PROJECT FINAL REPORT

Final Publishable Summary Report

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Project acronym: SOFC-Life

Project title: Solid Oxide Fuel Cells – Integrating Degradation Effects into Lifetime Prediction Models

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Project website[1] address: www.sofc-life.eu

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[1] The home page of the website should contain the generic European flag and the FCH JU logo which are available in electronic format at the Europa website (logo of the European flag: http://europa.eu/abc/symbols/emblem/index_en.htm; logo of the FCH JU, available at: http://ec.europa.eu/research/fch/index_en.cfm). The area of activity of the project should also be mentioned.

2.1 Final publishable summary report

This is a comprehensive summary of results, conclusions and the socio-economic impacts of the project. The publishable report shall be formatted to be printed as a stand alone paper document. This report should address a wide audience, including the general public.

Please ensure that it:

- *Is of suitable quality to enable direct publication by the FCH JU.*
- *Is comprehensive, and describes the work carried out to achieve the project's objectives; the main results, conclusions and their potential impact and use (including the socio-economic impact and the wider societal implications of the project). Please mention any target groups such as policy makers or civil society for whom the research could be relevant.*
- *Includes where appropriate, diagrams or photographs and the project logo, illustrating and promoting the work of the project.*
- *Provides the following information:*
    - *List of all beneficiaries with the corresponding contact name and associated coordinates*
    - *The address of the public Website of the Project as well as relevant contact details.*

Declaration by the scientific representative of the project coordinator

I, as scientific representative of the coordinator of this project and in line with the obligations as stated in Article II.2.3 of the Grant Agreement declare that:

- The attached final report represents an accurate description of the work carried out in this project
- The project (tick as appropriate):

  ☐ has fully achieved its objectives and technical goals

  ☒ has achieved most of its objectives and technical goals

  ☐ has failed to achieve critical objectives
- The public website is up to date, if applicable.
- To the best of my knowledge, the financial statements which are being submitted as part of this report are in line with the actual work carried out and are consistent with the report on the resources used for the project (section 6) and if applicable with the certificate on financial statement.
- All beneficiaries, in particular non-profit public bodies, secondary and higher education establishments, research organisations and SMEs, have declared to have verified their legal status. Any changes have been reported under section 5 (Project Management) in accordance with Article II.3.f of the Grant Agreement.

Name of scientific representative of the Coordinator: .L.G.J. (Bert) de Haart......................

Date: ......June 2nd, 2014

Signature of scientific representative of the Coordinator: ....

FINAL PUBLISHABLE SUMMARY REPORT

Solid Oxide Fuel Cells – Integrating Degradation Effects into Lifetime Prediction Models

Summary description of project context and objectives

Long term stable operation of Solid Oxide Fuel Cells (SOFC) is a basic requirement for introducing this technology to the stationary power market. Electricity generation equipment usually is designed for lifetimes of 10 years and well above, corresponding to 40,000 to over 100,000 hours of operation. The continuous degradation of fuel cell voltage commonly observed has to be reduced such that the loss of power remains within acceptable limits during the lifetime. The SOFC-Life project aimed at a better understanding of the degradation phenomena as a tool for mitigating these effects and as a first step towards developing accelerated testing methods.

The SOFC-Life project concentrated on identifying, understanding and quantifying degradation effects occurring in high temperature Solid Oxide Fuel Cell (SOFC) devices. It followed a systematic approach to analyse a selected number of the most important degradation mechanisms. These selected degradation mechanisms had been prioritized based on the work performed and results obtained in earlier projects (Real-SOFC, SOFC600) and results presented at international meetings.

The work concentrated on the 'continuous' (baseline) degradation phenomena determining stack behaviour in the long term. By deconstructing the SOFC stack into isolated elements and interfaces (see Fig. 1), these were exposed to the physical conditions found in typical SOFC system operation (and beyond). At regular intervals, specimens were taken from the experiments and thus a time series of gradual development of degradation effects was recorded. This time-lapse photography type approach was designed specifically to allow the modelling of physical changes over time.

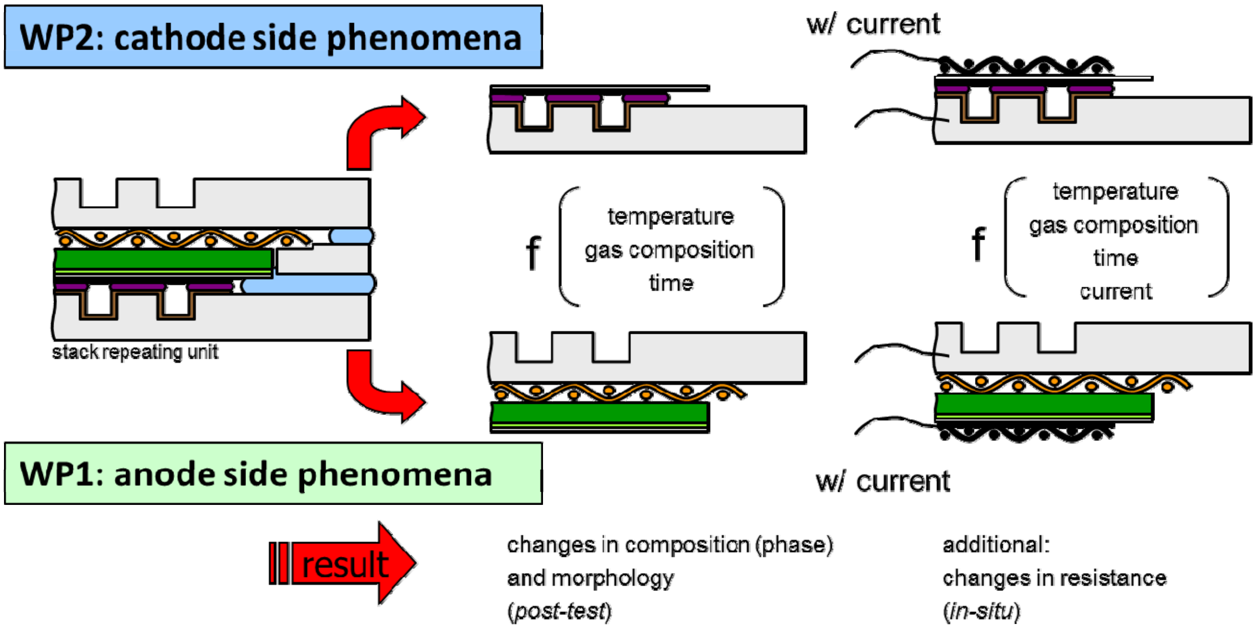


Figure 1
Project approach for the investigation of single degradation mechanisms in SOFC-Life; de-constructing the SOFC stack (repeating unit) into isolated elements and interfaces

The **objectives** addressed in the SOFC-Life project were:

- Understand the details of the major SOFC continuous degradation effects
- Develop models that predict single degradation phenomena
- Transfer the physical-chemical models to electrochemical models
- Re-assemble the single effect models to a full SRU life-time prediction model

The **themes** (degradation mechanisms) addressed in SOFC-Life were:

- Morphological change in the anode cermet (impacting on anode activity and electrical continuity),
- Nickel-steel corrosion (impacting on electrical continuity and conductivity),
- The stability (chemical, kinetic and morphological) of state of the art cathode materials (impacting the cathode activity), and
- Processes at the cathode-interconnect interface (impacting electrical continuity and chemical composition of components, thus their electrochemical performance).

The outcome of the SOFC-Life project was intended to be of a generic nature, so that all industrial partners of the consortium would benefit from the results, and also other SOFC developers would be able to further develop their cells and stacks. For this reason state-of-the-art materials and materials combinations which were investigated in the SOFC-Life project were selected based on the preferences of the industrial partners and their availability. The materials test matrix (see Table 1) contained materials both used for anode substrate cells (ASC) as well as for electrolyte supported cells (ESC).

Table 1 Materials test matrix used in SOFC-Life
ASC: anode supported cells / ESC: electrolyte supported cells

ASC	1st selection	alternative	**ESC**	1st selection	alternative
steel interconnect	Crofer 22 H	Crofer 22 APU	steel interconnect	Cr5Fe1Y2O3	Crofer 22 H
contact element	Ni mesh		contact element	Ni mesh	
anode substrate	Ni/YSZ cermet		anode	Ni/CGO cermet	
cathode	LSCF (w/ CGO barrier)		cathode	LSM/YSZ	

Description of work performed and main results

Materials exposure tests and microstructure analyses

The overall objective of studying the single degradation phenomena was to develop a quantitative, mechanistic, validated description of how the microstructure of Ni-YSZ and Ni-CGO anodes and their contacting to steel interconnect changes with time under operating conditions and how this changed the electrochemical performance of the anode and its contribution to cell performance degradation. In parallel the LSM and LSCF cathodes and their contacting to steel interconnect were investigated with the same objective.

Exposure tests of the selected materials and materials combinations were performed at selected conditions as defined by the experimental test matrix (see Table 2) for durations of 300, 1000 and 3000 hours. At each interval samples were extracted for post-test analyses.

Table 2 Experimental test matrix used in SOFC-Life
ASC: anode supported cells / ESC: electrolyte supported cells

ASC		1st	2nd	3rd	4th	**ESC**		1st	2nd	3rd	4th
temperature (°C)		700	750	800		temperature (°C)		800	850	900	
current density (A/cm^2)		0	0.35	0.70		current density (A/cm^2)		0	0.35	0.70	
fuel composition (mol %)	H_2	97	20	55	10	fuel composition (mol %)	H_2	97	20	55	10
	H_2O	3	80	45	60		H_2O	3	80	45	60
	CH_4	-	-	-	30		CH_4	-	-	-	30
air humidity		0		3		air humidity		0		3	

Ni-YSZ anode substrates exposed at 800 °C in hydrogen show an increase in resistivity of close to 24% after 3000 h. The time evolution of the resistivity could be described with a second-order exponential decay. This decay shows to be faster at high humidity (80% steam) in comparison to the case with low steam content (3%), but the relative increase is similar for both cases after 3000 h. Similar observations were also made during investigation of the influence of current passing through the samples during the exposure tests. During the total 2000 h of exposure no differences could be observed in the relative increase of resistivity for samples exposed to 0.7 A/cm² and samples not exposed to current flow. As opposed to the data obtained at 800 °C surprising difference in degradation behaviour of the samples exposed for 1000 h at 700 °C is seen for 97%H_2+3%H_2O and 20%H_2+80%H_2O atmospheres: 25.7…29.3% degradation for 3% water content in the gas and only 2.6…3.1% for 80% water content (see Fig. 2). This result is unexpected because so far high water content in the gas was considered by many researchers as the main reason of Ni-anode degradation. Nevertheless there is no doubt that degradation of all samples exposed at 700 °C in 20%H_2+80%H_2O atmosphere is very low.

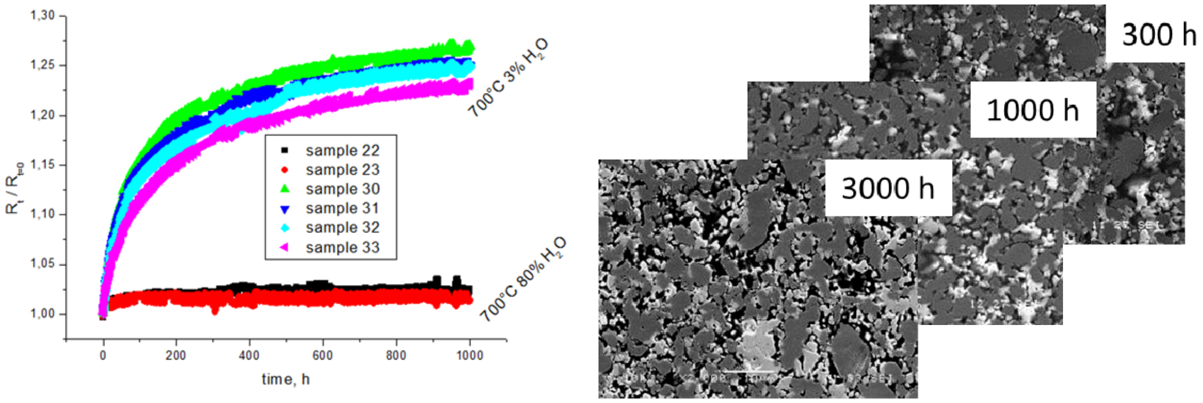


Figure 2
Left: Time dependences of relative resistance of Ni-YSZ cermet samples exposed at 700 °C in 97% H_2 + 3% H_2O and 20% H_2 + 80% H_2O atmospheres.
Right: SEM images of Ni-YSZ cermet samples extracted after 300, 1000 and 3000 h exposure, resp. at 800 °C in 97% H_2 + 3% H_2O.

The microstructure of the Ni-YSZ cermet samples was studied using SEM-image analysis (see Fig. 2) and the Ni-content has been determined by X-ray fluorescent spectroscopy. These analyses suggested that the fraction of Ni-phase in the substrates decreases with time at some of the experimental conditions (see Fig 3). Correlation between relative electrical resistance and the tortuosity factor of Ni-phase in Ni-YSZ cermets calculated by the Monte-Carlo simulation method were found.

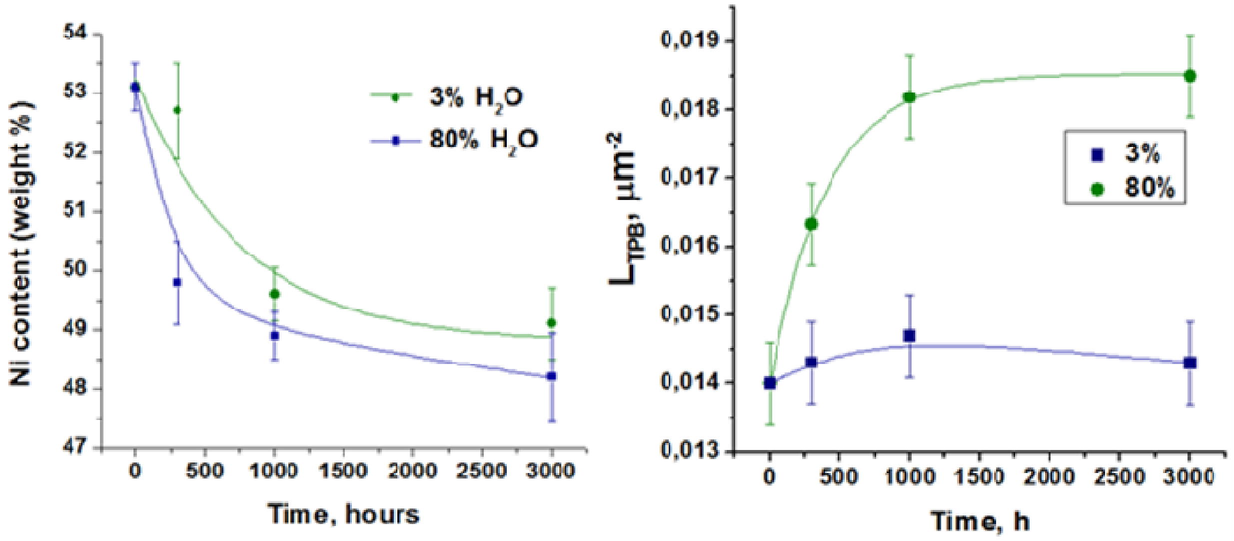
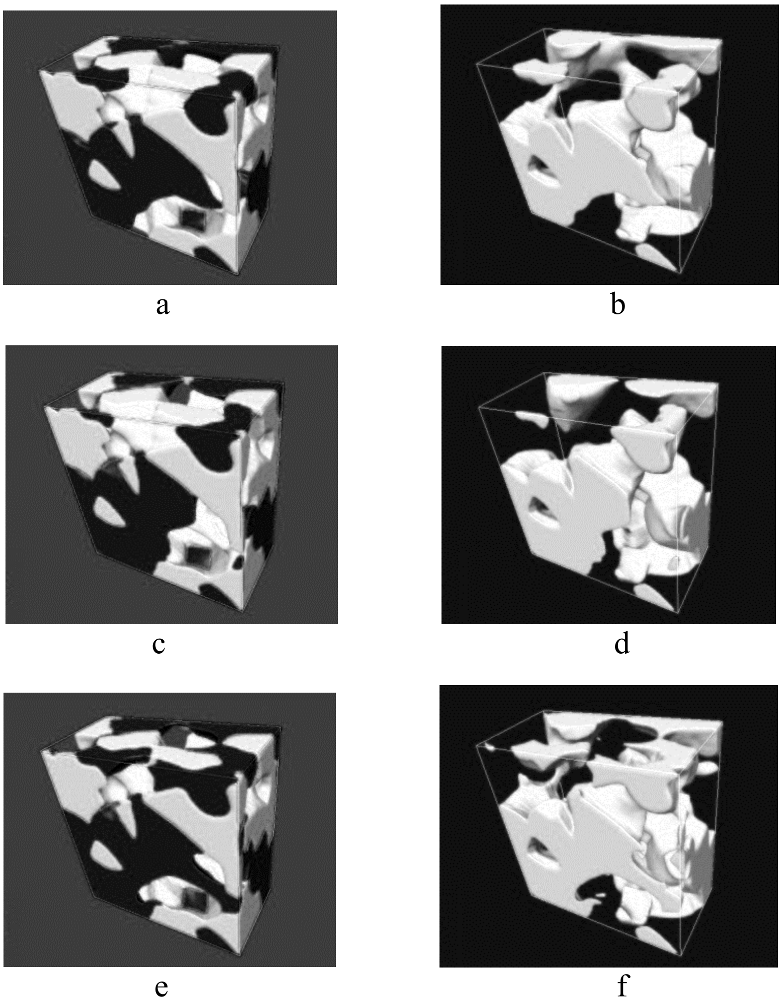


Figure 3.
Left: Ni-phase content from image analysis as a function of time
Right: Triple phase boundary length calculated from 2D image analysis
Ni-YSZ cermets exposed at 800 °C; in 97% H_2 + 3% H_2O and 20% H_2 + 80% H_2O atmospheres.

A general empirical model was developed to describe all sets of our experimental data in terms of a polynomial function. This empirical description was used for the validation of the physical model proposed. Two competing processes leading to degradation of the anode substrates were considered in the physical model: volatilization and coarsening of the nickel phase in Ni-YSZ composite material. The original physical approach developed was based on the diffuse Fick law on conditions of the surface evaporation. Two parameters were included to the physical model: the volatilization rate of nickel and the coefficient of nickel surface diffusion. Fitting the experimental time dependences of the relative resistivity values with the function based on the physical model and taking into account the volatilization rate evaluated from the image analysis the nickel surface diffusion coefficient could be calculated. It was found to be in good agreement with literature data, which means that the rate-determining stage of the nickel particles coarsening process is diffusion of nickel over its surface.

A new Cellular Automata (CA) approach of simulating microstructure evolution could be applied to model the complicated topological and morphological changes in the real microstructure of a porous nickel cermet anode (see Fig. 4). It has been demonstrated that at least in the initial stage the microstructure changes are very sensitive to the wettability of Ni on YSZ. A better wettability of Ni on YSZ would lead to slower, or even no coarsening of the Ni phase and a slower decrease of the percolated TPB length density. Poor wettability leads to rapid coarsening and loss of percolation. In order to use this approach to predict the evolution on a real timescale it will be necessary to calibrate the model using some more observations and additional experiments such as measuring the wettability of Ni on YSZ. The model can then be used to predict the long term evolution of microstructure and electrochemical performance of real Ni-based anodes from short term experiments. This constitutes a scientific basis for accelerated testing of anode performance in the future.



a b c d e f

Figure 4

a) *Reconstructed 3D microstructure for the functional layer of a Ni cermet anode;*
b) *Ni-only microstructure corresponding to Fig.4a.*
c) *The simulated 3D microstructure after 200 time steps assuming poor wettability of Ni on YSZ;*
d) *Ni-only microstructure corresponding to Fig.4c.*
e) *The simulated 3D microstructure after 200 time steps assuming good wettability;*
f) *Ni-only microstructure corresponding to Fig.4e.*

The electric conductivity transient of a typical Ni-CGO current collector shows a sigmoidal evolution (see Fig. 5). After an initial steep increase of the specific conductivity from roughly 600 S/cm to 1200 S/cm within the first 50 hours, the conductivity increases steadily during the following 1000 hours to around 1500 S/cm. This time roughly corresponded to a levelling out of Ni phase mean particle size radius. The volume fraction of Ni was stable for the duration of the experiment, indicative of negligible Ni volatilisation and loss.

In contrast 3000 h aging of a current-collecting Ni-CGO layer in a high $p(H_2O)$ atmosphere resulted in coarsening of the microstructure (see Fig. 6) and decrease in electronic conductivity, with the latter reasonably explained by the results of XRD analysis, which suggested Ni volatilisation and loss with time of exposure, although redox cycling should also be considered as a contributing factor to the observed degradation.

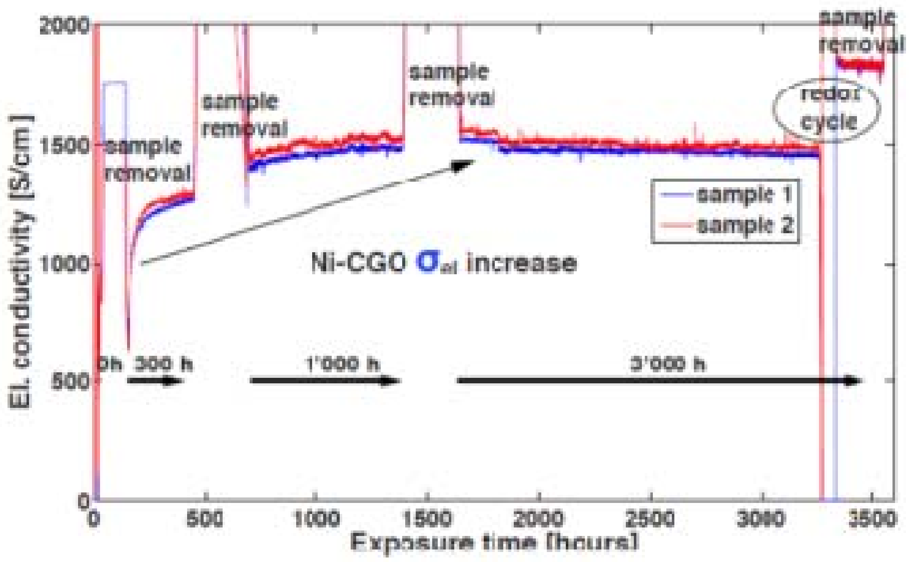


Figure 5
Electric conductivity of current-collecting Ni-CGO layers (sample 1, sample 2) supported on ScSZ electrolyte during 3,000 h exposure in 5%H_2/N_2 containing ~ 2% water vapour at 900 °C.

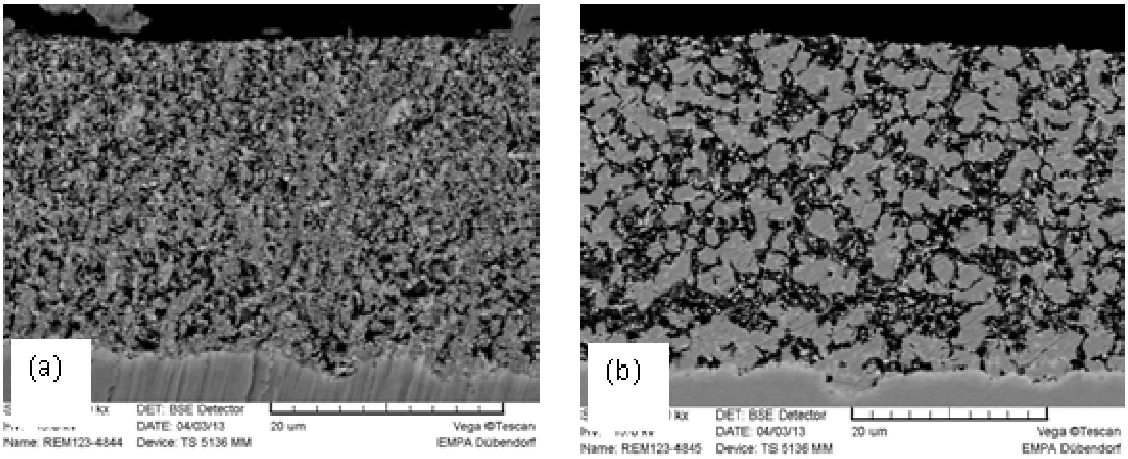
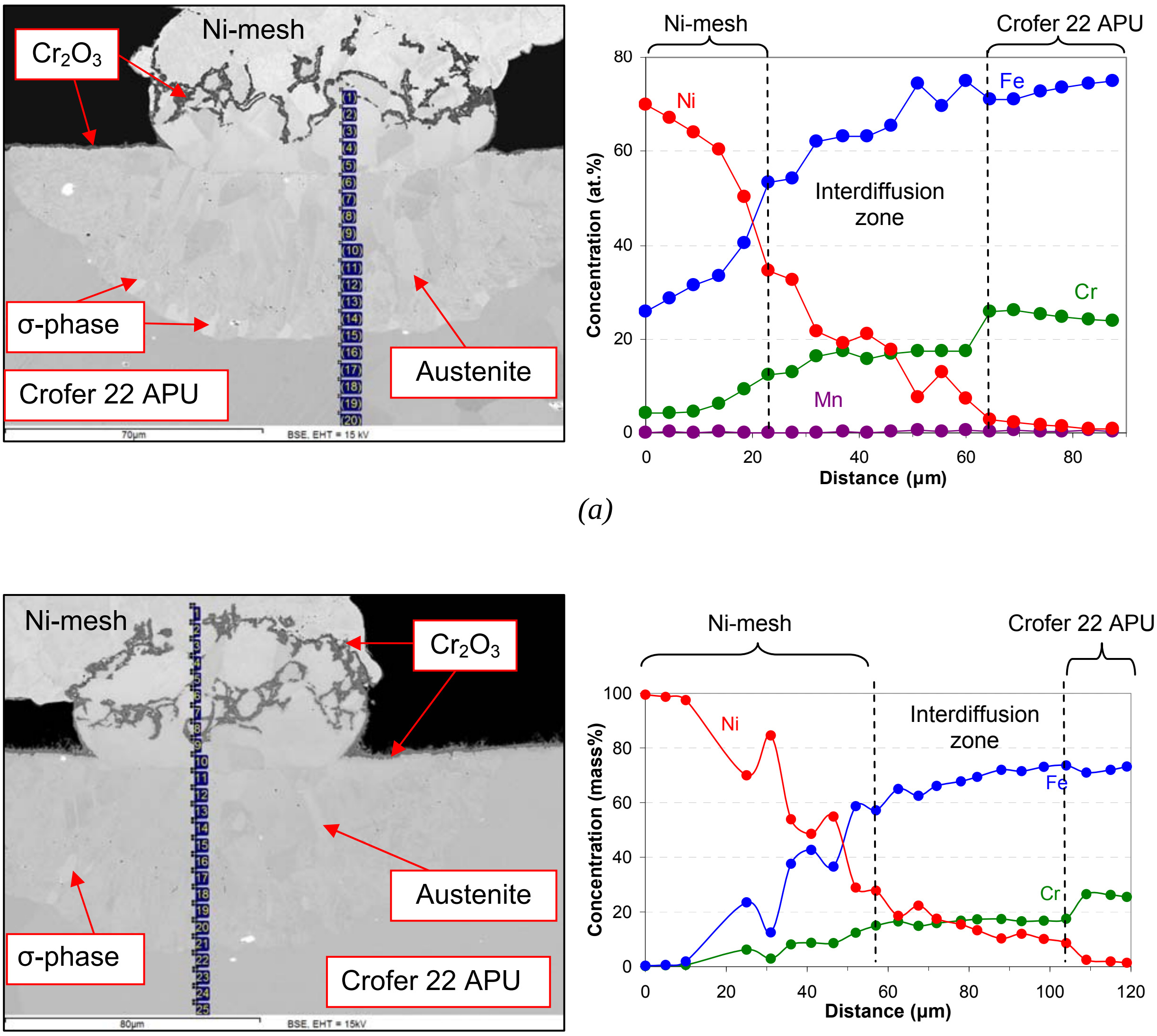


Figure 6
Electron micrographs showing the microstructure of current-collecting Ni-CGO layer supported on ScSZ electrolyte after (a) 0 h and (b) 1,000 hrs exposure in 5%H_2/N_2 containing ~ 16% water vapour at 900 °C.

The investigations on the Ni-mesh/Crofer 22 APU and Ni-mesh/Crofer 22 H joints showed that during long term exposure austenitic grains form in the steel adjacent to the contact area (see Fig. 7). Ni diffuses from the wire-mesh into the steel whereas Fe, Cr and Mn diffuse from the steel into the Ni-mesh. An σ-phase formed near the electrical contact between steel and Ni-mesh, i.e. at the ferrite-austenite interface, in both steels, Crofer 22 H and Crofer 22 APU. The amount of σ-phase was considerably smaller in Crofer 22 APU than in Crofer 22 H. Nickel diffused into Crofer 22 APU up to a depth of 60 µm and up to 40 µm in the case of Crofer 22 H.



(a)

(b)

Figure 7
SEM cross-sections and element profiles of Crofer 22 APU in contact with Ni-mesh after exposure in Ar-4%H_2-2%H_2O at 700 °C for: (a) 1000 hours and (b) 3000 hours

Monitoring the resistivity of the Ni-mesh/steel joints during exposure did, however, not reveal a direct influence of the formation of the austenitic grains on the resistance. Over 3000 h of exposure at 800 °C the resistivity of the sandwiches showed in general a steadily increase, except for those samples which showed during post-test analysis oxide formation on the wires of the Ni-mesh.

Similar observations were made during the exposure tests of steel/Ni-mesh/anode substrate/Ni-mesh/steel sandwiches. Current did not seem to have a large effect on the resistances and also the humidity impact was quite small; the increase of resistance was only slightly larger in the high (80%) humidity conditions.

The steel grade seemed to affect the contact between cermet and Ni-mesh. It was seen more clearly in the 3000 h 3% RH test (see Fig. 8) where the resistance in the Crofer 22 APU sandwiches increases steeply after 2000 h and the contact boundary where the increase occurs in the Ni-mesh – cermet – Ni-mesh. In the Crofer 22 H steel sandwiches there is practically no increase. In the high humidity test until 1500 h such behaviour was not seen.

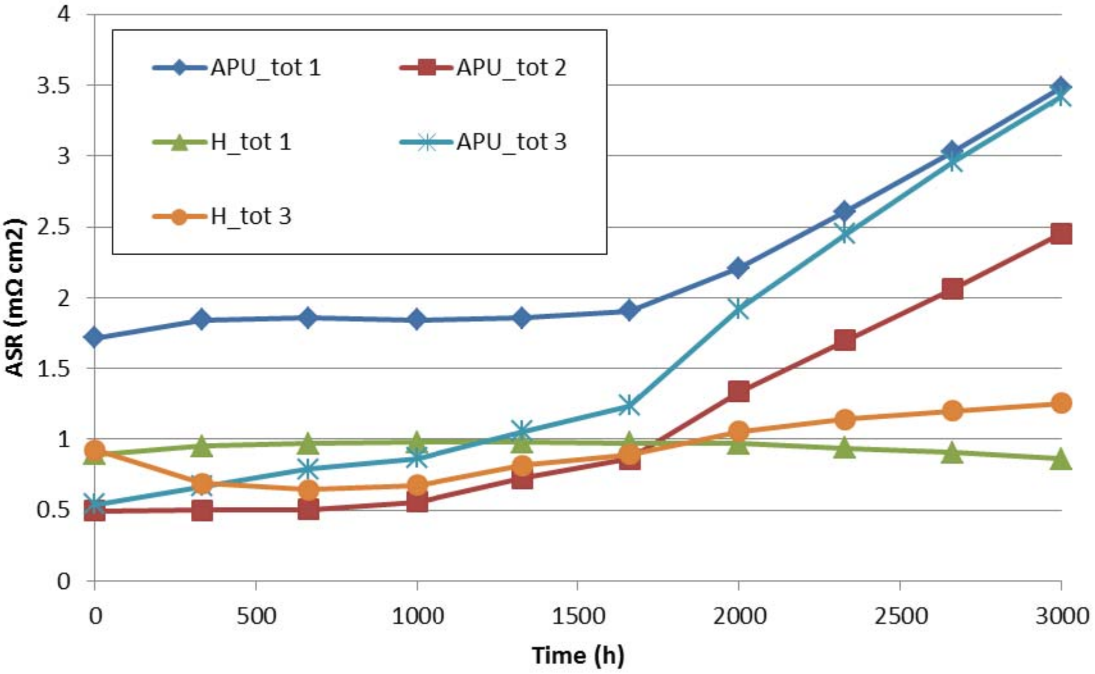


Figure 8
Results of resistance measurements during the 3000 h test in 3 % RH hydrogen for different sample sandwiches.

The conductivity of LSM-YSZ composite cathode layers on YSZ exposed at 900 °C in air with 4.4% humidity increases non-linear over time during the total period of 3000 h (see Fig. 9). The increase in conductivity amounts to over a factor of 2 to 2.5. In dry atmospheres the conductivity increases linearly at a slower pace. Lowering the temperature of exposure to 800 °C hardly any degradation is observed any more in dry atmosphere. Post-test examination of the microstructure of the LSM YSZ composites showed that the length of the triple phase boundary (TPB) at 900 °C is approximately 16% lower compared to the 800 °C case (see Fig. 10). Quantitative 3D analysis of a 3000 h exposed LSM-YSZ (800 °C, dry air) compared to a pristine sample showed a loss in connected TPB of 5%, which would amount to an equivalent loss of 1%/1000h in cathode activation polarisation (at 800 °C); even the correct magnitude of cathode conductivity (which was measured and found to be low with 1 S/cm) was captured by the microstructural model analysis.

The state-of-the-art cathodes of today are very good. During exposure for 3000 h only very minor changes were observed in the conductivity measurements and microstructural parameters, also for LSCF (see Fig. 11). Fewer experiments and analyses than planned were thus performed to retrieve the needed parameters. Some electrochemical degradation occurred but since the cells were not tested electrochemically for extended periods of time (it was not a part of the project work) a complete comprehensive evaluation of this degradation could not be assessed. Two sets of microstructural parameters were retrieved as input for the electrode models. The conclusion for the LSM-YSZ and the LSCF cathodes is that the conductivity changes related to temperature and atmosphere are not involved in major degradation mechanisms. With respect to microstructural changes, they are very subtle yet could be captured by a detailed analysis (e.g. 5% loss in connected TPB after 3000 h). Such analyses, however, demand repetition.

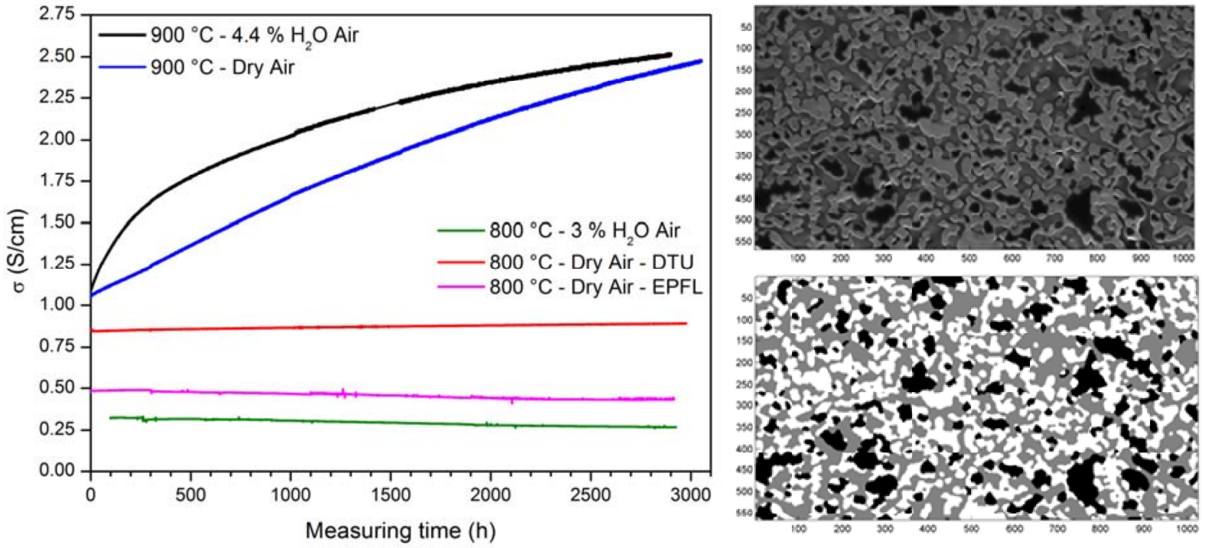


Figure 9

Left: *Conductivity data of an LSM-YSZ cathode films measured at 800 and 900 °C in dry and wet air (4.4% H_2O content) over 3000 hours.*

Right: *Segmentation method applied to the 0 h reference sample.*
(top) The InLens detector image.
(bottom) The segmentation with LSM, pore and YSZ as black, grey and white.
The axes are in pixel units with a pixel size of 14.6 nm.

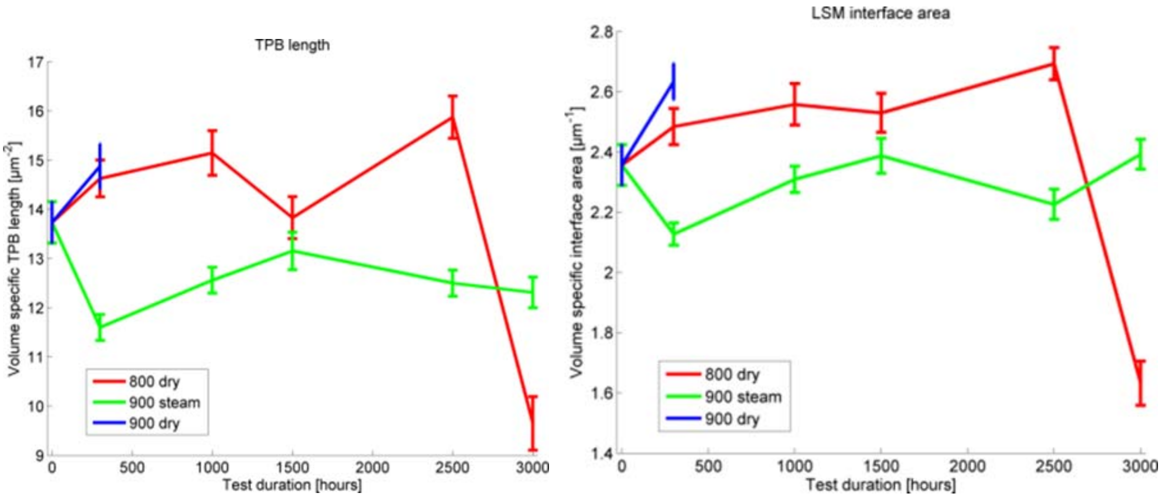


Figure 10
Right: Volume specific LSM interface area and Left: TPB length.
The error bars indicate 95% confidence intervals for the mean of all image measurements

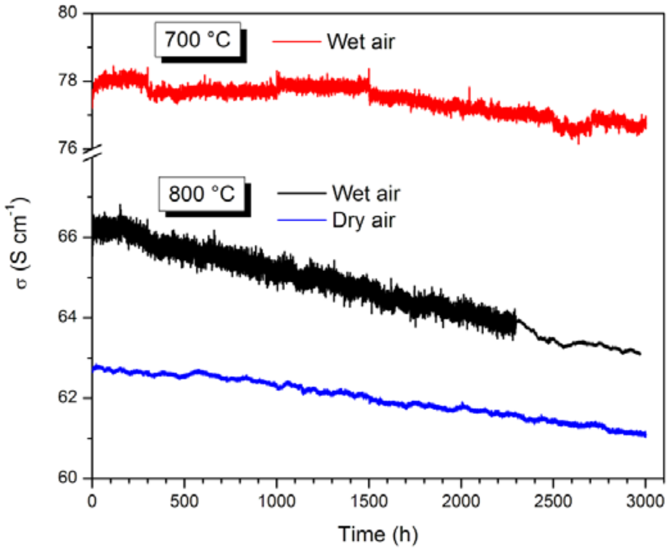


Figure 11
Conductivity data of an LSCF cathode films measured at 700 and 800 °C in dry and wet air (4.4% H_2O content) over 3000 hours.

Contact resistance measurements conducted on Crofer-steel/(Mn,Fe)-oxide coating/LSM contact layer joints at 800 °C in air show a marked difference in the behaviour between Crofer 22 H and Crofer 22 APU samples over 3000 h of exposure. For the Crofer 22 APU the resistance decreases whereas for Crofer 22 H the resistance increases. The latter increase can be described using a parabolic law (see Fig. 11). Similar parabolic behaviour is observed for Cr5Fe1Y2O3 steel samples with LSM coatings and contacts exposed at 900 °C in air. No averse affect from humidity (3% H_2O in air) was noted for all steel-cathode contact resistance measurement samples.

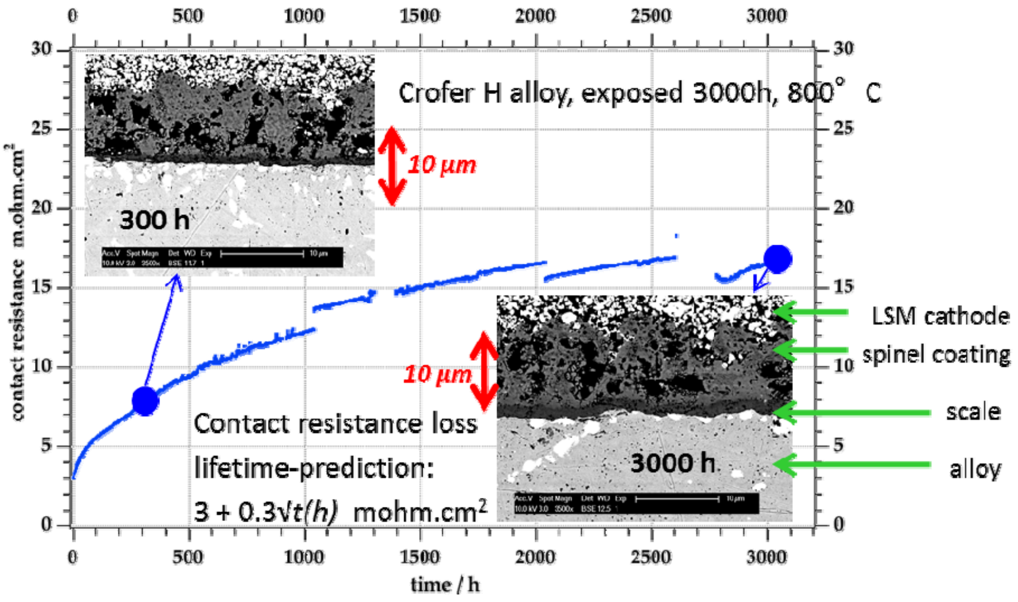


Figure 11
Time evolution of the contact resistance of Crofer 22 H / spinel coating / LSM sandwiches, 800 °C, dry air, 0.35 A/cm^2.

Main results of the materials exposure tests assessed towards the stated objectives:

- The conductivity of Ni/YSZ and Ni/CGO anodes show only marginal degradation or even improvement over time. This can be considered to be not a major contribution to the overall degradation observed in SRUs and stacks.
- The evolution over time of the resistances of interconnect steel/mesh interfaces in anode gas environment also can be considered to be not a major source of degradation.
- Description of the conductivity and microstructural changes in LSM-YSZ and LSCF cathodes from several 3000 h continuous conductivity measurements and 2D and 3D microstructural analysis. Only a slight degradation was found, which can be considered to be not a major contribution to the overall degradation observed in SRUs and stacks.
- The interconnect steel with and without coating in air shows an increase of resistivity with time, which can be considered to be a major contribution to the overall degradation observed in SRUs and stacks.
- Microstructural parameters as function of operating conditions and time for cathodes and anodes have been extracted for use in the respective sub-models.
- Cellular automaton model developed to predict 3D microstructure evolution, and corresponding degradation of polarization resistance, of Ni/YSZ anodes
- A micro-model of SOFC electrodes has been developed for LSM-YSZ material (see below). The model validation has been performed by implementing microstructural and electrochemical data from 3D reconstruction available on fresh LSM-YSZ.

Model development and validation

A quantitative time-dependent stack model for lifetime predictions, based upon the degradation analyses of the materials and materials combinations was developed. Continuum composite electrode models were developed for this purpose. Their level of complexity was selected to adequately capture the degradation measured for the different materials and material combinations, yet to allow their implementation directly in stack level models.

Comparison between the initial electrode performance predicted by the continuum models and experiments showed satisfactory agreement over the range of local conditions found in operating SOFC stacks. The electronic conductivities predicted by the 3-D analytical methods were in line with the results reported before; in particular, the model correctly captured the low effective conductivity of the LSM phase, in the range of 1 S/cm, which suggests that the set of models developed coherently treat and retrieve microstructural effects in stack models. Limitations in terms of the volume sample size that could be treated with standard computation resources were encountered and could be solved.

The empirical degradation laws as obtained from the materials exposure tests were compiled to prepare their implementation in the calibrated continuum composite electrode models. Three semi-empirical laws were provided: two for the degradation of the conductivity of the uncoated LSM/MIC interface and one for the degradation of the total conductivity of the Ni-YSZ anode. These electrode models including degradation were then implemented in stack models for lifetime prediction under practical operating condition and delivered to the industrial partners TOFC, HTceramix/SOFCPower and HEXIS for comparison against experimental data.

TOFC

The stack part contained the results and conclusions from the agreed stack tests (3x3000h), plus other long term stack tests performed to verify these data. The tests were performed on 14 stacks

including two 4 stack modules, and a total of more than 40.000 test hours could therefore be included in the interpretations.
Considering the facts that models existed for selected parameters and the lack of time before project closure it was impossible for TOFC to adapt and incorporate the available degradation expressions into our model, run it, and perform a near-satisfactory evaluation against the results from our stack tests.
The project provided us with qualitative information on degradation phenomena that will be very valuable in our future work with understanding and modelling of degradation mechanisms. The extensive stack testing carried out within this project did for sure increase our knowledge on long term stack behaviour and highlighted which areas we should focus on in our future work.

HTceramix / SOFCPower:
Durability tests have been performed on three short stacks consisting of 3 to 6 repeat units. All stacks include anode supported cells with LSCF cathodes as studied in the project.
The short stack model including the empirical laws for Ni-coarsening and evaporation, and the change in the conductivity of the YSZ phase was compared to three steady-state degradation tests performed on short stacks. The model could predict the initial transient degradation (< 800 h) and matched the long-term degradation rate for the new design short-stack, indicating that changes in the anode Ni-network play an important role in the initial degradation of the stacks. For the other two stacks, corresponding to a former design, the degradation rate was underestimated, indicating that other degradation mechanisms are involved that have not been taken into account in the model. In particular, EIS measurements, performed on one of the former design stacks, indicated an important increase of the ohmic resistance over time. The latter could be attributed to non-homogeneous contacting or/and to the formation of interfacial reactive layers.

HEXIS:
Operation times of > 3000 h without incidents were achieved for 3 stacks: they were started within the frame of the SOFC-Life project and showed a representative behaviour (more stacks were operated in the background), for three different operating conditions.
The SOFC-Life ESC-type lifetime-predicting model was successfully applied and validated at Hexis as follows: data from stack testing was trimmed, into internal resistances only, to enable a valid comparison with model-based results. Therefore an automated, model-based analysis of current-voltage data was performed for the stack results.
The lifetime/degradation predicting model, developed within the framework of the SOFC-Life project, well describes Hexis stack behaviour and is thus adapted for industrial application and is actually in use. The current (0D) model also exhibits limits for understanding local RU effects within a SOFC stack, and is therefore foreseen to be extended into a 2D model that should account for local degradation effects that depend, for instance, on local gas concentrations.

Main results of the model development and validation assessed towards the stated objectives:

- The SOFC-Life ESC-type lifetime-predicting model was successfully applied (HEXIS).
- The short stack model including the empirical laws for Ni-coarsening and evaporation, could predict the initial transient degradation (<800h) and match the long-term degradation rate for the new design short-stack (HTceramix).
- The project provided qualitative information on degradation phenomena that are very valuable in future work with understanding and modelling of degradation mechanisms (TOFC).

Lessons learned and project recommendations

The exposure tests conducted in SOFC-Life on the selected materials and materials combinations did not render a breakthrough insight in the degradation behaviour of SOFC stacks. Most of the degradation mechanisms selected for investigation at the start of the project did not contribute to a substantial level to the overall stack degradation. This supports the impression that the materials are less of an issue with respect to SOFC degradation than the choice of materials combinations and the resulting interfaces, which in the end have more influence on performance and lifetime than the materials themselves.

This showed to be problematic also with respect to the aim of SOFC-Life to develop degradation models of a generic nature. Already the existence and use of different cell technologies (ASC and ECS) increases not only the number of materials combinations, but also the different temperature windows of operation for these two technologies constitute a major hurdle for the development of generic models.

Project recommendations:

- Degradation models will require further refinement to make them applicable to a wider range of cell types and operating conditions.
- Basic understanding should be applied to develop soundly based accelerated tests.

Final results and potential impacts

The SOFC-Life project aimed at a better understanding of the degradation phenomena as a tool for mitigating these effects and as a first step towards developing accelerated testing methods.

From the selected four themes (degradation mechanisms), all contributing to the overall ohmic part of the SRU impedance, three could be identified as having only minor or even no influence on the degradation behaviour observed in SOFC stacks. Only the contact resistance between the metal interconnect and the cathode (contact layer) showed substantial increases over time and can be considered to be a major contribution to the overall degradation observed in SRUs and stacks.

Continuum composite electrode models were developed. Three semi-empirical degradation laws as obtained from the materials exposure tests could be implemented. These electrode models including degradation were then implemented in stack models for lifetime prediction under practical operating condition.

Implementation of the results from the model development was performed within the scope of the model validation with real stack testing. Due to the participation of major European SOFC manufacturers this process resulted in direct industrial implementation of results.

SOFC-Life addressed basic research activities directed to **degradation and lifetime fundamentals** of SOFC technology, **focusing on SOFC materials available and in industrial application today** (cf. MAIP section 3.4.3 page 15 - updated version adopted November 2011) and as such contributed towards market introduction and economic development of the stationary fuel cell sector.

Partners in the consortium

Partner	Beneficiary Name	Role	Country	Beneficiary Contact	Contact E-mail
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