SOFC-Life
(256885)

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Programme Review Day 2012, Brussels, 28 & 29 November 2012

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

project data	
reference	FCH JU 256885
start date	01/01/2011
end date	31/12/2013
duration	36 months
total costs	5.700.000 €
FCH JU funding	2.400.000 €
	42 %

partners - research & university			
DTU-EC	Denmark	EPFL	Switzerland
VTT	Finnland	EMPA	Switzerland
CEA	France	ZHAW	Switzerland
FZ Jülich	Germany	Imperial College	United Kingdom
IHTE	Russia		

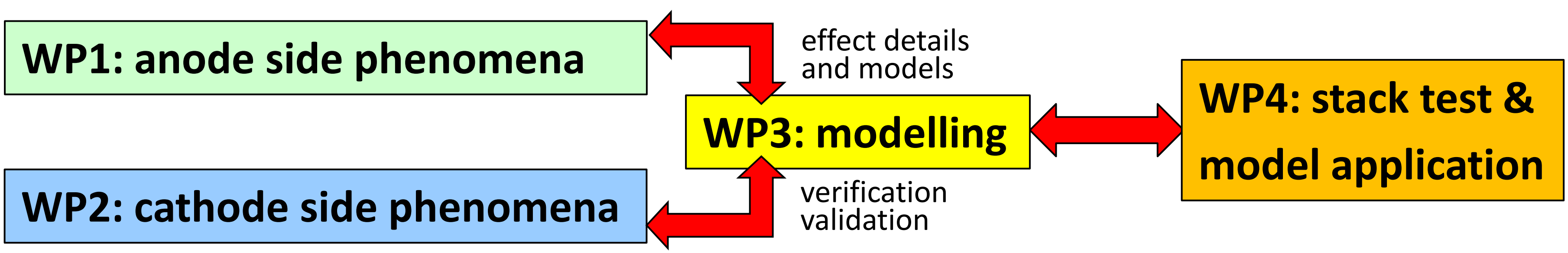
partners - industry			
TOFC	Denmark	HTCeramics	Switzerland
EDF	France	HEXIS	Switzerland

Objectives

- 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

Approach

- dis-assemble the SOFC single repeating unit to model elements representing single degradation phenomena (anode and cathode compartment)



SOFC Life

Main topics (degradation mechanism)

WP2: cathode side phenomena

- the stability (chemical, kinetic and morphological) of state of the art cathode materials (impacting the cathode activity)
- processes at the cathode-interconnect interface (impacting electrical continuity and chemical composition of components, thus their electrochemical performance)

WP1: anode side phenomena

- morphological change in the anode cermet (impacting on anode activity and electrical continuity)
- nickel-steel corrosion (impacting on electrical continuity and conductivity)

Generic test matrices

ASC	1st selection	alternative
steel interconnect	Crofer22H	Crofer22APU
contact element	Ni mesh	
anode substrate	Ni/YSZ cermet	
cathode	LSCF (w/ CGO barrier)	

ESC	1st selection	alternative
steel interconnect	Cr5Fe1Y2O3	Crofer22H
contact element	Ni mesh	
anode	Ni/CGO cermet	
cathode	LSM/YSZ	

ASC		1st	2nd	3rd	4th
temperature (°C)		700	750	800	
current density (A/cm²)		0	0.35	0.70	
fuel composition (mol %)	H_2	97	20	55	10
	H_2O	3	80	45	60
	CH_4	-	-	-	30
air humidity		0		3	

ESC		1st	2nd	3rd	4th
temperature (°C)		800	850	900	
current density (A/cm²)		0	0.35	0.70	
fuel composition (mol %)	H_2	97	20	55	10
	H_2O	3	80	45	60
	CH_4	-	-	-	30
air humidity		0		3	

selection based on

- state of the art materials used by industrial project partners and other major stack developers
- availability of materials / components

All tests to be performed on at least two identical samples, preferably simultaneously!

Test durations: 0, 300, 1000 and 3000 h. Sample extraction for post-test analyses.

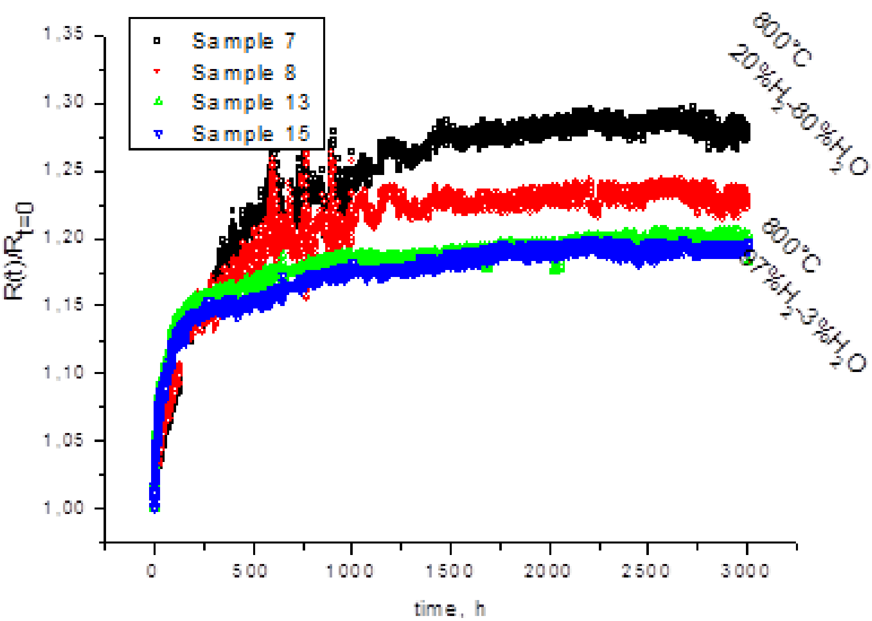
WP1: anode side phenomena

Nickel Agglomeration and Volatilization Issues

ASC matrix: Ni/YSZ cermet

$97\%\ H_2 + 3\%\ H_2O$
$20\%\ H_2 + 80\%\ H_2O$

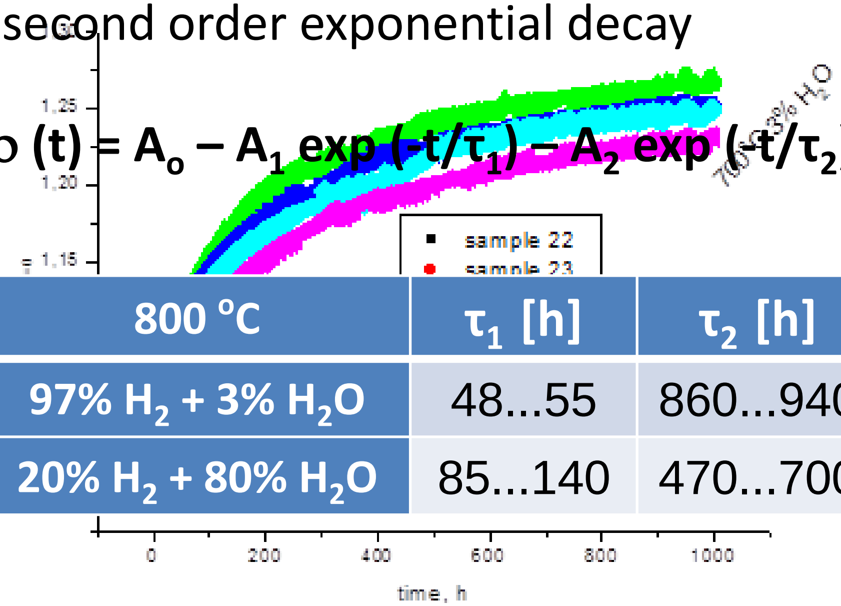
800 °C



700 °C

second order exponential decay

$$\rho (t) = A_o - A_1 \exp(-t/\tau_1) - A_2 \exp(-t/\tau_2)$$



800 °C	τ_1 [h]	τ_2 [h]
$97\%\ H_2 + 3\%\ H_2O$	48...55	860...940
$20\%\ H_2 + 80\%\ H_2O$	85...140	470...700

WP1: anode side phenomena

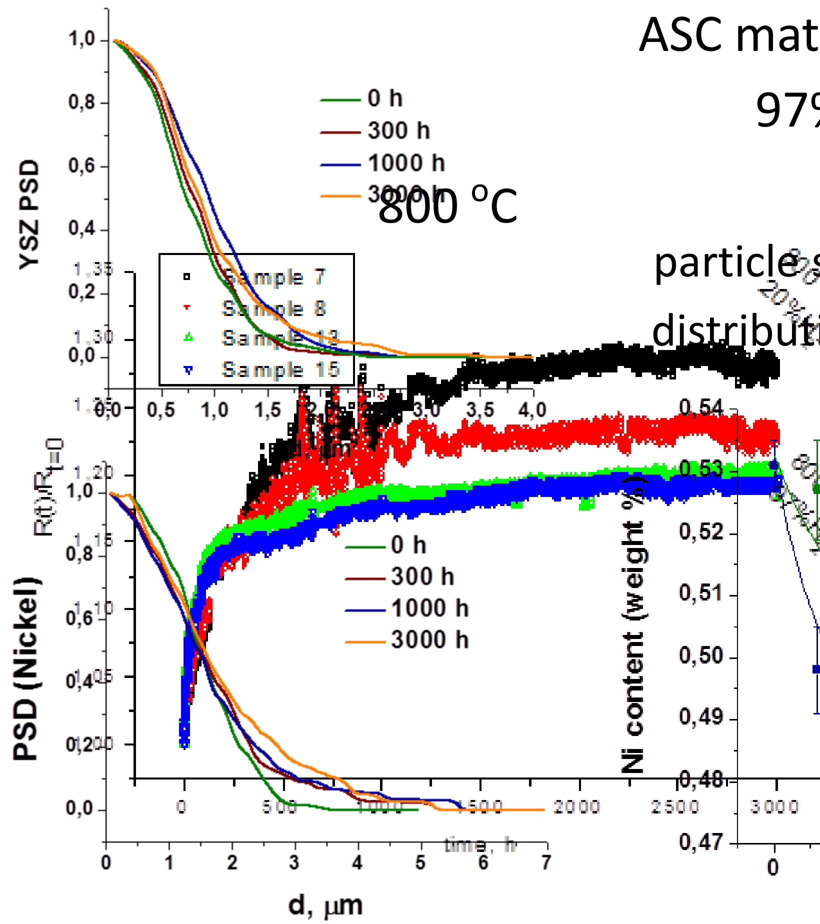
Nickel Agglomeration and Volatilization Issues

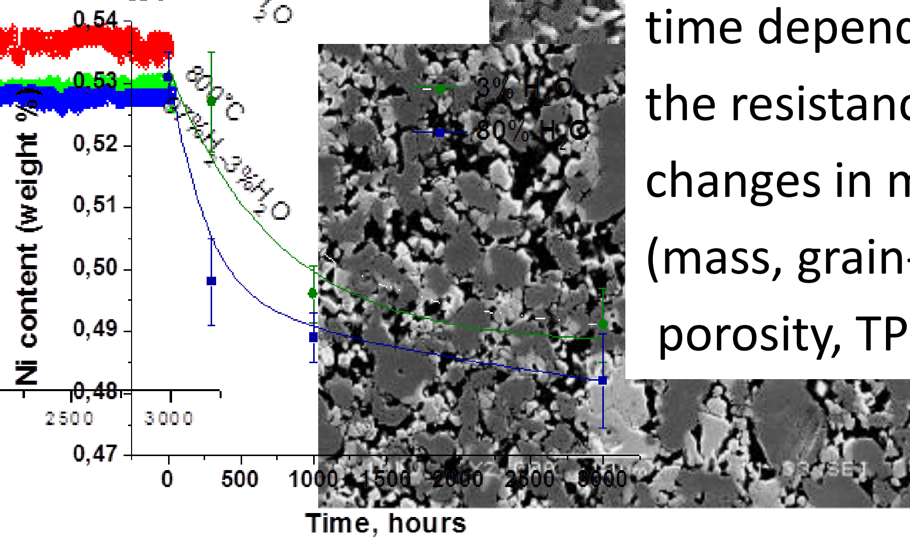
ASC matrix: Ni/YSZ cermet

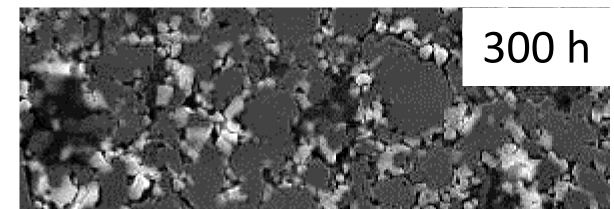
97% H_2 + 3% H_2O

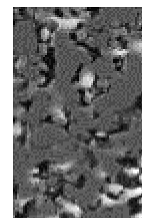
800 °C

particle size distributions







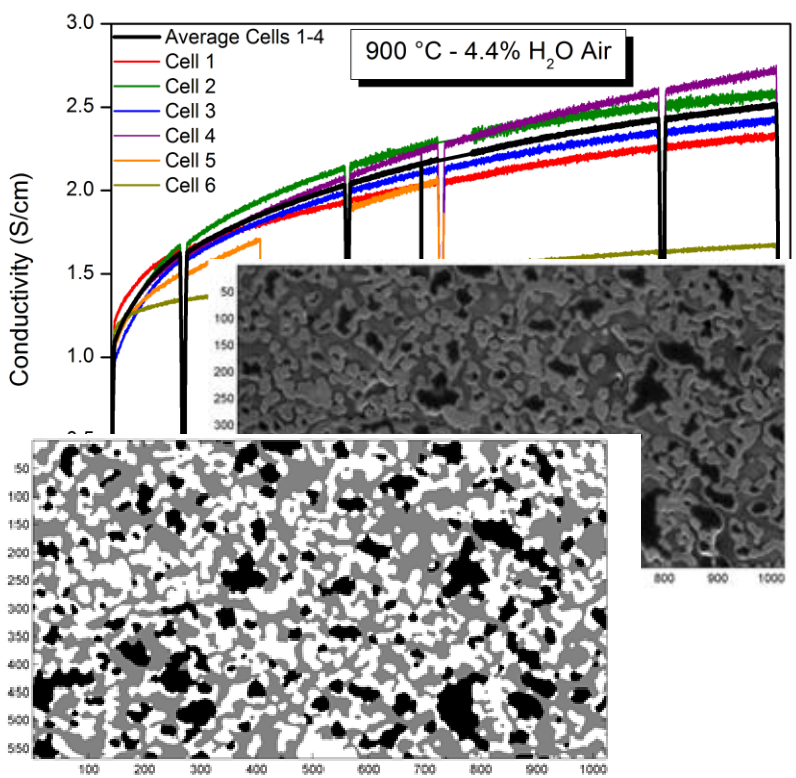


next steps:

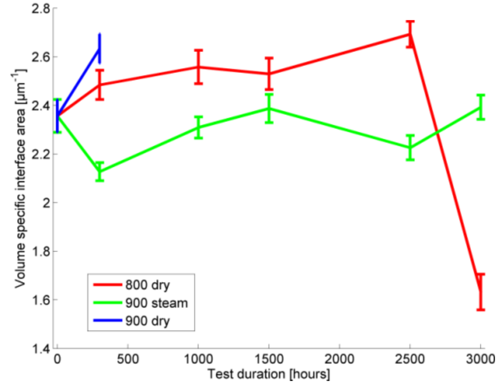
correlation of the time dependences of the resistance with changes in microstructure (mass, grain-size, porosity, TPB-length)

WP2: cathode side phenomena

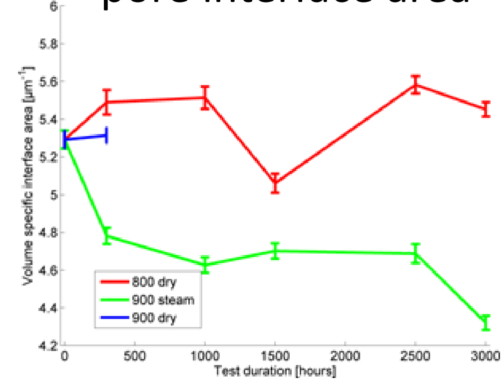
Time dependences of conductivity of LSM cathodes exposed at 900°C in 4.4% humidified air



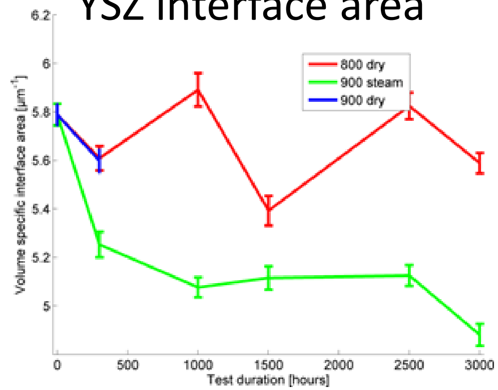
LSM interface area



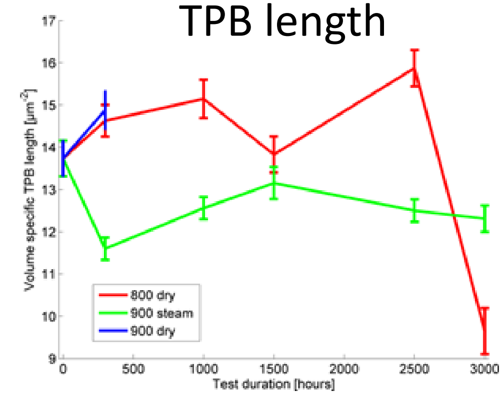
pore interface area



YSZ interface area

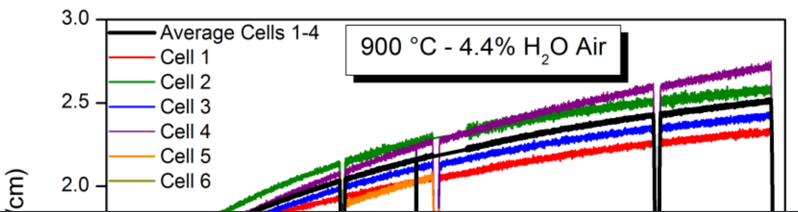


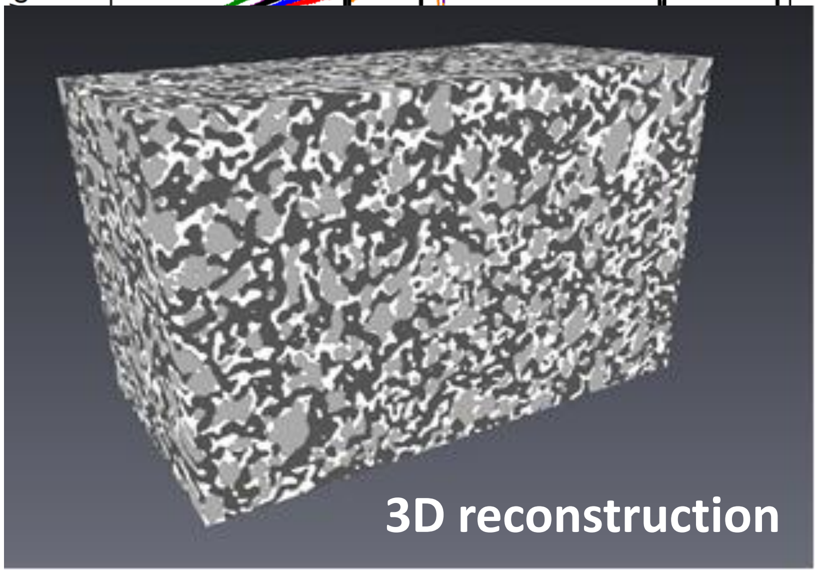
TPB length



WP2: cathode side phenomena

Time dependences of conductivity of LSM cathodes exposed at 900°C in 4.4% humidified air





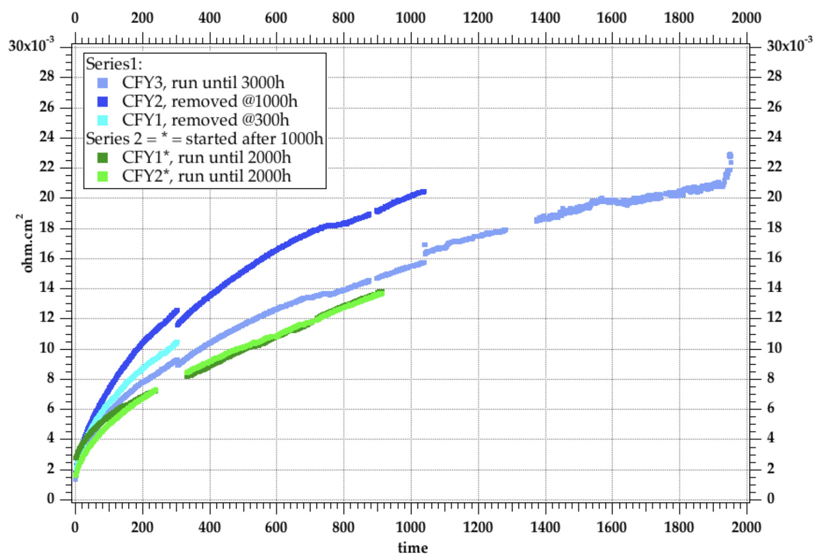
Measurement (reference sample)	3D-1 (CEA)	3D-2 (DTU)	2D (DTU)
Pore phase fraction [%]	50	48	42
YSZ phase fraction [%]	25	24	39
LSM phase fraction [%]	25	28	19
TPB [µm/µm^3]	7	17	14
Percolating TPB [%]	49	74	NA
Pore surface area [µm^2/µm/3]	9.1	4.2	5.3
YSZ surface area [µm^2/µm/3]	19.9	4.8	5.8
LSM surface area [µm^2/µm/3]	10.4	3.5	2.4

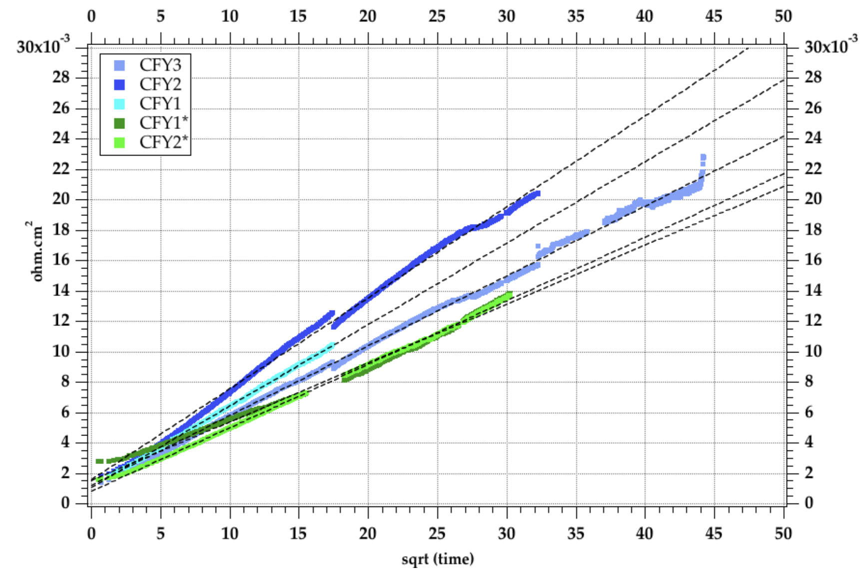
WP2: cathode side phenomena

Interface resistance of interconnect w/ protective coating

CFY 900 °C dry air

parabolic dependence
➔ oxide scale growth

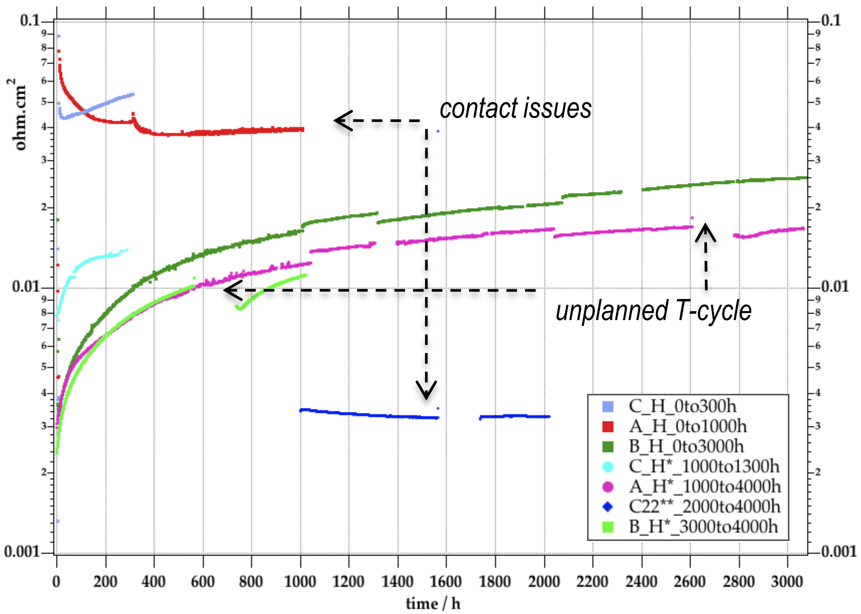




WP2: cathode side phenomena

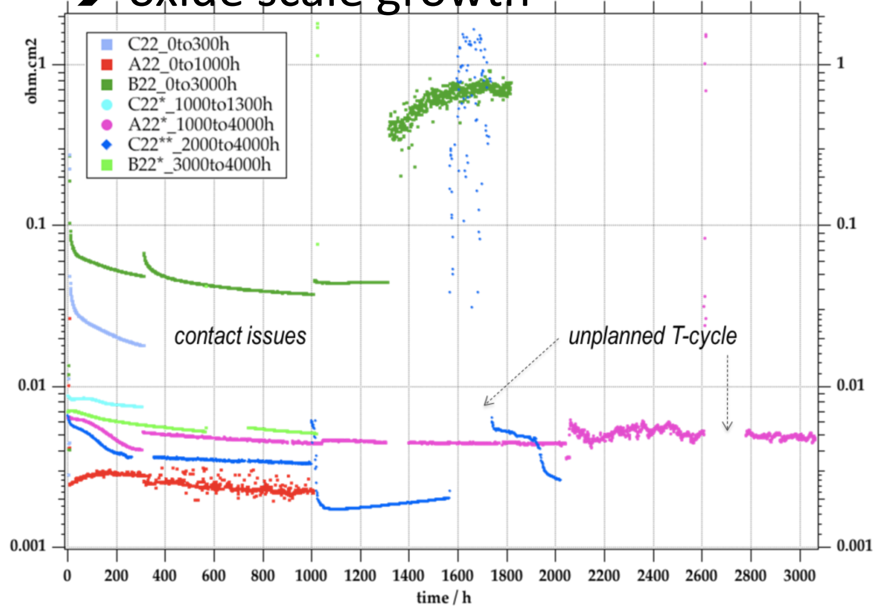
Interface resistance of interconnect w/ protective coating

Crofer22H 800 °C dry air



parabolic dependence also
➔ oxide scale growth

Crofer22H 800 °C dry air



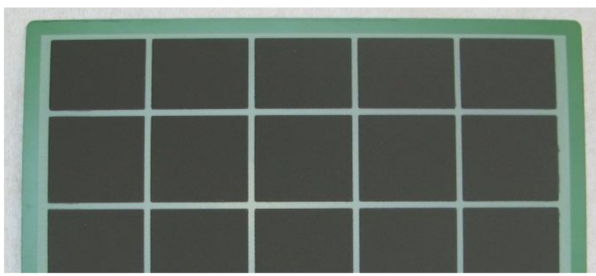
5 mΩ.cm^2, potentially stable;
promising for long term operation

1. Project achievements (10/10)

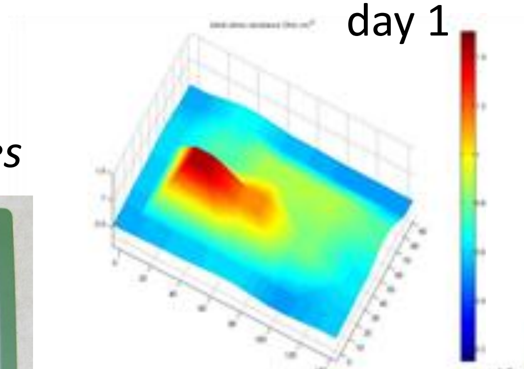
WP3: modeling and verification

Localization of effects:

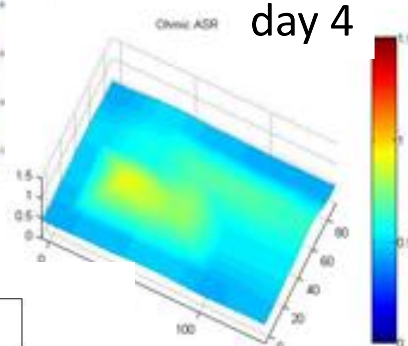
ASC with segmented cathodes



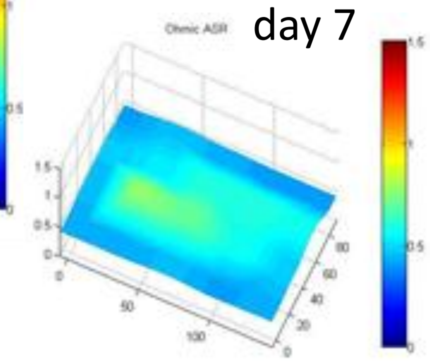
day 1



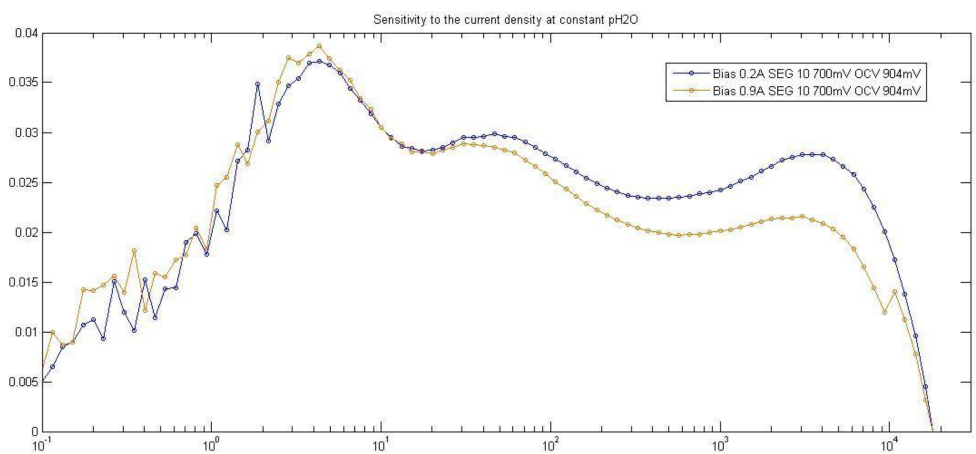
day 4



day 7



sensitivity to current density



Dissemination & public awareness

- website under construction
- workshop on SOFC degradation to be held in 2013

Technology Transfer / Collaborations

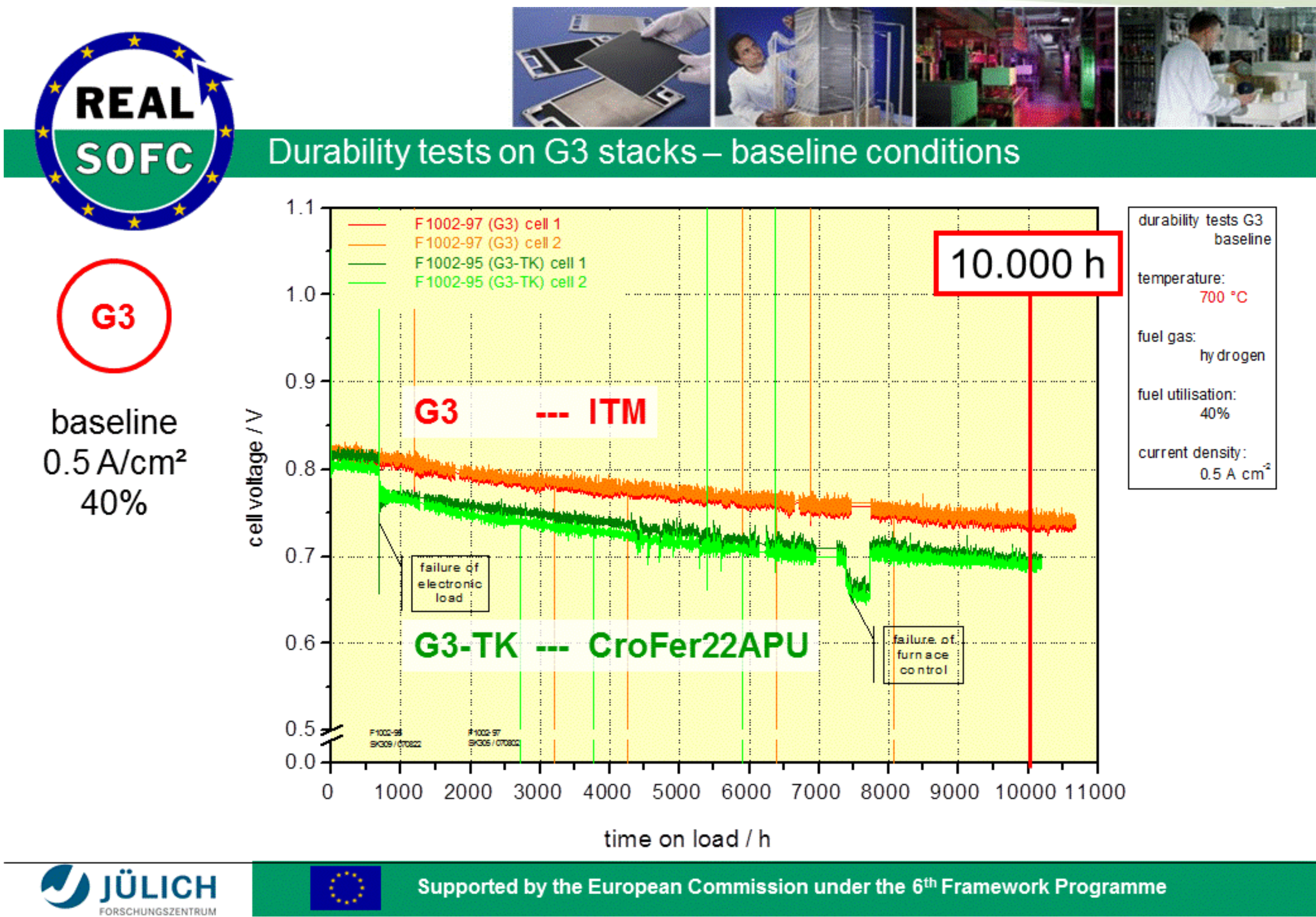
- direct use of results by participating industries and SMEs
- data from Real-SOFC, SOFC600
- German project on SOFC Degradation to start March 2013

intermezzo

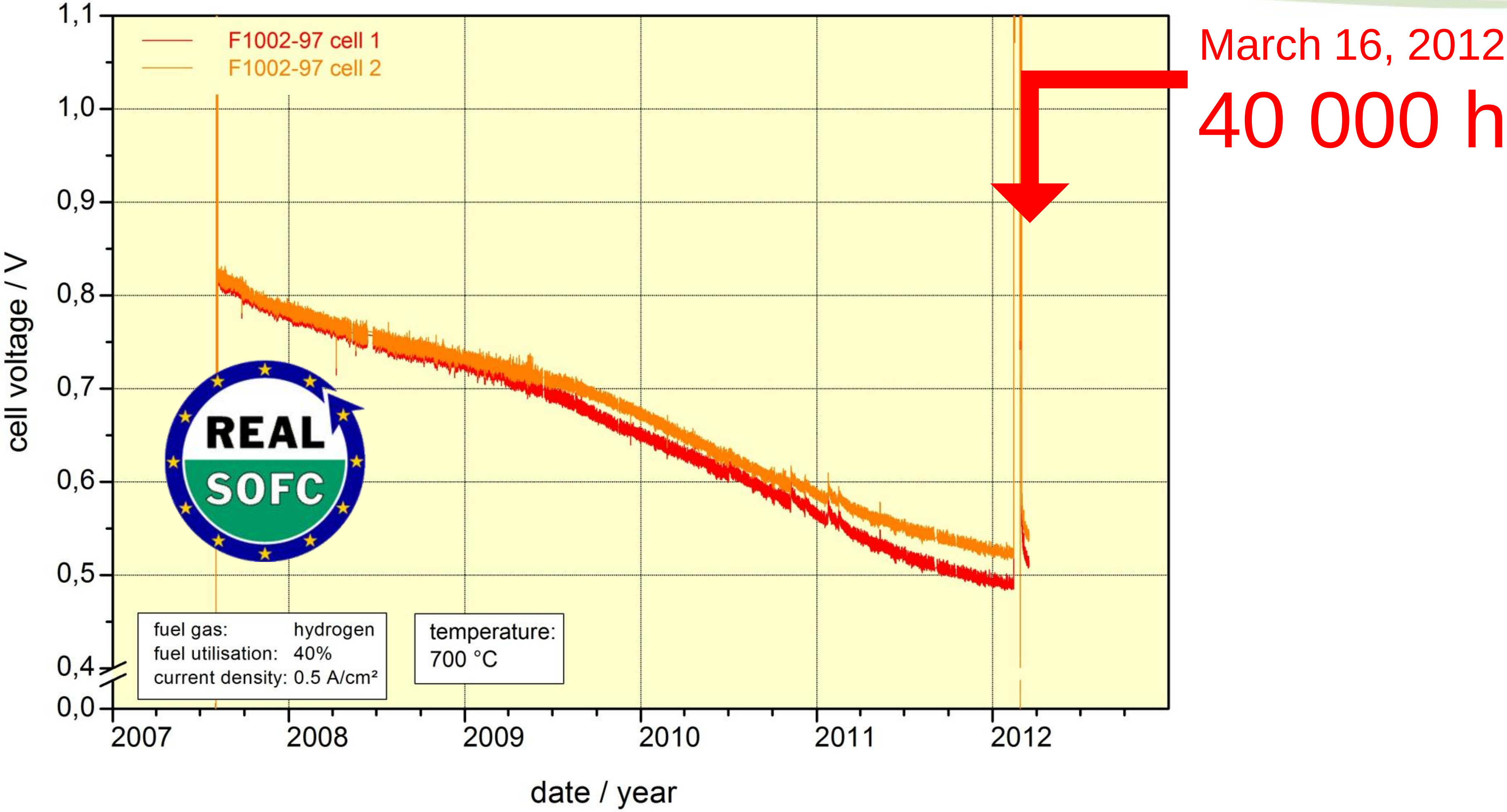
pre SOFC-Life

6th FP project
Real-SOFC (2004-08)
Understanding and reducing degradation of SOFC stacks

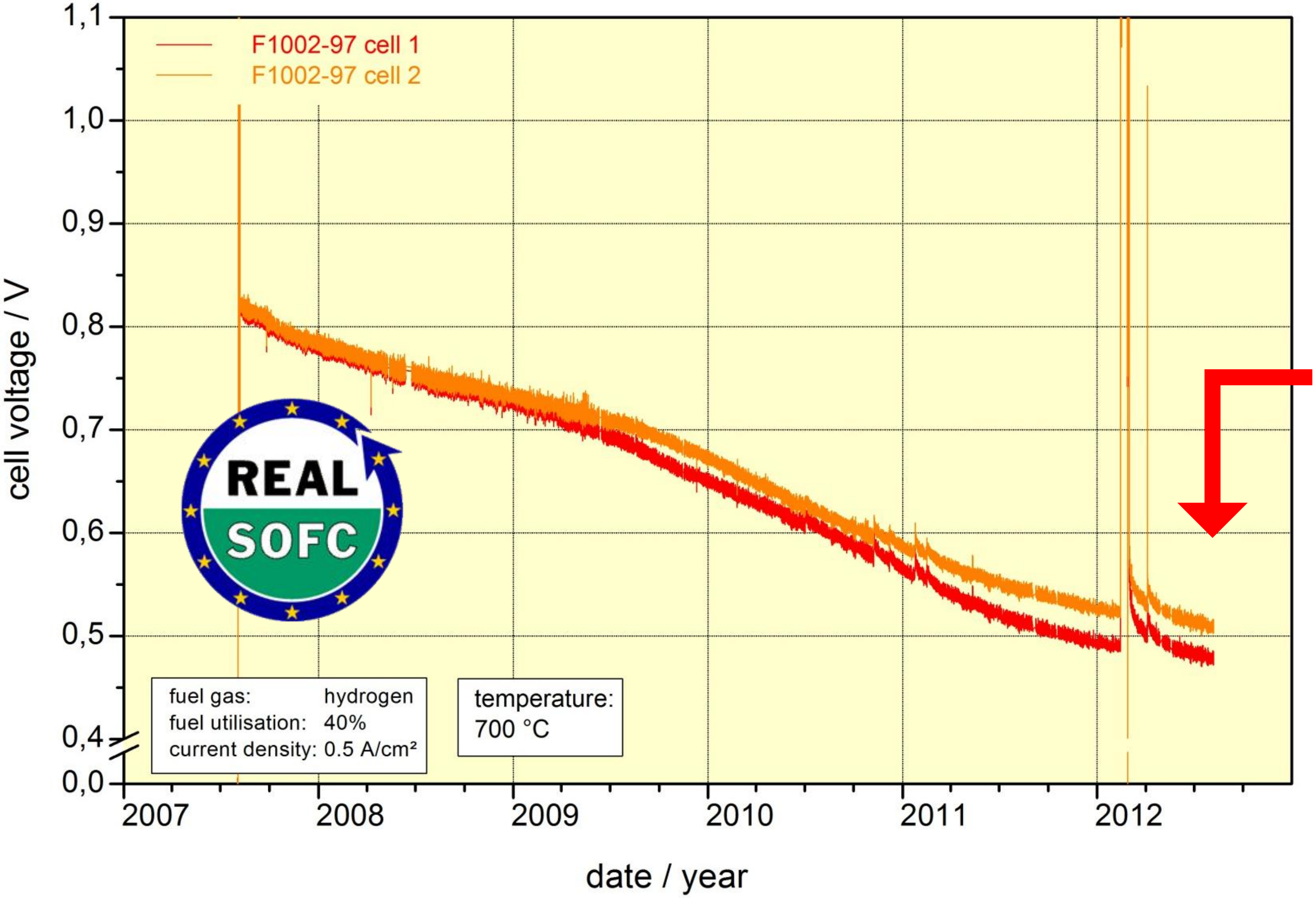
milestone 2008:
2 stacks 10,000 h of continuous operation



post Real-SOFC



post Real-SOFC



March 16, 2012

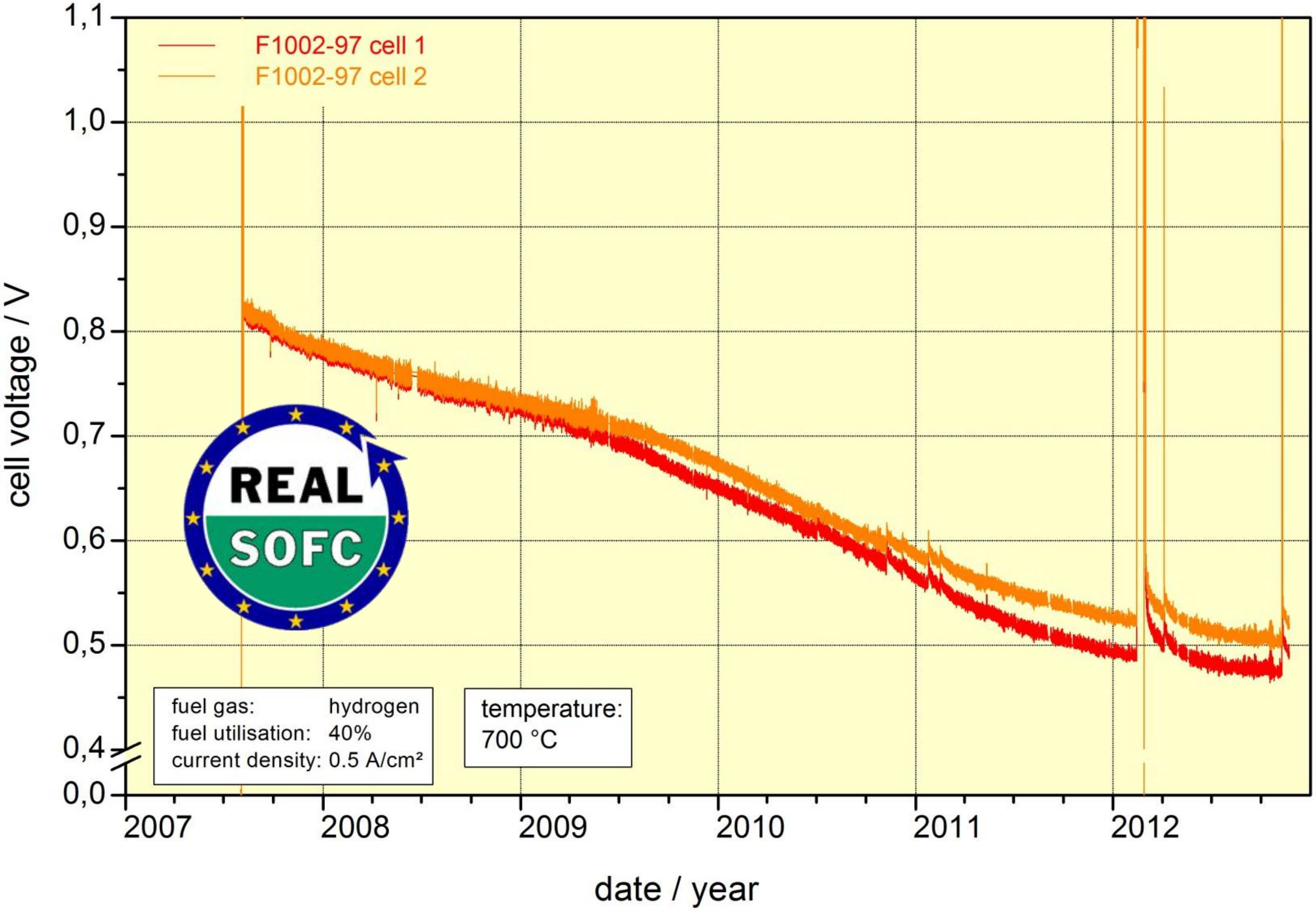
40 000 h

Aug 6, 2012

5 years

intermezzo

post Real-SOFC



March 16, 2012

40 000 h

Aug 6, 2012

5 years

Nov 21, 2012

46 000 h

~1%/kh

Thank you for your attention

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