

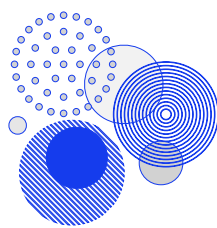
ADVANCED MATERIAL IN HYDROGEN STORAGE & TRANSPORT – UNLOCKING A \$200B+ GLOBAL OPPORTUNITY & INDIA'S STRATEGIC ROLE

Strategic assessment of the \$200B global market in hydrogen storage materials, with India's \$25B opportunity in technology, policy, and manufacturing.

KEY QUERIES ANSWERED

- What are key materials for hydrogen storage and transport?
- How big is the global and Indian market opportunity for H₂ storage material by 2040?
- How can India capture a \$25B hydrogen materials opportunity?
- Which global best practices can India adopt and localize?





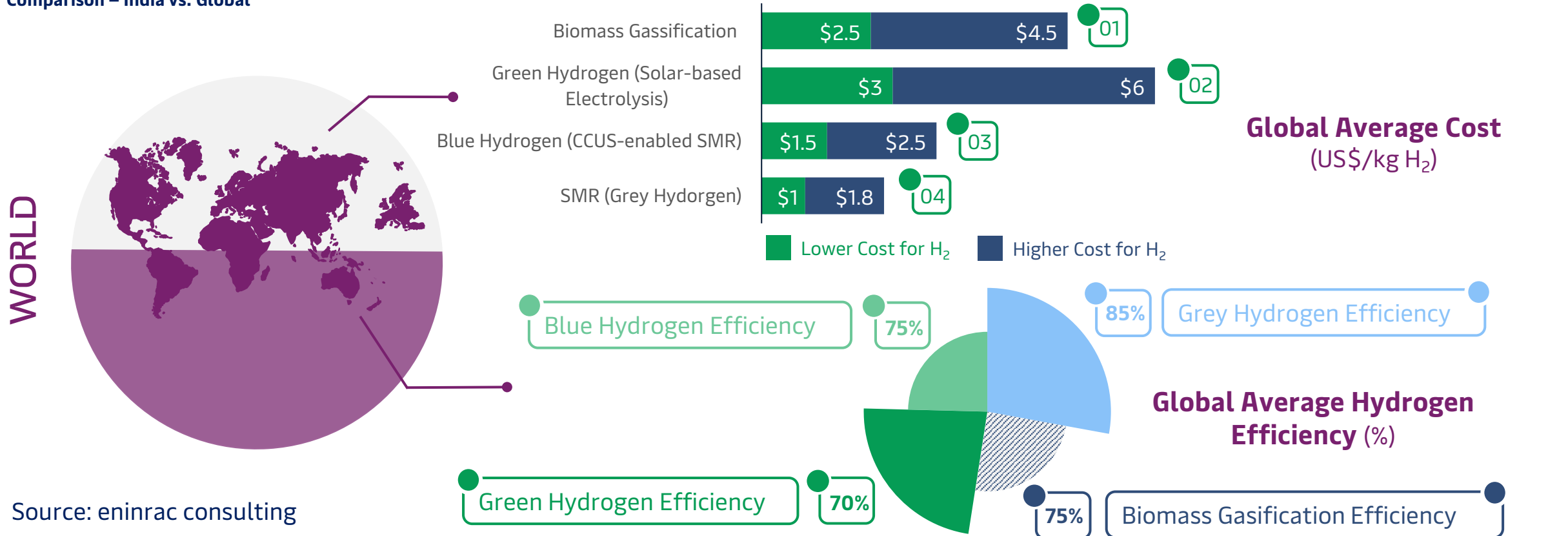
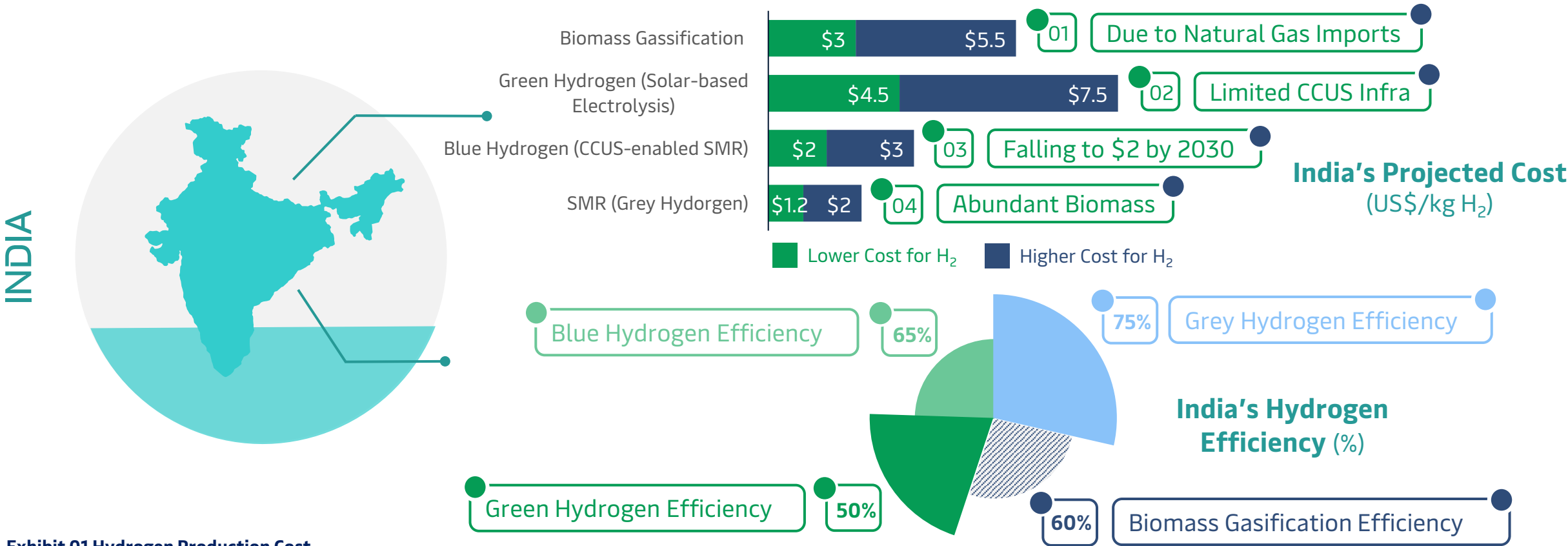
Why is Eninrac's market research report on advanced materials for hydrogen storage and transport essential for decoding a \$200Bn+ global opportunity and mapping India's manufacturing, R&D, and deployment potential across high-impact hydrogen value chain segments?

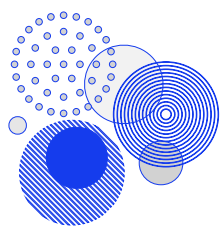
Will India's hydrogen production cost competitiveness unlock global market opportunities or remain limited by infrastructure and feedstock constraints?

Why is a comprehensive assessment of hydrogen production cost competitiveness critical to unlocking India's global market potential—spanning green hydrogen exports, industrial decarbonization, and domestic mobility, while informing strategic decisions for public sector undertakings, private developers, electrolyzer OEMs, and infrastructure planners?

Hydrogen production costs and efficiencies vary widely by method and geography. In India, reliance on imported natural gas raises the cost of grey and blue hydrogen compared to global averages. While green hydrogen remains costlier today, aggressive renewables expansion and policy support are **expected to bring costs down to ~\$2/kg by 2030**. Biomass gasification, leveraging India's agricultural residue, offers a promising decentralized route. This comparative analysis highlights how India's hydrogen strategy must balance technology maturity, **feedstock availability, and infrastructure readiness to realize its green hydrogen ambitions**.

Further, aligning cost competitiveness with global benchmarks is essential for India to emerge as a key hydrogen exporter. Electrolyzer localization, viability gap funding, and scale-driven cost reductions will be crucial. Strategic production clusters near RE zones, ports, and industrial hubs can enhance economics. Policy clarity and cross-sectoral coordination will determine India's pace in **capturing its share of the \$100B+ global green hydrogen trade opportunity**. Moreover, regional production incentives, **carbon pricing mechanisms, and renewable energy banking policies will shape investor confidence**. India's ability to integrate hydrogen into refining, fertilizer, steel, and mobility sectors will directly influence demand scaling. The convergence of public-private capital, innovation ecosystems, and strategic international partnerships will define India's leadership in the hydrogen economy.



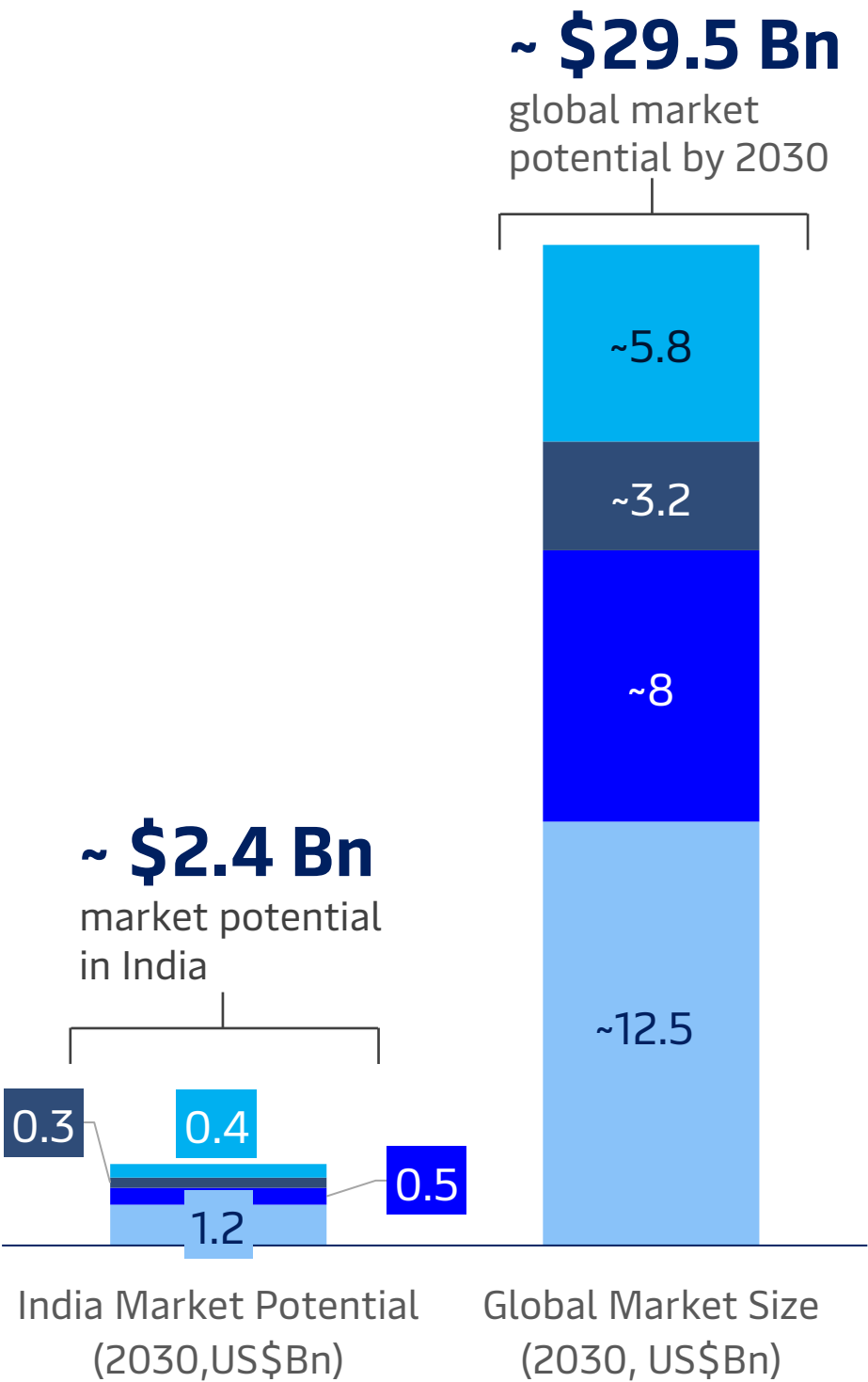


How Are Global and Indian Hydrogen Storage Trends Shaping Up? Insights by Eninrac Analysts

Understanding hydrogen storage trends is key to building a robust hydrogen economy. Eninrac analysts assess emerging technologies—like compressed gas, cryogenic liquid, hydrides, and LOHCs—highlighting their market potential, efficiency, and material challenges. With India targeting leadership in green hydrogen, decoding storage economics and readiness becomes vital for OEMs, policymakers, and investors eyeing a share in the \$30B+ global opportunity.

Hydrogen storage remains a critical enabler for realizing the hydrogen economy—impacting transport, distribution, and end-use efficiency. As per Eninrac’s market intelligence, the global hydrogen storage market is poised to cross **\$30 billion by 2030, with India contributing an estimated \$2.4 billion**, led by compressed gas and emerging cryogenic solutions.

Compressed **hydrogen gas storage (350–700 bar) continues to dominate early deployments, but its low energy density (1.2–1.5 kWh/kg)** and energy-intensive compression present safety and cost trade-offs. India’s share in this segment is projected **at \$1.2 billion**, driven by mobility and backup power applications. However, advanced Type IV tank materials and improved valve technologies remain critical to cost optimization. In parallel, liquid hydrogen (LH2) offers higher energy **density (2.3–2.8 kWh/kg), yet faces challenges of ~1% daily boil-off losses**, impacting viability in long-haul and maritime use cases. Eninrac analysts note India’s **LH₂ potential at \$0.5 billion, backed by ISRO’s legacy and recent public-private interest**. **Metal hydrides (e.g., MgH₂)** and Liquid Organic Hydrogen Carriers (LOHCs) are gaining traction in R&D and pilot phases. While their energy densities range from 1.5 to 2.2 kWh/kg, their limitations—such as slow kinetics for hydrides and high regeneration temperatures for LOHCs—require further breakthroughs.



Source: eninrac consulting, DOE, Hydrogen Council

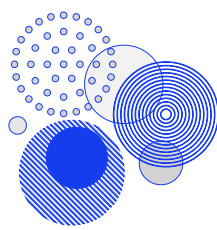
Exhibit 02 Hydrogen Storage Technologies – Market Readiness & Adoption (Global vs. India)

| Storage Methods for Hydrogen | Key Challenges | | Energy Density (kWh/kg) |
|------------------------------|------------------------------|--------------------------------|-------------------------|
| | LOHCs (Toluene/MCH) | High energy loss, safety risks | 1.2-1.5 |
| | Metal Hydrides (Mg-based) | High boil-off losses (~1%/day) | 2.3-2.8 |
| | Liquid Hydrogen Cryogenic | Slow absorption kinetics | 2.3-2.8 |
| | Compressed Gas (300-700 bar) | High de-hydrogenation temps | 1.7-2.2 |



Key Insights for India

- Compressed gas storage leads due to existing infrastructure (e.g., IOCL’s pilot projects)
- LOHCs & metal hydrides are in early R&D phase (IITs, CSIR labs working on materials)
- Liquid H₂ adoption is low due to high costs and lack of cryogenic logistics.



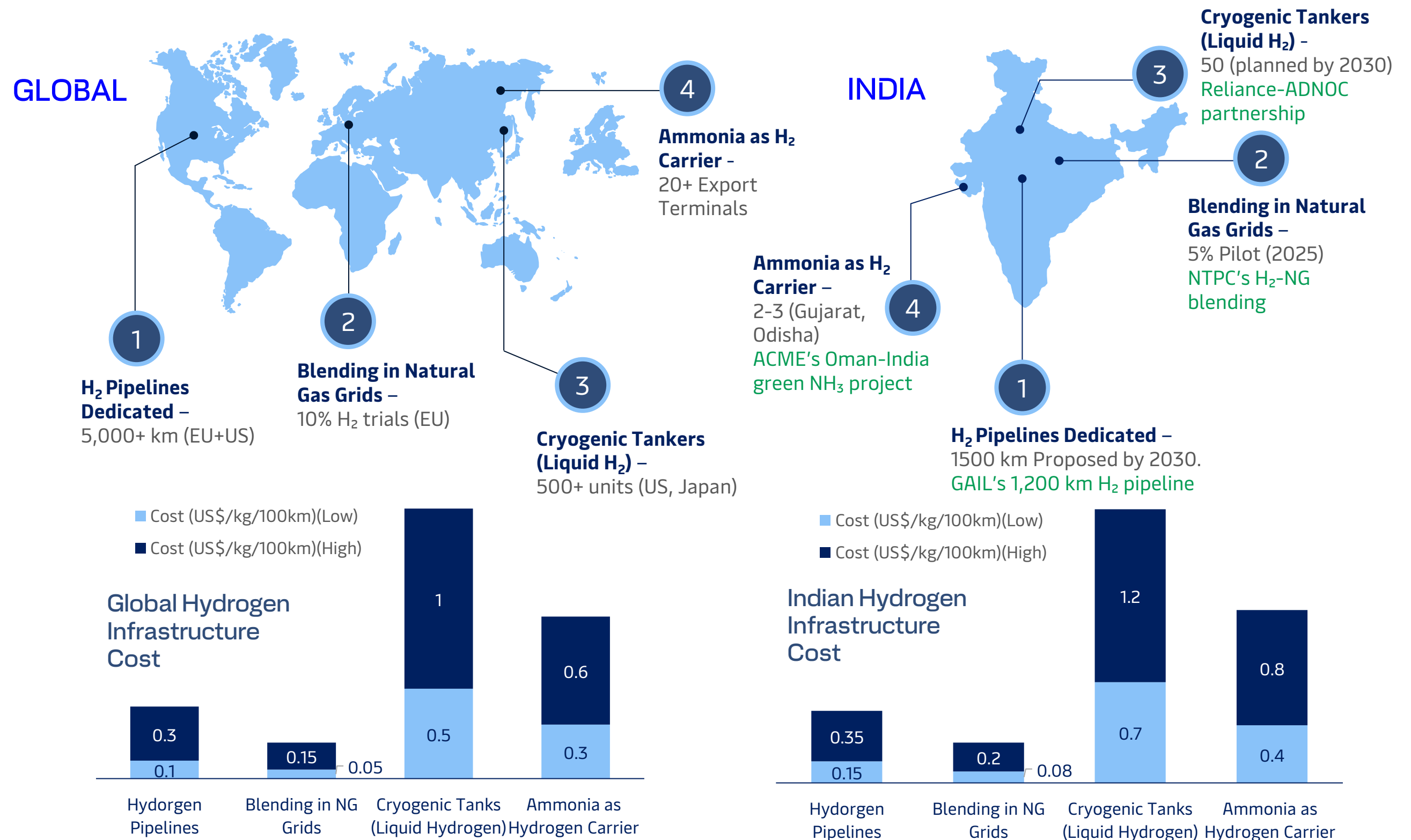
Team Eninrac's assessment underscores that a **diversified storage portfolio**, tailored by application (stationary, mobility, maritime) and **aligned with material science innovations**, will be vital to India's competitive positioning in the \$200B+ global hydrogen value chain.

How Does India's Hydrogen Transportation Infrastructure Compare with Global Benchmarks?

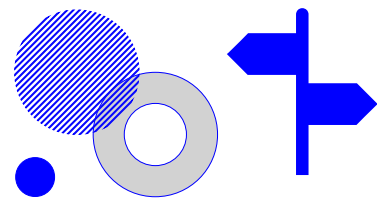
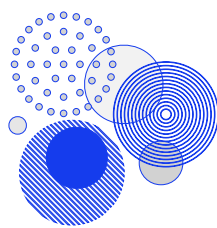
India's hydrogen transportation infrastructure is gradually aligning with global benchmarks. **Eninrac's market research reveals that while the EU and U.S. lead with 5,000+ km of dedicated hydrogen pipelines, India is targeting 1,500 km by 2030 led by GAIL's 1,200 km project.** Blending hydrogen into natural gas grids is also gaining traction, with NTPC spearheading 5% pilot programs. On the cryogenic front, India plans 50+ liquid hydrogen tankers, compared to 500+ globally. Meanwhile, green ammonia is emerging as a viable export carrier, with terminals in Gujarat and Odisha planned by 2030. As India builds out this logistics backbone, infrastructure investments will be pivotal in unlocking cost-efficient hydrogen delivery.

Eninrac analysts highlight that transport mode selection must balance cost, scalability, and technological maturity. While pipelines offer long-term economic advantages for bulk transport, blending remains a quick-start solution for early market activation. Cryogenic and ammonia-based routes will likely dominate export-oriented strategies, especially with Reliance, ACME, and Greenko actively pursuing partnerships. The development of standards, right-of-way frameworks, and carrier-specific safety protocols will be vital. India's success in this space will hinge on synchronized action between public utilities, private developers, and regulatory bodies under the National Green Hydrogen Mission. Furthermore, leveraging India's existing gas infrastructure for low-blend hydrogen integration could reduce near-term CAPEX and fast-track regional hydrogen hubs. Eninrac analysts also emphasize the importance of indigenizing tanker manufacturing and developing specialized port infrastructure to handle ammonia and liquid hydrogen safely. As global hydrogen trade corridors evolve, India's proactive alignment with international codes and certification standards will be crucial for market access and competitiveness.

Exhibit 03 Hydrogen Transportation – Global Vs. India Infrastructure Status



Source: eninrac consulting, IEA, Shell, Wood Mackenzie



Key Signpost – Why Advanced Materials Will Be the Game-Changer in Hydrogen Storage & Transport for India’s \$200B Clean Energy Play?

Lightweight, Efficient, and Future-Ready – Advanced Materials to Redefine Hydrogen Storage & Transport in India’s \$200B Green Energy Push

Advanced Materials for Hydrogen Storage & Transport represent a next-gen innovation critical to resolving **India’s clean energy trilemma enabling secure, scalable, and efficient hydrogen systems**. With high energy densities, modular applications, and growing R&D traction, these technologies are pivotal for accelerating India’s green hydrogen economy and global export ambitions.



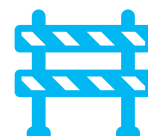
For Developers

- **First-mover advantage in a rapidly evolving market** backed by the National Green Hydrogen Mission and ‘Make in India’ manufacturing schemes.
- **Greenfield opportunities** to develop integrated hydrogen ecosystems (e.g., mobility corridors, industrial clusters, export terminals) leveraging advanced storage and transport materials.
- **Technology localization potential** by partnering with global material innovators to **co-develop cost-effective**, application-specific solutions for Indian conditions.



For Material Innovators & R&D Institutions

- **Strong IP opportunity** in developing next-gen composites (carbon fiber, MOFs, hydrides, aerogels, LOHC materials) tailored for Indian climate and use cases.
- Government and corporate R&D funding available through **MNRE, DST, and Mission Innovation partnerships**.



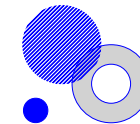
For Developers

- **Design and construct India’s emerging hydrogen transport backbone** – pipelines, cryogenic storage, terminals, and port-linked infra
- **New business lines in carrier-specific systems** (ammonia cracking, LOHC dehydrogenation) and cryogenic insulation solutions
- **Opportunity to build capabilities** in retrofitting existing gas infra for hydrogen compatibility (blending, sealing, coatings).



For OEMs

- **Scale domestic production of Type III/IV tanks**, cryogenic containers, MLI systems, and composite pressure vessels.
- **Access PLI schemes** for advanced materials manufacturing including carbon fiber, resins, and superalloys
- **Import substitution potential for high-value components** such as valves, liners, insulation, and hydrogen-rated sensors.
- **Global export prospects** by aligning with ISO/IEC standards and becoming part of clean hydrogen trade supply chains.



Must Buy For

- Green Hydrogen & Ammonia Project Developers
- Cryogenic & High-Pressure Storage System Manufacturers
- Pipeline & Hydrogen Logistics Infrastructure Developers
- Chemical Carrier Technology Providers (Ammonia, LOHC, Methanol)
- Composite Material Producers (Carbon Fiber, Resins, Liners)
- Solid-State Storage Material Innovators (Hydrides, MOFs, Graphene)
- Engineering, Procurement & Construction (EPC) Firms
- Port Authorities & Export Infrastructure Operators
- Public Utilities & Oil & Gas Majors (IOCL, GAIL, NTPC)
- Climate & Energy Transition Funds / Impact Investors



For Queries

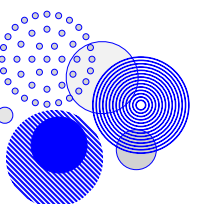
Research : Write to: connect@eninrac.com and alternatively you may reach our team at nsharma@eninrac.com

Please call at +91 93190 48963/93190 47963 for any other queries



Companies Mentioned

- L&T
- Walchandnagar Industries Limited
- Godrej & Boyce
- BHEL
- TATA Advanced Materials
- Artson Engineering
- Vijay Tanks
- Reliance Industries
- Adani New Industries Limited
- NTPC,
- IOCL
- ACME
- Greenko
- GHCL
- Praj Industries
- Grasim Industries
- BIS
- MNRE, India
- NITI Aayog
- CSIR
- TERI



“Discovery consists of seeing what everybody has seen and thinking what nobody has thought

- Arthur Schopenhauer

About Eninrac

Eninrac Consulting is a global market research and advisory firm that specializes in providing comprehensive insights and strategic solutions across various industries. Our services are designed to help businesses navigate market complexities, identify growth opportunities, and achieve sustainable success.

Eninrac's USP lies in its ability to deliver pragmatic, data-driven solutions tailored to the unique needs of each client. By maintaining close collaboration and adopting a hands-on approach, they ensure that their insights are actionable and aligned with clients' strategic objectives. This personalized guidance through diverse markets and cultures sets them apart in the consulting landscape. By leveraging the services offered, Eninrac Consulting empowers businesses to improve processes, understand customers, and solve problems effectively, thereby driving growth and maintaining a competitive edge in their respective industries.

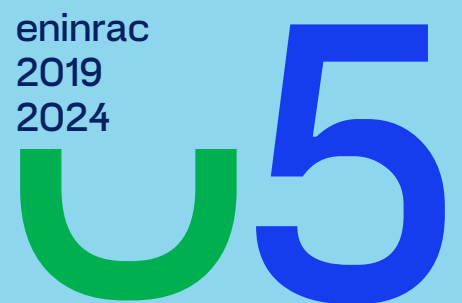
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2024 marks our 5th anniversary as a performance leader, delivering superior research and advisory services.