Realistic roles for hydrogen in the future energy transition

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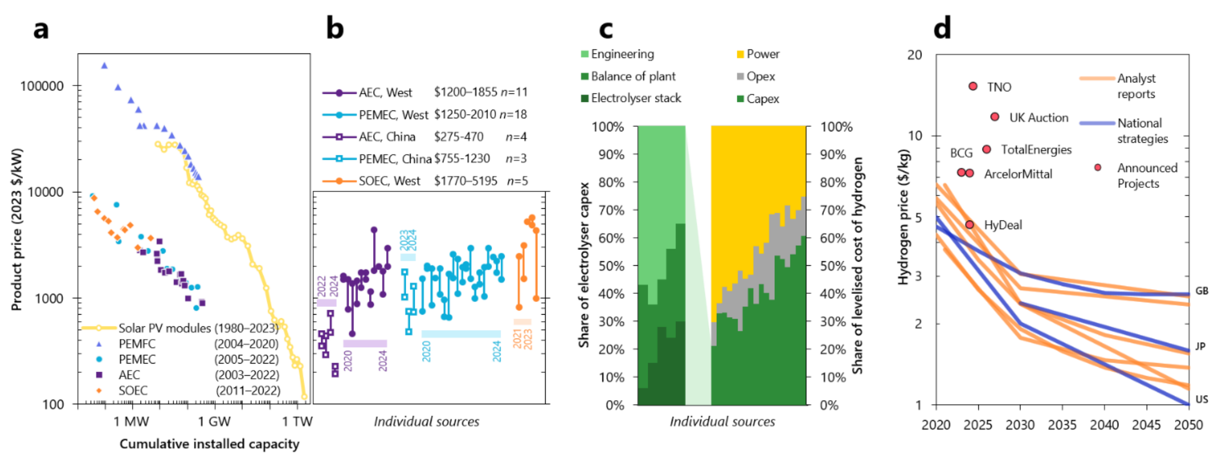
Overview

Hydrogen has been promoted as a revolutionary fuel for over fifty years, yet its current contribution to global energy systems remains marginal outside specific industrial processes. For hydrogen to drive global decarbonisation, numerous economic, technological, and policy barriers must be overcome. This keynote lecture will address the challenges hydrogen faces across its whole value chain, its rapidly evolving economic potential, its complex sustainability credentials, and the pressure it faces from rapidly advancing clean alternatives.

The properties of hydrogen – its low energy density, flammability, and tendency to leak – impose cost, safety, and infrastructure challenges. Production costs vary widely, and bold cost-reduction targets of $1/kg by 2030 are will likely be impossible to meet due to transport and storage costs. Unlike solar PV or lithium-ion batteries, hydrogen costs are dominated by engineering and energy inputs, limiting the potential for rapid cost reduction. Therefore, carbon abatement costs are currently \$500–1250/tCO_2, and are only expected to fall to \$200–500/tCO_2 in the most competitive applications by 2050, which is comparable to estimated costs for the mitigation technology of last resort: direct air capture.

The environmental impacts of “clean” hydrogen further complicate its role in achieving policy goals. Upstream leakage from the fossil fuel industry and consequential impacts on electricity systems must be addressed. In the short term, green hydrogen competes for renewable electricity that could more effectively displace fossil fuels. Long term, hydrogen may enable renewable integration by absorbing excess generation.

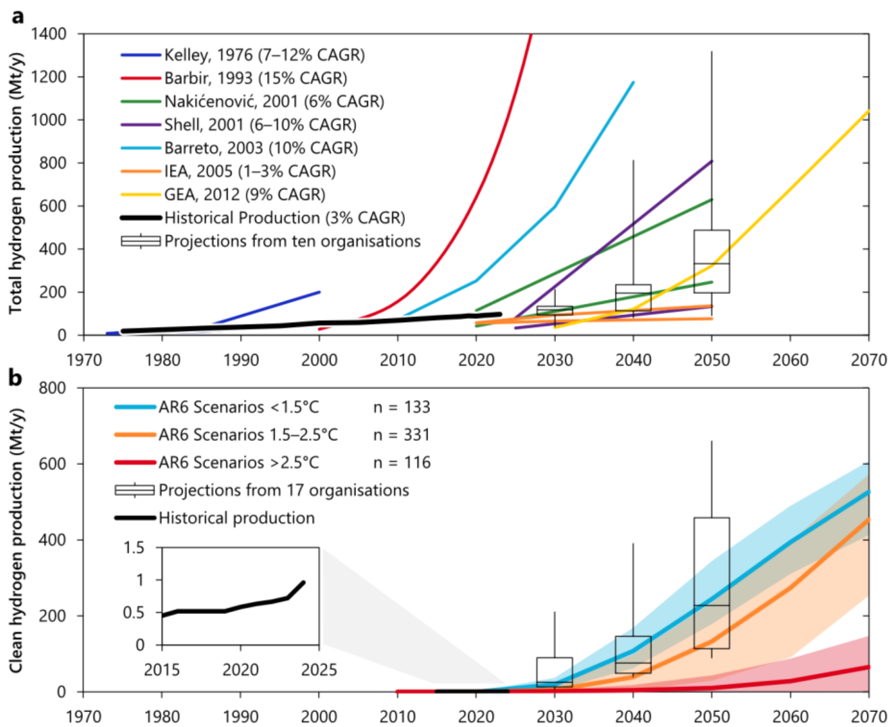


The cost of producing and distributing clean hydrogen. | ***a*** | *Experience curves for fuel cells and electrolysers, showing how cost has fallen with historical deployment, set against the experience curve for solar PV modules for context.* | ***b*** | *Estimates for electrolyser capital cost from 42 sources, split by technology and region of manufacture. Points in each group are ordered chronologically. The caption gives the IQR of prices for each group.* | ***c*** | *The breakdown of electrolyser system costs across 5 projects, and the breakdown of levelised hydrogen costs across 18 projects.* | ***d*** | *The evolution of levelised cost of hydrogen (LCOH) in three national roadmaps and six analysts’ projections, set against announced costs for six actual projects. National roadmaps are indicated by two-letter ISO codes.*

Policy and industry interest in hydrogen remains strong, targeting the enormously broad spectrum of possible applications that hydrogen could play a role in. This has led to decades of hype cycles and stagnation. Many applications, including hydrogen cars and home heating systems are now defunct. In 2023, more Ferraris were sold than fuel cell vehicles. Heat pumps outsold fuel cell heating systems by a factor of 200:1.

Hydrogen's greatest potential lies in strategic deployment where it outperforms alternatives like direct electrification or where there is no alternative. Promising uses include industry (petrochemicals and fertilisers), long-duration energy storage, and long-haul transport. These require significant cost reductions through large-scale deployment, which has been elusive despite decades of investment.

Grounded in the latest economic and environmental data, this keynote provides an evidence-based framework for evaluating hydrogen's competitiveness across all applications. By identifying deployment priorities and critical barriers, this can guide governments, industries, and stakeholders seeking to incorporate hydrogen into global pathways for cost-effective sustainable energy transitions.



Projections of global hydrogen production across 100 years. *| **a** | Total hydrogen production (high- and low-carbon) from selected historical scenarios (lines) and recent projections (boxes), set against actual production. Boxes represent the median and IQR, whiskers represent min/max. The compound annual growth rate (CAGR) of each scenario is given in the legend. | **b** | Clean hydrogen production (excluding unabated fossil fuels) from integrated assessment model scenarios (shaded areas) and recent non-academic projections (boxes), set against actual production. Shaded areas and thick lines show the IQR and median across 580 scenarios from the IPCC AR6 database, coloured according to global temperature outcomes in 2100.*