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Three way pipeline: Hydrogen storage and distribution through power-to-gas strategy, with full carbon capture and utilization

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The work aims to enable the efficient production, storage, and distribution of renewable hydrogen (H_2) through an integrated power-to-gas (P2G) and gas-to-power (G2P) system. The first stage focuses on green hydrogen production via water electrolysis, primarily addressed through system-level modelling. Mature technologies such as alkaline (AEC) and polymer electrolyte membrane (PEM) electrolysers are considered for near-term deployment, while more advanced and efficient solid oxide electrolysis cells (SOEC) are investigated at a fundamental level. Particular attention is given to the development of reversible SO systems capable of operating both as electrolysers (SOEC) and fuel cells (SOFC).
The produced hydrogen is subsequently converted into synthetic methane (SNG) through CO_2 methanation (Sabatier reaction), leveraging existing natural gas infrastructure for storage and distribution. CO_2 is sourced from capture processes associated with point emissions (e.g., combustion plants, biogas facilities), using evolving technologies such as absorption and adsorption systems.
In parallel, this work explores a more innovative circular concept based on a **three-pipeline gas grid (3PGG)**, integrating existing natural gas networks with additional pipelines for CO_2 and O_2 transport. This system enables closed-loop carbon utilization and near-zero emissions by continuously recycling CO_2 and using O_2 co-produced in electrolysis. Preliminary assessments suggest that such infrastructure could be realized at significantly lower cost (10–30%) compared to dedicated hydrogen pipelines, representing a promising alternative for energy storage and sector coupling.
The project also investigates different gas-to-power (G2P) strategies. One approach involves direct use of methane in solid oxide fuel cells (SOFC), which offer high efficiency (>55%) and the advantage of direct hydrocarbon utilization without external reforming. CO_2 produced in SOFC operation can be captured and reused in the methanation stage or reinjected into the 3PGG system. A second approach considers oxy-fuel combustion, where methane is burned with pure oxygen, producing a CO_2-rich stream that can be easily captured and recycled.
Experimental activities focus on small-scale systems (<1 kW), while modelling and design address integrated systems at 10–100 kW (pilot scale) and 1–16 MW (commercial relevance). Finally, multi-objective optimization, techno-economic analysis, and environmental impact assessment, demonstrate the feasibility of an integrated, circular energy system based on hydrogen and carbon valorization.