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Can Green Hydrogen Be a Cost Competitive Transportation Fuel by 2030?

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Issue

There is growing international interest in electrolytic hydrogen produced from renewable energy (often referred to as green hydrogen) as a potential zero-emission alternative to gasoline and diesel in a variety of on-road and off-road transportation applications. Currently, gasoline and diesel are priced around $4 per gallon at the pump and a gallon of either fuel is roughly the equivalent of one kilogram of hydrogen based on energy content. Although hydrogen vehicles are generally more efficient than those fueled by petroleum, transporting and dispensing hydrogen is more expensive than for conventional fuel, so hydrogen must reach a cost substantially below $4/kg, possibly as low as $2/kg, to be a cost competitive option. Is this achievable? In short, this depends on the extent to which green hydrogen markets scale up globally. Projections of future green hydrogen production costs are generally in the range of $2–$4/kg by 2030[1]; however, some expect faster and deeper declines reaching as low as $1.5/kg by 2030[2] and even $1/kg by 2030 under ideal conditions.[3] This brief examines the evidence in support of green hydrogen production achieving a cost at or below $2/kg starting from its current level of between $5 and $6/kg,[4] and assesses the time point at which this cost benchmark could be achieved.

Key Research Findings

Green hydrogen resource potential is more than adequate to meet potential demand. Today, the supply of electrolytic green hydrogen is limited, representing only a fraction of a percent of current vehicle fuel use in California. However, the limited supply stems from the early stage of market development which limits demand. If electrolytic green hydrogen is to be a significant fuel in a future California zero-carbon economy, several billion kilograms of green hydrogen will need to be produced each year.[5] The production potential is limited only by the potential supply of renewable electricity to power the electrolysis process and the availability of water, the other primary input to the process. Fortunately, California has an abundant solar resource, many times that required to support a full deployment of green hydrogen, and the water demand would be less than 1% of current water demand. In addition, electrolytic green hydrogen production consumes less water than production of the fossil fuels.[6]

To achieve a green hydrogen production cost of $2/kg, the electrolyzer capital cost must decline by as much as 80%. Green hydrogen is produced by splitting water (H2O split into H2 and O2) using an electrochemical cell, called an electrolyzer, powered by renewable electricity. Currently, the electrolyzer capital cost is about $1,200 per kilowatt (kW) of input energy capacity and represents about 70% of the total cost to produce green hydrogen (Figure 1). Input electricity accounts for the other 30% of cost (assuming self-generated renewable power at $0.03 per kilowatt-hour (kWh) and 30% capacity factor). An 80% reduction in cost is well within the forecast range for 2050 but on the lower end of the forecast for 2030 as will be discussed below.

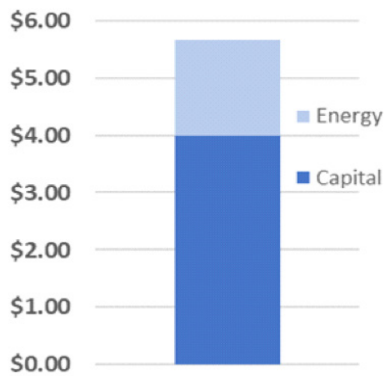

Figure 1. Current green electrolytic hydrogen production cost per kilogram of hydrogen.

Under current industrial electric rates, electricity supplied directly from dedicated renewables (that is, the electrolyzer is located at the solar or wind farm) is the most economic approach because no transmission and distribution charges are incurred as would be the case for grid-supplied energy.[7] Under this electricity supply approach, reaching the $2/kg cost benchmark would require roughly 80% reduction in capital cost assuming a 15%–20% reduction in energy cost due to continued advancement of wind and solar costs, and projected improvement in electrolyzer conversion efficiency of roughly 10%. If future electric grid rate structures allow electrolytic hydrogen production facilities to import additional renewable power, the 30% capacity factor (utilization) could be improved to 45% or more by blending wind and solar supply. This would move the capital cost reduction needed to achieve the $2/kg benchmark to 70%. Should large hydropower be deemed a qualified renewable resource providing an 80% capacity factor, the required cost reduction would be just over 50%. This is on the conservative end of the cost reduction projections.

Technologies with technical similarity to electrolyzers have shown cost reduction trajectories consistent with those assumed for producing green hydrogen at a cost of $2/kg by 2030. Other electrochemical and solid-state electronic technologies including batteries, solar photovoltaics and electronics have demonstrated cost reductions greater than those projected for electrolyzers.[8] Achieved cost reduction for technologies reinforces confidence in the likelihood of achieving targeted cost reduction for electrolyzers. These cost reductions reflect both achievements of large-scale production and learning/optimization from ongoing production that can be expected as well for electrolysis. As a concrete illustration, utility-scale solar power costs achieved an approximately 85% cost reduction from 2009 to 2018 (Figure 2). It should also be noted that progress in reducing the cost of solar energy directly contributes to reducing the cost of electrolytic hydrogen because renewable electricity is a primary input. For every $.01/kWh reduction in input electricity cost, the cost of electrolytic hydrogen is reduced by roughly $0.50/kg.

Although renewable hydrogen produced from biomass pathways will not show the same degree of cost decline as renewable electrolytic hydrogen,[9] biomass-to-hydrogen via thermochemical conversion is significantly less costly than hydrogen produced by electrolysis today and will provide a second pathway for producing renewable hydrogen at or below $2/kg.

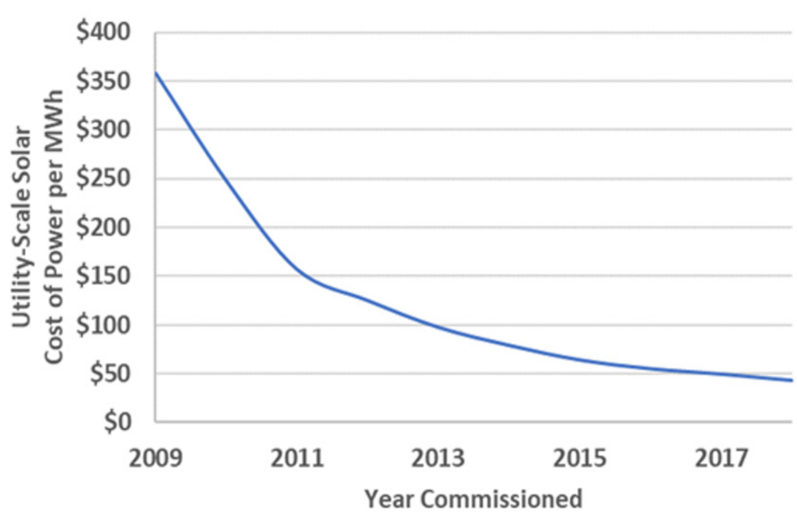

Figure 2. Cost evolution of utility-scale solar power. Data source: Lazard Levelized Cost of Energy Report 2020.

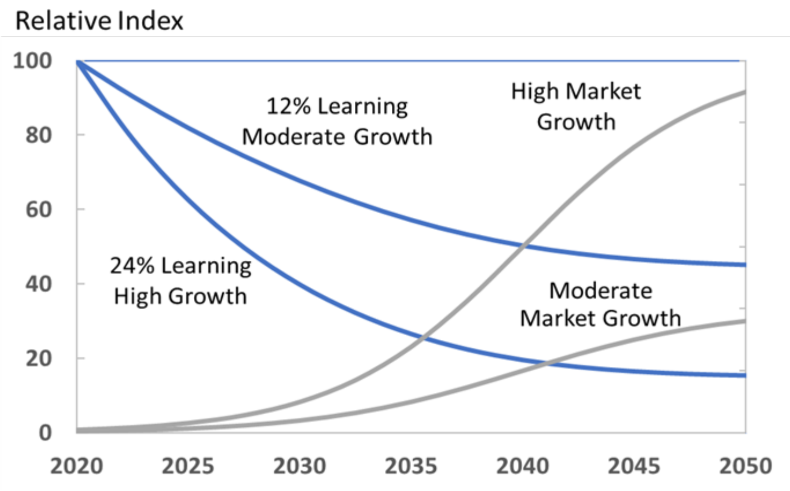

Figure 3. Learning-curve projections of electrolyzer cost evolution (blue curves) based on a lower estimate of learning rate of 12% and an upper estimate of 24% for two different market growth scenarios (grey curves).

Cost reductions for producing green hydrogen primarily come from production scale with secondary contributions from improvements in technology. Expected cost reductions come from manufacturing scale, factory automation, transition to lower-cost materials, and other types of optimization and learning that do not require technology breakthroughs. While learning curve analysis has proven to be an accurate technique for forecasting costs, it says nothing about how these cost reductions can be achieved. The U.S. Department of Energy continually updates future design concepts for fuel cell and electrolyzer systems,[10] which helps explain how the cost reduction projected by the learning curve analysis can be achieved. At higher production volumes, "mass production" techniques and high levels of automation are feasible. For example, membranes that currently must be produced in single sheets cut or stamped to final shape can be produced on roll-to-roll machines operating at high rates when production volume is high. Fundamental design improvements and technology advancements can further reduce costs, including improvements in catalyst performance to reduce the quantities of precious or rare metals (such as platinum and cobolt) needed for electrolyzer membrane electrolyte assemblies, and advancement of high-temperature electrolyzers that have the potential for significantly higher efficiency than current technologies.

Projected green hydrogen cost reductions are supported by well-validated forecasting techniques. Common methods for projecting technology cost reduction include: polling of experts (i.e., "expert elicitation"); future-generation design concept analysis coupled with estimation of cost savings from things like design simplification, material changes, and increased manufacturing automation; and learning curve or progress ratio analysis, which projects cost savings as the cumulative production of a technology increases. All these methods have been applied to electrolyzer cost projections and all point toward the expectation of cost reduction in line with achieving a $2/kg production cost target.[11]

The learning curve method is well validated for projecting electrolyzer cost reduction and indicates capital cost reduction of between approximately 40% to 80% by 2030 (relative to 2020) as shown in Figure 3. A common version of learning curve analysis known as Wright's Law posits a consistent reduction in cost by a given percentage for each doubling of cumulative global production of a technology. For example, a learning rate of 10% means that the unit cost for the technology being evaluated declines by 10% for each doubling of cumulative global production (in this case, the total megawatts of electrolyzer capacity produced since market introduction of the technology). Typical observed learning rates for a broad range of technologies are in the range of 5% to 15%.[12] However, some technologies, such as solid-state and electrochemical technologies, can show significantly higher learning rates. Utility-scale solar and lithium-ion batteries have shown learning rates of over 20%. Electrolyzers have exhibited a historical learning rate of 18%.[13] In addition to learning rate, cost improvement over time depends on how fast the market for the technology of interest is growing (i.e., how long it takes for cumulative production to double). Figure 3 employees a forecast by the International Energy Agency that projects global electrolytic hydrogen production capacity of 3,500 gigawatts in 2050.[14]

More Information

This brief is one in a series highlighting the latest research findings and insights related to the role, production, and use of hydrogen in achieving a zero-emission energy future for California. To learn more about this series, visit www.ucits.org/research-project/rimi-3n. For more information about findings presented in this brief, please contact Jeffrey Reed at jgreed@uci.edu .

[1] Ibid. Reed, J. G., et al. (2020). Roadmap for the Deployment and Buildout of Renewable Hydrogen Production Plants in California: Final Project Report. California Energy Commission (CEC). (RH2 Roadmap).

[2] See, for example, projections of low-end Goldman Sachs https://www.goldmansachs.com/insights/pages/gs-research/carbonomics-the-clean-hydrogen-revolution/carbonomics-the-clean-hydrogen-revolution.pdf page 5, and Bloomberg New Energy Finance https://twitter.com/bloombergnef/status/1186221503274201088 .

[3] The U.S. Department of Energy has established a stretch goal of $1/kg, which includes the cost for producing hydrogen delivered at modest pressure at the electrolyzer facility, but does not include costs associated with transport, storage, and dispensing to vehicles; however, these supply chain costs are projected to decline as network utilization increases and, over the longer term, as pipeline transport replaces trucking.

[4] See footnote 1. pp. 25-30 interpolated to 2022 and adjusted to 30% capacity factor.

[5] See footnote 1 reference, Chapter 2.

[6] A. Mehmeti, A. Angelis-Dimakis, G. Arampatzis, S. J. McPhail, and S. Ulgiati, “Life cycle assessment and water footprint of hydrogen production methods: From conventional to emerging technologies,” Environ. - MDPI, vol. 5, no. 2, pp. 1–19, 2018, doi:. 10.3390/environments5020024.

[7] All projects awarded in the CEC grant solicitations to date are planned to be co-located with solar facilities and the recently announced Plug Power green hydrogen project will be co-located with a large solar farm https://www.ir.plugpower.com/press-releases/news-details/2021/Plug-Power-to-Build-Largest-Green-Hydrogen-Production-Facility-on-the-West-Coast-2021-9-20/default.aspx .

[8] O. Schmidt, A. Hawkes, A. Gambhir, and I. Staffell, “The future cost of electrical energy storage based on experience rates,” Nat. Energy, vol. 2, no. 8, pp. 1–8, 2017, doi: 10.1038/nenergy.2017.110.

[9] See technology assessment chapter of reference noted in footnote 1.

[10] B. D. James, D. A. Desantis, and G. Saur, “Final Report: Hydrogen Production Pathways Cost Analysis,” no. September, pp. 1–55, 2013.

[11] Reed et al. 2020, n1.

[12] O. Schmidt et al. 2017, n5.

[13] Ibid.

[14] https://iea.blob.core.windows.net/assets/e57fd1ee-aac7-494d-a351-f2a4024909b4/GlobalHydrogenReview2021.pdf

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