ENERGETICS

DENERG - Optimal design and operation of hydrogen-based energy storage systems: A multi-level approach from components to system Integration

Funded By	Dipartimento DENERG
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Context of the research activity	The penetration of renewable energy sources requires long-term energy storage solutions . This challenge is relevant for remote and off-grid applications, and becomes even more critical in Arctic environments, where additional constraints such as weight, volume, transportability, and harsh operating conditions must be considered. In this context, hydrogen-based energy storage systems can effectively complement electrochemical storage to achieve high-autonomy renewable energy systems.
Objectives	The objective of the PhD is to investigate the optimal design and operation of hydrogen-based energy storage systems for renewable energy applications. The research proposes an innovative two-level approach, combining detailed component-level modelling with system-level optimal sizing and operation of hybrid renewable energy systems including chemical and electrochemical storage. Particular attention will be devoted to the integration of degradation effects enabling a more realistic assessment of system performance, reliability, and lifetime. The activity will also include engineering and experimental activities on hybrid hydrogen-battery prototypes, including system integration, characterization, testing, and control strategy development. Specifically, the research will address both numerical modelling and experimental validation of components and prototype systems developed within ongoing national and European projects, exploiting real experimental and operational data to improve the robustness and reliability of the developed models. Advanced optimization methodologies will be adopted for the optimal sizing and operational management of the systems under different application scenarios. In addition, data-driven and artificial intelligence techniques may be explored to support degradation prediction, operational optimization, and performance analysis based on experimental and operational datasets. Attention will also be devoted to thermal management strategies and sector integration approaches, including the

	recovery and use of waste heat to improve overall system efficiency and support potential interactions with thermal demands and district heating systems. The research will be carried out within the framework of the HORIZON Europe project SUSTAIN-ARCTIC, where hydrogen-based storage systems using compressed hydrogen are being developed and tested in Arctic regions to increase the energy autonomy of research stations and remote infrastructures. Additional synergies will be established with the projects H2SCORE and H2@EDGE, where similar systems are studied for both off-grid and grid-connected applications, also considering alternative storage technologies such as metal hydrides. These technologies enable compact and low-pressure storage solutions, although advanced thermal management strategies are required. The research will also benefit from the experience and know-how gained within the completed REMOTE project, where hybrid hydrogen-battery systems were installed and operated across several European sites under real operating conditions.

Skills and competencies for the development of the activity	Modeling, optimization, H2 systems, batteries.