The Integrated Project SOFC600

Low-Temperature SOFC development

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General Assembly FCH-JU, Brussels, 26/27 October 2009

Project data

- FW6 Integrated Project SES6-2006-020089
- Priority 6.1 Sustainable Energy Systems (SUSTDEV-1)
- Research activities medium and long-term (SUSTDEV-1.2)
- Fuel cells and their applications (SUSTDEV-1.2.1)
- Duration 1st March 2006 – 28 February 2010
- 21 participants

- Research and development project with emphasis on development of novel materials, (near-nano) microstructures and manufacturing processes
- Relatively high level of basic R&D, less application targeted (generic)

EU SOFC600 Project Consortium

7 Universities
- Basic research

11 R&D organisations
- Basic research + development

3 Industrial companies, all SMEs
- Development + implementation

ECN	Netherlands
HTceramix	Switzerland
CEA	France
EMPA	Switzerland
FZJ	Germany
Imperial College	United Kingdom

Uni Karlsruhe	Germany
Uni St.Andrews	United Kingdom
Uni Oxford	United Kingdom
Uni Leoben	Austria
CNRS Bordeaux	France
TOFC	Denmark
AECA (NTDA-SOFC)	Spain
NRC	Canada
DICP	China
IPMS	Ukraine
SJTU	China
BIC	Russia
PMI	Belarus
VTT	Finland
DTU	Denmark

Project objectives and scope

- Specification of stack components for operation at 600°C aiming for endurance and cost
  - Anodes, cathodes and electrolytes
  - Interconnect materials
  - Contact and barrier/protective coatings
  - Seals
- Components are demonstrated by integration in the current cell and stack technology of the developers
- The development and delivery of full cells and stacks itself is outside the scope of the project
- Non technical objectives (WP6)
  - Dissemination and communication project achievements
  - Project website
  - Workshops (internal and external)
  - Initiate and contribute to European HFP-SOFCnet

Motivation for LT-SOFC = FCH-JU relevant topics

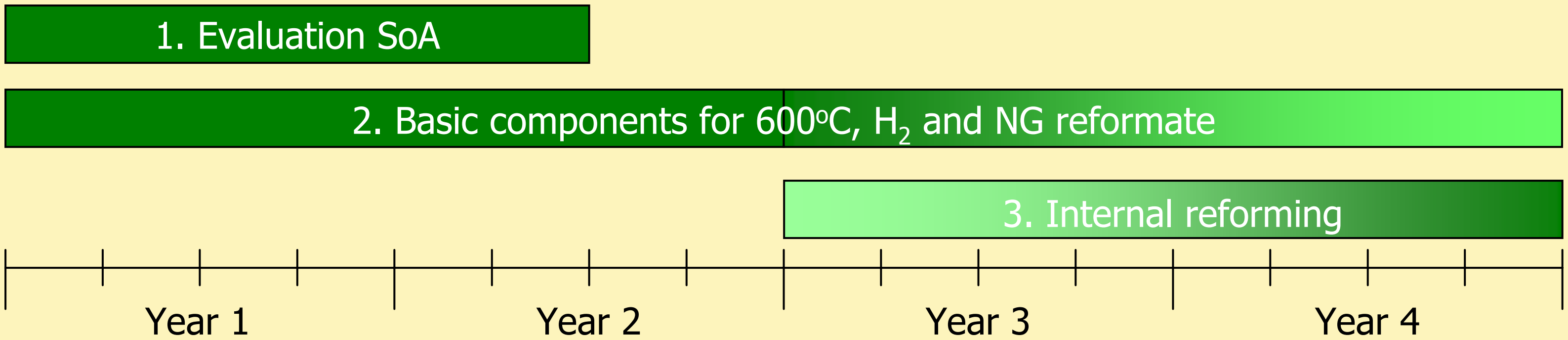
- Lifetime/degradation
  - Reduced degradation rate of thermally activated cell degradation mechanisms
  - Reduced corrosion rate of preferably cheap steels for interconnects
  - Metal, metal-ceramic (compressible) seals and non crystallizing glass
  - Stability of contact coatings
  - Lower sensitivity for combined thermal-redox cycles
- Costs
  - Lifetime
  - Cheap interconnect steels and BOP materials
  - Industrial, cost effective manufacturing processes
- Fuel flexibility and high efficiency
  - H_2 and reformates
  - Internal reforming of NG (simplest and most efficient system)
    - Low catalytic activity for C deposition

Project targets

- SOFC cell at 600^{o}C
  - Area Specific Resistance (ASR) below 0,5 $\Omega.cm^2$
  - Degradation rate below 1.5 $m\Omega.cm^2.khr^{-1}$ (0.05 $\%V.khr^{-1}$)
  - For ISR at S/C = 2: 0.8 $\Omega.cm^2$ and 3 $m\Omega.cm^2.khr^{-1}$
  - Robustness: 5 ppm S, 100 redox cycles, internal reforming capability, reduced coke formation activity
- Single repeating unit (cell + coatings + interconnect)
  - ASR below 0.7 $\Omega.cm^2$
  - Degradation rate below 3 $m\Omega.cm^2.khr^{-1}$
  - For ISR at S/C = 2: 1.0 $\Omega.cm^2$ and 5 $m\Omega.cm^2.khr^{-1}$
- Gas tightness seals
  - External leakage below 0.5% of fuel/oxidant flow at ΔP = 20 mbar
  - Internal leakage below 0.5% at ΔP = 20 mbar
- Main precondition: projected stack costs < 2500 Euro/kW_e
  - Developments based on cost-effective materials and manufacturing

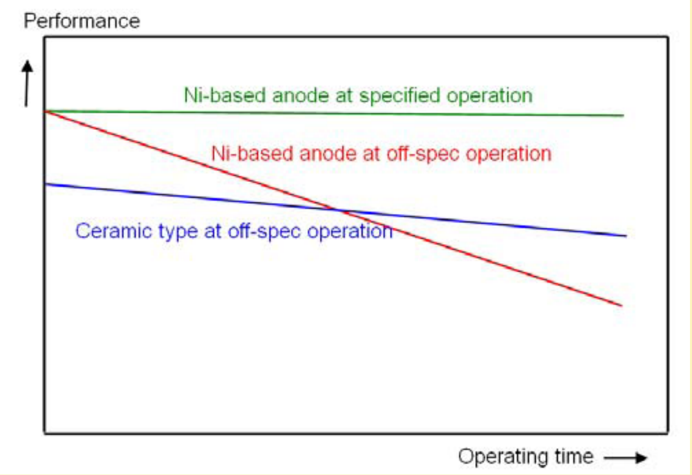
Phases and time schedule

- Evaluation State-of-the-Art components
  - Identification of most critical components
  - Reference for monitoring progress
- Basic components
  - 'Easy' fuels like H_2 and reformate
  - Focus is performance and endurance; sub-focus thermal and redox cycling
- Advanced components
  - Components for internal reforming of natural gas
  - Focus is reforming catalysis; sub-focus S tolerance and low catalytic activity for C deposition



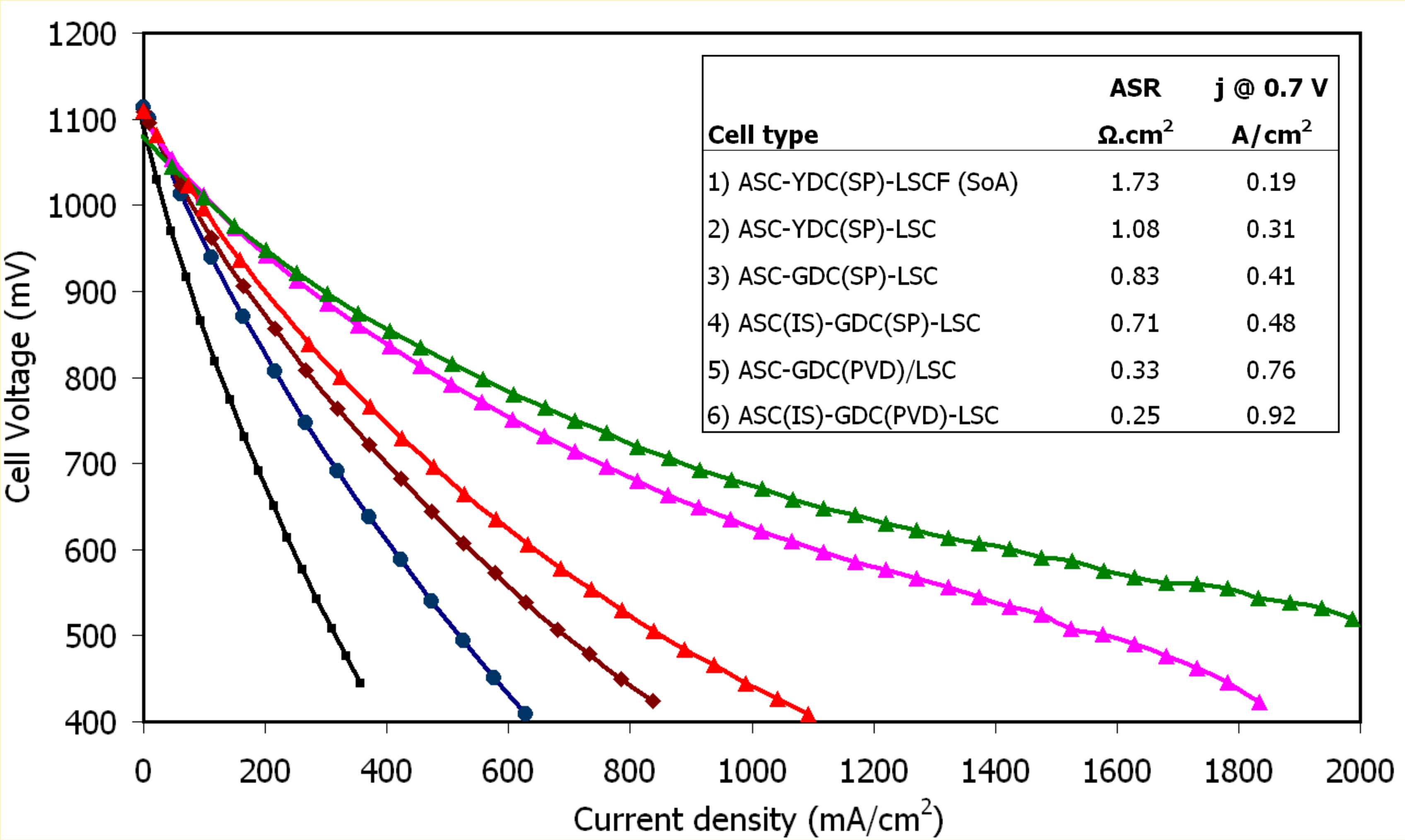
Cell development lines

- High(est) performance and endurance at stationary operating conditions
  - Large scale stationary systems
  - ASC: Ni based anode – SZ electrolyte – Sr containing cathodes
- High robustness cell
  - Redox, Sulphur and Chromium tolerance, reduced C depostion
  - For cycling and off-spec operating conditions
  - Small scale stationary & transport applications
  - ASC: titanate anode – SZ electrolyte – nickelate cathode
  - ESC: Ni based anode – 10Sc1CeSZ electrolyte – nickelate cathode
- Performance and robustness evaluated/demonstrated with
  - H_2 (reformate)
  - Internal Steam Reforming of NG



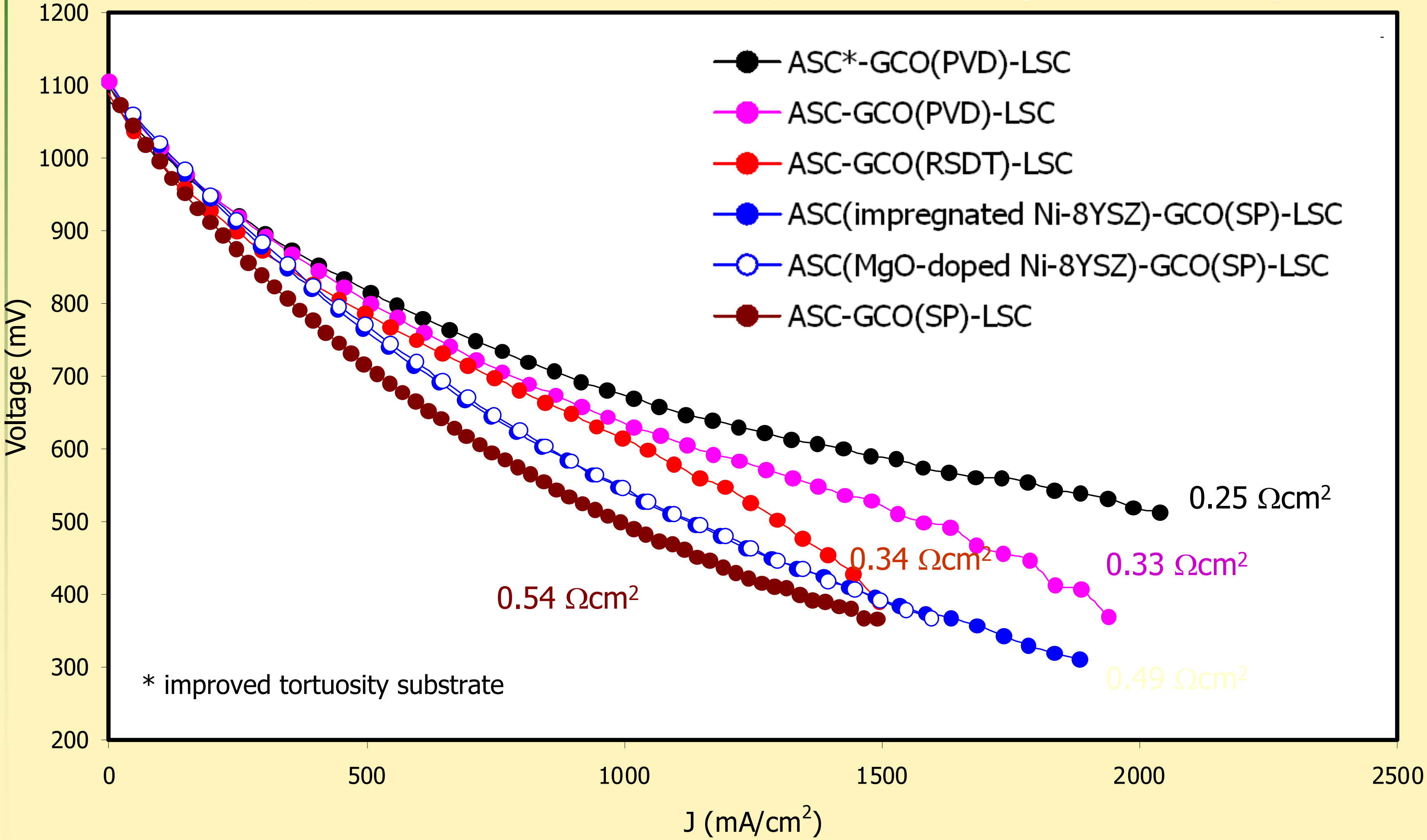
Main Achievements - High Performance Cell

T 600ºC, Fuel 60 H_2 – 40 H_20

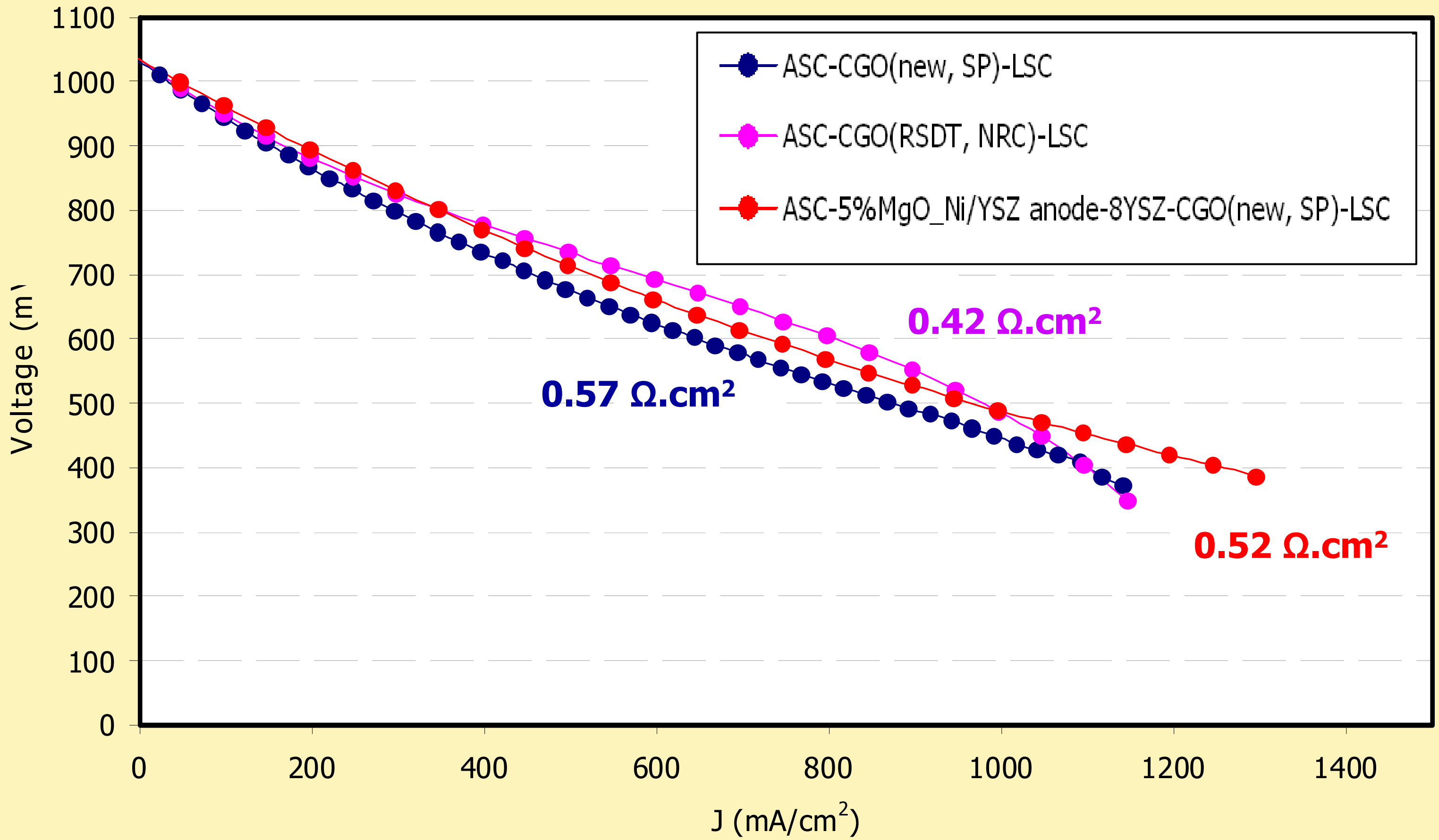


Cell optimisations / alternatives

PVD-GCO by FZJ | RSDT-GCO by NRC | MgO doped AFL by DICP

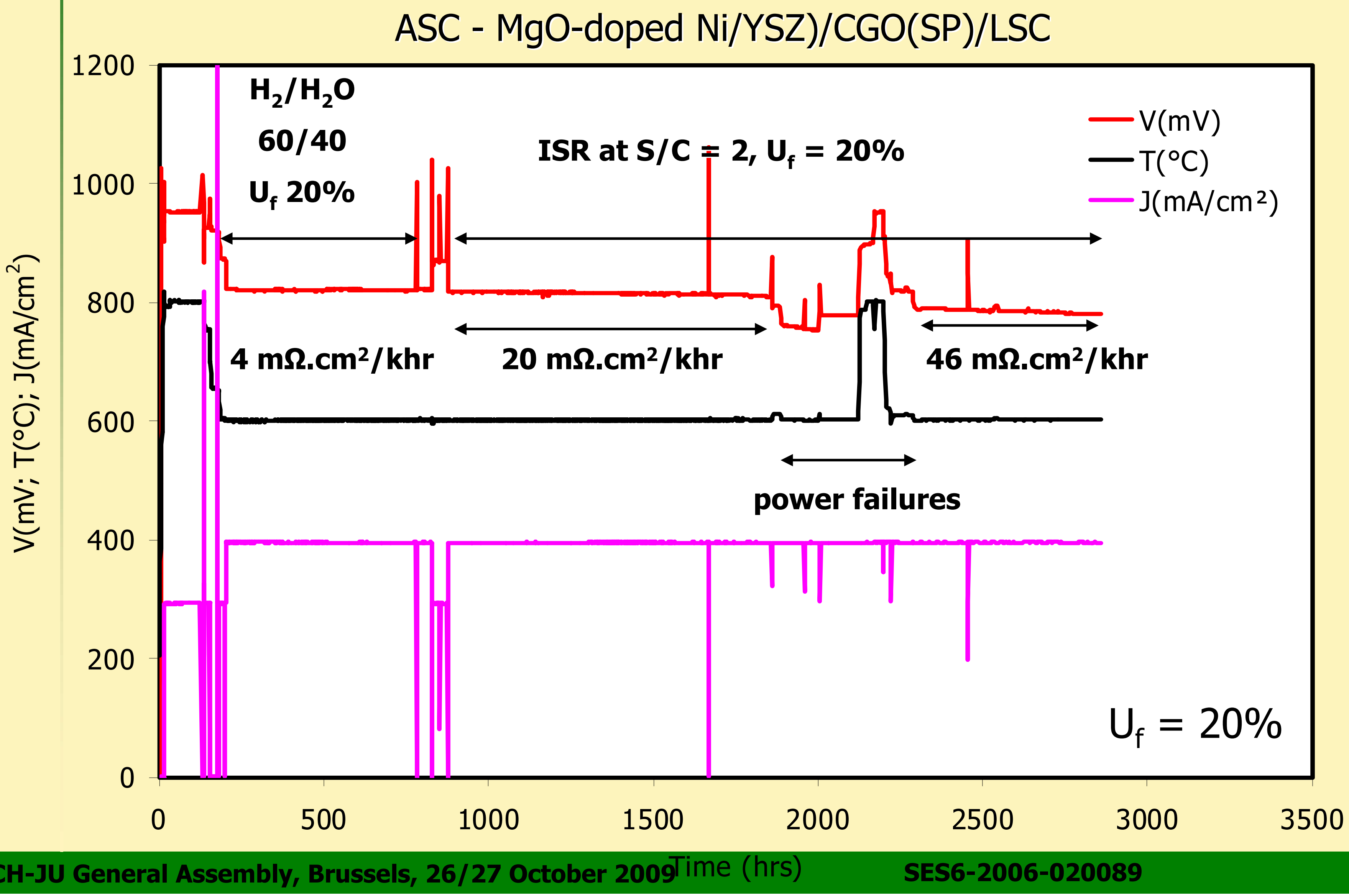


Performance with ISR operation at 600ºC

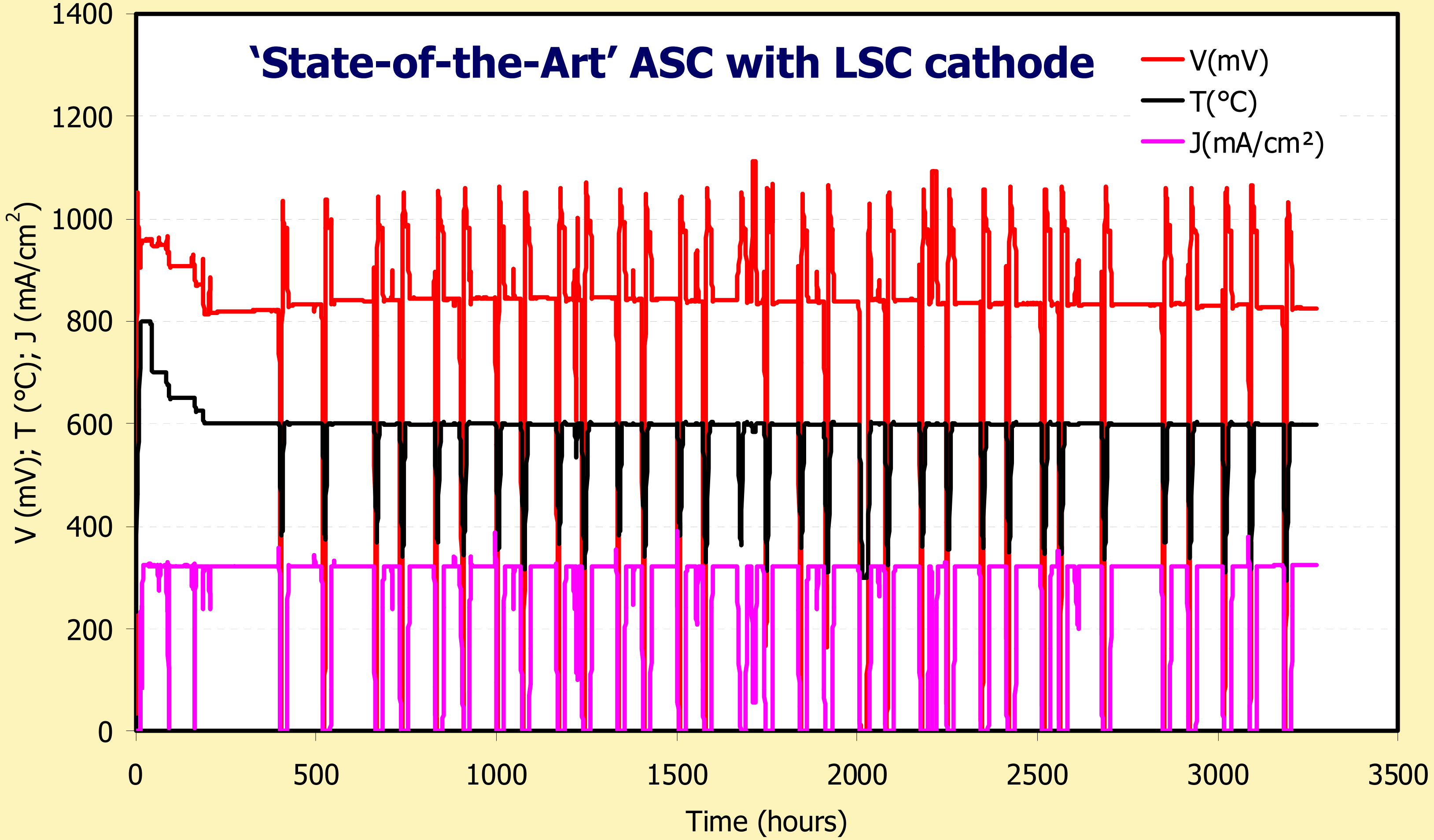


- Performance target (0.8 Ω.cm²) amply met
- Further activities will focus degradation at ISR conditions
  - First short-term results show values similar to H_2 operation

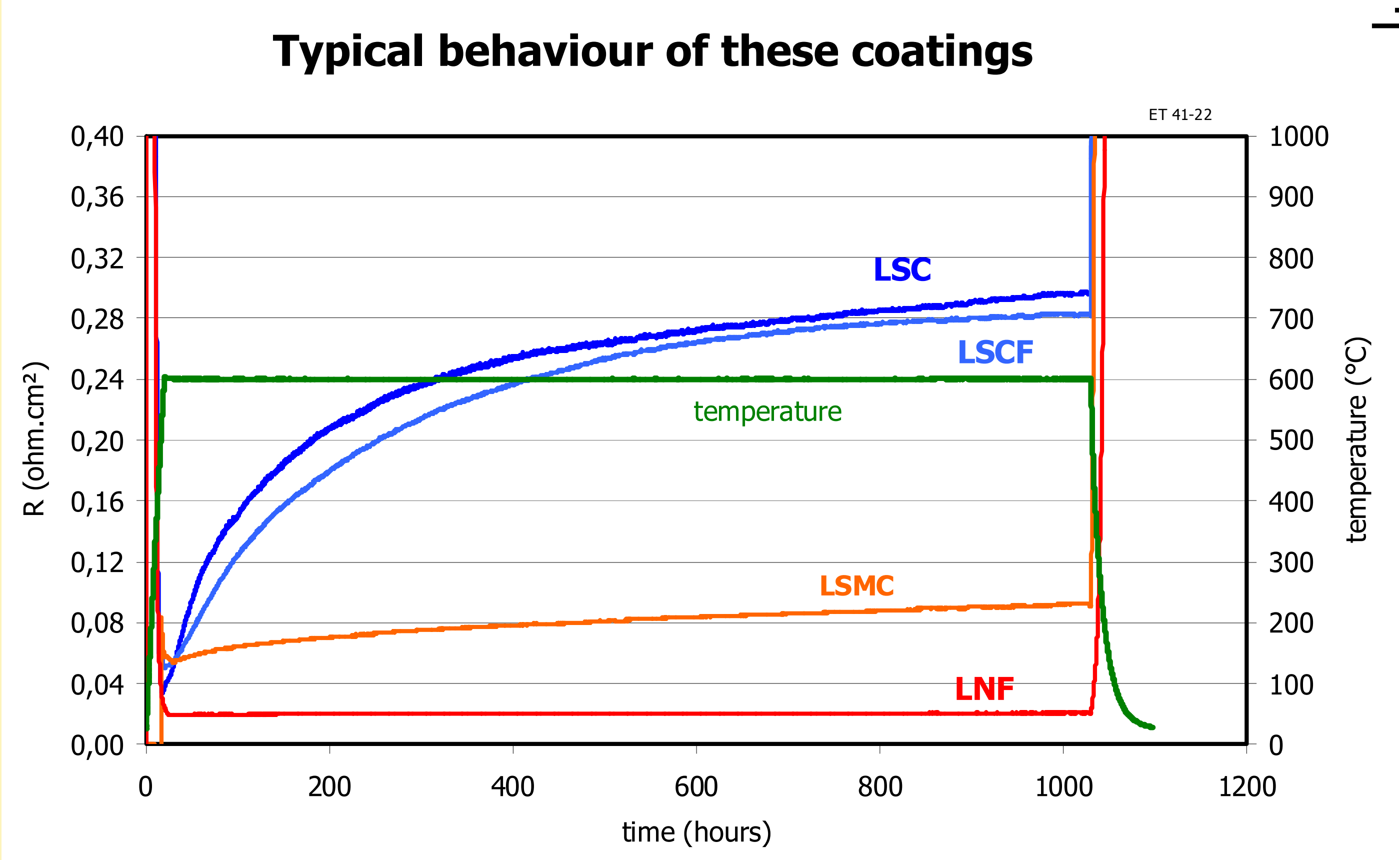
Performance and Endurance at ISR operation

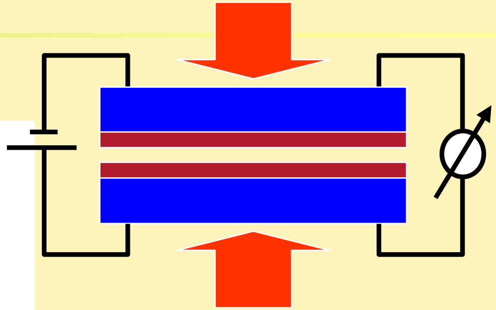


Combined thermal and redox cycle



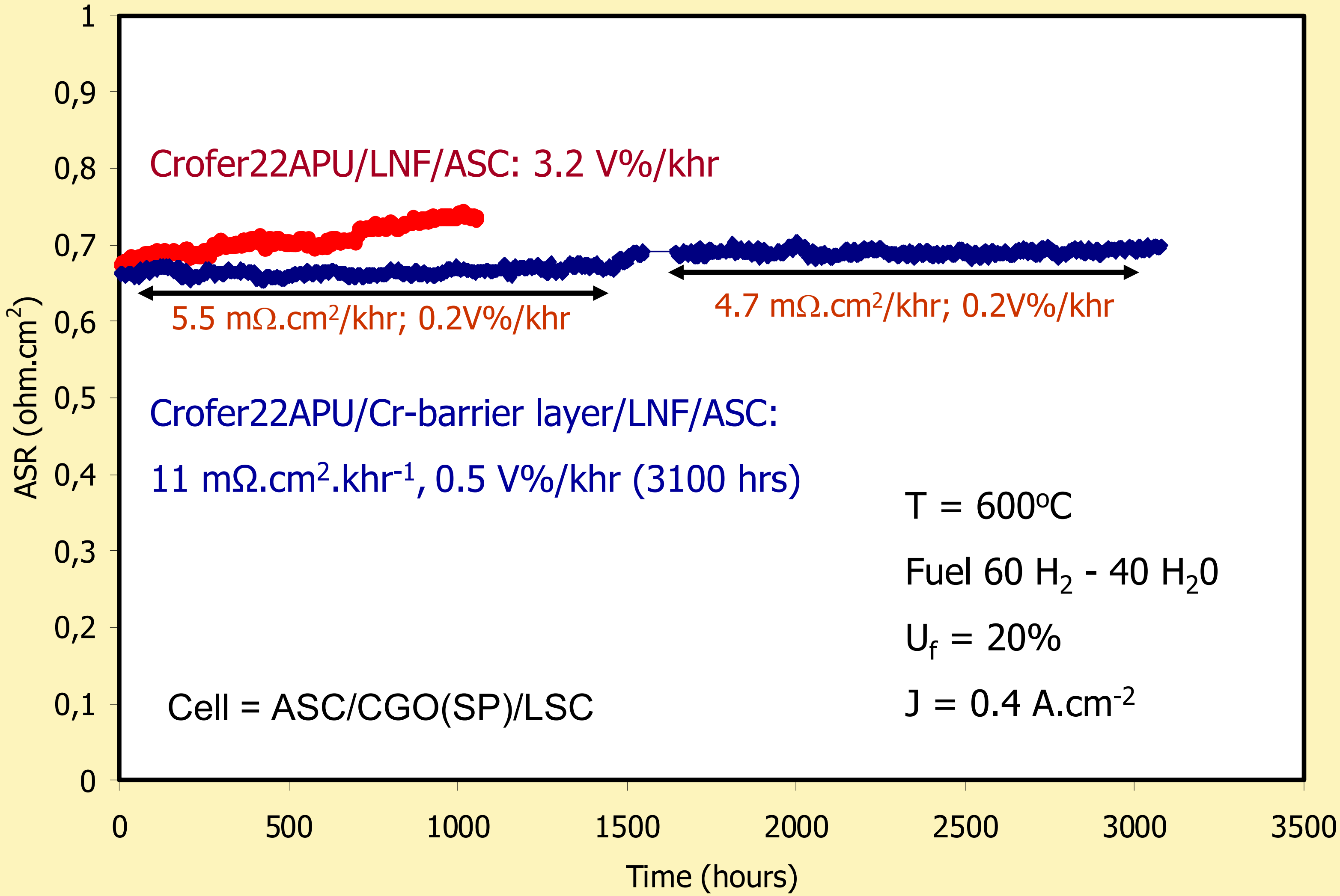
Steel and contact coating





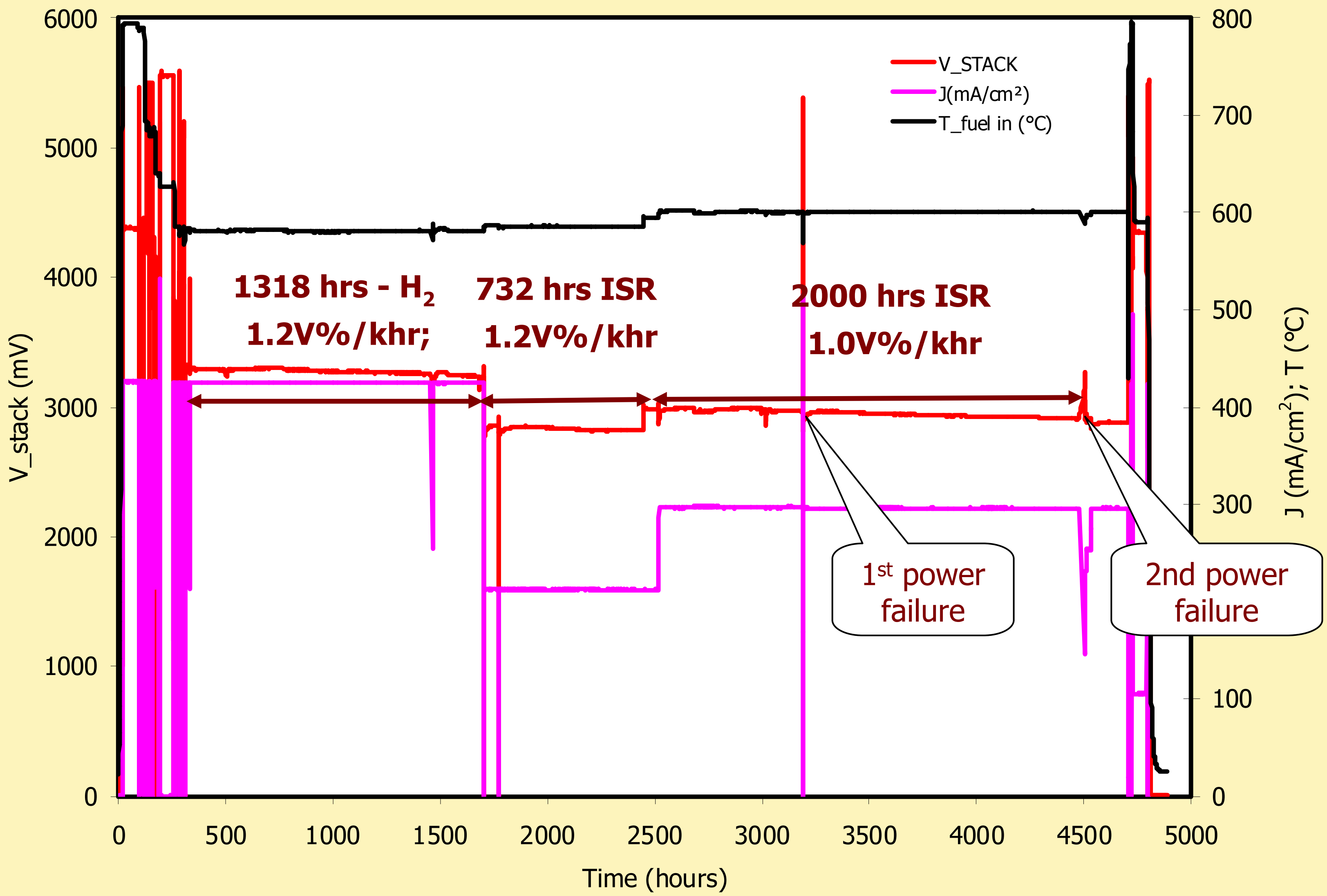
- Steels: 1.4509, Crofer22APU, 1.4016, 1.4521, 1.4435, 1.4845, 1.4520
- Contact coatings: LSC, LSCF, LSMC, LNF, $Pr_2NiO_{4+\delta}$

SRU Performance & Endurance

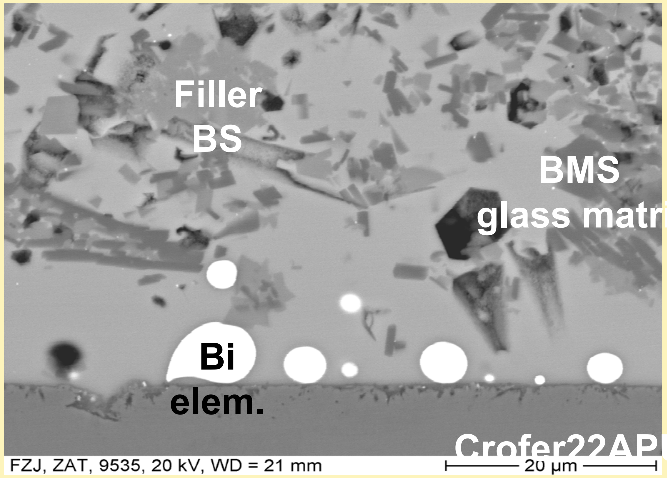


Targets: ASR 0.7 $\Omega.cm^2$ Δ ASR 3.0 $m\Omega.cm^2.khr^{-1}$ equivalent to 0.15 V%/khr

HTceramix stack with SOF600 cells



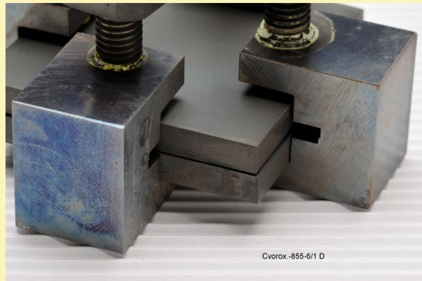
Seals

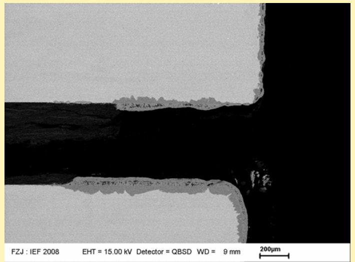


Glas seals that settle at low temperatures

Untreated steel

Pre-oxidised





Mica seals cause corrosion of Crofer; pre-oxidation seems to prevent this

Metal + mica seal for HTceramix stack

Powder manufacturing

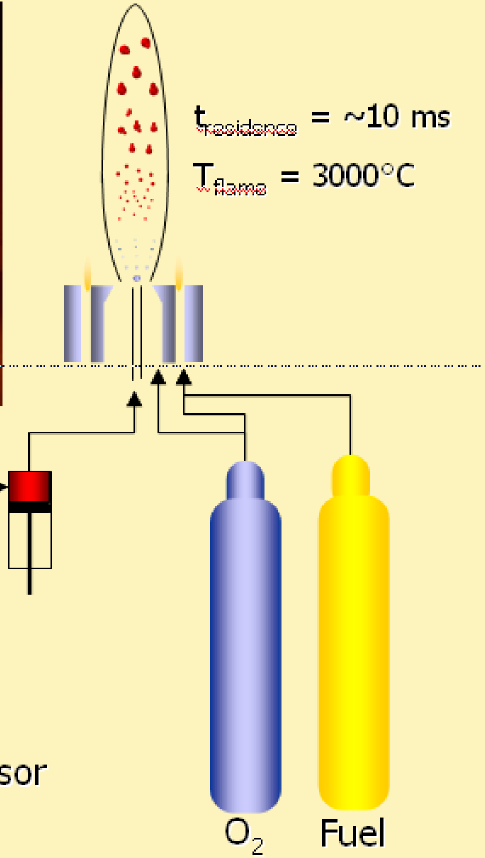
Advantages

- synthesis of nanopowders
  - high temperature & quenching rate (250 000 K/s)
  - one-step synthesis
- no after treatment
- high production rates (400 $g.h^{-1}$)

Powders manufactured

- Cathode and contact coating materials
  - LSC, LSCF, LNF
  - Pr_2NiO_4, $NiNd_2O_4$, $NiPr_2O_4$
- Electrolyte materials
  - $Ce_{0.036}Y_{0.014}Sc_{0.648}Zr_{3.17}O_{7.5}$
- Anode materials
  - $La_{0.7}Sr_{0.2}Ti_{1.0}O_3$

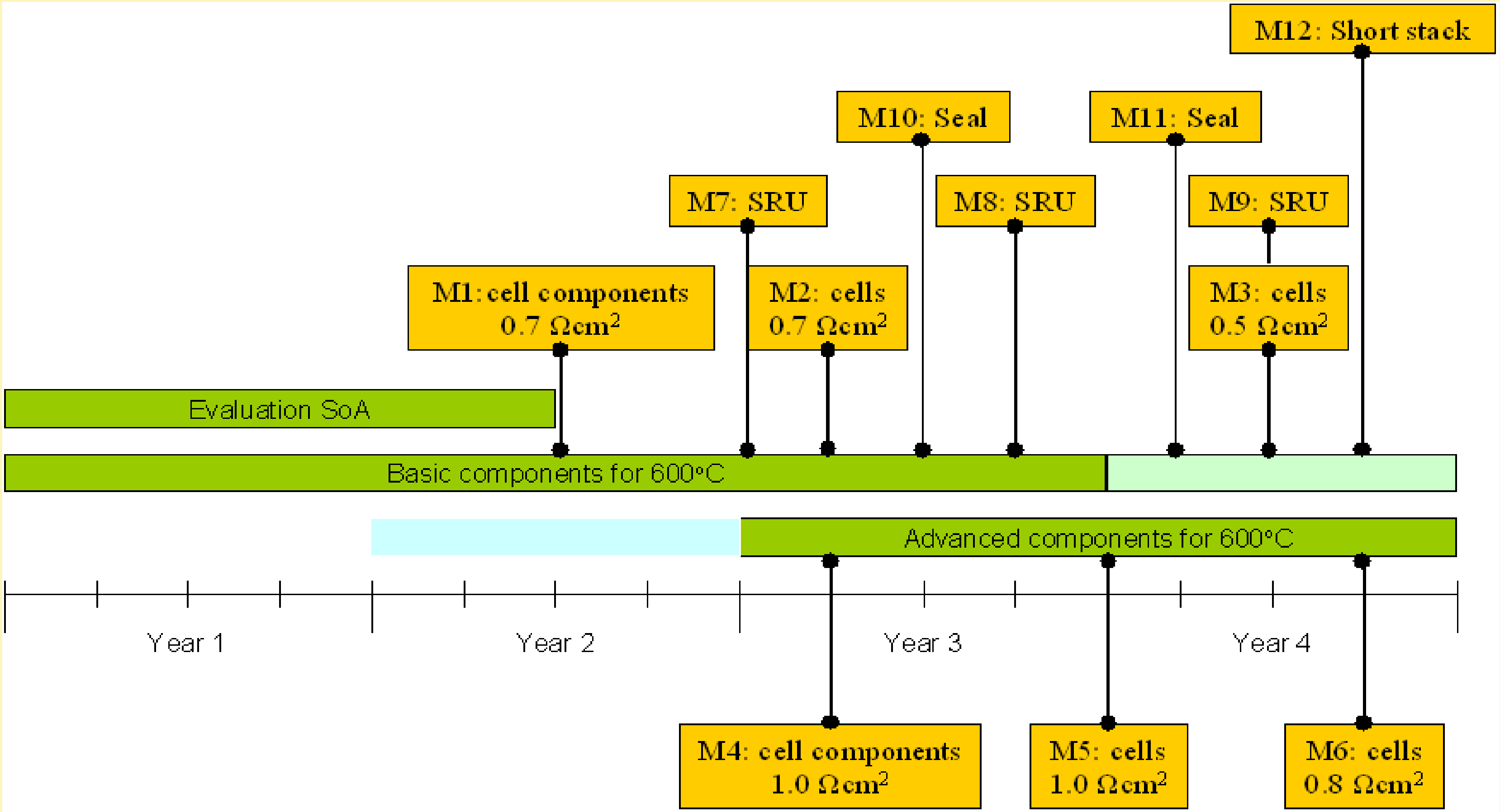
Flame Spray Synthesis



Conclusions

- Cells and cell components
  - Intermediate and final performance targets achieved
  - Degradation targets achieved, but further research required to explain scatter
  - Robust components identified
- Interconnects and coatings
  - Resistivity and corrosion targets met based on 1000 hours tests
- Development low-temperature seal options on schedule
- Powder manufacturing fully operational and fulfilling project needs
- Independent EWGS established
  - Workshop in Sofia on Development needs for SOFC
  - Possible solution for Luzern SOFC conference created: Swiss AG supported by SOFC stakeholders

Good practices: targeted development approach



Good practices: targeted development approach

Breakdown of overall target and time schedule towards final targets

Breakdown of the final cell development target at month 48, in cell components and in time. The top table shows the targets for hydrogen fuels, the bottom table for internal steam reforming of methane

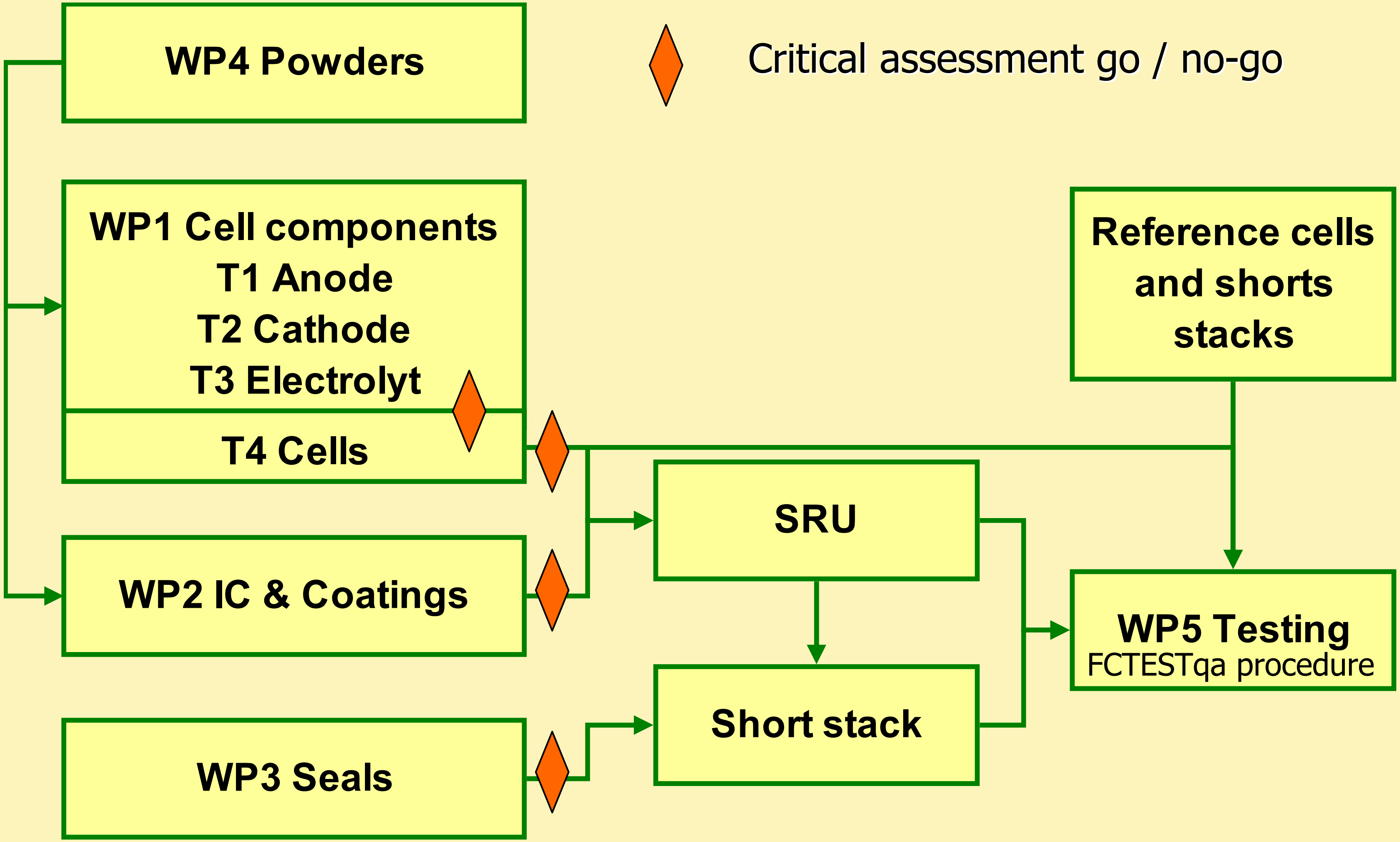
Milestones / Months	0	3	6	9	12	15	M1 18	21	24	M2 27	30	33	36	39	M3 42	45	48
Cell (hydrogen)																	
ASR [Ωcm²]					1.00		0.70		0.70	0.70			0.60		0.50		0.50
Degradation [V% / khr]					0.40		0.20		0.20	0.20			0.10		0.05		0.05
Degradation [mOhm.cm² / khr]					8.60		4.30		4.30	4.30			2.20		1.10		1.10
Anode (hydrogen)																	
ASR [Ωcm²]					0.30		0.20		0.20	0.20			0.20		0.15		0.15
Degradation [V% / khr]					0.20		0.10		0.10	0.10			0.05		0.03		0.03
Degradation [mOhm.cm² / khr]					4.30		2.20		2.20	2.20			1.10		0.70		0.70
Cathode (air)																	
ASR [Ωcm²]					0.50		0.40		0.40	0.40			0.30		0.25		0.25
Degradation [V% / khr]					0.20		0.10		0.10	0.10			0.05		0.02		0.02
Degradation [mOhm.cm² / khr]					4.30		2.20		2.20	2.20			1.10		0.40		0.40
Electrolyte (hydrogen)																	
ASR [Ωcm²]					0.20		0.10		0.10	0.10			0.10		0.10	0.10	0.10
Degradation [V% / khr]					-		-		-	-			-		-		-
Degradation [mOhm.cm² / khr]					-		-		-	-			-		-		-

Regular critical assessments based on achieved results (go/no-go)

Page Break

Milestones / Months	0	3	6	9	12	15	M1 18	21	24	M2 27	30	33	36	39	M3 42	45	48	Material / Remarks
Anode targets (hydrogen)																		
ASR [Ωcm²]					0.30		0.20		0.20				0.30		0.25		0.25	Values presented by ECN from months 24 on, are ASRs for full cells,
Degradation [V% / khr]					0.20		0.10		0.10				0.05		0.03		0.03	for which the month 36 target was 0.6 Ω.cm2
Degradation [mOhm.cm² / khr]					4.30		2.20		2.20				1.10		0.70		0.70	
CEA																		ESC: Ni-10Sc1CeSZ / ASC: Ni-10Sc1CeSZ / LSTN
ASR [Ωcm²]					1.30		1.30		2.1				0.42					0.42 / 0.05 - 1.3 / 2-4.5
Degradation [mohm.cm2/1000hours]									--				--					high / TBD / NA
ECN																		MgO doped / Dispersed NiO / Ni-10Sc1CeSZ
ASR [Ωcm²]	0.86				0.40		0.40		0.40				0.48					0.48 / 0.48 / 1.1
Degradation [mohm.cm2/1000hours]	250				200		200		200				--					TBD / TBD / TBD
CNRSBX																		Niobate development stopped
ASR [Ωcm²]					1000		33		16.5				1.05					(La,Sr)TiO3 (Cu impregnated)-anode/GCO/8YSZ
Degradation [mohm.cm2/1000hours]									--				--					
USTAN																		Cu-impregnated LST-matrix; ESC with Cu and ceria-impregnated LST
ASR [Ωcm²]							<0.1		<0.1				0.67					For a full cell an Rs of 1.07 has been measured, hence a total ASR of 1.74
Degradation [mohm.cm2/1000hours]									--				--					Note : data in M18 and M24 are on symmetrical cells; M36 data are at full cells
DICP																		
ASR [Ωcm²]							0.77		0.77				0.29					Mg doped Ni/YSZ type anode
Degradation [mohm.cm2/1000hours]									--				--					

Project flow sheet and go / no-go



Good practices

- Targeted development approach
- Regular/frequent meetings of all consortium partners
  - 4 times per year, plus some ad hoc meetings on specific topics
  - Critical assessments at each meeting
    - Insufficient perspective -> stop
    - Sufficient perspective -> continue development
    - Target achieved -> integration next phase: cell, SRU, stack
- Internal and 'public' workshops, in conjunction with progress meetings
  - Degradation (2x)
  - Internal reforming
  - Methods for determining performance of cell components
  - EU-ASIA workshop in China
- Intensive email and telephone contacts of coordinator to partners
  - Particular on critical and complex issues
- Exchange of staff between organisations if there is a strong interdependency

To keep partners involved and active

Not for all of them the project is core business