POWER-TO-AL: TECHNO-ECONOMICS OF ALUMINIUM AS AN ENERGY CARRIER

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Abstract

Towards a global sustainable transition decarbonization of the energy system is recognized as a key enabler. Increasing deployment of renewable energy (RE) technologies result in rapid demand increase on the storage technologies (e.g., electrochemical, chemical, and thermal energy storage technologies). In this context, Power-to-X (P-to-X) is often referred to be a sustainable solution for the intermediate storage of the fluctuating RE generation. Besides energy carriers such as hydrogen (H_2), methane, and ammonia, metals and in particular aluminium (Al) provide high potential to serve as an energy carrier with their significantly larger volumetric energy storage densities. In this study, techno-economics of a Power-to-Metal (P-to-M) concept is investigated and compared with other high potential P-to-X options. Preliminary findings imply the high techno-economic competitivity and superior flexibility of Al metal as an electricity-based energy carrier.

Content

Global warming and its impacts necessitate immediate actions against greenhouse gas (GHG) emission reduction on a global scale. As a major contributor, decarbonization of fossil-fuelled energy generation and mobility sector determined to reduce significant fraction of CO_2 emissions. Hence, availability of carbon-free electricity and H_2 at all times is essential for ensuring the supply-demand balance. Furthermore, conventional storage technologies respond this demand with different flexibility levels, but PtX technologies combined with solar and wind power are proposed as effective solutions due to high energy density (on a gravimetric or volumetric basis) of storage medium (e.g., H_2, methane, ammonia). However, abundant reactive metals (i.e., Al, Mg, Fe) are volumetrically dense energy carriers and so far, they have not been adequately considered as a P-to-X option.[1]–[3] Especially, Al is identified as a very promising metal energy carrier due to its largest energy density (among other metals), high H_2 storage capacity (0.111 kg_{H2} per kg_{Al}), long-term availability, large-scale production, and prospective carbon-free/-neutral production potential.[4] Furthermore, techno-economic potential of such energy carrier for the supply of electricity and H_2 is evaluated in this study to make first explorative investigation and comparison with other P-to-X alternatives aiming high circularity and sector-coupling.

Methodology

An Al wet-combustion system design is developed for the re-electrification and H_2 supply. The system is consisting of a combustion unit, steam turbine for the utilization of the released combustion heat, a solid-oxide fuel cell (SOFC) for the electrical conversion of H_2, and a heat recovery section employing a gas turbine for efficiency improvement.[4] The H_2 supply to external loads is realized via the load partition of the SOFC. The technical assessment in this case starts from the operation of the Al production (P-to-Al), which is the common practice Al production method Hall-Héroult process. By this integration, necessary equipment and investment is eliminated as P-to-Metal conversion takes place within a well-established industrial process. This is a positive aspect, as there is no demand on conversion equipment for converting renewable electricity into materials unlike in the P-to-H_2 electrolyzer and fuel cell combination. Within the defined system boundaries, required technical aspects are obtained for a P-to-

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P round-trip conversion concept using simulation results. Obtained technical data is used for the required capital investment estimations for the re-electrification plant. The operational economics are estimated across varying flexibility levels and a benchmark analysis is conducted to identify the hotspots for creating a business case between Al producers and energy suppliers. Obtained results are compared with other P-to-X alternatives.

Results

Based on the explained methodology, techno-economics of the offered system is evaluated. From technical performance perspective, an electrical conversion efficiency of ~81% for the Al-to-P conversion system based on Al wet combustion is proven with the simulations, which yields a theoretical round-trip efficiency (P-to-Al and Al-to-P) in the range of 36 – 40% based on the load partition and the assumed Al energy intensity. Hence, the P-to-P system based on Al as energy carrier proves very competitive higher than H_2 PEM electrolyzer/ PEM fuel cell combination (30%), and lower H_2 Solid-oxide electrolyzer/ SOFC combination (48%). However, Al demonstrates higher volumetric energy densities around 23.5 kWh L^{-1} where H_2 PEM and H_2 SOFC systems provide 0.53 kWh L^{-1} and 0.2 kWh L^{-1}, respectively. Regarding the economics, a comparison under same operational conditions (3,000 annual equivalent full load hours (FLHs)) is made considering P-to-H_2, P-to-Methane, and P-to-Liquid as P-to-X alternatives. The economic evaluation results prove that Al-based P-to-X concept provide very competitive levelized cost of electricity (LCOE) values for the full conversion of renewable electricity to secondary renewable electricity 198 – 410 €/MWh. (see Figure 1) Future activities will focus on the electrochemical conversion paths as e.g. primary Al-Air Batteries which show promising efficiencies in the range of 70%.

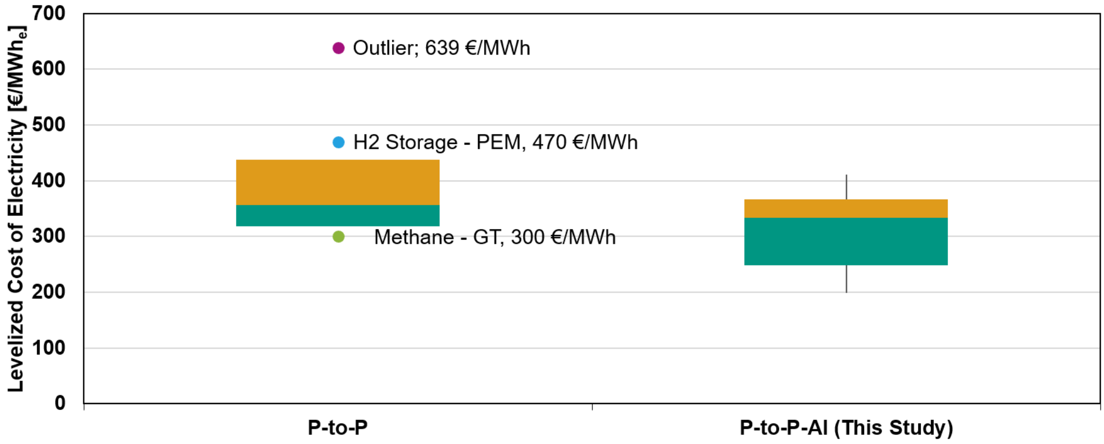

Figure 1 Levelized cost of electricity comparison of alternative Power-to-X technologies including re-electrification.

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