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

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CEA LITEN/Program Manager
A European dimension with a good balance between academics, R&D centres and industries.

4 years collaboration project: 01-01-2008 to 31-12-2011
Total budget: 4’535 k€
Total funding: 2’900 k€

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<th>Participant</th>
<th>Country</th>
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<td>CEA</td>
<td>France</td>
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<td>Risoe DTU</td>
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<td>Eifer</td>
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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 mgH₂/cm²/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

- Good cells
- No compromise in stacks nor SRUs between durability and efficiency

→ Integration of optimised materials and innovative design in a reliable and efficient laboratory electrolyser prototype

- Design innovations
  Thermo mechanics, Tightness, Water management

- Materials optimisation
  Durable electrodes/electrolyte, Sealing, Material compatibility and stability, Cost effective materials and processes

RelHy 25-cell stack prototype, operated at 800°C
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

Coordination

Materials
Prototyping
Testing & Analysis

Modelling and simulation

Competitiveness assessment

Dissemination

RelHy Innovative Laboratory Electrolyser Prototype

Toppsoe Fuel Cell
Risø DTU National Laboratory
Imperial College London
**Cells:** target $= -1.0 \text{ A cm}^2$ at 1.5 V at 800° C with a steam utilisation $> 60\%$; degradation rates $\sim 1\%$ 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:** $ASR<0.05 \Omega \text{cm}^2$ after 1000hrs ageing in ex situ testing

- Protective + Contact coating made of $\text{Co}_2\text{MnO}_4$ 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
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.
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 a 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 conditions found with no degradation
😊 High current densities at degradation rates < 5% per kh (SRU and short stack)
😊 Long duration experiments (> 4000h)

😊 Some issues encountered:
- reproducibility especially at single cell level
- steam production stabilisation

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”.

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<th>Development of multifunctional low cost material</th>
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<td>☑ Most promising materials (from in Hi2H2, REAL-SOFC and SOFC600) have been further improved for HTE operation conditions.</td>
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<tr>
<th>Integration of innovative material into durable components for a new generation of electrolyser (SOEC)</th>
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<tr>
<td>☑ Improved cell materials, interconnect coatings and sealants have been demonstrated both at the SRU and full stack level</td>
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<tr>
<th>Design construction and testing of an innovative laboratory prototype electrolyser with potential for increased efficiency and lifetime and lower capital cost</th>
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<td>☑ A 25-cell electrolyser stack prototype integrating most promising materials is under operation since September with promising results</td>
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<th>Assessment of the integration of a prototype with renewable sources</th>
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<td>☑ Integration of SOE with wind turbines has been evaluated in WP5 highlighting potential interest</td>
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<th>High efficiency electrolysis</th>
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<td>☑ 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%</td>
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<th>Cost competitive electrolysis processes</th>
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<td>☑ The conditions for obtaining competitive H₂ price have been assessed in the project</td>
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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)
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
• 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 CO₂ valorisation)