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Green or Blue: The Hydrogen Debate Heats Up.

May 08, 2024

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Introduction (I)

- Hydrogen is a key to decarbonizing the economy, but various pathways may significantly differ in environmental footprint and cost.

- When comparing the two, production costs, emission intensity, resource dependency, and policy impacts are observed to discern the two types of hydrogen.

Source: (IEA, 2021)

Introduction (II)

- For example, new production costs of green hydrogen range from $3 to $8 per kilogram depending on the location; blue hydrogen from natural gas can achieve typical costs of $2.00-3.50 per kilogram.

Source: (IEA, 2021)

Comparison Criteria (I)

- Emission Intensity: Blue hydrogen can lower emissions to 9-12 kg CO_2 per kg H_2 - but only if carbon capture works well.
- Production Costs: Green hydrogen: $3.00-8.00 per kg, Blue hydrogen: $2.00-3.50 per kg
- Policy Impact: Subsidies (e.g., EU €3.2 billion) are critical to competitiveness.

Source:IEA (2021), PwC (2022), GEP (2025), arXiv:2402.12211 (2025)

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Comparison Criteria (II)

- Resource Dependency: Green relies on renewable electricity; blue depends on natural gas.
- Government Role: Carbon taxes and subsidies shape the market (e.g., IRA in the US).
- Market Feasibility: Green hydrogen offers long-term potential, but blue hydrogen is viable in the short term.

Source: (IEA, 2021)

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Green Hydrogen: Electricity Cost Dependency

- The cost of producing green hydrogen directly correlates with the costs of renewable electricity. Green hydrogen's production cost depends significantly on regional electricity costs.
- Production costs range from $3 to $8 per kg depending on access to renewable resources.

Source: (IEA, 2021)

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Green Hydrogen: Technology Advancements (I)

- There is likely a continuous decline in the cost of electrolyzers to improve the competitiveness of green hydrogen by cutting down on the required initial capital.

- Electrolyzer costs could decrease by around 50% by 2030, potentially bringing green hydrogen production costs between €1 and €1.5 per kilogram in regions with renewable solid resources.

Source: (IEA, 2021) and (PwC, 2022)

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Green Hydrogen: Technology Advancements (II)

- This is due to projected electrolyzer cost reductions from \$600/kW today to approximately \$300/kW by 2030.

Source: (IEA, 2021) and (PwC, 2022)

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Green Hydrogen: Regional Cost Variability (I)

- On-grid systems are costlier because of the grid fees, although they are much closer to renewable sources than off-grid systems.
- Cost reductions could be contingent on increasing renewables and not incurring any grid fees by directly integrating renewables.

Source: (PwC, 2022)

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Green Hydrogen: Regional Cost Variability (II)

- By 2050, green hydrogen costs are expected to range between €1 and €1.5 per kilogram in areas with abundant renewables, while regions with fewer renewables may see costs above €2 per kilogram.

Source: (PwC, 2022)

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Green Hydrogen: Timeline to Cost Parity (I)

- Thus, to reach cost parity with blue hydrogen by 2035, the costs of renewable power must come down considerably.

- Technological developments and the scale-up of renewable systems worldwide will define green hydrogen's ability to achieve near-term cost competitiveness.

Source: (Ajanovic et al., 2022)

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Green Hydrogen: Timeline to Cost Parity (II)

- Policy-driven investments in infrastructure and renewable energy expansion are critical to accelerating this transition.

Source: (Ajanovic et al., 2022)

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Blue Hydrogen: Natural Gas Dependency

- The cost of blue hydrogen depends on the price of natural gas, which will increase after 2022. Production costs closely follow natural gas price \fluctuations.
- Lower gas prices make blue hydrogen competitive; high prices close its cost advantage over green hydrogen.
- Example: In the EU, $40/MWh natural gas increases blue hydrogen costs significantly

Source: (Kim et al., 2024)

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Blue Hydrogen:
CO2 Capture Requirements

- Blue hydrogen must achieve CO_2 capture rates of 90% or higher to remain competitive, particularly in regions with strict carbon policies.
- Low methane leakage, inexpensive natural gas, and advanced capture technologies improve economic feasibility.
- Long-term success requires robust policy backing for infrastructure and emission-reduction technologies.

Source: (Kim et al., 2024)

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Blue Hydrogen: Methane Leakage Impact

- One of the noticeable challenges associated with blue hydrogen is methane leakage, which raises questions about its cost advantages.
- It is ominous that low-leakage (<1%) operations are necessary in regions with high carbon prices to avoid losing competitiveness to green hydrogen, which is much less emissive.

Source: (Shell, 2022)

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Blue Hydrogen:
Policy Dependence

- This indicates that blue hydrogen technologies are viable only when there is a considerable level of subsidies or when the price of CO2 is relatively high enough to accommodate the high costs of emission.

- The sustainability of long-term competitiveness remains ambiguous without robust policy backing, especially in areas with high natural gas costs.

Source: (Noussan et al., 2020)

Future Competitiveness Factors

- Thus, the competitiveness of hydrogen is linked with the policies and measures related to emissions.
- Blue hydrogen may serve short-term needs where natural gas prices remain low.
- While cost remains an issue, green hydrogen's low-emission credentials may propel it as CO2 pricing and regulation rise.

Source: (PwC, 2022).

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Lifecycle Emissions: A Key Distinction (I)

- Blue hydrogen has more emissions per lifecycle, even with CO2 capture, since the production process involves the release of methane.

- Green hydrogen, made from renewable sources, is radically less carbon-intensive and, therefore, preferable as carbon-cutting measures become more stringent worldwide.

Source: (PwC, 2022).

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Lifecycle Emissions: A Key Distinction (II)

- Even though green hydrogen presents some environmental advantages, concerns about its scalability stem from its dependence on renewable energy and electrolyzers.

- Achieving cost reduction will require policy support, capacity addition in infrastructure with scale economies, and growth in renewable power capacity.

Source: (PwC, 2022).

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Challenges in scaling green hydrogen

- Even though green hydrogen presents some environmental advantages, concerns about its scalability stem from its dependence on renewable energy and electrolyzers.

- Achieving cost reduction will require policy support, capacity addition in infrastructure with scale economies, and growth in renewable power capacity.

Source: (Younas et al., 2022).

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Market Projections for Hydrogen Demand

- Worldwide hydrogen consumption is expected to rise in industries, transportation, and electricity generation.
- While blue hydrogen can provide immediate needs, the declining cost and creeping emission standards make green hydrogen the primary long-term solution.

Source: (Ajanovic et al., 2022).

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Investment Risks for Blue Hydrogen

- Risk factors exist in the case of blue hydrogen due to the reliance on natural gas prices and future regulations on CO2 emissions.
- Market speculations and increased focus on new green hydrogen production methods may hinder large-scale investments in blue hydrogen.

Source: (Younas et al., 2022).

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Advances in Hydrogen Production Technology (I)

- By 2023, SOEC and PEM electrolyzers had achieved Technology Readiness Levels (TRL) 8-9 and were nearing commercial deployment.
- Technological advancements enhance efficiency and reduce production costs for green and blue hydrogen.

Source: (Shell, 2022).

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Advances in Hydrogen Production Technology (II)

- Reduced material costs and innovations in electrolysis could significantly lower green hydrogen costs, driving its economic viability in the coming years.

Source: (Shell, 2022).

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Hydrogen and Policy: Further Discussion (I)

- Subsidies and CO2 pricing give hydrogen a competitive edge. Green hydrogen has support constructs such as renewable energy incentives, and blue hydrogen relies on CO2 capture incentives to offset emission costs.

- Political changes might quickly cause significant shifts in the market and investing behavior.

Source: (Khan et al., 2021).

Hydrogen and Policy: Further Discussion (II)

- As global focus on emission reduction increases, policy support for hydrogen could become an even more critical factor in future competitiveness.

Source: (Khan et al., 2021).

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Blue Hydrogen as a Bridge (I)

- Due to the availability of scarce green hydrogen, blue hydrogen can have a competitive advantage in the short run. However, establishing green hydrogen-producing plants at cheaper costs than other energy production sources and formulating strict emissions standards may attract and shorten the bridge period.

Source: (Shell, 2022).

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Blue Hydrogen as a Bridge (II)

- Regional energy prices and emission regulations largely dictate the transitional role of blue hydrogen.

Source: (Shell, 2022).

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Summary

- Blue hydrogen costs ~$2-$3.5/kg but depends on low methane leakage and stable natural gas prices.
- Green hydrogen costs ~$3-$8/kg; projected to reach ~$1-$2/kg by 2035 with renewable energy expansion.
- Policy measures such as CO_2 pricing and subsidies are important in shaping cost trajectories and attracting investments in both hydrogen types.

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