How green hydrogen conquers the world—An outlook on the global clean hydrogen market

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Abstract

While clean hydrogen is now clearly recognised as one of the key elements for reaching climate neutrality, its uptake remains subject to many uncertainties. We develop a global hydrogen delivery chain optimization model to identify cost-efficient trajectories towards the establishment of a global clean hydrogen market. Our findings show that the supply is dominated by renewable hydrogen (above 500MtH_{2eq}, 85% by 2050) from the beginning. Global trade, covering a fifth of total demand between 2030 and 2050, is crucial to reduce costs, facilitate development of a decentralised and diversified market with numerous suppliers, and bolster energy security and resilience.

Context

Limiting global warming to 1.5 °C requires greenhouse gas (GHG) neutrality by no later than 2050[1]. This involves notably, the transformation and decarbonization of energy consumption and industrial processes, which represented more than 80% of global GHG emissions in 2019[a].

The existing literature on the decarbonization of energy systems highlights the importance of large-scale renewable development and electrification as possible levers to help speed up the energy transition[2-5]. More sectoral studies on the decarbonization of electricity systems[6-10], industry (e.g., steel, chemicals)[11-13] and transport[14-16] also identify clean hydrogen as a possible key pillar to overcome the challenges raised by deep electrification of end-uses and high penetration of renewable energy. These studies highlight how clean hydrogen could play a major role to help decarbonize hard-to-abate sectors like industry and transport that are difficult or costly to electrify[17]. Such clean hydrogen can be produced either via electrolysis based on low-carbon electricity[b] or natural gas with abated CO_2 (blue hydrogen).

While hydrogen has been included by some policymakers in their decarbonization roadmaps[c], the development of a clean hydrogen market is still subject to several uncertainties. The current literature focuses on the economic competitiveness of different clean hydrogen supply routes[18-20], transport options[21,22] and its potential end-uses in different sectors[17,23-25]. Nevertheless, the analyses remain either at national and regional levels, or they are technically focused on the decarbonization of a specific sector. The trade implications are only focused on specific regions as potential importers or exporters[17,26,27]. They don't consider the dynamics of the global trade environment nor take into account the competition between potential exporters and importers among themselves and the role that hydrogen's derived commodities, such as ammonia, play in such a trade. This Deloitte study aims at creating an outlook for the global clean hydrogen market that looks at the supply and demand of hydrogen commodities, key potential exporters and importers and trade formation in a climate-neutrality context.

Method

The study combines two modelling frameworks: First, following a mixed top-down and bottom-up approach, the global hydrogen demand has been estimated. The end-use demand of each sector is identified following the International Energy Agency's (IEA's) net-zero

[a] https://www.wri.org/insights/4-charts-explain-greenhouse-gas-emissions-countries-and-sectors

[b] If this electricity comes from renewable sources (especially wind and solar power), it is called green hydrogen.

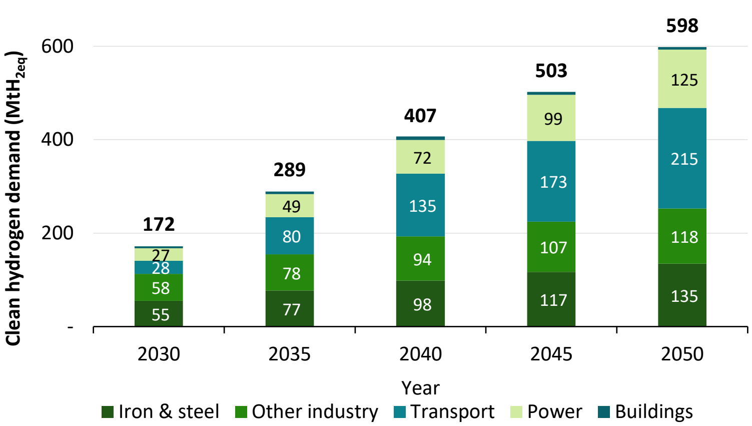
[c] Several countries have announced national hydrogen strategies, such as France, the United States, the United Kingdom, Australia, etc.

pathway[28], where the electrification potential, and the potential penetration of hydrogen as energy and feedstock source are identified. A global clean hydrogen supply, conversion/reconversion, and transport optimization model (HyPE – Hydrogen Pathway Explorer) was developed by Deloitte where the overall supply and delivery chain is optimized using the potential clean hydrogen supply and transport technologies. Using the estimated demand values for each country, the HyPE model finds cost-efficient pathways to balance point-to-point hydrogen demand and supply and the transport between different countries around the globe in the period from 2025 to 2050.

Results

The demand-side analysis shows that clean hydrogen demand can reach as high as 170 MtH_{2eq} by 2030 and almost 600 MtH_{2eq} by 2050 (**Error! Reference source not found.**. The demand initially builds on decarbonizing the existing industrial uses of hydrogen (95 MtH_{2eq}[d]), notably for fertilizer production. Then, the net-zero transition underpins fast growth in demand, cementing the role of hydrogen as a key pillar of climate neutrality. By 2050, industry (e.g., iron and steel, chemicals, etc.) and transport (i.e., aviation, shipping, and heavy-road transport) may account for 42% and 36% of the total clean hydrogen demand respectively. Overall, clean hydrogen can lead to the abatement of up to 85 $GtCO_{2eq}$ cumulative emissions by 2050 (more than twice global CO_2 emissions in 2021).

Figure 1. Global clean hydrogen demand by sector from 2030 to 2050



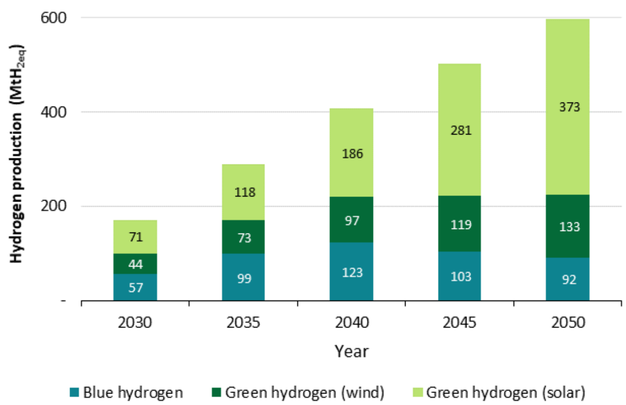
Data source: Deloitte HYPE model

The findings of this study showcase a steady growth in the clean hydrogen market, from US$642 billion/year in 2030 to US$1.4 trillion/year in 2050. According to the modelling results, green hydrogen dominates the global clean hydrogen supply from the beginning of the outlook period, accounting for 115 MtH_{2eq} by 2030, and more than 500 MtH_{2eq} (85% of overall hydrogen supply) by 2050 (**Error! Reference source not found.**). Such a supply mix requires 2,050 GW of dedicated wind and solar installed capacity by 2030, and 9,200 GW by 2050. While such high values can be seen as significant challenges, it can also bring significant synergies to the decarbonization efforts, especially in the power sector. Leveraging storage and hydrogen-fired gas turbines (for power generation), green hydrogen can significantly facilitate the integration of renewables into the power system by providing flexibility and mitigating congestion. While the share of blue hydrogen remains relatively low (33% in 2030 and 15% in 2050), it can be very useful to build up the demand and the global hydrogen economy. This is especially the case for regions with natural gas reserves such as the Middle East, North Africa, North America, and Australia. This role is contingent on natural gas availability and the compliance of industries with the most stringent environmental standards (via high carbon capture rates and methane emission reduction[e]). Blue hydrogen production peaks in 2040 at almost 125 MtH_{2eq}. As a new investment cycle starts in the 2040s, the business case for blue hydrogen diminishes as green hydrogen becomes cheaper while tightening environmental standards diminish the environmental case of blue hydrogen.

Figure 2. Global clean hydrogen supply mix from 2030 to 2050

[d] https://www.iea.org/reports/hydrogen

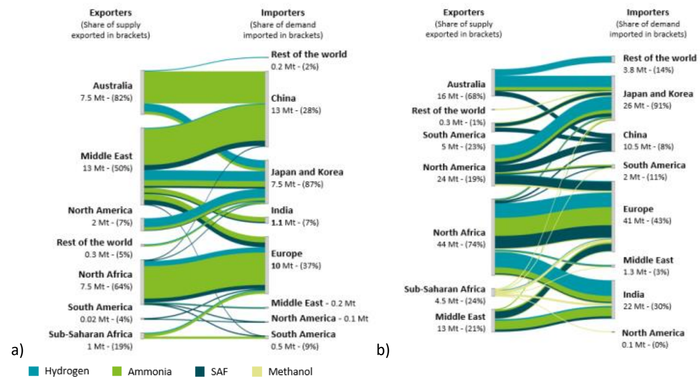
[e] Blue hydrogen can be traded only if its GHG footprint (including residual CO_2 emissions during production and upstream methane emissions) complies with the existing sustainability thresholds and follows a best available technology adoption trajectory to minimize CO_2 and methane emissions over its whole supply and delivery chain.



Data source: Deloitte HYPE model

While ample availability of renewable energies ensures the productibility of green hydrogen at global scale, the cost of green hydrogen supply can vary significantly among different geographies. Moreover, limited land availability in dense regions such as Japan, Korea and Europe can limit the potential of clean hydrogen supply. Global trade can facilitate the shift towards clean hydrogen around the globe. Global trade between major regions represents almost a fifth of the global clean hydrogen demand throughout the period between 2030 and 2050, reaching about 110 MtH_{2eq} in 2050 (**Error! Reference source not found.**). It revolves primarily around hydrogen derivatives (ammonia, methanol, and synthetic aviation fuels (SAF)), which are easier to transport over long distances. Ammonia also becomes a medium for transporting hydrogen, implying conversion and reconversion steps. By 2050, four regions could collectively account for about 45% of the global hydrogen production and 90% of global trade: North Africa (which exports 44 MtH_{2eq}) and Australia (16 MtH_{2eq}) have the greatest export potential compared to their domestic consumption. North America and the Middle East also appear as export leaders (respectively 24 MtH_{2eq} and 13 MtH_{2eq}), on top of supplying large internal demand. South American and Sub-Saharan African countries also actively take part in global trade with almost 10% of traded volumes, mostly via trade of SAF and methanol. On the import side, Japan and Korea could face resource and land availability constraints and heavily depend on global trade (90% of their demand between 2030 and 2050). Europe, India and China produce substantial amounts of hydrogen but also need to rely on imports throughout the transition (41 MtH_{2eq}, 22 MtH_{2eq} and 10.5MtH_{2eq} of imports respectively).

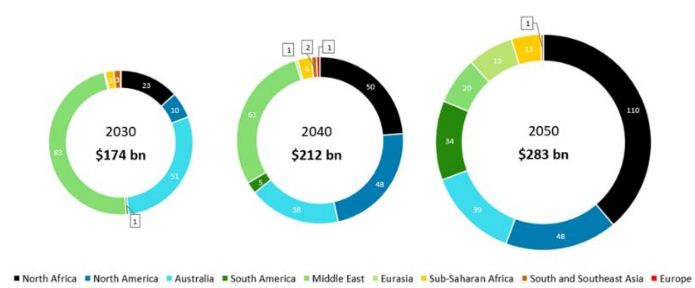
Figure 3. Global hydrogen trade flows between key regions in (a) 2030 and (b) 2050



Data source: Deloitte HYPE model

Global trade between major regions can generate more than US$170 billion of annual revenues in 2030 and US$280 billion in 2050 (**Error! Reference source not found.**). The main revenue recipients in 2050 include North Africa (US$ 110 billion/year), North America (US$48 billion/year), Australia (US$39 billion/year) and the Middle East (US$ 34 billion/year). Free and diversified trade can significantly reduce costs, improve energy security and foster economic development in developing and emerging markets. A 75% reduction in global trade volumes could lead to significant shortage in hydrogen supply (40 MtH_2/year in 2050), and up to 25% (US$350 billion) increase in overall hydrogen supply and delivery costs in the long run.

Figure 4. Annual export revenues between 2030 and 2050 (US$ billion/year)



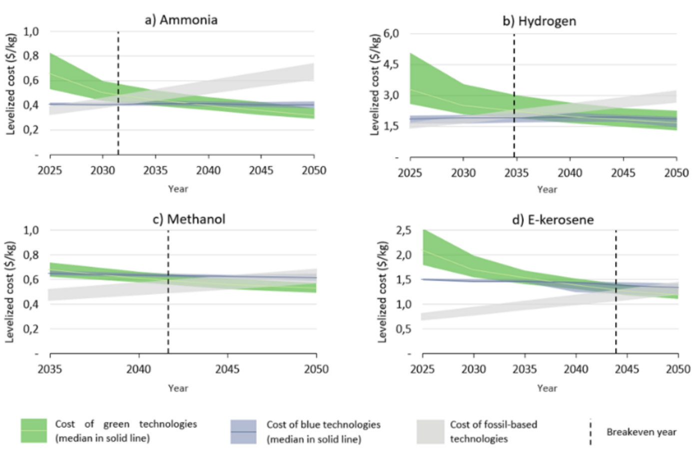
Data source: Deloitte HYPE model

While over 130 countries (88% of global CO_2 emissions) have adopted net-zero targets by the beginning of 2023[f], clean hydrogen projects announced worldwide would at most provide a collective production capacity of only 44 MtH_{2eq} by 2030[f]. Moreover, clean hydrogen is currently more expensive to produce and transport than its fossil-based counterparts. Active policy support is thus needed until green hydrogen catches up with

[f] https://zerotracker.net/

fossil-based alternatives in terms of costs, leveraging economies of scale and tightening CO_2 pricing. With time, green hydrogen can be cost competitive: the break-even point could be reached before 2035 for ammonia, by 2035 for pure hydrogen, between 2040 and 2045 for methanol and by 2045 for SAF (**Error! Reference source not found.**). However, until these breakeven dates, targeted policy support to green hydrogen is crucial to help ensure current projects can compete on a level playing field and enter the market.

Figure 5. Future production costs of green, blue and carbon-intensive grey hydrogen and their derivatives from 2025 to 2050[g]



Data source: Deloitte HYPE model

Conclusions

Development and growth of the global clean hydrogen economy can hold immense potential to help synergistically support the realization of a range of UN SDGs. Integration of green hydrogen priorities into national policy frameworks provides mechanisms for public-private discourse mainstreaming climate focused imperatives into decision-making in support of SDG Target 13.2. Beyond the setting of clear targets, policymakers should prioritize the development of transparent, accountable, and predictable decarbonization pathways as a key enabler of the hydrogen economy.

Technology development and deployment can positively impact domestic renewable energy production furthering SDG Target 7.2, lays the foundation for access to affordable and consistent clean energy in line with SDG Target 7.1, and provides the basis for cooperation, technology transfer, and capacity building advancing SDG Targets 7.A and 7.B. National and regional hydrogen strategies can make a significant contribution to all stakeholders of the hydrogen economy by providing visibility and credibility on development prospects in production, transport and end-uses. The combination of a clear vision, ambitious targets, and a comprehensive support toolkit can stimulate the pipeline of projects with government support through specialized programs paying a key role.

More broadly, systemic reforms to advance clean hydrogen infrastructure can create an enabling environment for resilient, inclusive and sustainable industrialization and innovation (SDG 9), enhanced opportunities for equitable livelihoods (SDG 8) and reduced inequalities (SDG 10), and promotion of sustainable cities and communities (SDG 11). Many hydrogen applications are not just about replacing conventional energy sources or feedstocks with clean hydrogen commodities, but also entail full technology switches or capital-intensive repurposing of assets (e.g., green steel production, ammonia and methanol use in the maritime transport, adoption of hydrogen fuel-cell electric vehicles). International cooperation can help in mitigating political friction that may arise from economy transformation and facilitate free trade.

Positive sustainable development co-benefit of green hydrogen infrastructure can be effectively realized through integration of engagement channels with local communities as mechanisms to help align project development outcomes with domestic needs. Highly capital-intensive in nature, the economic feasibility of green hydrogen projects remains grounded in collaborations, existence of subsidy schemes, potential for industry coupling, and blended finance solutions. International cooperation will be crucial to ensure the timely growth and level-playing field of the clean hydrogen market. While the potential of green hydrogen generation is high, the role of governments and public private partnerships to create the necessary nurturing conditions for these technology solutions to scale will be central to our ability to realize sustainable development outcomes.

[g] The production cost is calculated as LCOH (levelized cost of hydrogen), a metric accounting for all capital and operating production costs in the levelized manner over a unit produced hydrogen and its derivative ($/kg). The green and blue coloured areas represent the production cost distribution of 80% of clean hydrogen and its derivatives than can be produced in our outlook (solid lines representing the median). The cost of grey pure hydrogen directly accounts for detailed modelling assumptions, while the cost of grey hydrogen derivatives (ammonia, methanol and SAF) relies on average 2019 world market prices and increasing carbon price in line with the IEA's net-zero pathway.

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