Integrated Hydrogen Energy Systems

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ABSTRACT: Due to the increasing share of volatile renewable energy sources, more flexibility and stability options are needed. In this context, scalable, long-term storage solutions based on Power to Gas (PtG) and Gas to Power (GtP) concepts remain a promising technology. The use of integrated high-temperature processes (IHTP) enables the avoidance of cost-intensive catalysts, the simultaneous increase of the overall efficiency and the utilization of a broader fuel spectrum range. Therefore, IHTP presents a significant contribution to the resilience of the future energy supply system.

1. INTRODUCTION

The European Decarbonization Strategy comprises two essential development phases of our future energy system. The first phase involves the increased use of intelligent linked sector coupling strategies based on already available and economically viable technologies. These include power-to-heat and power-to-cool solutions using heat pumps, as well as electro-mobility. The necessary legal framework to improve the competitiveness of such decentralized energy systems is currently under implementation (EU Directive, 2018). However, with the increasing integration of volatile energy sources such as solar and wind, long-term storage capacities in the form of power to gas (PtG) and gas to power (GtP) must also be integrated. For this reason, scalable, reversible fuel cell systems will be additionally required in the second development phase (slated for 2030, see Fig. 1).

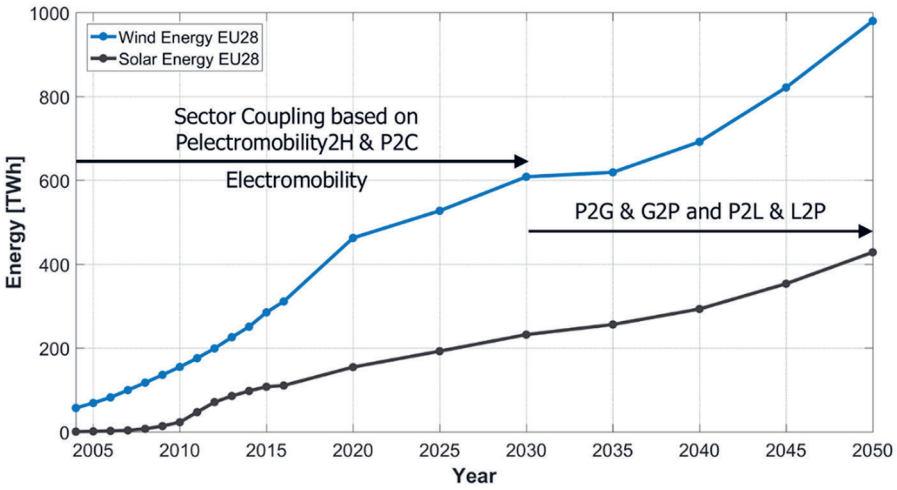


Fig. 1: Chronological development steps for the decarbonization of the EU28 energy system (Data basis: Europe 2018 and Eurostat 2018).

Long-term storage solutions are essential since the fluctuating power generator profiles contain a significant seasonal component. To offer complementary long-term storage services, the additional use of gaseous energy carriers in the form of PtG technologies is necessary (Jentsch, 2014). Currently, however, PtG storage technology is still in the development and demonstration phase, hence a need for further research is required primarily at the system but also the component level. Current developments are focused on energy carriers such as pure hydrogen or hydrocarbon compounds.

Hydrogen-based PtG storage technologies have several advantages: (1) The energy density is much higher than other energy storage media. (2) The stored hydrogen is a flexible energy storage medium that can be used for stationary applications (fuel cells, gas turbines, etc.) as well as for mobility (combustion engines, fuel cells, turbines, etc.). (3) The self-discharge rate is very low, making this technology suitable for seasonal or long-term storage applications. (4) The use of stack modules enables high scalability as well as compact design. The associated economies of scale for mass production will concurrently promise cost-efficient system solutions and a wide range of applications and performance. Thus, future decentralized performance requirements for energy storage capacities are realized "affordably".

2. INTEGRATED HYDROGEN ENERGY SYSTEMS

An essential basis of PtG storage technology is the electrolysis of water into hydrogen and oxygen. According to the state of the art, alkali and polymer electrolyte membrane electrolysis processes are used for this purpose. However, high-temperature electrolysis with solid oxide cells (SOEC) is a promising alternative. In terms of thermodynamic conversion properties, this has significant potential for improving efficiency.

The total energy required in SOEC operation is almost independent of the process temperature used. However, as the temperature increases, the demand for electrical energy for hydrogen production decreases. The remaining energy requirement is covered with the aid of thermal energy (see Fig. 2).

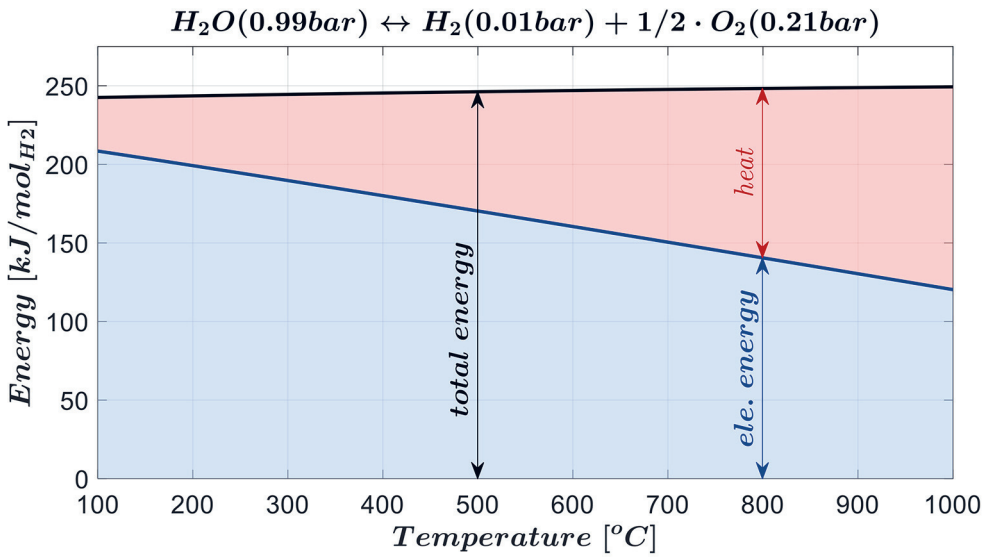


Fig. 2: Temperature dependence of the energy demand for hydrogen electrolysis (ideal process control, total pressure 1 bar).

Shifting energy demand in the direction of heat has significant advantages. On the one hand, available high-temperature waste heat potentials can be utilized with appropriate integration. On the other hand, the dissipation heat generated in the stack (due to activation and concentration losses, ohmic losses, etc.) can be used directly on site. In practical implementation, this allows a very efficient electrolysis operation. In addition, if CO_2 or CO sources are available, high-temperature electrolysis enables efficient methanation of the hydrogen. Thus, sector coupling strategies with new, diverse, feed-in structures into existing heat and gas grids can be promoted.

The components used in high-temperature electrolysis also allow fuel cell operation (SOFC operation) so that the hydrogen or hydrocarbon compounds produced can be converted back into electrical energy. Systems that can switch between electrolysis mode (SOEC) and fuel cell mode (SOFC) are referred to as reversible solid oxide cell (rSOC) systems. If pure hydrogen is used as the energy carrier, round-trip efficiencies of over 80% are achievable at an operating temperature of 600°C under ideal conditions. If hydrocarbon compounds are used, even higher round-trip efficiencies are attainable. The remaining energy is available as high-temperature waste heat and this can be temporarily stored and used for electrolysis or directly used for industrial processes and buildings (Heschl et al. 2017). Integrated rSOC system solutions can therefore achieve overall efficiencies of over 90%.

The ability to use a wide fuel band in SOFC operation and switch flexibly between electrolysis and fuel cell operation are vital reasons why rSOC is a promising technology for grid flexibility. In addition, the plant design is more compact compared to different system solutions and economies of scale of mass production can be used. In addition, alternating between electrolysis and electricity production increases operating times and hence economic efficiency.

Within the project FIRST (FIRST 2021), an integrated reversible high-temperature solid oxide system (rSOC) with a nominal power of 15 kW_{el} in SOEC operation and a nominal power of 5 kW_{el} in SOFC operation, will be developed. The chosen system design promises flexible integration (photovoltaic and wind farm / smart energy building / industry) and high scalability of the nominal power. In addition to thermodynamic system development, intelligent control algorithms are also being designed for optimal system integration. For demonstration purposes, a Smart Energy Building, the Living Lab ENERGETIKUM (ENERGETIKUM 2021) of the Forschung Burgenland GmbH is accessible for setting an integration scenario. Among other aspects, data-driven, model-based, predictive control algorithms are used to adapt the operating mode of the rSOC system and the load profile of the building as closely as possible to the yield of the photovoltaics and wind energy systems. The system development will be integrated, tested and validated in the Living Lab ENERGETIKUM between 2022 and 2023.

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