

Efficient water splitting via a solar hybrid thermochemical cycle with sulphur dioxide depolarized electrolysis

Kai Risthaus^{1*}, Dimitrios Dimitrakis¹, Vamshi Krishna Thanda¹, Larissa Queda¹, Georgios Arvanitakis¹, Joao Humberto Serafim Martins¹, Alexander Hirt¹, Nikolaos I. Tsongidis², Annukka Santasalo-Aarnio³, Michela Lanchi⁴, Niusha Shakibi Nia⁵, Jonas Michels⁶

¹ DLR German Aerospace Center, Institute of Future Fuels/Solar Research, Germany

² Chemical Process & Energy Resources Inst., Centre f. Research & Technology Hellas (CPERI/CERTH), Greece

³ Aalto University, Finland

⁴ ENEA, Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Italy

⁵ FEN Research GmbH, representing the Green Energy Center Europe, Austria

⁶ Grillo-Werke AG, Duisburg, Germany

*Correspondence: Kai Risthaus, kai.risthaus@dlr.de

1. Introduction

The solar hybrid sulphur cycle (HyS) is a promising way to generate hydrogen sustainably by utilizing solar heat and green electricity [1]. In a first step, the sulphuric acid splitting (SAS) is performed below 900 °C forming sulphur dioxide, oxygen, and water. The sulphur dioxide is used with water in a second step, the sulphur dioxide depolarized electrolysis (SDE), to form hydrogen and sulphuric acid, thereby closing the cycle. By utilizing the SDE, the cell potential can be significantly reduced compared to conventional water electrolysis (i.e. in theory to a fraction of only 14%) [2]. Though, the reduced electricity input must be compensated by heat. The heat for the SAS can be supplied by a solar tower system. In the European project HySelect, DLR, CERTH, Aalto, ENEA, FENR and Grillo work on demonstrating such a system. Here, heat for the SAS will be supplied by the centrifugal particle receiver CentRec [3] in Jülich and the SDE will be performed in Duisburg. This two-site approach demonstrates the potential separation of the SAS at a solar-rich location (e.g., Sahara Desert) and the SDE at a solar-lean location (e.g., central Europe) for a commercial application as indicated in Fig. 1.



Fig. 1: Scheme of the HyS. On the left side, the SAS is performed utilizing solar energy in Jülich; on the right side, the SDE is performed on a second site, Duisburg (both Germany)

2. Methodology

In a first step, lab-scale setups for the SAS and SDE have been put into operation. The upscaling and demonstration of pilot operation will be performed in the step of the project. For SAS, different catalyst materials and structures have been tested in a 2-kW tube-furnace setup for an extended time period (i.e. 100s of hours) with a continuous sulphuric acid flow [4]. For the SDE, a setup was built from commercial components designed for water electrolysis. Different potentials were applied and tests were performed for several hours. The active cell area was 5 cm².

3. First results and outlook

For the SAS, a Fe₂O₃ catalysts on a SiSiC foam reached nearly the equilibrium composition, resulting in approximately 90 % sulphur trioxide conversion at 850°C and ambient pressure. The SDE setup showed promising results, indicating a specific energy consumption of 30-40kWh/kg H₂ and stability of over 40 hours. However, a cross over of SO₂ was observed and an overpotential of 0.43 to 0.78 V was required. Currently, tailored materials for the SDE are prepared and tested.

The upscaling and optimization of the SAS reactor and SDE is ongoing. The targeted size for the SAS reactor is in the range of 50-80 kW_{th} and for the SDE 30-40 kW_{el}. In 2026, tests with a 750 kW_{th} solar centrifugal particle receiver and hot particle storage will be performed for six months. The particle system will be coupled with the SAS reactor and the generated sulphur dioxide will be used for the SDE. Further scaleup for commercial application will be drafted and techno-economically assessed.

References

- [1] L.C. Brown et al., "Final Technical Report from General Atomics Corp. to US DOE. GA-A24285", General Atomics: San Diego, CA, USA, 2003.
- [2] V.K. Thanda et al., "Solar thermochemical energy storage in elemental sulphur: Design, development and construction of a lab-scale sulphuric acid splitting reactor powered by hot ceramic particles", AIP Conf. Proc., 2445 (1): 130008, 2022.
- [3] M. Lubkoll et al., "Development progress of the CentRec® particle receiver technology". AIP Conf. Proc., 2445 (1): 110005, 2022.
- [4] Agrafiotis et al., "Structured sulphur trioxide splitting catalytic systems and allothermally-heated reactors for the implementation of Sulphur-based thermochemical cycles via a centrifugal solar particle receiver", Applied Catalysis B: Environmental, 324 (2023) 122197, doi: <https://doi.org/10.1016/j.apcatb.2022.122197>

Funded by the European Commission through the Clean Hydrogen Partnership HORIZON JU Research and Innovation Actions HORIZON-JTI-CLEANH2-2022-01-06 programme, under grant agreement No 101101498.