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A man runs over rails to reach a regional hydrogen train in the station of Wehrheim, near Frankfurt, Germany, early Monday, Aug. 26, 2024. (AP Photo/Michael Probst)

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Stimulating Clean Hydrogen Demand: The Current Landscape

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Hydrogen is expected to play an important role in the global energy transition as a chemical feedstock and fuel; when produced with renewable energy, hydrogen offers a means of decarbonizing hard-to-abate industrial processes and the heavy transportation sector.[1] To support market growth, current hydrogen programs aim to expand clean[2] (also called "green") hydrogen production by providing substantial subsidies in the form of supply-side funding and tax incentives. In 2023, global public investments in clean hydrogen reached $308 billion, with the vast bulk of funding allocated to production-side support.[3]

While worldwide clean hydrogen production targets[4] reached 27-35 megatons (Mt) in 2023, demand targets have stalled at just 14 Mt.[5] This trend reflects regional asymmetries in production and demand uptake. Under current projections, demand for renewable hydrogen in Europe is expected to hit 8.5 Mt by 2030, far behind the region's planned 20 Mt of supply.[6] Similarly, although the passage of the United States' (U.S.) Inflation Reduction Act (IRA) in 2022 spurred an explosion of announced clean hydrogen projects, project offtake has lagged behind policy ambition. Supply-side incentives alone are insufficient to build robust markets for clean hydrogen; therefore, stakeholders must investigate additional demand-side innovation policies to facilitate market growth and development.

In the remainder of this brief, we summarize the hydrogen policy landscape in the United States and European Union (EU), concluding with an examination of the causes of demand-side stagnation in the clean hydrogen market.

U.S. Regulatory Landscape

U.S. federal policy support for clean hydrogen has primarily centered on tax credits and research, development, and demonstration (RD&D) programs. The 2021 Bipartisan Infrastructure Law (BIL), also known as the Infrastructure Investment and Jobs Act (IIJA), included nearly $20 billion in federal funding for hydrogen programs, including $8 billion for the creation of clean hydrogen hubs throughout the country, $8 billion for carbon capture, and $2 billion in electrolyzer manufacturing and R&D programs.[7] The seven regional hydrogen hubs are expected to produce upwards of 3 Mt of clean hydrogen each year while attracting over $40 billion in private investments.[8]

The 45V and 45Q tax clauses introduced in the 2022 IRA[9] extends generous tax incentives for companies investing in clean hydrogen production and associated infrastructure.[10] The 45V tax credit provides up to $3 per kilogram of clean hydrogen produced, agnostic to production method provided that its "greenhouse gas emissions intensity [is]...less than 0.45 kilograms per kilogram."[11] Valid for 10 years after a plant's construction, the 45V production tax credit (PTC) is "uncapped," as it applies to every kilogram of "qualified" hydrogen produced – regardless of volume. As a result, it is seen by many as the most competitive hydrogen-incentive scheme available in the world today. Additionally, the IRA extended the 45Q carbon-capture tax credit until 2026; this credit provides up to $50 per ton of CO_2 captured and stored,[12] thereby acting as an important fiscal incentive for grey[13] hydrogen producers to capture carbon from fossil-based hydrogen production methods (e.g., steam-methane reforming or auto-thermal reforming of natural gas or coal, etc.).

Similarly, many state governments are pursuing regulations that directly or indirectly promote hydrogen markets. For example, California's Zero-Emission Vehicle (ZEV) Mandate bans the sale of new internal combustion engine (ICE) vehicles in California by 2035.[14] This ban has the potential to accelerate the development of not only electric vehicles (EVs), but also hydrogen combustion vehicles and hydrogen fuel-cell electric vehicles (FCEVs). Spillover effects from such state-level regulations can influence standards throughout the country, thereby expanding deployment in other markets.

By 2050, clean hydrogen deployment could reduce U.S. carbon emissions by about 8%; to realize a cost-effective transition to net zero by that time, however, U.S. hydrogen demand would need to grow to almost 7 times current market size.[15] Unfortunately, demand growth barriers are myriad. Across the country, hydrogen projects have stalled due to the delay in rule clarifications for IRA tax credits and subsidies; furthermore, concerns regarding the longevity of the tax credits further disincentivize final investment decisions.[16] The Trump administration may alter incentive structures or pause funding allocation completely,[17] as President Trump campaigned on a promise "to rescind unspent money" from the IRA.[18]

Under President Biden, the federal government began to address hydrogen demand-growth challenges. In January 2024, the U.S. Department of Energy (DOE) announced the selection of a group of private partners to manage a demand-side support program aimed at "de-risk[ing] clean hydrogen projects and increase[ing] demand certainty."[19] The consortium (which includes the EFI Foundation and S&P Global and Intercontinental Exchange) aims to help expand demand-side support for hydrogen hub projects while improving relations between hydrogen producers and consumers.

European Union (EU) Regulatory Landscape

European hydrogen regulations have multiplied over the past five years. As the COVID-19 crisis intensified in June 2020, the European Commission developed a broad hydrogen strategy as part of a regional green-recovery plan; this strategy presented hydrogen investments as essential tools for facilitating both the energy transition and economic recovery.[20] Notable goals among the 20 sub-strategies include: ramping up investment in hydrogen; scaling up hydrogen production and deployment; designing comparable standards and a compatible infrastructure for the hydrogen economy; and facilitating international cooperation and hydrogen partnerships.[21]

Under pressure to respond to soaring gas prices and energy dependency on Russia, the EU passed the *REPowerEU Plan* in May 2022.[22] A direct response to European energy hardships, security concerns, and supply challenges following Russia's invasion of Ukraine, REPowerEU outlined energy savings strategies, expanded energy diversification, and increased renewable deployment. Under the plan, the

EU aims to produce 10 million tons and import 10 million tons of renewable hydrogen by 2030.[23] Total European hydrogen production capacity reached 11.2 Mt in 2023; however, conventional hydrogen production methods comprised 95.6% this capacity.[24] Total water electrolysis-produced hydrogen was 31 kt.[25] Some experts predict that the renewable hydrogen production target will require an estimated 14% of the region's total projected electricity consumption in 2030.[26]

Evolving trade regulations across the bloc are also impacting clean hydrogen strategies. The EU's Carbon Border Adjustment Mechanism (CBAM) was passed in April 2023 as part of the "Fit for 55" package, which aims to reduce the EU's greenhouse gas emissions by 55% by 2030.[27] The CBAM tariff price will be linked to EU Emissions Trading System (ETS) allowances. The policy will apply to iron, steel, cement, electricity, aluminum, fertilizer, and some downstream products – all of which play critical roles in building the systems and infrastructure necessary for the energy transition. If fully implemented, the CBAM will not only have significant implications on the EU's trade relations; it will also shape the carbon intensity of hydrogen, fertilizer, and ammonia production in neighboring countries.

The EU's hydrogen strategies are significantly behind schedule, with both the production and uptake of renewable hydrogen far below the region's aspirational targets. In 2022, hydrogen represented less than 2% of the region's energy consumption, 96% of which was natural-gas-based.[28] As of 2024, only 3.6% of European supply-side projects planned to open prior to 2030 reached final investment decisions or are operational.[29] Furthermore, while the EU strives to achieve 20 Mt of domestic hydrogen consumption by 2030, current quotas would achieve just 2-3.8 Mt.[30] Overall, 2030 low-carbon hydrogen production targets appear to be out of reach.

Challenges of Building Clean Hydrogen Demand

Despite expanded support for clean hydrogen producers over recent years, demand-side policy considerations remain nascent. The expanding gap between supply- and demand-side incentives complicates the development of a green hydrogen market, as there are insufficient buyers to scale the market, reduce prices, and achieve meaningful decarbonization goals. Accordingly, the International Energy Agency (IEA) has warned that hydrogen demand policies are insufficient to achieve long-term climate goals.[31] The challenges of scaling clean hydrogen demand include high costs, technological uncertainty, a lack of market signals, underdeveloped supply chains and infrastructure, and public distrust – as discussed below.

High Costs

High production and sales costs for clean hydrogen complicate demand expansion. As of 2023, both green ($4.50-$12.00/kg) and blue hydrogen ($1.80-$4.70/kg) cost more to produce than grey hydrogen ($0.98-$2.93/kg).[32] Genoese[33] highlights a vital challenge in reducing production costs within the present energy landscape: "Producing H_2 from steam reforming implies H_2 having a higher cost than natural gas; producing H_2 from water electrolysis implies H2 having a higher cost than electricity." As clean hydrogen prices remain higher than those of both electricity and natural gas, producers are disincentivized from synthesizing clean hydrogen. Therefore, both natural gas and renewable electricity costs would need to fall significantly to reduce production costs for clean hydrogen.[34]

Moreover, inflation has augmented both the financial and capital costs of low-carbon hydrogen production, with a 3% rise in capital costs potentially raising total project costs by almost one-third.[35] Storage and distribution costs introduce additional financial barriers.[36] Increased production costs discourage end-users from adopting clean hydrogen, as the switch would make their products and services more expensive and less cost competitive than their fossil-based equivalents.

Green hydrogen prices may[37] decline over the coming decade, if electrolyzer and renewable energy costs also fall.[38] These estimates further disincentivize present-day uptake, however, as end-users wish to avoid "long-term contracts that would effectively lock them into paying higher prices than they otherwise would."[39] Such challenges threaten the long-term financial viability of large-scale green hydrogen production and are difficult to overcome without significant demand-side incentives and policy stability.

Technological Considerations and Uncertainty

Legacy and prospective hydrogen consumers face unique challenges in transitioning to clean alternatives. About 2.5 million metric tons of hydrogen produced in the United States each year are a byproduct of industrial and/or chemical processes; such operations use the very hydrogen they produce.[40] Converting to clean hydrogen would require these firms to construct new infrastructure and develop new supply chains, thereby introducing novel costs, insecurities, and risks to their business models.[41] Certain fossil-fuel-intensive, hard-to-abate industries will also need to retrofit production equipment for hydrogen usage. For example, existing natural gas turbines and steel reheat furnaces must be retrofitted for green hydrogen in order to account for the element's higher burn temperature and lower flash point.[42] Few incentives exist, however, for downstream industries to offset the costs of developing new or retrofitting existing infrastructure to utilize clean hydrogen.

Furthermore, uncertainty around certain key end-use technologies hinders demand expansion. Examples that are being explored for commercial applications include hydrogen fuel cells for heavy-duty transportation; hydrogen blending in natural gas appliances, turbines, and pipelines; and hydrogen-based aviation fuels. For example, while low-percentage hydrogen blending is already occurring in some natural gas pipelines across the United States, hydrogen's unique thermodynamic properties raise concerns regarding pipeline cracking, potential leakages, and other infrastructural considerations.[43] These challenges must be addressed in order to increase blend percentages – and to improve public trust of the process. Long permitting times further complicate and disrupt uptake.[44] Demand-side support can help to provide the market certainty that both producers and end-users need during the early years of production to unlock private investment and break ground on large-scale projects.

Price Transparency and Market Signals

Endogenous information diffusion allows producing firms and consumers to learn by observing each other's behavior.[45] In new markets (such as the clean hydrogen market), early entrants face uncertainties with regard to product quality; however, each subsequent entry allows consumers to learn about the product and transfer their insights to other market actors, thereby shaping demand signals.[46] Learning occurs in stages, as evolving prices, R&D, and technology experience develops knowledge stock.[47] Inadequate price transparency currently hinders clean hydrogen demand growth, as bilateral offtake agreements do not inform external actors.[48] Early adopters provide insufficient price signals to future consumers, thus impeding the knowledge exchange necessary to spur demand, thereby creating additional demand-side risks.[49]

Some regional hydrogen markets have begun addressing these challenges. For example, the newly formed European Hydrogen Bank aims to connect suppliers with consumers while enhancing price transparency across the market. The Bank's first auction occurred from November 2023 to February 2024. Upon assessing 132 project bids, the Bank distributed almost €720 million to subsidize hydrogen production among 7 projects with bid prices between €0.37 and €0.48 per kilogram.[50] The issued funding will "help successful bidders to bridge the difference between their production costs and the price that their industrial consumers are willing to pay," according to the EU Directorate-General for Climate Action.[51] Furthermore, the Bank's forthcoming "pilot hydrogen mechanism" hopes to match producers and consumers while increasing price, demand, financial, and logistical transparency across the aisle.[52]

Supply Chains and Infrastructure

Building effective supply chains is crucial for market development; while expensive to develop, supply chains directly impact firm operations and, by extension, procurement decisions, including whether or not to employ clean hydrogen.[53] Green hydrogen storage and transportation infrastructure is costly, however, and will be slow to develop, with hydrogen pipelines potentially taking up to 12 years to design and construct.[54] Moreover, hydrogen infrastructure development involves numerous actors, projects, and regions, thereby presenting significant coordination challenges.[55] Furthermore, demand itself represents an important parameter of supply-chain design, as "the forecasted growth, seasonality," "geographic dispersion," and current market size inform supply-chain parameters.[56] These cyclical challenges are inherent to the green hydrogen market. Demand uncertainty increases project risk while deterring investors from critical supply-chain and infrastructure investments,[57] thereby hindering the means of demand expansion.

Lead-market development offers a partial solution to these challenges, as it would simultaneously expand green hydrogen consumption, scale hydrogen technologies, and mature the green hydrogen market in critical sectors.[58] Lead markets describe the countries or regions in which the "diffusion process of an innovation first takes off"; this local diffusion enhances the likelihood that the product will achieve global uptake.[59] Industrial and transportation sectors can serve as such lead markets.[60] For example, pipeline construction across Europe has signaled a willingness to import, transport, and consume hydrogen within the region.[61] Approved in October 2024, the 9,040 km pipeline network will provide 87 GW of output capacity by 2032, with the first lines coming online as early as 2025.[62] Such infrastructure expansion may signal foreign producers to scale green hydrogen production for export.

Public Acceptance of Hydrogen in the United States

Public acceptance is critical for scaling demand. Unfortunately, poor project transparency and insufficient public participation has threatened clean hydrogen projects across the United States. In Oregon, for example, local stakeholders demanded that utility company NW Natural halt a multi-year hydrogen/natural gas blending pilot project due to public health and emission concerns; a previous project was dissolved in 2022 due to a lack of community input and transparency.[63]

The Department of Energy's regional Hydrogen Hubs, including the Appalachian Regional Clean Hydrogen Hub (ARCH2) and the Mid-Atlantic Clean Hydrogen Hub (MACH2) face similar scrutiny.[64] Public interest groups, such as Earthjustice, have criticized the hubs' lack of community engagement (particularly with regards to potential adverse production externalities on local communities) and project transparency (particularly concerning planned safety measures to safeguard communities against pipeline leakages and potential explosions).[65] Public acceptance adds an additional element of uncertainty to green hydrogen demand expansion, as delayed projects and community criticism may deter end users from finalizing offtake agreements or publicly supporting market development.

Conclusion

In order to transition to green hydrogen, current hydrogen consumers will require 1) reduced prices for clean hydrogen, 2) production security (i.e. assurance that producers can consistently manufacture and deliver necessary clean hydrogen quantities), 3) reliable transportation systems, and 4) pipeline and storage infrastructure.[66] In addition, new end-users in speculative future hydrogen industries would also require assurance that hydrogen technologies are effective and dependable for their specific industrial processes and that choosing hydrogen technologies will not reduce their competitiveness within regional or global markets.

The systemic nature of these requirements highlights that supply-side incentives alone cannot ameliorate outstanding concerns and, thus, demand-side innovation policies are necessary to build robust markets for clean hydrogen. If unaddressed, insufficient demand-side policies risk not only pushing consumers towards impractical technologies, stranding assets, and wasting government funding, but also stunting nascent green hydrogen markets – to the detriment of industrial decarbonization progress. Additional research, pilot mechanisms, and experiments are required not only to determine the best policy mechanisms to bolster green hydrogen demand but also to support early adopters and reduce market-wide uncertainties.

About the Future of Hydrogen Project

The Future of Green Hydrogen project is a joint student, faculty, and staff research initiative assessing critical questions around future green and blue hydrogen markets. This is the first in a series of policy briefs exploring the importance, challenges, and policy considerations of augmenting clean hydrogen demand. The project is a joint initiative of the Environment and Natural Resources Program and the Science, Technology, and Public Policy Program at the Belfer Center for Science and International Affairs.

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