D2.2 Delivery of the 1st generation SEU

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Executive summary

This deliverable reports on the delivery of the first generation of single engineering unit (SEU) in the GAMER project. The first generation integrates several of the main elements constituting the SEU. It is designed to enable GAMER partners to evaluate the functionality of the electrochemical cells, the robustness of assembling the end-caps and sealing, and the reduction procedure of the catalytic Ni based electrodes. Additional key elements such as those required for current collection are here selected based on their simplicity of use for carrying out electrochemical measurements of the produced assemblies. They will not be part of the final design of the SEU, which is under consideration for patenting by GAMER partners.

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1 Introduction

1.1 The GAMER project

The GAMER project aims at developing a novel cost-effective tubular Proton Ceramic Electrolyser (PCE) stack technology integrated in a steam electrolyser system to produce pure dry pressurized hydrogen. The electrolyser system will be thermally coupled to renewable or waste heat sources in industrial plants to achieve higher AC electric efficiency and efficient heat valorisation by the integrated processes. The project aims at establishing a high volume production of novel tubular proton conducting ceramic cells. The cells will be qualified for pressurized steam electrolysis operation at intermediate temperature (500-700°C). They will be bundled in innovative single engineering units (SEU) encased in tubular steel shells, a modular technology, amenable to various industrial scales. GAMER focuses on designing both system and balance of plant components with the support of advanced modelling and simulation work, flowsheets of integrated processes, combined with robust engineering routes for demonstrating efficient thermal and electrical integration in a 10 kW electrolyser system delivering pure hydrogen at minimum 30 bars outlet pressure.

Partners of GAMER are:

Partner (short name)	***Country***
SINTEF (SINTEF)	*Norway*
Coorstek Membrane Science AS (CMS)	*Norway*
CSIC, Instituto de Tecnología Química (CSIC)	*Spain*
Carbon Recycling International (CRI)	*Iceland*
University of Oslo (UiO)	*Norway*
MC2 Ingenieria y Sistemas SL (MC2)	*Spain*
Shell Global Solutions International B.V. (SGSI)	*Netherlands*

The consortium covers the full value chain of the hydrogen economy, from cell and SEU manufacturer (CMS), system integrators (MC2, CRI), through researchers (SINTEF, UiO, CSIC), to end users in refineries, oil and gas, chemical industry (CRI, SGSI, with advisory board members YARA and Air Liquide). All along the project, these experienced partners will pay particular attention to risk management (technical, economic, logistic, business) and ensure progress of the technology from TRL3 to TRL5. The overall consortium will perform strategic communication with relevant stakeholders in order to ensure strong exploitation of the project's results.

1.2 The novel tubular SEU

In the GAMER project, we focus on the demonstration of an innovative, low cost and modular hydrogen production technology utilising *tubular proton conducting ceramic cells* and their inherent advantages for steam electrolysis:

- *Scalability and modularity* of the electrolyser system: the electrolyser is designed for scale (small, medium, large);

- *Reduced operation and maintenance costs* compared to planar stack towers: possible to "isolate" one or several SEUs from the system without shutting it done completely; possibility to change some SEUs;
- *Reduced risks* in case of leakage due to low volume of SEU;
- *Lower operating temperature* (600°C) than SOE reducing degradation associated to cation diffusion, and enabling use of lower cost steel for pressure vessel;
- *Production of pure dry hydrogen* at the anode side, preventing risk of oxidation encountered in SOE (see figure 2);
- *Increased safety*: In PCE, any increase in pH_2O increases the pH_2. In contrast, the SOE must have a high pO_2 alone at one electrode to balance the pH_2O+pH_2 at the opposite electrode. Pure hot high pressure O_2 is risky;
- *Increased robustness of tubular cells*, in particular, when exposed to pressure differentials compared to planar cells;
- *Reduced sealing area* compared to planar cells.

This novel design concept has also challenges, which are addressed in GAMER:

☝ Current collection is challenging compared to planar technology. This is alleviated in GAMER by the use of lower current density cells.

☝ Lower current density of the cells compared to SOE. This is compensated in GAMER by increased surface area and lower cost of PCE cells.

The tubular cells in GAMER integrate a proton conducting electrolyte based on Y-doped $Ba(Zr,Ce)O_3$ (BZCY). The cells will consist of a porous Ni-BZCY cathode for the H_2 side (also ensuring mechanical strength), a thin dense BZCY-based electrolyte, a porous anode for the H_2O+O_2 side, and a current collector system. They are assembled in a steel pressure vessel enabling safe pressurized operation of at least 30 bars and 700 °C in high steam content.

In this report, we present the first generation of tubular cells assembled with proprietary sealing technology and state of the art current collection system mounted in a steel vessel and produced in GAMER for qualification of the electrochemical cells.

It is emphasized that the actual design of the SEU (including current collection system) to be integrated in the electrolyser system is under patenting action, and will therefore not be detailed here.

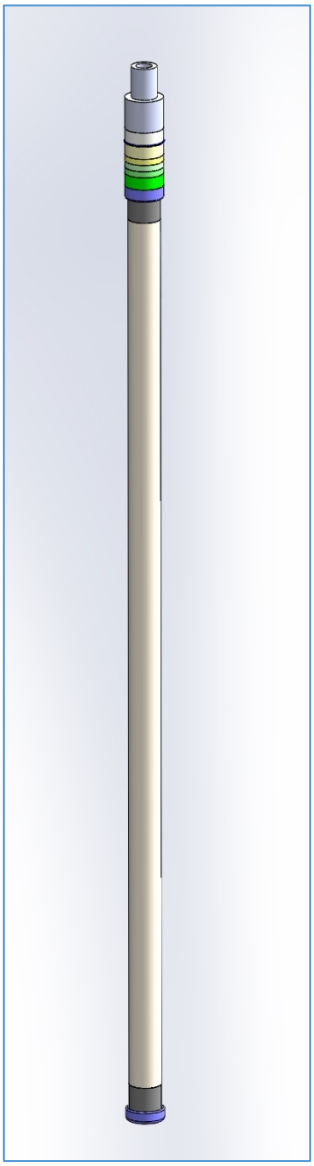
2 Design of the first generation

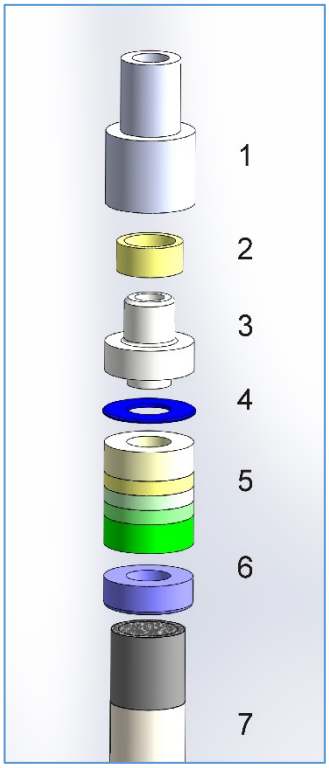
The first generation SEU is based on long tubular cells (20-25 cm) consisting of:

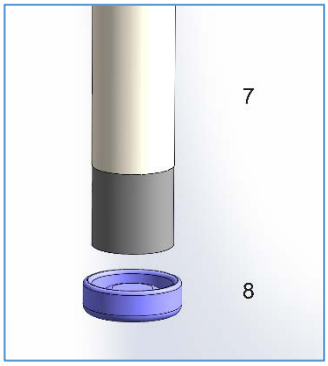
- a porous Ni-BZCY cathode for the H_2 side
- a thin dense BZY-based electrolyte,
- a porous anode BZCY-LSM composite with Pr-Ce catalysts
- a current collector system: Ag paste and Ag wire

The tubular cells are end-cap sealed and mounted on a ferritic header, as shown in the drawing below. The tubular cells are then placed in a steel vessel.

For electrochemical testing of the cells at SINTEF, the tubular cells were also mounted on alumina risers using a proprietary sealing technology developed by CMS. The cells were then mounted in steel vessel for high pressure steam electrolysis measurements.







Components

1. Ferritic header
2. PSZ top seal
3. PSZ ferrule
4. PSZ to gradient sealing gasket
5. Gradient segment
6. Gradient to BCZY face seal
7. BCZY membrane tube with electrodes
8. End cap seal

Figure 1. Components which make up 'tube-in-shell' assembly (shell not shown)

3 Delivery

GAMER partners CMS and SINTEF have delivered the first generation SEU, as illustrated in the figures below, showing some selected process steps:

- Production of long cells with LSM-BZCY electrodes
- Capping and riser assembly of the cells
- Steel vessel assembly and testing

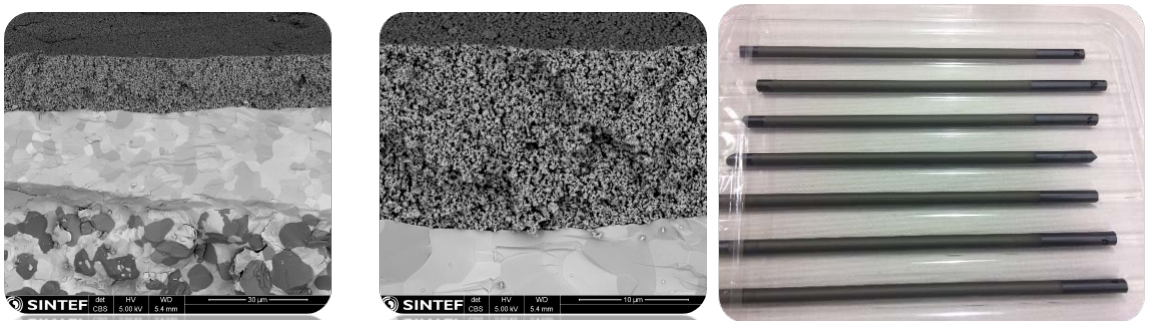


Figure 2. SEM micrographs of LSM-BZCY electrode coated on BZCY based cells (left: all three layers; middle: electrode and electrolyte interface); and camera picture of long cells coated with LSM-BZCY electrode (right)

Figure 3. 15 cm and 25 cm long cells cap-sealed and mounted on alumina risers in GAMER for further electrochemical testing

Figure 4. Camera pictures of : Left: complete cell with current collection; middle: riser connected to gas supply system before enclosure in the steel vessel; right: first generation SEU mounted in test rig for electrochemical measurement

The long tubular cell shown in this report has been operated at at 10 bar total pressure on both sides, was fully gas-tight and exhibited a satisfactory open circuit voltage (OCV) at 1V upon heating at 600°C.

4 Next steps

The project partners are currently assessing the functionalities of the produced cells upon high pressure electrochemical measurements. It is emphasized that the project is also focusing on another set of electrodes, such as the BGLC/BZCY composites. Due to the lower maturity of the up-scale production process, this set of cells has not been selected for the first generation of SEU.

In parallel of this evaluation, further evaluation of the current collection system is in progress. This is a major challenge of the tubular design, and large efforts are focused on achieving suitable solution, easy to up-scale. This will be further presented in the next deliverable of GAMER.

5 Acknowledgements

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