Renewable energy sources and low-emission hydrogen (H_2 produced without carbon emissions) are considered pillars of the energy and industry transition towards a zero-net economy. Among many solutions, Solid Oxide Cells (SOC) seem to be a very promising technology, as they can be used as highly efficient electricity and heat generators in fuel cell mode (SOFC), as a low-emission hydrogen generators in electrolyser mode (SOE), or for energy storage (reverse operation between SOFC and SOE modes). Moreover, solid oxide cells may efficiently utilize CO_2 during operation in the co-electrolysis mode (co-SOE), where steam and CO_2 occur simultaneously and syngas ($CO + H_2$) is produced. The obtained syngas may be used for synthetic fuel production or further processes in chemical processes. It is worth mentioning that, under specific operating conditions, direct methane production is also possible during co-SOE.

The main challenge in the implementation of the co-SOE installation is the durability of the cells. State-of-the-art cells can obtain high performance, much better compared to the low-temperature solutions available on the market, however, their life span is limited. The drop in the SOC performance is mainly caused by the degradation processes occurring at the fuel electrode, i.e. nickel coarsening, agglomeration, reoxidation, and carbon deposition. Thereby, the project aims to develop a highly efficient fuel electrode adjusted for stable operation in co-electrolysis mode. Moreover, the goal of the project is to provide a thorough explanation of the electrochemical principles and processes during co-SOE using an interdisciplinary, basic scientific approach. A combination of experimental research and numerical modeling will be used to verify stated in the project hypothesis. In order to enhance the performance and durability of the SOC in the co-electrolysis, fuel electrode catalytic activity will be modified by impregnation of the electrode surface with catalytically active materials and/or the addition of the MIEC (mixed ionic-electronic conductors) oxides into the Ni-8YSZ-based functional layer of the fuel electrode. The Ce-containing suspension or solution with the addition of alkaline metals (Ca, Ba, Sr) and/or *3d* metals (Fe, Cu, Mo, and/or Co) will be used for surface modification through impregnation, while the selected Ti-based perovskites from the $La_{1-x}Sr_xTi_{1-y}(Fe,Ni)_yO_{3-\delta}$ group (where $0.2 \leq x \leq 0.6$; $0.05 \leq y \leq 0.4$) or proton-conducting Ce-based perovskite (i.e. from $BaCe(Zr,Y,Yb)O_{3-\delta}$) will be introduced to the cathode functional layer. Additionally, in the project a generalized model of SOC operating in the co-electrolysis of CO_2 and H_2O with a modified composition and surface of the fuel electrode will be developed. The formulated in the project hypothesis will be verified by applying a combination of experimental and numerical research activities, followed by the statistical analysis of the obtained data and their interpretation. The research methodology includes the advanced manufacturing methods of SOC, the electrochemical characterization techniques, the post mortem analysis, and the numerical research - mathematical techniques for computational fluid dynamics (CFD) modeling, taking into account electrochemical processes, that will provide data that cannot be measured in experimental investigations. In the project, dedicated equipment capable of measuring current-voltage curves and EIS measurements, or accurately delivering working gases, will be used. Moreover, international cooperation with one of the leading groups in the field – the team of Prof. Rak-Hyun Song from the Korean Institute of Energy Research is planned within the proposal.

The proposed project will contribute to a detailed analysis of the techniques and approaches used to understand the mechanisms of co-electrolysis and to optimize the performance and durability of solid oxide cells in this mode. Successful completion of the project will significantly advance our understanding of high-temperature electrochemical processes in co-electrolysis mode. The project's outcomes will directly impact the progression of solid-state electrochemistry in power engineering, chemical processing, as well as material science and engineering. In the long term perspective, the realization of the project will promote the use of electrochemistry as a tool for sector decarbonization, with co-electrolysis of steam and carbon dioxide playing a significant role in Power-to-X systems.