Optimizing Heavy-Duty Green Hydrogen Refueling Stations: A Techno-Economic Analysis of Turbo-Expander Integration

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Abstract : Hydrogen has been proven to be a viable alternative to standard fuels as it is easy to produce and only generates water vapour and zero carbon emissions. However, despite the hydrogen benefits, the widespread adoption of hydrogen fuel cell vehicles and internal combustion engine vehicles is impeded by several challenges. The lack of refueling infrastructures remains one of the main hindering factors due to the high costs associated with their design, construction, and operation. Besides, the lack of hydrogen vehicles on the road diminishes the economic viability of investing in refueling infrastructure. Simultaneously, the absence of accessible refueling stations discourages consumers from adopting hydrogen vehicles, perpetuating a cycle of limited market uptake. To address these challenges, the implementation of adequate policies incentivizing the use of hydrogen vehicles and the reduction of the investment and operation costs of hydrogen refueling stations (HRS) are essential to put both investors and customers at ease. Even though the transition to hydrogen cars has been rather slow, public transportation companies have shown a keen interest in this highly promising fuel. Besides, their hydrogen demand is easier to predict and regulate than personal vehicles. Due to the reduced complexity of designing a suitable hydrogen supply chain for public vehicles, this sub-sector could be a great starting point to facilitate the adoption of hydrogen vehicles. Consequently, this study will focus on designing a chain of on-site green HRS for the public transportation network in Nantes Metropole leveraging the latest relevant technological advances aiming to reduce the costs while ensuring reliability, safety, and ease of access. To reduce the cost of HRS and encourage their widespread adoption, a network of 7 H35-T40 HRS has been designed, replacing the conventional J-T valves with turbo-expanders. Each station in the network has a daily capacity of 1,920 kg. Thus, the HRS network can produce up to 12.5 tH2 per day. The detailed cost analysis has revealed a CAPEX per station of 16.6 M euros leading to a network CAPEX of 116.2 M euros. The proposed station siting prioritized Nantes metropole's 5 bus depots and included 2 city-centre locations. Thanks to the turbo-expander technology, the cooling capacity of the proposed HRS is 19% lower than that of a conventional station equipped with J-T valves, resulting in significant CAPEX savings estimated at 708,560 € per station, thus nearly 5 million euros for the whole HRS network. Besides, the turbo-expander power generation ranges from 7.7 to 112 kW. Thus, the power produced can be used within the station or sold as electricity to the main grid, which would, in turn, maximize the station's profit. Despite the substantial initial investment required, the environmental benefits, cost savings, and energy efficiencies realized through the transition to hydrogen fuel cell buses and the deployment of HRS equipped with turbo-expanders offer considerable advantages for both TAN and Nantes Metropole. These initiatives underscore their enduring commitment to fostering green mobility and combatting climate change in the long term.

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