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WP-2023-09
Research Brief

Advances in Power-to-Gas Technologies: Cost and Conversion Efficiency

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Widespread adoption of hydrogen as an energy carrier is widely believed to require continued advances in Power-to-Gas (PtG) technologies. Here we provide a comprehensive assessment of the dynamics of system prices and conversion efficiency for three currently prevalent PtG technologies: alkaline, polymer electrolyte membrane, and solid oxide cell electrolysis. We analyze global data points for system prices, energy consumption, and the cumulative installed capacity for each technology. Our regression results establish that, over the past two decades, every doubling of cumulative installed capacity resulted in system prices coming down by 14-17%, while the energy required for electrolysis was reduced by 2%. Incorporating multiple forecasts of future deployment growth, our calculations project that, in the coming decade, all three technologies will become substantially cheaper and more energy-efficient. Specifically, the life-cycle cost of electrolytic hydrogen production is projected to fall in the range of $1.6-1.9/kg by 2030, thereby approaching but not reaching the $1.0/kg cost target set by the U.S. Department of Energy.

In the intensifying debate about alternative pathways for rapid decarbonization, hydrogen is increasingly viewed as a critical building block for storing and flexibly dispatching large amounts of carbon-free energy[1;2]. Among alternative hydrogen production technologies, Power-to-Gas (PtG) in the form of electrolytic hydrogen has received particular attention[3–5]. Large-scale deployment of these technologies, however, is generally expected to hinge on substantial cost declines and energy conversion improvements. To accelerate the pace of these improvements, governments around the world have recently introduced sizeable regulatory initiatives and subsidy programs for the development, deployment, and manufacturing of hydrogen equipment[6;7].

This paper projects cost and conversion efficiency improvements for three prevalent PtG technologies: alkaline, polymer electrolyte membrane (PEM), and solid oxide cell (SOC) electrolysis. Our analysis is grounded in a learning-by-doing model that postulates that system prices for electrolyzers and their conversion efficiency decline at a constant rate with every doubling of cumulative installments of the technology in question. Such learning models have proven highly descriptive in the context of solar photovoltaics, onshore wind turbines, or lithium-ion batteries. Scarcity of data has so far limited the estimation of learning curves to alkaline electrolysis or to a single equipment manufacturer. Some earlier studies estimate the rate of past cost declines of PtG technologies against time or rely on expert opinions about future cost developments.

Our analysis provides a comprehensive assessment of the dynamics in system prices and energy efficiency for the three PtG technologies by tracking global observations on investment expenditures and energy consumption. This information is linked to capacity installations at facilities commissioned worldwide between 2000–2020. Our estimates return significant and robust learning curves for system prices in the range of 83–86% (Figure 1). Thus, system prices declined by 14–17% compared to the price levels prior to the doubling of cumulative installments. The relatively young SOC technology is projected to show the sharpest price decline at a 17% learning rate. PEM electrolyzers, in contrast, have experienced high capacity growth and a rapid price decline between 2003 and 2020. Here, our estimates yield a relatively slow learning rate of 14%. For conversion efficiency, we estimate that every doubling of cumulative installed capacity reduces the required kilowatt-hours (kWh) per kilogram (kg) of hydrogen produced by approximately 2% across all three technologies.

Our regression results can be extrapolated to yield forecasts for the system prices and conversion efficiencies of the three PtG technologies in question by the year 2030. Even for divergent growth forecasts issued by different industry and policy sources, the extrapolated values fall into a relatively narrow range. These calculations, in turn, lead us to conclude that the *Hydrogen Shot* target by the U.S. Department of Energy[7] of producing clean hydrogen at a cost of $1.0/kg by 2030 is ambitious but not unrealistic. Because electricity prices will become the dominant component of the life-cycle cost of hydrogen by 2030, the attainment of the *Hydrogen Shot* target via electrolytic hydrogen ultimately hinges on the availability of inexpensive and clean electricity.

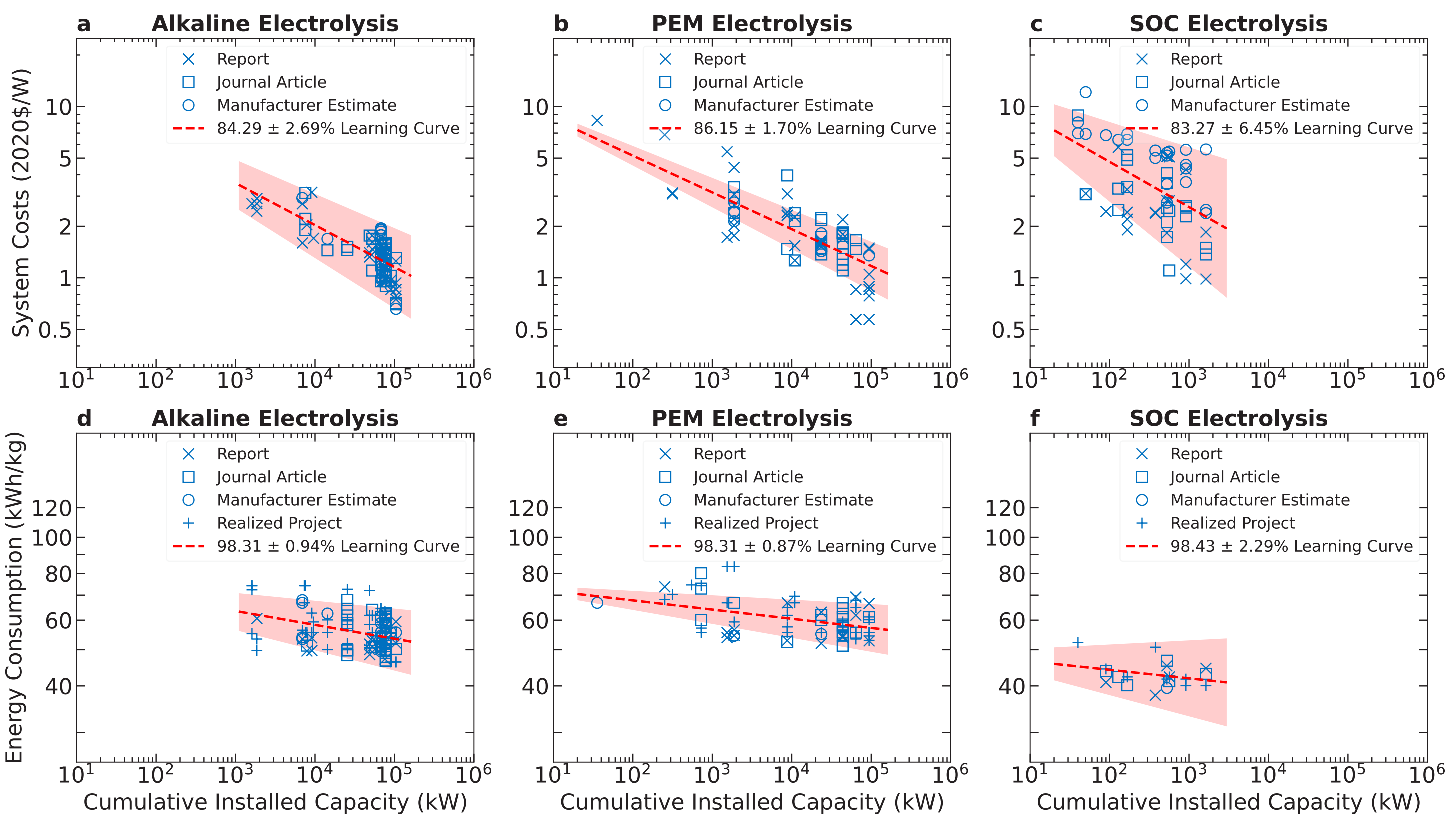

Figure 1: Estimates of learning curves.

This figure plots the global system prices in 2020 $US against the global cumulative installed capacity together with our estimates of the corresponding learning curves for (a) alkaline, (b) PEM, and (c) SOC electrolyzers. The figure also plots the energy consumption against the global cumulative installed capacity together with our estimates of the corresponding learning curves for (d) alkaline, (e) PEM, and (f) SOC electrolyzers. Areas shaded in red represent 95% confidence intervals.

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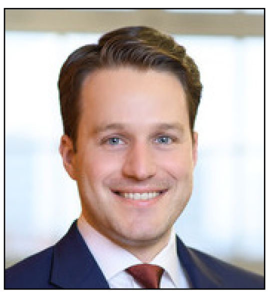
About the Authors



Gunther Glenk is an Assistant Professor for Business at the University of Mannheim. His research examines questions related to corporate transitions toward zero net emissions. Specific topics include the economics and management of corporate carbon emissions, decarbonization and sustainable energy technologies, and incentives for climate action. Recent work has focused on the competitiveness of clean energy technologies, such as energy storage, renewable hydrogen, and electric mobility. Professor Glenk received his B.Sc., M.Sc., and Doctorate in Management and Technology from the Technical University of Munich.

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