FLEXIBLE HYDROGEN SUPPLY FOR INDUSTRIES: THE CASE OF FRANCE IN 2030

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Overview

Low-emission hydrogen is set to play a key role in the transition to carbon neutrality, with applications ranging from established industrial processes to emerging uses in transport and electricity storage. Decarbonizing hydrogen production – shifting from fossil-based sources to electrolysis powered by clean electricity – is essential to this transition. Nevertheless, the main barrier to the adoption of low-emission hydrogen is its high cost, predominantly driven by the price of electricity required for electrolysis. France benefits from a clean electricity mix that enables the use of grid-connected electrolyzers. However, these electrolyzers face fluctuating electricity market prices, which can reach high levels, especially during demand peaks where fossil capacities may enter the electricity mix. Industries are poised to lead the adoption of low-emission hydrogen due to its existing applications, regulatory incentives, and national objectives. To meet their constant hydrogen demand, these industries could rely on electrolyzers operating as baseload, but risk paying high electricity market prices during certain periods. Alternatively, production could be reduced or suspended during high-cost periods, but such a strategy of flexible electrolyzer operation requires larger electrolysis capacity as well as underground hydrogen storage to maintain a consistent low-emission hydrogen supply. Moreover, the spatial disparity in underground storage availability makes pipelines a critical additional element to analyze. This study aims to optimize the tradeoff between variable electricity costs and fixed hydrogen infrastructure costs, and integrates the geographic realities of France in the economic analysis. Our research question is the following: **what is the impact of flexible electrolyzer operation on infrastructure sizing and costs for industrial hydrogen demand in France by 2030?**

Methods

The low-emission hydrogen demand sectors examined in this study are Power-to-X (e-kerosene, ammonia and methanol), steel, refining and other chemical industries using hydrogen. We quantify the 2030 industrial hydrogen demand in France and locate it geographically, resulting in four hubs: Dunkirk, Le Havre, Fos-sur-Mer, and the Rhône valley. As steel and refining industries are likely to alternate between low-emission hydrogen and fossil inputs[1] for flexibility at the 2030 horizon, flexible electrolyzer operation emerges as a key strategy for Power-to-X applications. Our analysis hence focuses on this end-use, beginning with the generic case of a grid-connected electrolyzer supplying a constant annual hydrogen demand of 40 ktH_2 for Power-to-X. The electrolyzer may function flexibly, which would require resorting to hydrogen underground storage via pipelines. The method applied is techno-economic optimization using PERSEE, a tool developed by CEA (the French Alternative Energies and Atomic Energy Commission) for energy system studies under the Mixed Integer Linear Programming (MILP) formalism. PERSEE optimizes the hourly operation and sizing of the system components (electrolyzer and storage) over a year with perfect foresight to minimize the total system cost. As inputs, we use time series of historical electricity prices in France and we test different scenarios to compare baseload operation to flexibility. We perform sensitivity analyses on the cost of the electrolyzer, its reduced efficiency due to flexible operation, and the consequences of switching from hydrogen underground to surface storage. The analysis then shifts from the generic case to more realistic applications. We estimate the maximum length of pipelines that flexibility savings may fund in our case study and compare it to the distance between each hub and the nearest storage site to analyze the geographic constraints and question the spatial distribution of these industrial projects.

Results

Our results under historical French electricity prices indicate that the flexible operation of electrolyzers reduces system costs. These cost reductions are the same order of magnitude as the cost of the salt caverns. Given access to storage by pipeline, flexible operation reduces the variable electricity costs beyond the additional fixed costs of the oversized electrolyzer and new underground hydrogen storage. However, baseload operation may still be preferred if electrolyzer capital costs remain too high. A larger demand or more contrasting electricity prices lead

[1] Respectively natural gas for steel and fossil or bi-product hydrogen for refining

to more savings from flexibility. The system operation is not equivalent to a price limit strategy, as the electrolyzer may operate in a contradicting manner to limit the size of the storage. Upscaling our results from the case study to the level of the four French hubs raises several questions given the geographical constraints. On one hand, our results highlight the advantage of concentrating Power-to-X projects in hubs near underground hydrogen storage sites such as Fos-sur-Mer, and the Rhône valley at the 2030 horizon. On the other hand, pipeline financing remains a bottleneck, as flexibility savings alone are unlikely to justify their construction for access to underground storage. We discuss different funding strategies for the pipelines, as well as other alternatives for flexibility such as using hydrogen surface storage or choosing other locations for the Power-to-X plants. In this analysis, we also consider constraints on CO_2 sourcing or the availability of downstream refining and treatment facilities nearby.

Conclusions

This study illustrates the benefits of flexible electrolyzer operation to supply mainly industrial low-emission hydrogen demand in France in 2030, and provides a critical analysis of the underlying constraints for hydrogen infrastructure. Using a simple MILP model, we examine the conditions under which electrolyzer flexibility is favored and the role of hydrogen storage. We then extrapolate our findings on system sizing and costs to the scale of the four French hubs, accounting for their geographic constraints. From a policy perspective, our results suggest concentrating Power-to-X projects near salt caverns. Our findings also emphasize the critical role of pipelines in providing access to storage, beyond their conventional role in hydrogen transit and trade, as a key enabler of flexibility. Consequently, establishing an appropriate financing structure for pipelines beforehand is crucial. Building on this study, our subsequent work explores how flexible industrial demand affects system costs and sizing, by investigating the flexible operation of Power-to-X plants with intermediate or final product storage.

References

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