# Innovative Solid Oxide Electrolyser Stacks for Efficient and Reliable Hydrogen production (213009)

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*CEA LITEN/Program Manager*

SEVENTH FRAMEWORK PROGRAMME

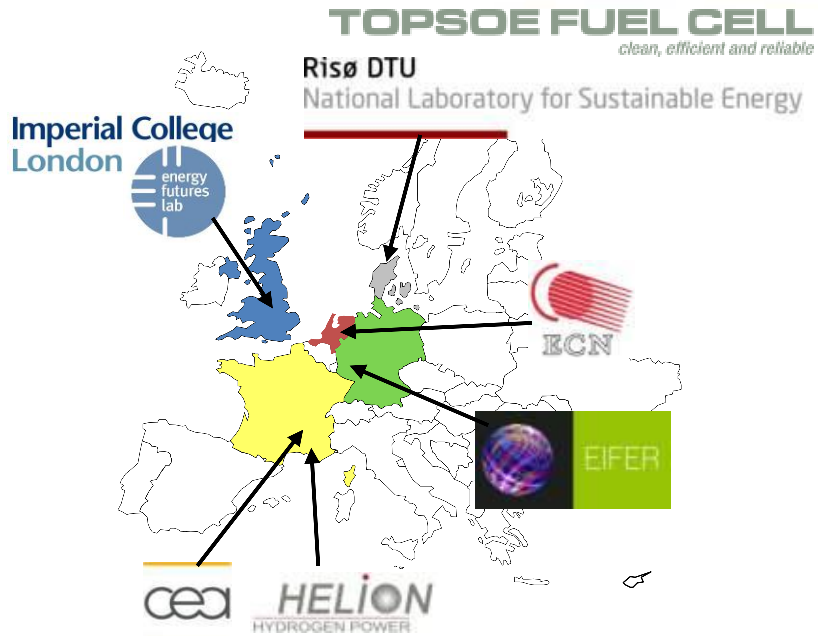
# RelHy Partnership & Budget

**4 years** collaboration project: 01-01-2008 to 31-12-2011

Total budget: 4’535 k€

Total funding: 2’900 k€

| Participant | Country | Type |
|---|---|---|
| **CEA** | France | R&D |
| **Risoe DTU** | Denmark | University |
| **Eifer** | Germany | R&D |
| **ECN** | Holland | R&D |
| **IC** | England | University |
| **TOFC** | Denmark | Industry/SME |
| **Helion** | France | Industry/SME |

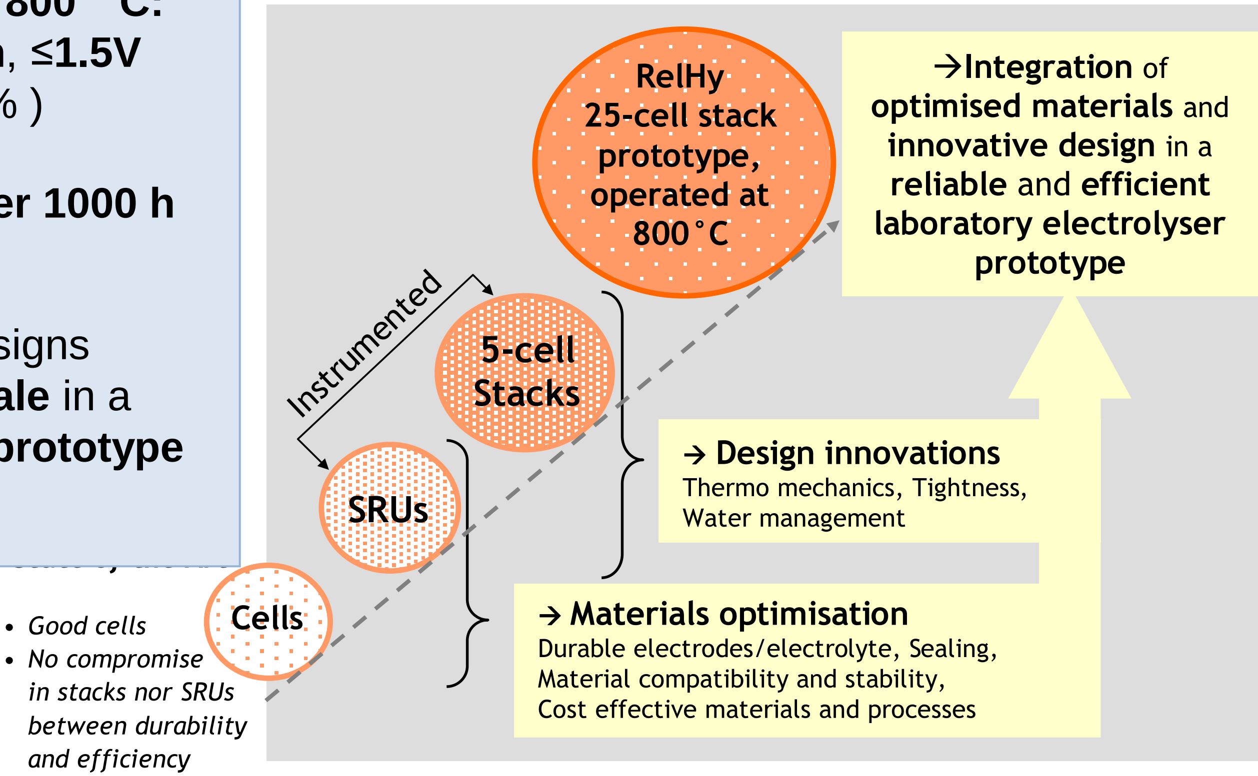



A European dimension with
a good balance between academics,
R&D centres and industries

# RelHy Goal & Targets

Aims at reaching a **satisfactory compromise** between **performance** and **durability** at the **stack level,** with **cost effective** materials.

- **High cell performances at 800° C: -1 A cm$^{-2}$** or **37 mg$H_2$/cm$^2$/h**, **≤1.5V** (with water conversion >60% )
- **Degradation rate ↘ ~1% per 1000 h** at SRU level
- Optimised materials and designs integrated **at laboratory scale** in a **25-cell electrolyser stack prototype** to be operated few 1000 h



# RelHy Goal & Targets

Aims at reaching a **satisfactory compromise** between **performance** and **durability** at the **stack level,** with **cost effective** materials.

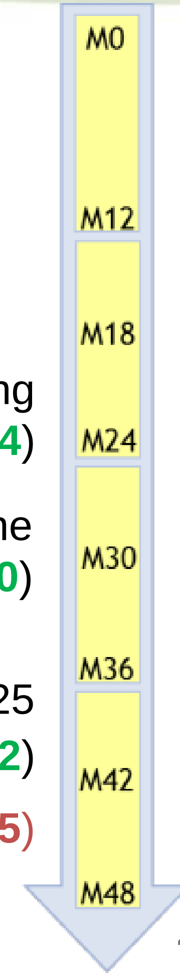
- **Optimisation of state of the art SOFC components for SOE operation** (cells, interconnect + coating and seals)
- **Assessment of improved components** in single cell tests and in ex-situ experiments
- Assessment of **best ones** in SRU and in Short stack operation and by modelling
- **Selection for integration in a 25-cell electrolyser stack prototype** to be operated few 1000 h

Selection of most promising materials (☺ **M24**)

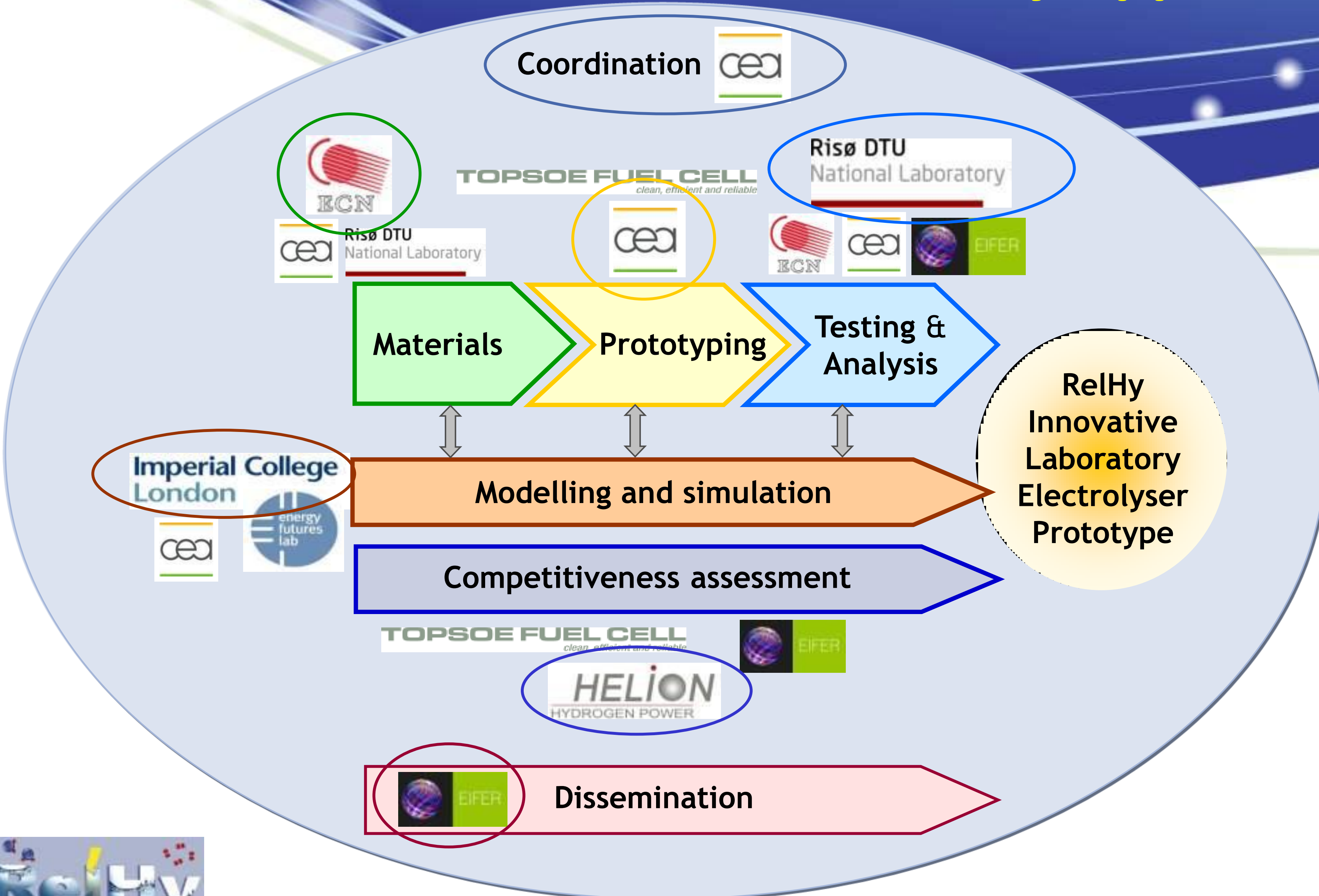
Selection of materials for the 25-cell prototype (☺ **M30**)

Assessment of materials and design for 25 cell stack prototype (☺ **M42**)

Kick off of the 25-cell stack prototype operation (☺ **M45**)



# RelHy Approach



# Successful material improvement

**Cells:** *target = -1.0 A cm$^{-2}$ at 1,5 V at 800° C with a steam utilisation > 60%; degradation rates ~ 1% per 1000 h at the cell level*

**Cathode supported cells: LSM-YSZ** $O_2$ electrode replaced by **LSCF/CGO**

- ☺ High performances of improved Ni-YSZ /YSZ / CGO / LSCF/CGO
- ☹ Degradation always pronounced, but stabilisation plateau (around 1% per 1000h) obtained after few 100 hours at intermediate current densities;

**Electrolyte supported cells: 3YSZ** electrolyte replaced by **10Sc1CeSZ**

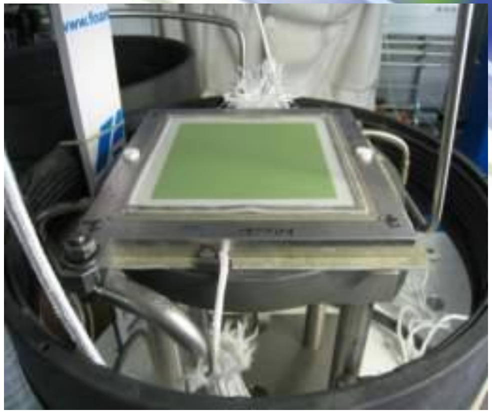
- ☺ Good performances of cells with 215µm thick 10Sc1CeSZ electrolyte
- ☺ Good durability of reference cells 90µm thick 3YSZ electrolyte

**Coating:** *ASR<0,05 Ωcm$^2$ after 1000hrs ageing in ex situ testing*

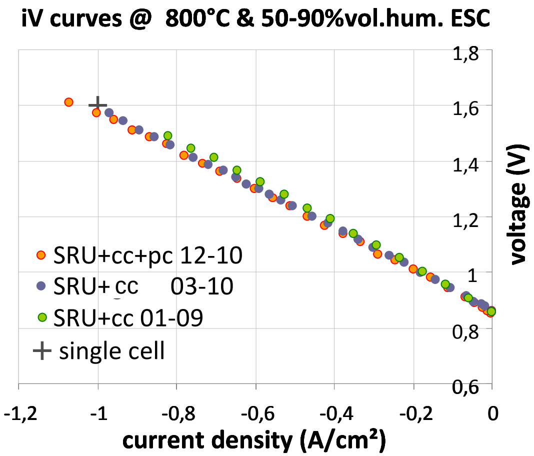
- ☺ Protective + Contact coating made of $Co_2MnO_4$ spinel deposited on Crofer by PVD + screen-printed LSM show stable ASR at 800° C in ex situ testing and in operation

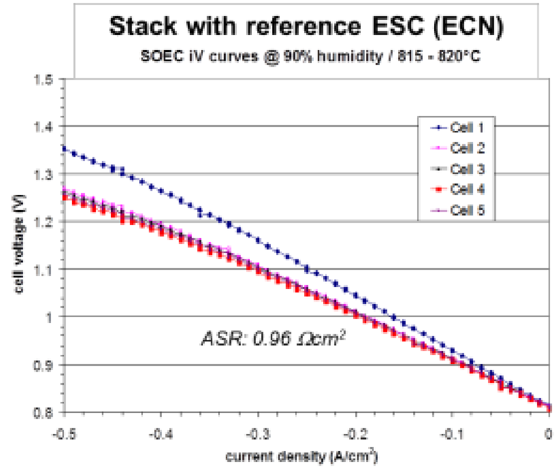
**Seal:**

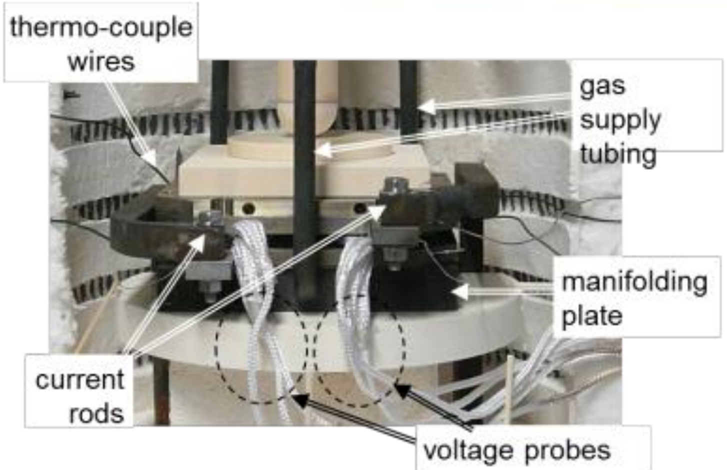
- ☺ Several glass seals Schott AF45, YS2B and Schott G018 304 and mica (Thermiculite®) show good compatibility with hydrogen electrode and interconnect material after 1000h ageing at 800° C in steam environment, exhibit leak rates below 0.5% of the anode/cathode flow at a pressure difference of 20 mbar.
- ☺ Tightness ensured for 4500h with a combination of Schott G018 304 + Macor®



# *RelHy Technical Accomplishment*
# SRU and short stack adapted to electrolyser conditions



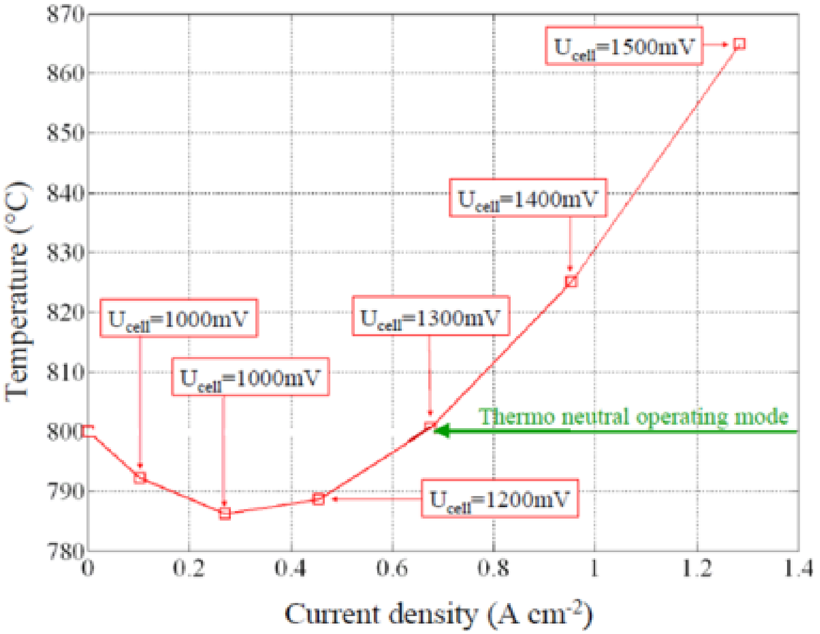




- Good reproducibility at the SRU and short stack level,
- Good tightness maintained for both during more than 4000 h (Faradaic efficiency ~ 100%)
- End plate contacts in short stack improved to withstand high steam content,
- Satisfactory homogeneity between cells and high initial performances
- Degradation rate decreased with protective + contact coating and limited even at high current density

# *RelHy Technical Accomplishment*

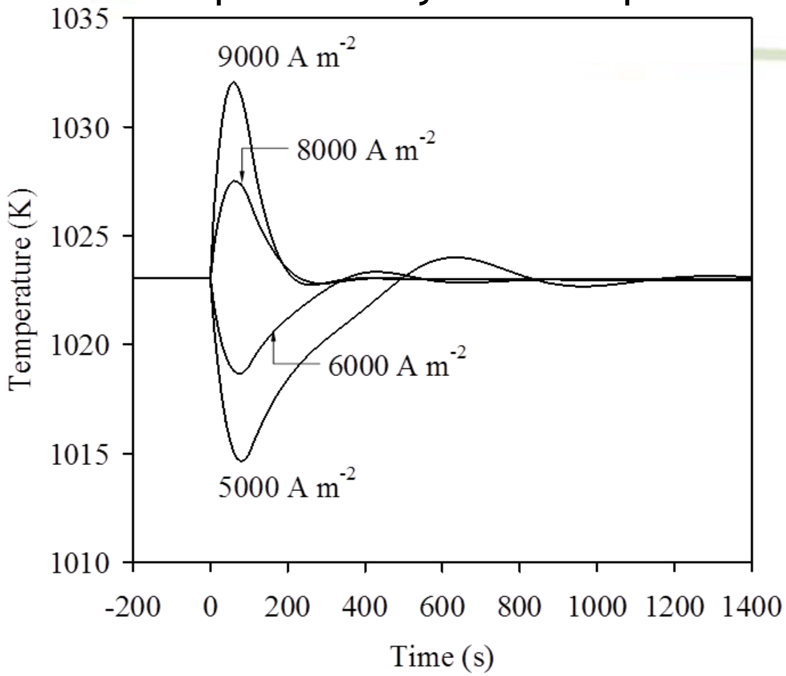
# Simulation and Thermal Management Issues

Simulation in Stack




*J. Laurencin et al., J. Power Sources, 196 (2011) 2080–2093.*

Temperature dynamic response



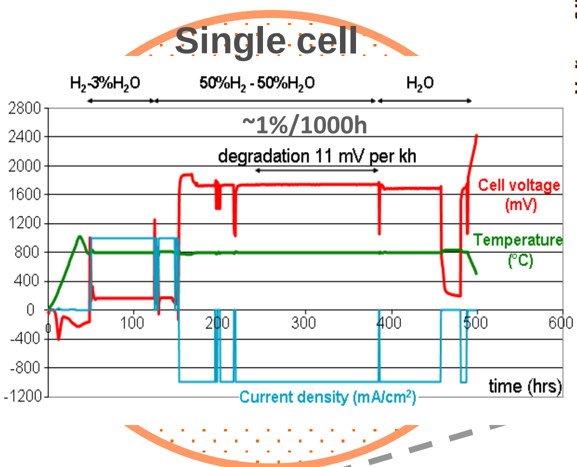

- In stack configurations, with limited heat dissipation, significant thermal gradient can occur across cells..
- Upon transient temperature excursions are unavoidable
- **Major influence of the chosen operating conditions**

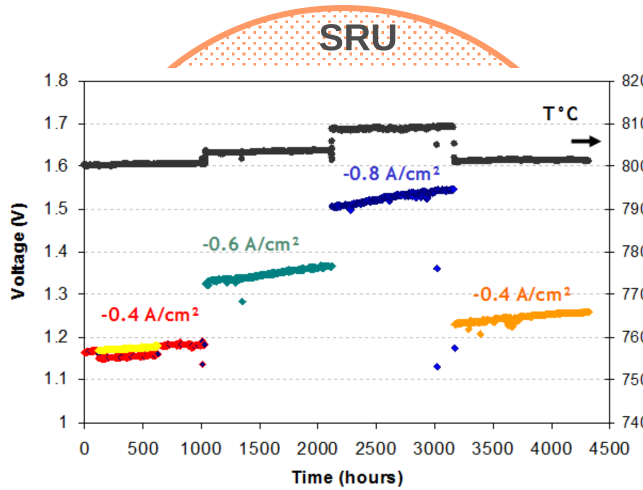
# *RelHy Technical Accomplishment*

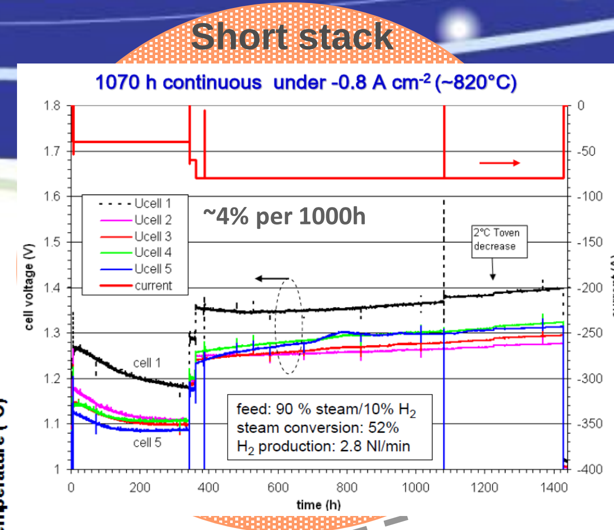
# Two test campaigns from cell to stacks

**Performances** and **long duration tests (4000h) on reference** and **improved components** at

- the single cell level
- the SRU level
- the short stack level



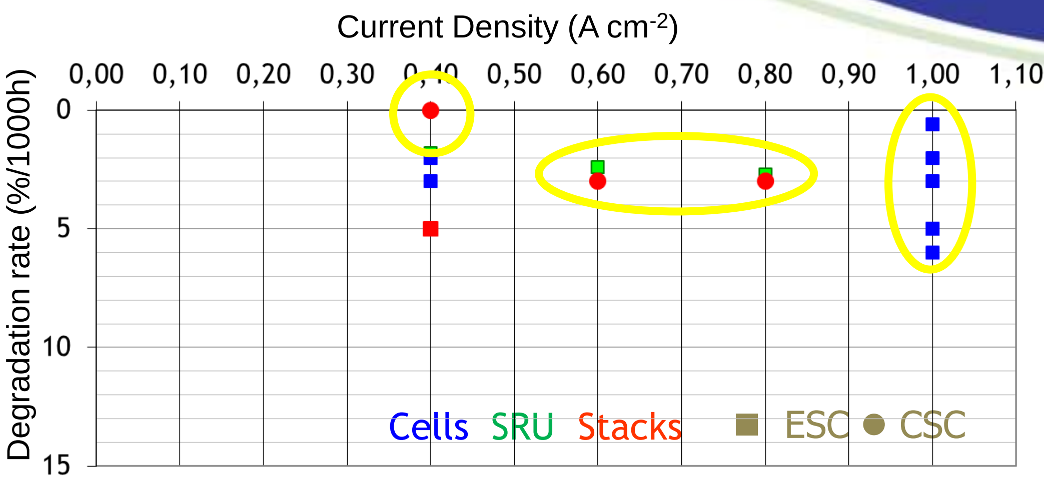

**Some outstanding results;** Many difficulties encountered;
We have learned at lot!

☺ Testing SOEC is not testing SOFC: **Reliable tests required** at all scales**;**

☺ **Major influence of the operation point for stabilisation, for avoiding high degradation rate while maintaining process efficiency and economical relevance;**

# RelHy Technical Accomplishment

# Outcomes of the RelHy project



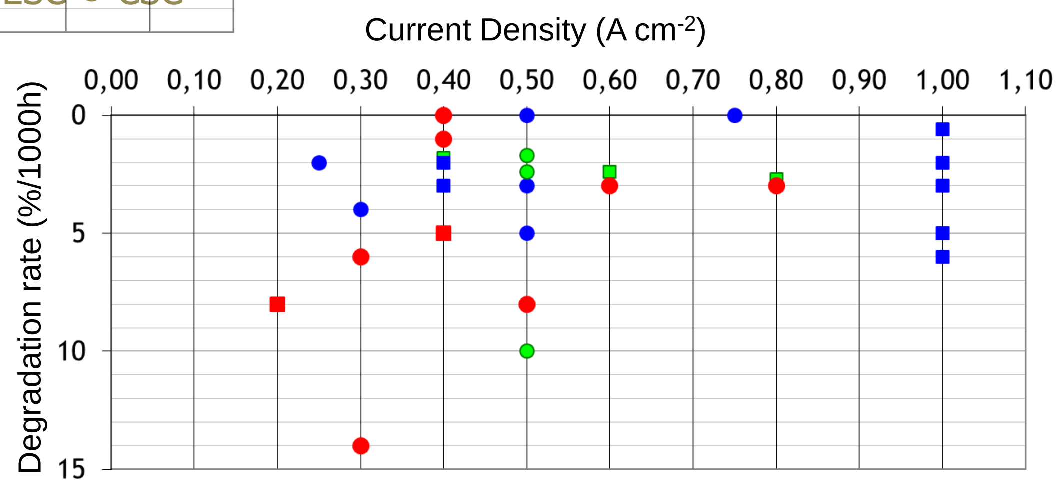

😐 Some issues encountered:

- reproducibility especially at single cell level
- steam production stabilisation

☺ Some conditions found with no degradation

☺ High current densities at degradation rates < 5% per kh (SRU and short stack)

☺ Long duration experiments (> 4000h)




Results in good agreement with current results published worldwide

→ Most promising for HTE technology

# Relevance to the overall objectives of the ENERGY priority

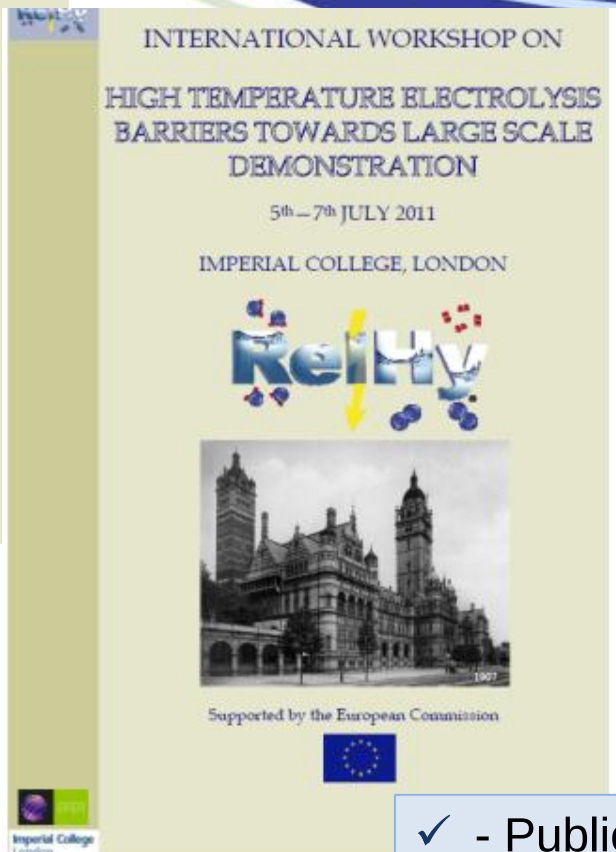
| |
|---|
| *1. To promote the achievement of significant, fundamental breakthroughs in **the understanding of the physical and chemical aspects** of the various materials included within stacks* |
| The approach from cell to stack including EIS and post test characterisation has allowed **understanding degradation mechanisms** and **establishing best operation conditions**. |
| *2. To promote the discovery of novel high-performance, low-cost materials, and their synthesis/manufacturing processes* |
| RelHy was built on the results of previous programs both on SOEC (Hi2H2) and SOFC (REAL-SOFC, SOFC600). The **most promising materials** have been adapted and assessed for HTE conditions. |
| *3. To enable **new concepts for stacks,** which can be used in the next generation of fuel cells by 2015* |
| Best dimensioning for SOE operation has been calculated ; **Efficient SOE stack design** has been derived from proven SOFC stack. |
| *4. **Upstream collaborative research effort** aimed at achieving breakthrough on critical materials, processes and emerging technologies* |
| Achieved thanks to the RelHy consortium composition (two university laboratories, three research institutes, one fuel cell stack manufacturer, and one energy company) and to effective collaboration during the project duration. |

# Relevance to the objectives of the call 1.2.1 “New Materials and Processes for advanced Electrolysers”.

| |
|---|
| *Development of multifunctional low cost material* |
| ☺ Most promising materials (from in Hi2H2, REAL-SOFC and SOFC600) have been further improved for HTE operation conditions. |
| *Integration of innovative material into durable components for a new generation of electrolyser (SOEC)* |
| ☺ **Improved cell materials, interconnect coatings and sealants** have been **demonstrated** both at the SRU and full stack level |
| *Design construction and testing of an innovative laboratory prototype electrolyser with potential for increased efficiency and lifetime and lower capital cost* |
| ☺ **A 25-cell electrolyser stack prototype integrating most promising materials is under operation since September with promising results** |
| *Assessment of the integration of a prototype with renewable sources* |
| ☺ Integration of SOE with wind turbines has been evaluated in WP5 highlighting potential interest |
| *High efficiency electrolysis* |
| ☺ **Good balance high efficiency / high durability** can be obtained close to thermoneutral voltage (1,3V) with current densities between 0,4 to 0,8 $A.cm^{-2}$ and SC rate close to 50% |
| *Cost competitive electrolysis processes* |
| ☺ The conditions for obtaining **competitive $H_2$ price** have been assessed in the project |

# *Cross-cutting issues:*
# Education, Training & Dissemination

**www.relhy.eu**



- ✓ - Public website
- ✓ - Organisation of 2 international workshops
- ✓ - >30 publications or presentations
- ✓ - 1 student exchange (IC, EIFER, CEA)

# Technology transfer and collaboration

**EU collaborations:**

- The project was built on the achievements of FP6 Hi2H2, RealSOFC, and SOFC600

**National collaborations:**

- The project has taken advantage of
  - Danish National Program on Hydrogen (*Danish funded projects (Energinet.dk; Danish Energy Authority; Danish Program Committees for: Energy and Environment; and Nano Science and Technology, Biotechnology and IT; Topsoe Fuel Cell A/S*)
  - French ANR initiative on Hydrogen and Fuel Cells (*programs Icare, Moise, Fidelhyo*)

**Future research approach:**

- FCH JU - ADEL was built on the outcome of SOFC600 and of RelHy
- Current proposals (both European and National) focused on co-electrolysis

# RelHy Future market perspectives

- **Common "International" agreement on HTE Technological Targets:**
  - Each solid oxide cell should be run close to thermo-neutral voltage
  - Solid oxide cell temperature should range between 700 - 800° C
  - At the cell level a steam conversion rate between 60 to 80% should be targeted
  - Stack lifetime should be at least 2 years
  - Accordingly, the voltage degradation rate should be lower than 2% per 1000h and even in the medium term, lower than 1% per 1000h
  - To improve the complete system integration and efficiency, the next step is to work under pressure (5-50 bars) in order to avoid the first pressurisation step of hydrogen.

- **Current performances suitable for niche markets entry (in particular in association with $CO_2$ valorisation)**