems. Excess electricity e.g. from wind power is spend to create hydrogen with the help of SOEC units ("power to gas") [9]. The energy can be stored in form of hydrogen until the demand of electricity increases. Then SOFC systems convert the hydrogen again to electricity which can be provided for the electrical power supply ("power to gas to power") [10].

4. Test Procedure

The test procedures will include and specify the complete testing system, the different operating modes, the test conditions and the electrochemical characterisation methods. The aim is to provide robust and easy-to-use protocols for experimental characterisation of the specified SOC test items and the interpretation of measured data. Therefore the test procedures contains different parts or modules as shown in Figure 2. In order to document and compare the initial and the final performance of the SOC cell/stack assembly unit the test procedures typically include special start and end test programs. The test modules of the application specific test programs vary in kind and quantity depending on the system application. Available test modules are e.g. current-voltage curves, electrochemical impedance spectra, dynamic cycles or long term stationary operation. Within the project, these test modules and test programs will be established and experimentally validated. At the end the results of the different test modules will lead to standardized test protocols.

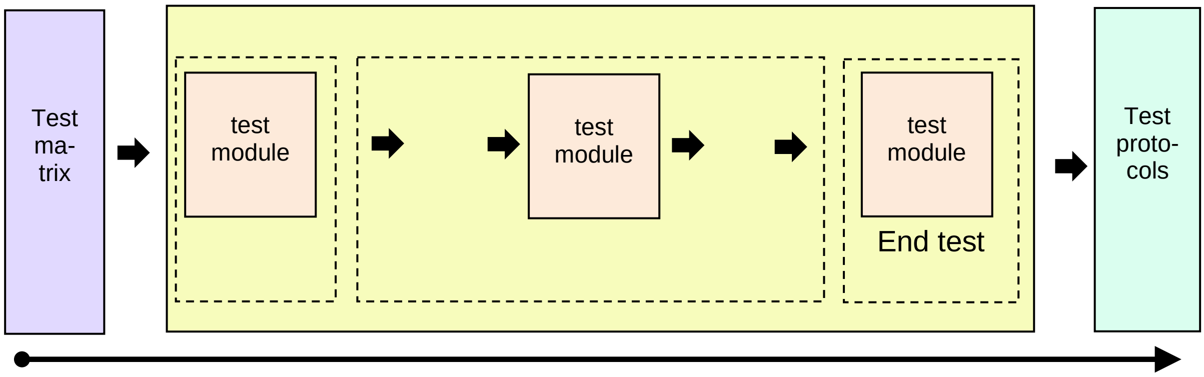

Figure 2: Illustration of a complete test procedure for SOC cell/stack assembly unit

5. Work packages

The project structure is based on two main activities, the liaison activities and the joint research activities. As illustrated in Figure 3 the activities are organized in different work packages which interact with each other. The first steps will be the definition of the specifications, the overall test matrix and the elaboration of generic harmonized test procedures (WP 2 and 3). These results will represent the basis for the testing and validation of the cell/stack assembly unit for SOFC, SOEC and the combined SOFC/SOEC operation modes in WP 4, 5 and 6. After review and modification of the test modules and program a final round robin test will be performed to ensure comparability of the results obtained by different test laboratories. To be sure that the developed test procedures correspond to the needs of the industry, liaison activities to relevant industrial stakeholders will take place. Additionally a continuous dialog with standards developing organizations (SDO) is aspired with the aim to implement the results successfully into international standards (WP 7).

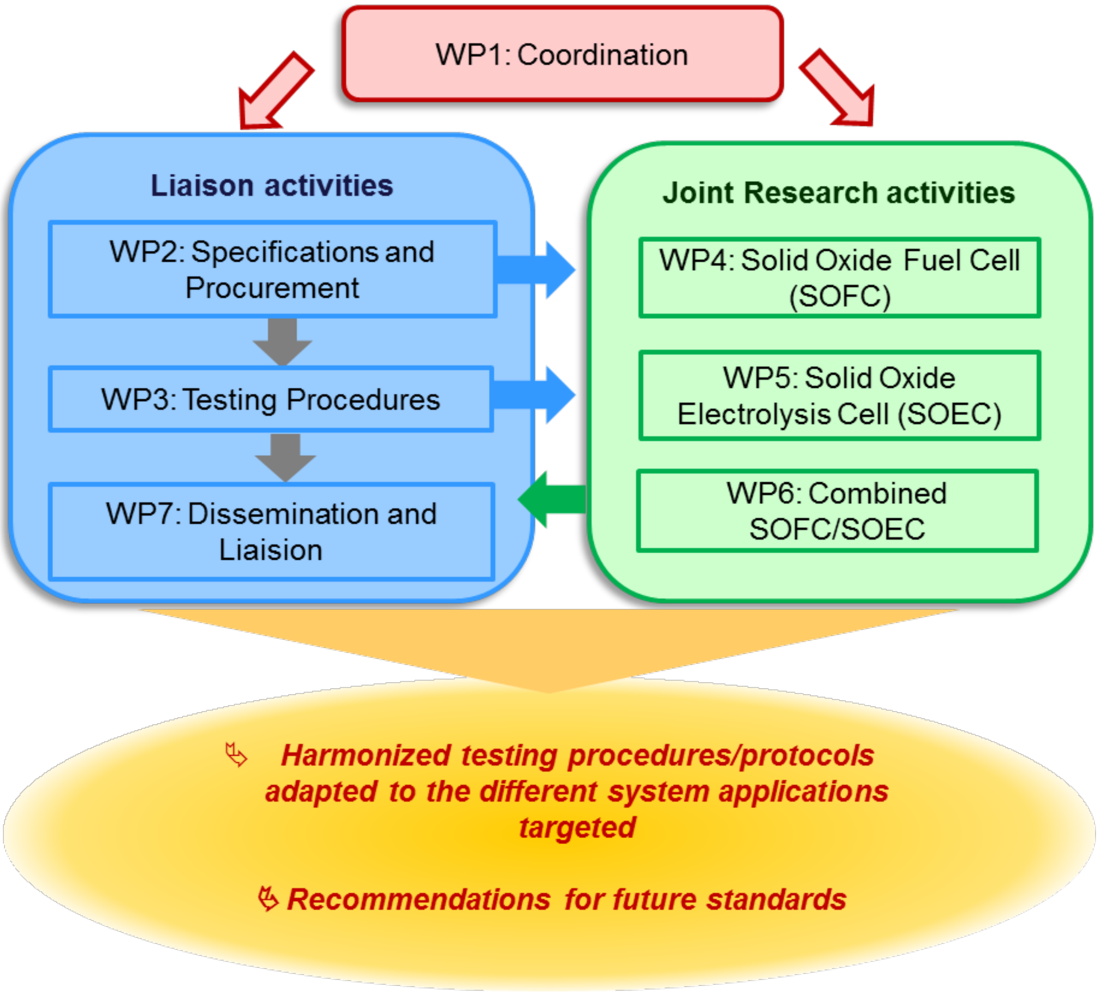

Figure 3: Overview of the project work packages

6. Workflow Diagram

A detailed overview over the project activities and the timetable is given in Figure 4. The project starts with an initial phase, which contains the literature review, the definition of all specifications and the test matrix and the commissioning of the test facilities. In the next phase, the generic test modules for SOFC, SOEC and SOFC/SOEC are developed and the short stacks are procured. After that the test modules and procedures are experimentally validated and reviewed. Several of these validation loops will result at the end of the project in test procedures, which will be confirmed by round robin tests and finalised in the corresponding test protocols. Throughout the project, there will be a strong interaction with industrial practice and needs in form of an industrial advisory board (IAB) and with national and international standards developing organizations (SDO).

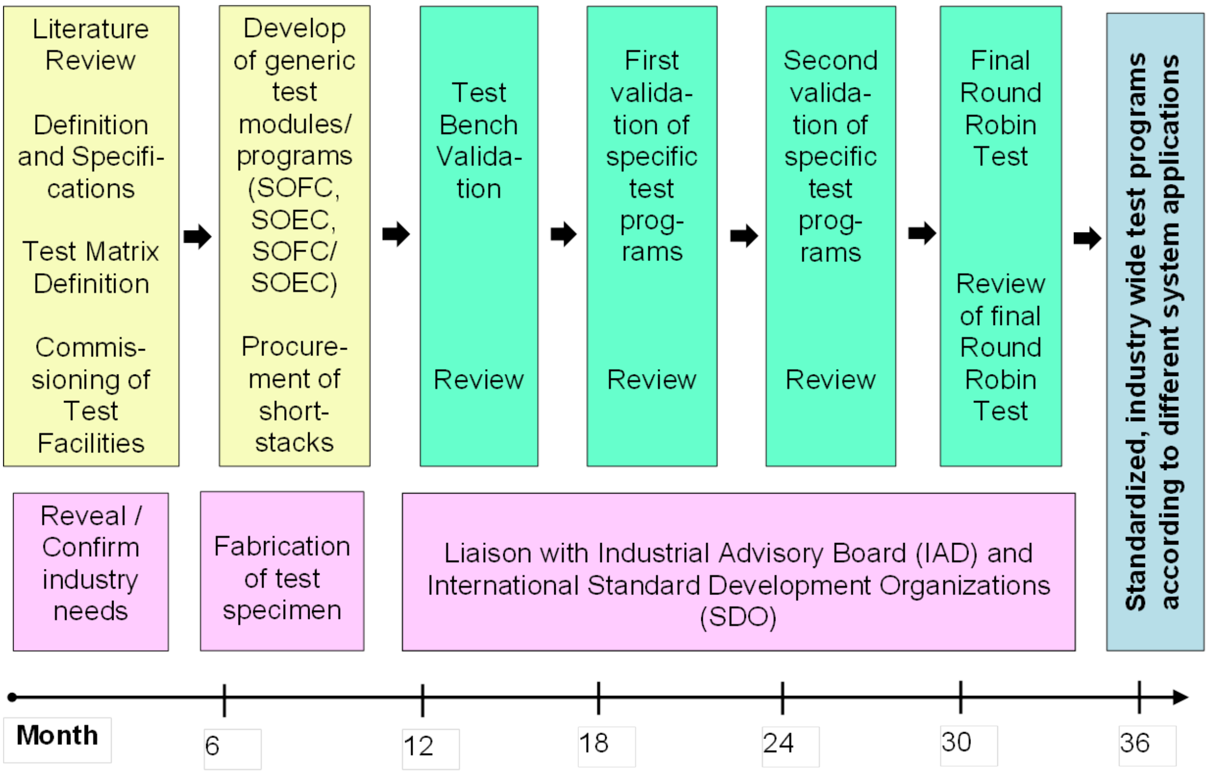

Figure 4: Project workflow diagram

7. Overall Project Consortium

An overall project consortium consisting of three different organisation groups is in charge to reach the aims of the project: the project partner consortium, the industrial advisory board and the standards developing organization body.

The project partner consortium is formed of six leading research institutes from different countries in Europe and one non-European subcontractor to disseminate the project results on a broader, international level. The German Aerospace Center (DLR) is the largest engineering research organisation in Germany undertaking applied research and development in Aeronautics, Space, Energy, Transport and Security. The French Alternative Energies and Atomic Energy Commission (CEA) is a French Governmental Research Organization devoted to both fundamental and industrial R&D in the field of energy, information and health technologies and defense. The Technical University of Denmark (DTU) is one of Europe's foremost technical universities with a leading role in R&D and testing of solid oxide fuel cells. The Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) is a scientific R&D organisation with a commitment to sustainable development and environmental safeguard. The Joint Research Centre of the European Commission (JRC) in Belgium provides scientific and technical support for the conception, development, implementation and monitoring of community policies related to energy. The European Institute for Energy Research (EIFER) in Germany is an European Economic Interest Grouping with wide experience in stack testing based on SOCs in both fuel cell mode (SOFC) and electrolysis mode (SOEC). Nanyang Technological University (NTU) of Singapore is a research-intensive public university with the aim to be a leading research institute for innovative energy solutions.

The liaison to industry is based on the establishment of an industrial advisory board consisting of key industrial SOFC and SOEC stakeholders. The members of this group will assist in the prioritization of the technical work thus ensuring a high industrial relevance and acceptance of the project outcome. The test procedures will be developed in close interaction with national and international standards developing organizations (SDOs), e.g. the International Electrotechnical Commission IEC and the International Organization of Standardization (ISO).

All three parts of the consortium have a profound understanding of needs and applications that enables them to develop the relevant test procedures and initialize standardization activities. The consortium as a whole is supposed to keep close contact to each other.

Acknowledgement

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