EXPLORING THE COMPLEXITY OF THE TRANSITION TO LOW-EMISSION HYDROGEN: A DYNAMIC SIMULATION APPROACH

Reza Fazeli, Research Fellow, School of Engineering, Zero-Carbon Energy for the Asia-Pacific Grand Challenge, Australian National University (ANU), Australia, +61-435-206-850, reza.fazeli@anu.edu.au
Thomas Longden, Crawford School of Public Policy, Australian National University, Thomas.Longden@anu.edu.au
Matt Stocks, School of Engineering, Australian National University, matthew.stocks@anu.edu.au
Fiona J Beck, Associate Professor, School of Engineering, Australian National University, Fiona.Beck@anu.edu.au

Overview

Accomplishing the goal of net zero emissions by 2050 will require an economical zero-emissions fuel, such as hydrogen in addition to electrification and deployment of renewable electricity. Currently, the high production cost of zero-emission ‘renewable’ hydrogen, produced from electrolysis powered by renewable electricity, is delaying its adoption (IEA, 2021).

Uncertainties in technoeconomic parameters are important as they can lead to different timelines for a transition between fossil-fuel based and renewable hydrogen, which in turn results in significantly different projected GHG emissions from hydrogen production over the next few decades. Reviewing the literature, the effect of some uncertainty factors (the capital cost and efficiency of electrolyser, the cost of renewable electricity) on the cost of hydrogen production have already been evaluated (Overbeek, et al., 2020, and Yates et al., 2020), yet other critical elements such as the gas price, and discount rate were not included.

We are already seeing a range of investments happening globally for both blue, and green, with proponents on both sides confident that their technology will be competitive (IEA, 2022). However, widespread early adoption of blue hydrogen could slow progress towards net-zero targets if the emissions associated with blue hydrogen are larger than expected due to low carbon capture efficiencies or high methane leakage rates (Longden, et al 2022).

Methods

To better understand the role of uncertainties on the transition to renewable hydrogen, we propose an integrated framework, linking techno-economic and Monte-Carlo based uncertainty analysis with quantitative hydrogen supply-demand modelling to examine hydrogen production by different technologies and calculate the associated greenhouse gas (GHG) emissions from feedstock supply and the production process. We explored the effect of varying 7 key parameters (the capacity factor and capital cost of solar PV, the capital cost of the electrolyser, the stack lifetime, the efficiency of electrolyser, the price of natural gas and discount rate) randomly within the ranges developed based on the literature (Fazeli, et al., 2022).

We have also developed a system dynamics model to evaluate price-based competition between technological options, accounting for different levels of hydrogen demand, variation in the levelised cost of producing hydrogen using each technology, and emission reduction targets implemented using carbon price pathways.

The simulation model will enable us to estimate the capacity of blue hydrogen plants that are at risk of early retirement, assuming different cost trajectories for hydrogen production, and under different carbon pricing scenarios. Demand curves are determined by calibrating a logistic function (Odenweller et al. 2022) to match the global demand trajectories in 2050 based on three IEA scenarios; Stated Policies Scenario (STEPS), Announced Pledges Scenario (APS) and Net Zero Emissions by 2050 Scenario (NZE) (IEA, 2021).

Results

The results show that the uncertainty around the cost of electrolyser systems, the capacity factor, and the gas price are the most critical factors affecting the timing of the transition to renewable H_2. In addition, we identify the thresholds needed for the transition to renewable hydrogen in 2030, in the absence of a carbon price.

While these thresholds are aligned with the most optimistic predictions for electrolyser and solar energy costs and capacity factors, they could be reached with economies of scale requiring aggressive expansion of the capacity of installed electrolysers around the world, and by targeting locations in Australia with the potential to support very low-cost, high-capacity factor solar power.

Uncertainty analysis also reveals that hydrogen production in Australia is likely to be dominated by fossil fuel based reforming technologies in the absence of a carbon price. As a result, the cumulative emissions from hydrogen production can reach 650 Mt CO_2-e by 2050, which is very significant considering Australia's annual emissions of 537 Mt CO_2-e in 2018. However, the application of a price on carbon emissions can expedite the transition to renewable hydrogen and reduce cumulative emissions to 110 Mt CO_2-e by 2050.

In addition, we investigate the effect of the volatility of the cost of gas and projected reductions in the capital cost of electrolysers on the risk of gas-based hydrogen projects becoming stranded. With low-cost gas, these assets are replaced by CCS projects with high capture rates. However, when a higher cost of gas and/or favourable conditions for green hydrogen are assumed, all types of blue hydrogen projects become uncompetitive within 10 years of operation. This analysis shows that there is a substantial risk that investments in blue hydrogen will lead to stranded assets.

Conclusions

Hydrogen is expected to play a key role in achieving decarbonization targets globally. However, even though there are no carbon emissions at point of hydrogen use, the production can contribute to significant carbon emissions. Based on the result of Mont Carlo analysis, the cumulative emissions from hydrogen production in Australia can reach 650 Mt CO_2-e by 2050, which is very significant considering Australia's annual emissions of 537 Mt CO_2-e in 2018.

Focusing on the development of blue hydrogen plants, across all net zero scenarios, we find that projects with low carbon capture rates become stranded assets, with operational lifetimes less than 20 years. With low-cost gas, these assets are replaced by CCS projects with high capture rates. However, when a higher cost of gas and/or favorable conditions for green hydrogen are assumed, all types of blue hydrogen projects become stranded with less than 5 years of operational lifetimes. This analysis shows that there is a substantial risk that investments in blue hydrogen will lead to stranded assets.

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