# Abstract

In the face of dynamic changes in the global energy sector and the growing importance of renewable energy sources (RES), exploring diverse energy storage solutions is essential. This study evaluates an innovative hybrid energy storage system developed by researchers at the Silesian University of Technology. The primary objective is to conduct a technological and economic analysis of a system that integrates $CO_2$ compression and expansion processes with water electrolysis, leading to the production of hydrogen ($H_2$) and synthetic natural gas (SNG). The patented system enables efficient energy storage and conversion into electricity in a scalable and environmentally friendly manner.

A comprehensive review of the literature and existing technologies includes a detailed analysis of energy storage methods such as pumped hydro storage, compressed air energy storage (CAES), liquid air energy storage (LAES), and chemical storage techniques utilizing hydrogen and synthetic natural gas. This study presents the operational principles of the hybrid system, which combines energy storage in compressed $CO_2$ with the synthesis and combustion of synthetic gas.

The research also assesses the potential use of existing infrastructure, such as mining shafts, and explores the development of innovative isobaric $CO_2$ storage tank technologies. The results indicate that the proposed system can achieve high energy and thermodynamic efficiency while meeting economic feasibility requirements. Economic analyses, incorporating net present value (NPV) and internal rate of return (IRR) methodologies, confirm the system's potential for profitable implementation within the Polish energy mix—though not under the current macroeconomic conditions for potential investment.

In conclusion, this study provides a comprehensive evaluation of a novel energy storage system, emphasizing its potential in the context of the ongoing energy transition. The hybridization of $CO_2$- and $H_2$-based systems addresses the challenges associated with surplus energy storage from RES while offering the operational flexibility and scalability necessary for future power systems.