ENERGETICS

AMMIN/DENERG - From real operation to modelling: integrating hydrogen technologies into sustainable multi-energy systems

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Context of the research activity	Despite increasing research on hydrogen technologies, a comprehensive understanding of how they perform within real, multi-vector energy systems is still limited. Current models often rely on theoretical assumptions and lack validation through field data, especially regarding installation, operation, and local context factors. There is a need for modelling approaches that combine real operational evidence with techno-economic and environmental assessments, to bridge the gap between laboratory-scale studies and real-world deployment. Within this broader framework, the H2SCORE and AMPS projects provide concrete case studies that support the development and validation of such integrated methodologies. Within the European H2SCORE project, coordinated by Politecnico di Torino, several of these technologies will be demonstrated in real environments. The Valsesia REC (Italy) provides a unique testbed that integrates reversible Solid Oxide Cells (rSOCs), PEM fuel cells and electrolysers, metal hydride storage and biomass gasifiers, all coupled with an existing district heating network and local renewable generation. This combination enables the study of how hydrogen can serve as both an energy vector and a storage medium in complex community-scale systems, offering flexibility and resilience while supporting grid stability. The AMPS project, focused on the automation and cost reduction of SOC manufacturing, provides a complementary perspective. The cost projections and industrial-scale data generated by AMPS can be used to assess the economic viability and market penetration potential of these technologies when integrated in local energy ecosystems such as RECs. Overall, the H2SCORE case studies provide valuable datasets that allow models to be validated against actual operating conditions and compared across different contexts. These data make it possible to extend the analysis beyond a single case study, capturing how local factors such as geography, climate, and regulation influence system performance. By combining the experimental evidence gathered through H2SCORE with the technological

	and cost insights developed in AMPS, the research will rely on a solid basis to evaluate the technical potential and economic competitiveness of hydrogen technologies in future renewable energy communities.

Objectives	The doctoral research aims to develop and validate an advanced modelling framework for hydrogen-based multi-energy systems, covering different levels of detail – from component simulations to full system analyses. The work will build on existing models and tools developed within the STEPS research group, adapting them to include new hydrogen technologies and their integration with thermal and electrical networks. The study will combine modelling, real operational data, and optimisation methods to evaluate the techno-economic and environmental performance of systems that couple electricity, heat, and hydrogen. Using the Valsesia demonstration site as a reference, the candidate will monitor the installation and operation of hydrogen technologies such as reversible Solid Oxide Cells (rSOCs), PEM fuel cells and electrolysers, metal hydride storage, and biomass gasifiers. The candidate will also contribute to on-site experimental activities at the Quarona demonstration site, collecting data and insights from real operation. This field experience will provide unique understanding of installation practices, operational challenges, cost drivers, and social acceptance aspects related to hydrogen deployment in community energy systems. The collected data will support model calibration and validation, ensuring that simulations accurately represent real operating conditions. Multi-layer models will then be developed to describe the interaction between individual components and the overall system. These models, implemented in Python, will be used to simulate and optimise the design and operation of integrated energy systems under varying conditions. Optimisation techniques – including mixed-integer linear programming (MILP) – will identify configurations that minimise costs and emissions, while maximising efficiency and sustainability. The modelling framework will explicitly account for environmental indicators, including greenhouse gas emissions, life-cycle assessment (LCA) metrics, and local air pollution factors. Once validated in the Valsesia site, the models will be applied to other replication sites in Spain, Switzerland, Italy and Canada. This comparative approach will make it possible to identify the key factors – economic, climatic and regulatory – that influence the competitiveness and replicability of hydrogen technologies across different contexts. The project will deliver a validated and flexible modelling tool able to support the design and operation of hydrogen-based multi-energy systems. By combining real-world data and simulation, it will quantify the technical, economic and environmental benefits of integrating hydrogen technologies into local and regional energy networks. To sum up, the doctoral research aims to develop a solid understanding of hydrogen technologies and their real operation within integrated energy systems, using data and experience gathered from real demonstration sites. Based on this knowledge, a flexible modelling and optimisation tool will be developed and validated to support the design and operation of hydrogen-based multi-energy systems. Combining operational data and simulation results will make it possible to quantify the technical, economic, and environmental performance of these systems and to identify the conditions under which hydrogen technologies can operate efficiently, competitively, and

	sustainably, considering not only technical and economic but also environmental dimension. References: [1] Marocco P, Gandiglio M, Santarelli M. When SOFC-based cogeneration systems become convenient? A cost-optimal analysis. Energy Reports 2022;8:8709–21. https://doi.org/10.1016/J.EGYR.2022.06.015. [2] Gandiglio M, Marocco P, Nieminen A, Santarelli M, Kiviaho J, Energy and environmental performance from field operation of commercial-scale SOFC systems, Int. J. Hydrogen Energy. 85 (2024) 997–1009. https://doi.org/10.1016/j.ijhydene.2024.08.332. [3] P. Marocco, M. Gandiglio, M. Santarelli, Optimising green hydrogen production across Europe: How renewable energy sources shape plant design and costs, Renew. Energy. 256 (2026) 124542. https://doi.org/https://doi.org/10.1016/j.renene.2025.124542.

Skills and competencies for the development of the activity	- Knowledge of hydrogen and electrochemical components - Good knowledge of Matlab and/or Python environment with programming skills. - Good knowledge of the English language, both oral and written.