THE FUTURE OF HYDROGEN: LEVELIZED COST OF HYDROGEN TRENDS AND REGIONAL COMPARISONS

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Overview

The hydrogen economy is increasingly seen as a critical component of global decarbonization strategies, particularly following commitments made at COP28 to accelerate the transition to net-zero emissions. Hydrogen has the potential to decarbonize carbon-rich sectors like heavy industry, transportation, and energy storage, which are challenging to electrify (Glenk & Reichelstein, 2019). Challenges include fluctuating electricity prices, geopolitical disruptions like the Russian-Ukrainian conflict, and the high costs of integrating hydrogen production with renewable energy systems (Gerloff, 2023). Previous research highlighted how electricity prices play a dominant role in hydrogen production costs (Glenk & Reichelstein, 2019). Furthermore, Gerloff (2023) analyzed the Levelized Cost of Hydrogen (LCOH) in Germany during the 2022 energy crisis, showing how elevated electricity prices affected competitiveness. Other studies have explored hydrogen production technologies, transport pathways, and scaling challenges, but these have often focused on specific regions or outdated scenarios (Schoenfisch et al., 2020; Dorigoni et al., 2019). While these works stress the need for cost reductions, there is limited comparative research on how hydrogen technologies perform in different developed economies under current conditions and how they are expected to develop in the future.

Accurate LCOH estimates are vital for policymakers designing subsidies, industry stakeholders evaluating investment risks, and researchers exploring conditions for hydrogen to compete with fossil fuels. While advancements in technology and shifts in regional factors have already shaped hydrogen costs, their future impact remains uncertain. Additionally, updated comparisons of LCOH across developed countries are needed to identify competitive regions and guide global hydrogen strategies. Friedl et al. (2023) emphasized the importance of harmonized methodologies for evaluating levelized costs across energy systems. The LCOH quantifies hydrogen production costs over a plant's lifecycle, including capital expenditures (CAPEX), operational expenditures (OPEX), and energy prices.

This study addresses the gaps in existing research by focusing on the comparative analysis of LCOH for hydrogen production technologies using grid- and renewable-based electricity. As an example, the German energy grid system and its forecast for future electricity prices are used to represent grid-based scenarios. For renewable energy-based production, the analysis is based on electricity generated from a mix of wind and solar energy in Europe, using current data and future projections. The study also compares three primary hydrogen production technologies—Alkaline Electrolysis (AEL), Polymer Electrolyte Membrane (PEM), and Solid Oxide Electrolysis Cell (SOEC)—and their expected developments in efficiency and costs over time. In addition, the analysis identifies and quantifies the key factors influencing hydrogen production costs, such as electricity prices, CAPEX, and OPEX, providing insights into how these factors drive LCOH dynamic.

Methods

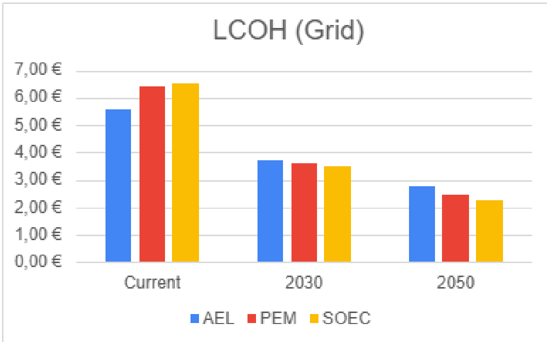
This study evaluates LCOH across AEL, PEM, and SOEC technologies for two electricity scenarios: grid-based electricity, represented by Germany, and renewable-based electricity (50% wind, 50% solar) for Europe. The analysis spans three time horizons—the current period, 2030, and 2050—to capture trends and provide a forward-looking perspective on hydrogen production costs. The inclusion of grid electricity data from Europe and other developed countries is planned, with data collection ongoing to ensure a comprehensive and reliable dataset encompassing electricity prices, hydrogen production parameters, and policy frameworks.

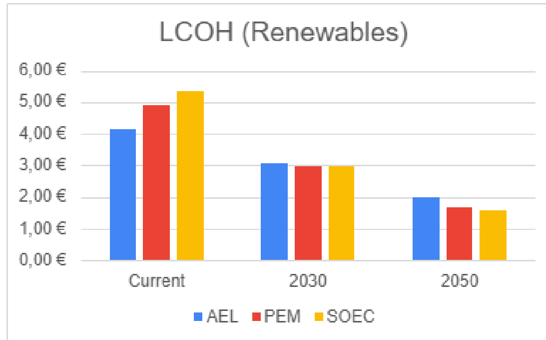
The analysis incorporates the most recent data from publicly available databases and established studies, covering electricity prices, OPEX, and efficiency improvements. It focuses on identifying the key cost drivers, such as electricity prices and technological advancements, and evaluates their impact on LCOH in both grid and renewable scenarios.

Results

The analysis highlights significant cost differences between grid-based and renewable-based hydrogen production, focusing on three technologies: AEL, PEM, and SOEC. Using the German energy grid as an example, current LCOH values are approximately €6/kg across technologies. Projected reductions by 2030 (€3–4/kg) and 2050 (€2–3/kg) reflect anticipated decreases in electricity prices and improvements in technology efficiency. For renewable-based production, modeled with a 50% wind and 50% solar mix in Europe, current LCOH values are slightly lower at around €5/kg, with projections dropping below €2/kg by 2050.

The findings confirm electricity costs as the dominant factor influencing LCOH, demonstrated by the consistent cost advantage of renewable electricity over grid-based sources, especially in the long term. Among the technologies, SOEC shows the lowest LCOH under most scenarios due to its higher efficiency, particularly in future forecasts. These results underline the importance of renewable integration and targeted investments in improving efficiency to achieve competitive hydrogen production.





Conclusions

This study updates LCOH estimates for 2024/25, incorporating stabilized electricity prices and renewable energy scenarios to reflect recent market developments. The findings confirm the critical role of electricity costs in hydrogen production (Gerloff, 2023; Glenk & Reichelstein, 2019), with renewable-based scenarios showing a significant potential to lower LCOH to below €2/kg by 2050. These costs are competitive with projections for gray hydrogen in the same timeframe and represent a step toward closing the gap with fossil fuels such as natural gas and oil in industrial applications. However, to accelerate the path toward cost-competitive green hydrogen, sustained policy support and targeted technological innovation are essential. Measures such as subsidies for green hydrogen production, carbon pricing, and support for infrastructure development are needed to reduce costs and incentivize market adoption in the near term. On the technological side, advancements in electrolyzer efficiency, scaling production capacities, and integrating renewable energy sources are critical to achieving further cost reductions. This study provides insights into how these factors influence LCOH and where interventions could have the greatest impact.

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