

# HIGHLY EFFICIENT, HIGH TEMPERATURE, HYDROGEN PRODUCTION BY WATER ELECTROLYSIS (HI<sub>2</sub>H<sub>2</sub>)

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## EXTENDED ABSTRACT

The wide variety of energy sources, including renewables, which can be used to produce hydrogen, makes the hydrogen more and more attractive as an energy vector. A way to transform renewable and other non-fossil sources of energy into hydrogen is water electrolysis.

The specific targeted research project “Highly Efficient, High Temperature, Hydrogen Production by Water Electrolysis” (Hi<sub>2</sub>H<sub>2</sub>) was launched in 2004 in the frame of the European Framework Program 6. The aim of the project was to demonstrate the feasibility of hydrogen production by high temperature water electrolysis using currently available Solid Oxide Fuel Cells (SOFC) technology. Coupled to renewable energy sources, this technology may meet the present environmental and economical request. The Hi<sub>2</sub>H<sub>2</sub> project is a consortium of four European research laboratories - EIFER (coordinator) and DLR in Germany, Risø-DTU in Denmark, and EMPA in Switzerland, bringing together skills and experience in the field of material science, electrochemistry, and renewable energy.

In order to determine the best operating conditions of the Solid Oxide Electrolyser Cells (SOEC) under High Temperature Electrolysis (HTE) mode, several experiments have been realized at different scales, from the cells and single repeated units (SRU) to the stack. Results obtained were then used to make the technical and economical analysis of the hydrogen production by high temperature water electrolysis.

## Introduction

The uniqueness of the concept is to perform water electrolysis at a rather high temperature, between 700 and 900°C. High temperature electrolysis of steam (HTE) is expected to consume less electrical energy as compared to electrolysis at low temperature as consequence of the more favourable thermodynamic and electrochemical kinetic conditions for the reaction (Dutta, 1990). Thermodynamic conditions are more favourable in the sense that the molar Gibbs energy of the reaction ( $\Delta G$ ) drops from  $\sim 1.23$  eV ( $237 \text{ kJ.mol}^{-1}$ ) at ambient temperature to  $\sim 0.95$  eV at 900°C ( $183 \text{ kJ.mol}^{-1}$ ), while the molar enthalpy of the reaction ( $\Delta H$ ) remains essentially unchanged ( $\Delta H \sim 1.3$  eV or  $249 \text{ kJ.mol}^{-1}$  at 900°C) (Larminie & Dicks, 2003). A significant part of the energy required for an ideal (loss free) HTE can thus be provided by heat.

## Experimental

Two types of planar SOFC designs with up to  $100 \text{ cm}^2$  active area were considered: an electrode (ceramic-metal compound) supported and a porous metal substrate supported Solid Oxide Electrolyser Cell (SOEC), based on advanced ceramic materials and stainless steels. Low cost industrial manufacturing techniques (like screen printing and tape casting) are applied with commercial, high volume, stainless steels to produce the ceramic component.

Performances of these SOECs were measured as a function of both the operating temperature and the percentage of humidity of the inlet gas. As expected the performance of the cell increases with increasing the operating temperature but also with increasing the humidification level. Very high performances were achieved using electrode supported SOEC's made at Risø - DTU. So far, no SOEC's have been reported to have better initial performance at similar operating conditions. A record-breaking performance was reached at 950°C, where steam electrolysis was operated at a current density of  $-3.6 \text{ A.cm}^{-2}$  and a cell voltage of only 1.48 V (Jensen *et al*, 2007) (Fig. 1). These current densities were obtained at very high electrical efficiencies which would correspond to a production rate of hydrogen of  $1.34 \text{ kg.m}^{-2}.\text{h}^{-1}$ .

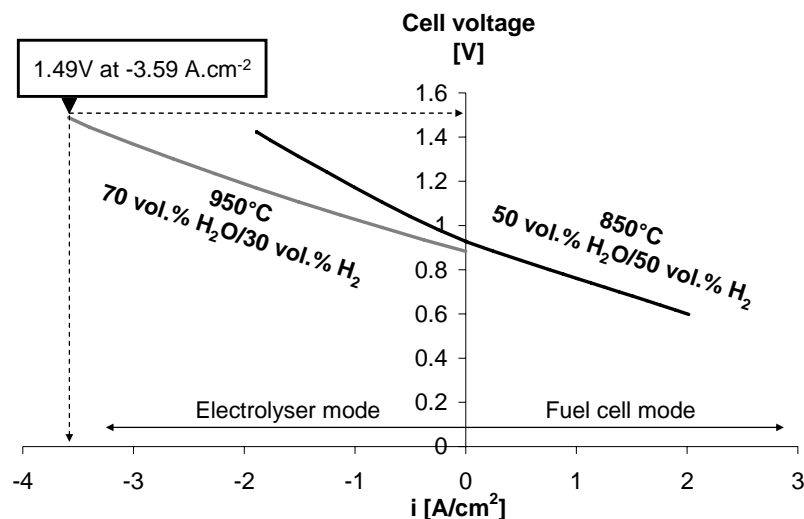


Fig. 1: Kinetics of a Risoe solid oxide cell as an electrolyser cell and as a fuel cell at different temperatures and steam partial pressures in the inlet gas to the cell (Jensen *et al*, 2007).

Durability tests of up to 2500 hours were performed with single cells. The tests demonstrated that a maximum degradation of 2%/1000h occurs at current densities between 0 and  $-0.5 \text{ A/cm}^2$ , temperatures between 800 and  $950^\circ\text{C}$ , and a steam percentage of up to 70 vol.%.

Cells were then assembled by stacking single repeated units (SRU). The SRU's are composed of a SOEC and metal alloy interconnect plates to ensure electrical contact and gas distribution between cells. Protective coatings of the interconnects were developed and validated during the project to face the corrosive operating conditions (high temperature and oxidizing atmosphere). Durability tests of SRU's demonstrated that detrimental corrosion of the interconnect can be hindered using protective coatings. However, in-situ impedance spectroscopy measurements revealed that the electrical conductivity of these coatings has to be further improved.

The passivation/activation phenomenon observed by Risø-DTU on the cells was clearly attributed to a silica deposition at the interface between the electrolyte and the hydrogen electrode, originating from the glass seal. A new sealing pre-treatment procedure was developed to avoid the initial passivation/activation process (Hauch *et al*, 2007).

The last development consisted of the assembly of two electrolyser stacks of 250 and  $600 \text{ cm}^2$  active areas. The first stack (of  $250 \text{ cm}^2$  active areas) was tested for more than 3500h at  $800^\circ\text{C}$  and  $-0.3 \text{ A/cm}^2$  leading to an average degradation rate during the first 2000 h of about 14 %/1000h (Fig. 2). After 2000 hours, the steam content was increased, leading to an improvement of the stack performance. Thereby, the degradation rate was reduced to 6 %/1000h.

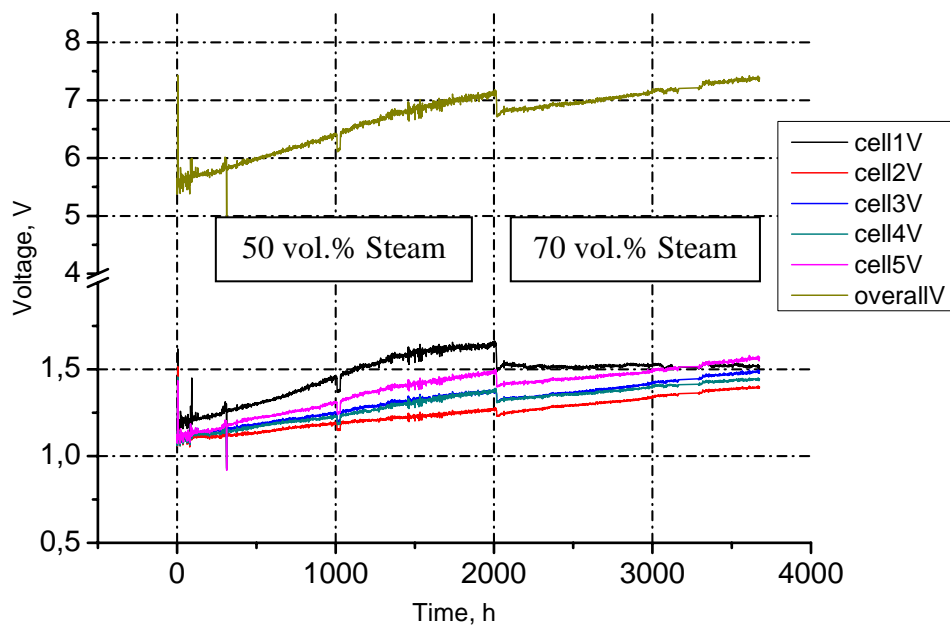


Fig. 2: Stack and cells voltage evolution during the test. Gas conditions before 2000 h are 1 NI/min  $\text{H}_2$  + 0.5 NI/min  $\text{N}_2$  at the hydrogen electrode side, 7.5 NI/min at the oxygen electrode side, and 50 vol.% of steam. After 2000 h, nitrogen flow was stopped and the steam constant was increased to 70 vol.%.

Based on the achieved results, a techno-economical analysis was made to predict the hydrogen production cost. A cost of around 2 €/kg was calculated assuming an average electricity price of 0.05 €/kWh and an endothermal operation mode using a water

vapour source at 200°C. This study also revealed that an increase in the temperature of the water source would not decrease the hydrogen cost significantly because the main factor influencing the hydrogen production cost is the electricity price.

## Conclusions

The excellent results obtained within the project have demonstrated that hydrogen can be produced through water electrolysis with extremely high efficiencies, greater than 90%. As a comparison, typical low temperature electrolyzers have an average efficiency of about 60-70 %. The consequence is a possible strong lowering of the production cost of hydrogen. The high efficiency also ensures that energy is not wasted in the process.

## References

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Web site: <http://www.hi2h2.com>

Project coordinator name: Mohsine ZAHID (EIFER)

## Partners



Germany



Denmark



Switzerland



Germany

## BRIEF BIOGRAPHY OF PRESENTER

Mrs Brisse has a background in materials science & electrochemistry, especially for high-temperature systems. Her field of expertise concerns ceramics elaboration and characterization for Solid Oxide Fuel Cells. Her PhD work, realised at the Atomic Energy Commission in France, was awarded in 2007 as the best PhD work in the field of ceramics materials by the French Society for Ceramics. Since one and a half year, Mrs Brisse is responsible of the high temperature electrolysis activity at the European Institute for Energy Research in Germany.