

GREEN HYDROGEN

Insights on Realizing its Inclusion and Impact in India





VALUE CHAIN OPTIMIZATION & COST REDUCTION

Achieving cost competitiveness is paramount for green hydrogen's widespread adoption in India. In this section, we examine critical aspects of value chain optimization, focusing on strategies to reduce transportation and distribution costs. We also explore the development and deployment of scalable, diverse storage solutions, which are essential for ensuring consistent supply and enhancing the economic viability of green hydrogen projects throughout the country.



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Achieving cost competitiveness is crucial for scaling green hydrogen across India's diverse sectors, including, industrial, mobility, and power. While the costs of electrolyzers and renewable power continue to fall, logistics, including storage, long-distance transport, and last-mile delivery, can account for a substantial portion of the final delivered hydrogen price, demanding equal attention. A crucial, yet complex, question for the green hydrogen sector is whether it is more economical to produce hydrogen near cheap renewable energy sources and transport it, to generate it closer to demand centres, or to find an optimal location somewhere in the middle. Answering this requires a careful cost-benefit analysis that considers the availability of renewable energy sources and the electricity prices at both the production and demand sites. Moreover, the design of the logistics chain critically depends on understanding how factors such as the transport route's length, the chosen mode of transportation, and storage methods collectively impact the overall cost, making these considerations paramount for achieving economical hydrogen.

Given the geographical disparity between renewable-rich states like Rajasthan, Gujarat, Tamil Nadu, Karnataka, and Maharashtra and the country's widespread demand, an optimized transportation strategy is essential. To encourage market development and identify sectors ready for scaled consumption, a focus on industries with high near-term demand potential is crucial. Refineries, ammonia/fertilizer plants, and steel/iron industry along with other mid-high energy intensive industries, in particular, are expected to be key demand centres by 2030, offering a foundation for creating a robust market. An optimized transportation strategy is crucial for a successful hydrogen economy. In many key industrial hubs, such as the refinery and fertilizer plants in Karnataka, chemical and fertilizer in Rajasthan, iron and steel clusters in Odisha, or the chemical, fertilizer, and export sectors in Maharashtra and Gujarat, local hydrogen generation using readily available solar resources could entirely bypass the need for long-distance transport. This localized approach is a highly effective way to minimize logistical costs and directly serve industrial demand clusters with green hydrogen.

The unique properties of hydrogen, such as its low density, flammability, and potential for leakage, boil-off, and material embrittlement, require specialized solutions.^{122,123} For long-distance transport, pipelines offer the most economical solution but demand significant capital investment.¹²⁴ Until such networks are widespread, specialized trucks and tanker ships, which carry hydrogen in compressed, cryogenic, or chemically-bound forms like ammonia, will remain vital, despite their higher costs and energy penalties. Similarly, a portfolio of storage solutions is needed to ensure a stable supply, especially given the intermittent nature of renewable energy. High-pressure gas tanks are a proven solution, though they are capital- and energy-intensive.¹²⁵ Other options include liquefaction, which increases density but carries a high energy cost and risk of boil-off, and chemical carriers like ammonia that provide a high-density, long-term storage option leveraging existing infrastructure. Additionally, underground salt caverns offer a low-cost, bulk storage solution where geology permits, providing a diverse set of options to balance cost, safety, and supply flexibility.¹²⁶

Pinpointing the single most cost-effective, long-term solution for these logistics remains challenging, as the ideal approach is heavily dependent on the hydrogen's final form and end-use application.¹²⁷ Therefore, the most viable strategy is a phased deployment that connects production hubs to demand centres through a multilayered approach, tailoring transportation and storage to the specific distance, volume, and end-use requirements of each project. Ultimately, a coordinated national plan that integrates these various technologies will be essential for building a robust and affordable green hydrogen economy in India.

Strategic Transportation & Distribution Cost Optimization

India's rising energy demand, robust renewable energy growth, and export ambitions call for a cohesive, future-ready infrastructure strategy. India must design a network that functions as the circulatory system of its green economy, where generation assets, transmission lines, pipelines, and ports serve as arteries delivering sustainable energy across regions and borders.

This strategy should integrate expansion of energy transmission, especially high-voltage direct current (HVDC), with modernization of natural gas networks and phased development of hydrogen, CO₂, ammonia, and methanol pipelines. Such comprehensive planning forms the backbone of a sustainable supply chain to maximize resource efficiency and reinforce India's global energy leadership.

Hydrogen blending in natural gas pipelines is under evaluation in Europe and India. However, hydrogen-induced cracking needs rigorous phased testing. Polymer pipelines or internal linings are globally being pursued as a safer alternative.

Government-industry partnership can establish integrated energy and storage corridors, combining HVDC lines and multi-product pipelines with connected storages. For example, Corridors from Rajasthan to North India and from Kutch to Saurashtra and South Gujarat can serve domestic and export markets, improve returns, and support multi-system, demand-driven hubs that produce and export green ammonia and methanol. Such efficient transport and storage systems can sharpen competitiveness under RFNBO emissions rules.

Achieving this vision requires regulatory foresight, legislative agility, and deployment of advanced technologies. Piloting new storage systems, evaluating commercial feasibility studies, and setting operational standards will enhance corridor flexibility.

KBC's Integrated Asset Modeling approach simulates thermodynamic and pressure-temperature conditions across energy and CO₂ value chains.¹²⁸ With such vision, integrated hydrogen value chain projects could reduce CapEx and OpEx projects by 30-70% while Bringing Decarbonization to Life® at scale.

Developing Scalable & Diverse Storage Solutions

India's hydrogen economy demands a storage portfolio as precise, predictable, and resilient as a high-performance supply chain, one tailored to fit generation hubs, energy corridors, and growing industrial hubs. A one-size-fits-all approach won't suffice; flexibility fuels the future of hydrogen.

Among the most immediate and accessible solutions is gaseous hydrogen, stored at 350–700 bar, is well-suited for short-term buffering but is limited in scale and very high in CapEx and OpEx.¹²⁹ Gaseous hydrogen in pipelines or blended in natural gas pipelines can be more scalable and cost effective, as it plays a dual role of strategic storage and transport.

For higher energy density and export potential, liquid hydrogen offers higher energy density, but liquefaction consumes about 30% of hydrogen's energy content.¹³⁰ Managing boil-off burdens, cryogenic challenges, and thermal threats demand advanced modeling, especially for industrial end users and export hubs.

Chemical carriers like ammonia offer an alternative. Ammonia excels in seasonal storage and long-distance transport. Its hydrogen density and handling familiarity make it attractive, but cracking for reconversion remains energy- and capital-intensive.

For long-duration, geological-scale storage, underground storage in salt caverns can be explored for long-term storage at competitive cost. However, India's geological constraints with limited salt dome formation pose a challenge to scaling this solution.¹³¹

Together, these technologies support a layered strategy, piped gas for daily demand, ammonia for monthly balancing, and underground reserves for seasonal or strategic stockpiling, can secure supply, stabilize markets, and cost control. Co-location and multi-system design across the hydrogen value chain is essential to improve system economics.

To accelerate this evolution, KBC supports these strategies via modeling and asset optimization as well as aligning infrastructure investments with policy objectives and demand trajectories across India's hydrogen value chain while Bringing Decarbonization to Life®.

