HYDROGEN INDIA

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Editorial

India's green hydrogen journey has been marked by ambitious goals and growing investments in renewable energy sources like solar and wind, aiming to position the country as a global leader in the clean energy transition. The government-launched National Green Hydrogen Mission (NGHM) in January 2023, focuses on boosting the production of green hydrogen, decarbonizing heavy industries, and enhancing energy security. Although national and international players have initiated several pilot projects and collaborations, major development at the project level remains elusive.

Scaling indigenous deep-tech electrolysers, fuel cells, and storage systems remains challenging. India's reliance on imports, particularly from China, which controls over 70% of global electrolyser manufacturing, exposes it to supply chain risks and price volatility. A September 2024 Council on Energy, Environment and Water (CEEW) report highlights that over 80% of rare earth element (REE) processing and 50% of nickel processing are concentrated in China and Indonesia, underscoring the urgency for resilient domestic supply chains.

A recent workshop at IIT Madras focused on two critical questions: How can India foster indigenous innovation? And how can promising technologies at Technology Readiness Levels (TRL) 3–5 scale to commercial viability? The workshop revealed five interconnected barriers preventing India from translating its R&D pipeline into market-ready solutions, each demanding urgent action. The key recommendation is a government-anchored, multi-stakeholder platform to accelerate commercial deployment of indigenous hydrogen technologies, as outlined within.

A study by RMI in July 2025, attempted to provide a detailed understanding of the dynamics of green hydrogen—to unpack cost economics, key project development considerations, and project risks, offering insights into India's evolving landscape at the national and state levels. It examines 17 distinct project locations across 17 states. The study assesses convergence driven by national-level policies as well as local divergences resulting from state-specific renewable potential and policy support. A summary of this study has been provided in this issue.

On a positive note, we have also covered TKIL Industries' strategic and exclusive partnership with SoHHytec SA, a Swiss deep-tech company, which has pioneered a proprietary artificial photosynthesis technology that combines concentrated solar power (CSP) and photovoltaics to produce hydrogen, oxygen, and thermal energy from a single integrated unit.

Hydrogen can also be applied across various stages of steel production, including agglomeration, blast furnace operations, DRI processes, and downstream activities, such as reheating and galvanizing. While partial hydrogen blends have already been successfully demonstrated, full hydrogen adoption is still under exploration. Despite challenges like feedstock availability and infrastructure requirements, technological advancements and supportive policy frameworks are facilitating a move toward a greener future for steel production. This April 2025 report has been prepared by WWF-India with research and inputs from EY Parthenon.

As announced in August 2025, India has initiated the construction of its first green hydrogen-powered ships, a significant move

CONTENTS

towards sustainable maritime transportation. The oil marketing companies are also moving ahead. Abu Dhabi-based renewable hydrogen project developer, Ocior Energy, has won a tender issued by state-owned refiner Hindustan Petroleum Corporation Limited (HPCL) for a 5,000 mt/year renewable hydrogen plant to be set up at its Visakh refinery, quoting a price of $3.82/kg for the fuel. The price is the lowest known in India so far, following Indian Oil Corporation's 10,000 mt/year tender that was secured by L&T in May 2025 at $4.65/kg including taxes. We will cover these details next quarter.

Hydrogen's role in Sustainable Aviation Fuel (SAF) production for India's aviation sector has also grown rapidly over the past decade, with domestic passenger numbers increasing from around 50 million in 2010 to approximately 230 million in 20241. To address the sector's rising emissions, the Ministry of Petroleum & Natural Gas, Government of India, set an indicative target of blending 1% SAF in Aviation Turbine Fuel (ATF) by 2027, increasing to 2% by 2028 and 5% by 2030 for international flights. While modest compared to the European Union (EU)'s ReFuelEU mandate (2% by 2025, 20% by 2035), this step is ambitious in India's context, translating into around 140 million liters (112 kilo tons) of SAF annually. Meeting even India's initial target will require a rapid scale-up in SAF production, but the availability of sustainable feedstocks remains a critical bottleneck.

AresTempoH_2™, a membrane-free, decoupled electrolyser that separates hydrogen and oxygen production in time and space, is an indigenous, IP-protected electrolyser technology backed by IIT Ropar and IIT Gandhinagar. Its modular, efficient, and durable design minimizes dependence on imported membranes and critical metals, addressing India's need to avoid mineral dependence while enabling local production at scale. A detailed description has been provided this time.

India's fertilizer industry, consuming 17–19 million tons of ammonia annually, is undergoing a transformative shift with the adoption of green ammonia under the NGHM. In August 2025, the Solar Energy Corporation of India (SECI) announced a record-low price of ₹49.75 per kg ($569 per MT) for green ammonia under the Strategic Interventions for Green Hydrogen Transition (SIGHT) program, a significant drop from the 2024 H2Global auction's ₹100.28 per kg ($1,153 per MT). This milestone promises to reduce India's reliance on imported ammonia by 30% (~720,000 tons per annum). An article examines the price discovery, auction winners, cost drivers, broader implications, including import substitution, export potential, market development, and associated risks and mitigants, along with a detailed table of the auction winners.

As we continue to bring you updates in the green hydrogen space, the Cogeneration Association of India (Cogen India) is poised at the right junction to assist industry to achieve their maximum potential. We look forward to your feedback to make this newsletter more useful to our readers, and hope all stakeholders will join us as members to take this "Green Revolution" forward. ■

India's Ministry of New and Renewable Energy (MNRE) held an extensive conference and exhibition on 'Green Hydrogen Research & Development (R&D)' in New Delhi during 11-12 September 2025. The first day saw the launch of the call for proposals for the 'Scheme Supporting New and Innovative Production Techniques and Applications of Green Hydrogen (Start-ups)' by Union Minister of New and Renewable Energy and of Consumer Affairs, Food and Public Distribution, Shri Pralhad Joshi. This new ₹100 crore scheme will provide up to ₹5 crore per project for pilot projects in innovative hydrogen production, storage, transport and utilization technologies. At the expo, 25 start-ups showcased their innovations, ranging from electrolyser manufacturing, to AI-driven optimisation and biological hydrogen solutions. The panel discussions are expected to provide clearer near-, medium- and long-term strategies. In addition, the second round of R&D proposals, launched on 14 July 2025, remains open till 15 September 2025. Further details are on pages 12-13.

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Green Hydrogen Achievements & Future Plans for India

By Suresh Agasti, Head – Green Hydrogen and Derivatives Business, TKIL Industries

A Decarbonization Imperative

In the current decade, the world stands at an energy crossroads. The global climate challenge demands nothing short of an industrial transformation—one that shifts our dependence from carbon-intensive fuels to clean, renewable, and sustainable alternatives. Among the emerging solutions, **green hydrogen** is gaining unparalleled attention for its ability to decarbonize industries where carbon reduction is hard to abate.

At **TKIL Industries**, we recognized early that green hydrogen would not be a passing trend, but a structural pillar of the low-carbon economy. Our decision to enter the green hydrogen space was not driven by short-term market opportunities alone—it was a strategic choice grounded in our engineering heritage, our diversification into sustainable business lines, and our alignment with national and global climate goals.

Rationale for Entering the Green Hydrogen Space

India's **National Green Hydrogen Mission (NGHM)** sets ambitious targets: producing 5 million tons of green hydrogen annually by 2030, export opportunities of additional 5 million tons, and positioning India as a global hub for hydrogen production and export. The Mission aligns perfectly with TKIL's ethos—leveraging advanced technology to create solutions that are **both commercially viable and environmentally transformative**.

Our experience in complex industrial systems—ranging from cement plants and sugar mills to energy and water treatment facilities—has given us a unique platform to integrate green hydrogen solutions into existing industrial infrastructure. We see our role as both a **technology enabler** and a **market catalyst**, building ecosystems for adoption in hard-to-abate sectors like steel, fertilizers, cement, chemicals, and heavy-duty transportation.

Partnership with SoHHytec: A Technological Edge

A critical milestone in TKIL's green hydrogen journey was our **strategic and exclusive partnership with SoHHytec SA**, a Swiss deep-tech company. SoHHytec has pioneered a proprietary **artificial photosynthesis** technology that combines concentrated solar power (CSP) and photovoltaics to produce hydrogen, oxygen, and thermal energy from a single integrated unit.

What makes this partnership transformative is **efficiency and scalability**. Unlike conventional PV-electrolyzer combinations, SoHHytec's system captures and utilizes both **electricity and thermal energy**, delivering one of the lowest projected Levelized Costs of Hydrogen (LCOH) globally. This allows for competitive economics even at relatively larger project scales—a crucial advantage for industrial customers seeking early adoption as well as looking for a mega-scale investments in the next few years.

For TKIL, the exclusivity of this partnership in India means we can **localize manufacturing**, adapt the technology to Indian climatic and industrial conditions, and offer integrated solutions from concept to commissioning.

Achievements to Date: Building Foundations

While the green hydrogen sector in India is still nascent, TKIL has already made tangible progress in three key areas:

1. Technology Validation

We have successfully completed feasibility studies for multiple industrial clients, assessing integration possibilities of SoHHytec's system into **steel plants, refineries, and chemical complexes**. Early simulations indicate we can achieve **production costs competitive with grey hydrogen**—even before factoring in carbon taxes or incentives.

2. Pilot Project Pipeline

TKIL, along with SoHHytec, is in the advanced planning stage for its **first pilot installation** in India, targeted for completion in 2026. This will be a **demonstration plant** producing green hydrogen for an industrial offtaker, with integrated storage and potential for hydrogen-based mobility trials.

3. Supply Chain Engagement

We have initiated partnerships with Indian micro, small and

medium enterprises (MSMEs) for **fabrication of key balance-of-plant (BoP) components**, including pressure vessels, piping skids, and automation modules. These collaborations not only support "Make in India" but also shorten lead times and improve cost competitiveness.

Creating a Localized Green Hydrogen Supply Chain

For green hydrogen to succeed in India, **localization is not optional—it is essential**. TKIL's roadmap for an indigenous supply chain covers two critical segments:

1. **Solar Concentrator Systems** – Engineering and fabricating CSP mirrors, support structures, and tracking systems domestically.
2. **BoP Manufacturing** – Developing India's supply chain and manufacturing of various components related to BoP.

Our end goal is to **reduce dependence on imports from over 50% today to below 30% by 2030**.

Integrating Solar with Hydrogen Electrolysers

SoHHytec's technology is unique in its ability to harness **both thermal and electrical outputs** from concentrated solar energy. In conventional setups, excess heat is often wasted. Our system channels that thermal energy for industrial heating, absorption cooling, or to boost electrolysis efficiency. The result is a **hybrid plant** capable of supplying multiple energy vectors—**hydrogen, oxygen, heat, and even fresh water**—from a single solar installation.

This integration is particularly valuable in **energy-intensive process industries**, where both hydrogen and heat are required. It also allows for **higher capacity utilization**, reducing the effective cost per kilogram of hydrogen produced.

Investment Outlook & Commercial Timeline

TKIL's green hydrogen investments are being rolled out in **three phases**:

- **Phase 1 (2024–26):** Pilot deployments, technology localization, and building in-house EPC capabilities.
- **Phase 2 (2026–28):** Scaling to multiple commercial plants in partnership with industrial offtakers.
- **Phase 3 (2028–30):** Full-scale manufacturing of BoP and solar concentrators in India, export opportunities to the Middle East, Asia, and Europe.

This will require significant investment in manufacturing as well as certain projects on development basis to support up to 100 MW projects by 2026.

Government Policy & Industry Ecosystem

The **NGHM** is providing a strong initial push—offering incentives for both electrolyzer manufacturing and hydrogen production. These measures are crucial for early adoption, but for deep localization, additional steps are needed:

- Long-term **offtake guarantees** from public and private sectors
- Establish export hubs with grants and support
- Reduced **GST rates** for hydrogen equipment
- Accelerated **permitting for hydrogen infrastructure**
- Establishment of **hydrogen hubs** with shared logistics and refuelling stations

The government's role will also be vital in **standardizing safety protocols** and facilitating **cross-sector collaborations** between power producers, industrial users, and mobility players.

Challenges Ahead

Technical and Economic: The most pressing challenge remains **cost parity** with grey hydrogen. While renewable energy prices in India are among the lowest globally, electrolyzer costs remain high. Our approach—through hybrid solar utilization and localization—is directly aimed at narrowing this gap.

Transportation and Storage: Hydrogen's low volumetric energy density makes transport expensive. Our strategy emphasizes **on-site or near-site hydrogen generation** to minimize logistics costs, complemented by regional hydrogen hubs for wider distribution.

Demand Aggregation: Industries often hesitate to commit to long-term offtake agreements for an emerging fuel. Building confidence through pilots, reliability guarantees, and competitive pricing will be essential.

Early Adoption Sectors & Mobility Potential

The most likely **early adopters** in India will be:

- **Refineries** (hydrotreating and desulphurization)
- **Fertilizers** (ammonia production)

- **Steel** (direct reduced iron processes)
- **Chemical manufacturing** (methanol, synthetic fuels)

On mobility, hydrogen has strong potential in **heavy-duty trucking, buses, and rail** segments, where batteries face limitations in range and refuelling time. TKIL is actively exploring partnerships for **hydrogen refuelling stations** to serve both industrial and mobility customers.

Is Green Hydrogen Cost-Effective?

Today, green hydrogen costs 2–3 times more than grey hydrogen in India. But history is instructive—solar PV was once several times more expensive than coal-based power. In a decade, it became the cheapest electricity source. We expect a similar trajectory for green hydrogen, driven by:

- Falling electrolyzer costs
- Scaling of manufacturing
- Improved plant load factors via hybrid energy inputs
- Policy incentives and carbon pricing

Our internal modelling suggests that by **2028–30**, green hydrogen will be competitive in multiple industrial applications without subsidies.

The Road Ahead: TKIL's 3–5 Year Milestones

Over the next five years, TKIL's green hydrogen ambitions are anchored in **scaling with purpose**:

1. **Commission at least 3–4 pilot and commercial plants** in industrial hubs.
2. **Establish a manufacturing base** for BoP and related systems for green hydrogen in India
3. Develop **Hydrogen Refuelling stations** for green highway projects
4. Develop **Hydrogen Blending stations** for city gas distribution projects
5. Expand into **hydrogen derivatives** like green ammonia and e-fuels like methanol, ethanol, sustainable aviation fuel (SAF), etc.

By 2030, our goal is for TKIL to be recognized as a **top-tier green hydrogen solution provider in India**, with projects that are not just economically viable but **environmentally transformative**.

Conclusion: A Long Game Worth Playing

The transition to green hydrogen is not a sprint—it is a marathon. But the stakes are high, and the rewards are transformative. TKIL's combination of **technological edge, localization strategy, and industrial partnerships** positions us uniquely to lead this change.

India's green hydrogen journey will define its industrial competitiveness and environmental legacy for decades to come. At TKIL, we are committed to ensuring that this journey is **not only successful but also sustainable, inclusive, and future-ready**.

The author, Suresh Agasti, is the Business Head - Green Hydrogen of TKIL Industries Pvt. Ltd., a diversified industrial business spanning Mining, Cement, Power Plants & Boilers, Sugar Plants, along with a large service business that includes asset management/O&M. TKIL has been in existence for over 77 years in the country, with projects and equipment suppliers all over the world.

Prior to leading the Green Hydrogen business unit, Suresh was responsible for heading the Communications and Business Strategy portfolio at TKIL Industries. Since joining TKIL Industries in 2016, his vision and efforts in sustainability and energy transition have been instrumental in the establishment and growth of the Green Hydrogen business, furthering TKIL Industries' commitment to addressing global energy demands and environmental concerns.

With over 25 years of experience across multiple industries—including energy & power (nuclear, thermal, and renewable), industrial engineering, metals & mining, oil & gas, fertilizers, and infrastructure—Suresh brings a wealth of expertise in several strategic areas. His earlier roles included leadership positions with the Department of Atomic Energy's Civil Nuclear Program under Nuclear Power Corporation of India, Siemens, the Adani Group, as well as consulting roles at Empire Industries, Markets & Markets, and Enrich Solar.

Suresh holds an Executive MBA from IIM Calcutta, a B.E. in Electrical Engineering from the University of Sambalpur, and a Post Graduate Diploma in Strategy in Design Thinking from Confederation of Indian Industry. He also holds a Post Graduate Diploma in Human Rights from Indian Institute of Human Rights, Delhi. He is a Certified Six Sigma Black Belt, an ISO 9001 Lead Auditor, and a Certified PLM SAP Consultant with Siemens, among other credentials.

Courtesy:
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Green Hydrogen Production Pathways for India

Techno-economic considerations for green hydrogen project development

Executive Summary

India's green hydrogen journey has been marked by ambitious goals and growing investments in renewable energy sources like solar and wind, aiming to position the country as a global leader in the clean energy transition. The government launched the National Green Hydrogen Mission in January 2023, focusing on boosting the production of green hydrogen, decarbonizing heavy industries, and enhancing energy security. Although national and international players have initiated several pilot projects and collaborations, major development at the project level remains elusive.

This study by RMI in July 2025, is an attempt to provide a detailed understanding of the dynamics of green hydrogen — to unpack cost economics, key project development considerations, and project risks, offering insights into India's evolving landscape at the national and state levels. Using the lens of a project developer, it examines 17 distinct project locations across 17 states. The study examines convergence driven by national-level policies as well as local divergences resulting from state-specific renewable potential and policy support.

An optimization model is used to prioritize the least capital-intensive investments, ensuring efficient asset allocation. Although project configurations can vary widely, the scenarios considered here are representative of the expected developments in India's green hydrogen ecosystem. These scenarios, though simplified, cover a variety of project configurations and their cost implications, recognizing that actual development will be influenced by economic feasibility, regional policies, and demand expectations. Distribution of production cost and landed power prices across some key scenarios is summarized in Exhibit ES1.

Key Findings & Insights

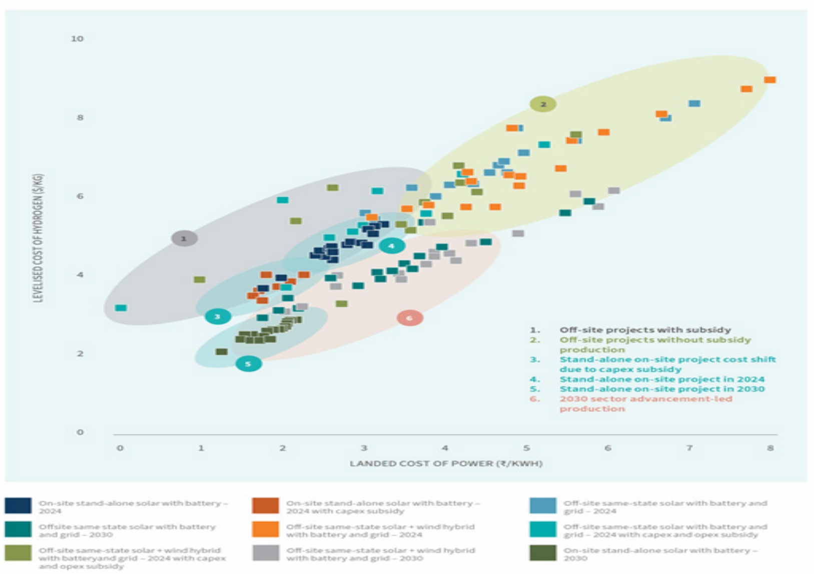
1. **State policy waivers, alongside national mission support, can reduce renewable power costs for green hydrogen projects by over 90%.**

In renewable-rich states like Gujarat, Maharashtra, and Rajasthan, on-site solar power costs are as low as Rs. 2.1 per kWh (US$0.26/kWh) and may drop to Rs. 1.5/kWh ($0.018/kWh) by 2030 due to technological advancements. Off-site projects face transmission charges that can raise the landed cost of power by as much as 104%, depending on state-specific charges and regulations. Under subnational policies, some states, including Odisha and Maharashtra, offer lower or waived surcharges for green hydrogen projects, improving affordability and project feasibility. Waivers in transmission charges across states can reduce landed power costs up to more than 90%. Odisha is leading in this respect by offering an additional Rs. 3/kWh ($0.036/kWh) waiver. Telangana offers a similar waiver, yet higher up-front charges restrict the reduction in landed power costs to 50%. On-site projects can also benefit from capital subsidies, cutting costs by 30% on average. Odisha's aggressive policies make it one of the most competitive states for green hydrogen production, slashing landed power costs by up to 94%.

2. **Stand-alone on-site green hydrogen projects with subnational capital expenditure (capex) subsidies can reduce the production cost by 20%–22%. However, these projects come with land and demand co-location constraints.**

Stand-alone green hydrogen projects are among the most cost-competitive arrangements for hydrogen production, with costs ranging from \$4.4/kg to \$4.8/kg. Various states, including Maharashtra, Uttar Pradesh, and Odisha, offer capital subsidies of 25% to 35%, reducing power costs by 20%–22%. However, the cost gap between green and grey hydrogen remains significant — ranging from \$1.6/kg to \$3.2/kg. Scalability is also constrained by land availability and proximity to industrial demand centers, as transportation

Exhibit ES1 Distribution of green hydrogen production cost against landed cost of power across project configurations and scenarios



RMI graphic. **Source:** RMI analysis.

costs can undermine economic advantages. The optimal sizing of these projects depends on local renewable energy potential — with required solar capacities varying from 1.9 to 2.8 gigawatts (GW) to produce 50 kilotons per annum (ktpa) of hydrogen, which also requires large parcels of land.

3. **Projects connected to the Inter-State Transmission System (ISTS) or the Central Transmission Utility of India (CTU) are the first choice for most developers, because they offer production prices that are 20% to 30% lower than projects without subsidies connected to State Transmission Utilities (STU).**

Green hydrogen production costs for projects connected to the ISTS, range from \$4.1/kg to \$5.0/kg, influenced by factors like renewable energy sources, grid availability, and storage solutions (placement and technology). CTU-connected projects can offer 20% to 30% lower costs than STU-connected projects, which bear different types of state transmission charges. Although capital subsidies for green hydrogen initiatives can help reduce costs, they typically apply only to specific equipment like electrolyzers and batteries. For ISTS projects sourcing renewable energy from different states, local subsidies may not be applicable, limiting cost-saving potential. For example, in Uttar Pradesh, a 35% capital subsidy can lower the green hydrogen production cost by about 10% for battery-supported solar projects.

4. **At least 50% reduction in green hydrogen production cost across off-site projects is required to put them in a competitive range with grey hydrogen.**

Transmission-related charges can raise the landed cost of power to 1.5–2.5 times the base electricity generation cost from renewable energy. Key factors in incentivizing green hydrogen production include the magnitude and duration of subsidies, which affect the final production costs. State-specific reductions due to waivers and incentives vary widely, from 1% in West Bengal to 61% in Odisha. Long-term economies of scale will enhance competitiveness, with production costs decreasing as projects scale up due to better resource utilization and technology. Odisha has emerged as a leader in cost competitiveness for green hydrogen. The state's comprehensive incentive package could bring down green hydrogen costs to as low as \$3/kg, which is roughly 42% below the average production cost across other states. Given the importance of waivers in the cost economics of STU-connected projects, in the long run, prices are bound to rise if state waivers are discontinued.

Critical Considerations for Project Development

1. **Better system utilization beyond a threshold yields marginal gains only.**

Lower utilization rates of around 25% require approximately 2.5 GW of electrolyzer capacity for a project producing 100 ktpa, whereas increasing the utilization to 85% reduces the required capacity by 70% to 720 MW. Currently, alkaline electrolyzer costs range from \$500/kW to \$1,400/kW, and at an average of \$741.5/kW, capital requirements decrease from nearly \$1.8 billion to ~\$537 million when utilization rises from 25% to 85%. Thus, higher system utilization is one of the key priorities for developers. Higher system utilization also significantly reduces the levelized cost of hydrogen (LCOH), with a 22% reduction when increasing system utilization from 25% to 50% and an additional 9% reduction when increasing to 75%. However, gains beyond 75% system utilization are marginal, about 2%. By 2030, as electrolyzer costs decline, the need for up to 100% utilization becomes less critical, allowing for system oversizing without prohibitive capital outlay.

2. **Choice between battery energy, hydrogen storage or a combination offers flexibility to developers depending on their business models.**

When planning green hydrogen projects, developers can optimize for battery storage, hydrogen storage, or a combination of both, significantly influencing project size. Battery storage enables theoretically up to 100% utilization, reducing the size of the electrolyzer required to 610 MW for a 100 ktpa project, but requires over 7 GW of oversized renewable energy (solar and wind) capacity. In contrast, hydrogen storage leads to around 33% utilization, necessitating a larger electrolyzer of approximately 1.9 GW but just 3 GW of renewable capacity. Whereas hydrogen storage limits excess power generation to nearly 20%, battery storage can yield up to 70% excess. The optimal configuration depends on the developer's business model — and is likely to change as demand for renewable energy grows in India. Although battery storage is currently less economically favorable, cost differences are expected to narrow, potentially making the two options equally viable by 2030. High utilization rates from battery storage may lead to excess generation challenges but can also create additional revenue streams to offset investment costs. An ideal and optimized green hydrogen project would involve a strategic combination of both battery storage and hydrogen storage.

This hybrid approach offers multiple advantages, balancing operational flexibility, cost-effectiveness, and resilience.

3. **The excess power produced from the oversizing of green hydrogen projects can generate additional revenue, helping to offset the LCOH.**

Excess solar generation can vary significantly, ranging from 11% to 41% of total solar electricity produced, whereas excess generation with wind power is lower, between 0% and 12%. Wind is usually a complementary source to solar, resulting in smaller-scale installations. In resource-rich states like Rajasthan and Tamil Nadu, excess generation becomes more predictable, with 14% for solar and 2% for wind. This excess generation can unlock an additional flow of revenue through participation in the electricity market. For instance, Maharashtra's combined solar-wind project has an excess of 22% for solar and 2% for wind. Selling this excess power at the fixed Green Day Ahead Market (GDAM) price can offset the green hydrogen production cost by 15%, lowering it by $3.9–$4.6/kg, considering state transmission charge waivers. In Gujarat, similar project arrangements could reduce production costs by nearly 33%, bringing them down by $3.2–$4.7/kg — with the potential to decrease further with electricity charge waivers.

4. **Beyond cost considerations, the path from conceptualization to operationalization of green hydrogen projects faces numerous risks that can affect project viability.**

There are numerous risks in the project development cycle that can impact their viability. Key risk factors include fluctuating renewable energy costs, regulatory uncertainties, technological challenges, and financial limitations. Green hydrogen production demands substantial capital and operational expenditures for installing electrolyzers and renewable infrastructure. Moreover, the technology, particularly electrolyzers, needs advancements to improve efficiency and durability, which are currently limiting factors. The availability and reliability of renewable power sources also play a crucial role, as variability can affect hydrogen production rates. Infrastructure development for grid integration, storage, and transportation is essential yet costly and underdeveloped. A complex regulatory landscape varies by region, complicating project navigation. Securing end-user adoption is vital for commercial viability, while financing hurdles arise from high costs and perceived risks. Additionally, supply chain disruptions from global dependencies can hinder raw material availability. Addressing safety concerns related to hydrogen handling and investment uncertainty in volatile markets is critical for the long-term success of green hydrogen initiatives.

The Way Forward

To unlock the full potential of green hydrogen in India, the following areas should be prioritized for future activities:

- **Infrastructure development:** Policymakers should focus on building robust infrastructure for grid integration, energy storage, hydrogen storage, and transportation. This will be crucial in order to support large-scale green hydrogen production and ensure reliable distribution across industrial hubs, minimizing variability in supply and optimizing energy usage.
- **Assessment for India's green hydrogen backbone:** The findings of this report should guide the creation of a comprehensive "Green Hydrogen Backbone" study. This will help design the necessary infrastructure and regulatory framework to support long-term growth, laying out the pathways to develop a robust green hydrogen ecosystem that can meet domestic and international demand.
- **Enhanced local supply chains:** Strengthening domestic manufacturing of key components like electrolyzers and renewable energy systems is vital. This will reduce India's dependence on international markets, mitigate potential supply chain disruptions, and ensure a stable and scalable development pipeline for green hydrogen projects.
- **Market creation and de-risking opportunities:** The study primarily focuses on green hydrogen production pathways, but without addressing offtake risks, the sector may struggle to succeed. Stimulating market demand is essential, including demand aggregation and offering incentives to offset the green premium. Financial instruments or risk-sharing mechanisms can help ensure that a demand pull is created, complementing policy efforts to promote green hydrogen production.

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For the complete report, refer: https://rmi.org/green-hydrogen-production-pathways-for-india/

India Begins Construction of First Green Hydrogen-Powered Ships

Credit: Audio und werbung/ Shutterstock.com.

As announced in August 2025, India has initiated the construction of its first green hydrogen-powered ships, a significant move towards sustainable maritime transportation.

The Union Minister for Ports, Shipping and Waterways made this announcement in response to a question raised by a Minister of Parliament in the Lok Sabha on 8 August 2025, according to a report by The Hindu.

Cochin Shipyard Limited and Mazagon Dock Shipbuilders are each constructing a vessel powered by hydrogen fuel cells (HFCs), employing indigenous technology. This initiative is part of the government's wider strategy to encourage the use of eco-friendly fuel alternatives and reduce pollution within the maritime sector.

The minister emphasized that the Central government's actions would position India as a leader in green hydrogen technology and pave the way for a more sustainable and prepared maritime industry for the future.

The Centre has allocated Rs. 1.15 billion ($13.1 million) under the National Green Hydrogen Mission to be utilized up to 2025-26. These funds are earmarked for ship design, technology testing, infrastructure enhancement, and pilot projects, supporting the transition to greener energy sources.

Implemented in two phases, the green hydrogen ship initiative aims to initially retrofit existing ships for hydrogen fuel operation, followed by the development of hydrogen refuelling infrastructure at major ports. Shipping Corporation of India and V.O. Chidambaranar Port Authority (VOCPA) are key partners in this endeavour.

VOCPA has already proposed a 750 m^3 green methanol bunkering facility in Tuticorin, which is one of the selected sites for green hydrogen infrastructure development. Additionally, ports such as Deendayal Port, Paradip Port, and Tuticorin Port are evolving into hydrogen hubs. This aligns with the government's vision to transform these locations into centres for the production and export of green hydrogen.

In a separate development, the Inland Waterways Development Council has announced an investment of Rs. 500 billion ($5.8 billion) to upgrade India's inland waterways network, further bolstering the nation's infrastructure.

As a major breakthrough in shipping transport and inland waterway transport, Union Minister of Science & Technology and Vice President CSIR (Council of Scientific & Industrial Research) hailed India's first indigenously developed hydrogen fuel sea vessel in April 2025.

Describing it as a success story emanating from the joint effort of public and private sectors, the minister disclosed that the country’s first indigenous green HFC inland waterway vessel, which may later pave the way for hydrogen fuel-driven larger sea vessels or ships, was developed by Cochin Shipyard featuring an HFC-based drivetrain built by KPIT Technologies, drawing upon the foundational work enabled by the CSIR.

As announced in April 2024, Norwegian shipyard Myklebust Verft was selected to build two hydrogen-powered ferries ordered by compatriot transport company Torghatten Nord. Once delivered, the newbuilds will be ‘the world’s largest’ hydrogen-powered ships and will be bunkered with hydrogen produced in Bodø.

Courtesy of Myklebust Verft

Designed by The Norwegian Ship Design Company to operate in the challenging waters of the Vestfjordstrekninga fjord in the Arctic Circle, the ships are scheduled for delivery in 2026.

Source: https://finance.yahoo.com/news/india-begins-construction-first-green-161124292.html & https://www.pib.gov.in/PressReleaseIframePage.aspx?PRID=2122190

Role of Green Hydrogen in India's Steel Sector

India is making substantial strides in its clean energy transition by investing in green hydrogen infrastructure, shifting from carbon-intensive hydrogen production methods to renewable-powered green hydrogen through electrolysis. The National Hydrogen Mission, launched in 2021, aims to establish India as a global leader in green hydrogen, targeting five million metric tons annually by 2030. The initiative is supported by the US$2.1 billion Strategic Interventions for Green Hydrogen Transition (SIGHT) scheme, which promotes electrolyzer manufacturing, hydrogen production, and the development of integrated hydrogen hubs, known as "hydrogen valleys", to facilitate production, storage, and utilization.

Table 1: Comparison of green hydrogen production technologies

Technology	Description	Efficiency	Infrastructure requirements	Key advantages	Challenges	TRL
Alkaline electrolysis	Uses an alkaline solution as the electrolyte. Long-established technology	60-70%	Moderate electricity supply, water source, alkaline electrolyte handling	Mature technology, relatively low cost	Lower efficiency, slower response to load changes	9 commercially ready)
Proton Exchange Membrane (PEM) electrolysis	Uses a solid polymer electrolyte. More flexible and responsive than alkaline	60-65%	High-purity water, stable electricity supply, platinum and iridium catalysts	Higher efficiency, faster response, compact system design	High cost due to noble metal catalysts	8-9 (Near commercial)
Solid Oxide Electrolysis (SOE)	Operated at high temperatures, uses a solid ceramic electrolyte, can integrate with waste heat sources	80-90%	High temperature heat sources, stable power supply, ceramic handling	High efficiency, potential for waste heat recovery	High operational temperature, expensive materials	6-7 (pilot to demonstration)
Anion Exchange Membrane (AEM) electrolysis	Uses an anion-exchange membrane, combines features of alkaline and PEM electrolysis	50-60%	Moderate electricity supply, scalable design, less noble metal dependency	Lower cost potential, promising for decentralized systems	Still in development, limited commercial availability	5-6 (pilot to demonstration)

The steel industry, responsible for 7% of global CO_2 emissions, is central to this transformation. Green hydrogen presents a sustainable alternative to traditional carbon-intensive methods. Alkaline electrolysis, the most commercially viable technology today, is priced at US$7/kg hydrogen. Other emerging technologies like biomass gasification with carbon capture and solid oxide electrolysis show potential but face challenges, such as feedstock availability and technological maturity. India's renewable energy and biomass resources make it well- positioned to integrate hydrogen technologies into steelmaking, supporting the country's commitment to sustainability and industrial innovation.

Integrating green hydrogen into steel production presents a significant opportunity for decarbonization. Hydrogen can be applied across various stages of production, including agglomeration, blast furnace operations, direct reduced iron (DRI) processes, and downstream activities, such as reheating and galvanizing. While partial hydrogen blends have already been successfully demonstrated, full hydrogen adoption is still under exploration. Despite challenges like feedstock availability and infrastructure requirements, technological advancements and supportive policy frameworks are facilitating a move toward a greener future for steel production.

Table 2: Shortlisted green hydrogen production technologies for steel sector

Technology	Electricity requirement (kWh/kg H2)	Water requirement (L/kg H2)	Water quality (PPM)	Electrolyser Cost (US$ / kW)	BoP Cost (US$ /kW)	Other Requirements
Alkaline electrolysis	50-55	9-10	< 10 PPM	600-700	300-400	None; no noble metal dependency; no CCUS required
Proton Exchange Membrane (PEM) electrolysis	55-60	10-12	< 1 PPM	1000-1200	400-500	Requires platinum and iridium; no CCUS required
Solid Oxide Electrolysis (SOE)	40-45	8-10	< 10 PPM	1200-1500	600-700	High-temperature heat source (700-900C); no noble metal dependency; no CCUS required
Biomass gasification with carbon capture	10-20	2-4	50-100 PPM	600-800	200-250	Biomass: dry, low-sulphur quality; 10-12 kg biomass per kg H2; heat source (800-900C from biomass combustion); CCUS required

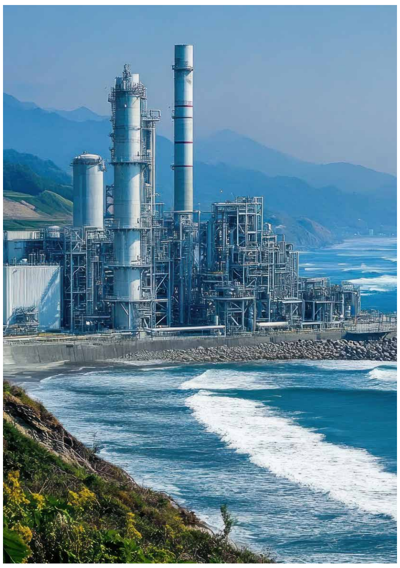
Our analysis in the whitepaper shows, under India's 2070 net zero scenario, the green H2-DRI and electric arc furnace (EAF) route is expected to contribute 13% of the projected 403 MMTPA crude steel output by FY50, growing to 41% of 597 MMTPA by FY70. Green hydrogen demand in the steel sector is expected to grow at a 13% CAGR, reaching 15.15 MMTPA by FY70. In the accelerated net-zero 2050 scenario, the H2-DRI steelmaking route will contribute to 39% of the crude steel production with green hydrogen demand of 9.82 MMTPA by FY50.

Our analysis shows, to achieve a 245 MMTPA H2-DRI capacity by 2070, investments of US$297-304 billion are needed. While initial costs for H2-DRI plants are higher than those for Blast Furnace-Basic Oxygen Furnace (BF-BOF) setups, falling green hydrogen prices—projected to drop from US$7/kg in 2024 to US$1.8/kg by 2040—and rising global carbon prices are expected to improve the cost competitiveness of H2-DRI by 2035. The production costs of steelmaking via the green hydrogen DRI-EAF route, by which a 90% reduction in emissions can be achieved, are anticipated to decrease from US$600/ton in 2024 to US$421/ ton by 2040, making this a viable and sustainable alternative to traditional steelmaking.

Despite these advantages, widespread adoption of green hydrogen faces significant barriers. High initial infrastructure and technology costs require government incentives, such as production-linked schemes, tax breaks, and public-private partnership (PPP) models. The government's role is central to enabling this transition. A comprehensive National Green Hydrogen Policy should include regulatory measures to reduce renewable power costs and establish adoption targets. Financial incentives, such as tax breaks and carbon pricing mechanisms, are essential to attracting investments to meet the US$264-297 billion funding requirements by 2050–70. Infrastructure development, particularly through hydrogen hubs and pipeline networks in industrial clusters, will centralize production and distribution, enhancing efficiency and reducing costs. These measures can reduce electricity and capital costs, making hydrogen adoption more affordable. Centralized hydrogen hubs, pipeline networks, and advanced storage solutions are essential to overcoming infrastructure gaps, reducing transport costs by up to 90%, and ensuring a reliable supply.

Additionally, fragmented supply chains and a lack of standardization further complicate adoption. Establishing industry-wide standards, optimizing logistics, and fostering global collaborations will streamline the hydrogen supply chain, facilitating access to advanced technologies and enabling widespread adoption. Significant investments in research and development (R&D) and workforce training are also critical to improving hydrogen technology efficiency and creating a skilled workforce to support the transition.

Steelmakers must adopt proven technologies like green hydrogen DRI-EAF and explore hydrogen production emerging solutions such as solid oxide electrolysis and biomass gasification with CCUS. Public-private partnerships can help co-develop infrastructure, optimize supply chains, and reduce hydrogen delivery costs, accelerating the transition. Collaboration between domestic and international electrolyzer manufacturers in R&D can improve electrolyzer's technology efficiency by 30% to 40%.

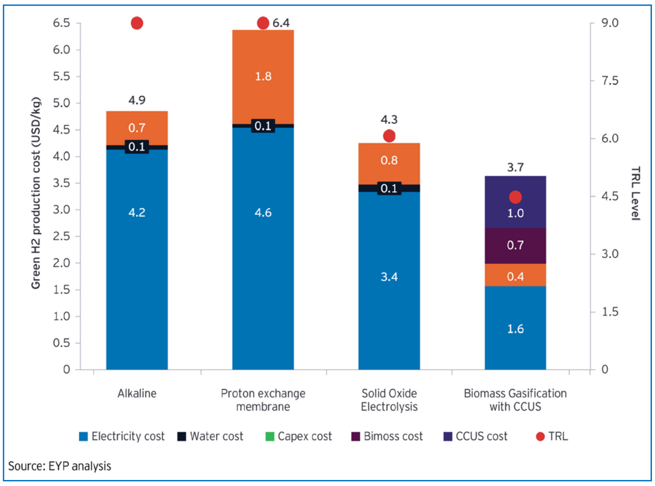


In conclusion, India's commitment to green hydrogen presents a transformative opportunity to decarbonize its steel sector, a major emitter of global CO_2 emissions. Addressing economic, technological, and logistical challenges through strategic interventions will enable India to lead the global transition to sustainable steel production. This effort supports broader goals of industrial innovation, energy security, and climate action, ensuring long-term competitiveness and environmental sustainability.

For hydrogen usage in steel production in India, alkaline electrolysis and biomass gasification with Carbon Capture, Utilization, and Storage (CCUS) emerge as the most viable options, supported by the following factors:

- Cost-effectiveness: Alkaline electrolysis has a relatively low capital cost, both in terms of electrolyzer (US$600-700/kW) and balance of plant (US$300-400/kW). This makes it economically attractive for large-scale hydrogen production, crucial for cost-sensitive steel manufacturing
- Mature technology: Alkaline electrolysis is a commercially ready, reliable, and established technology (TRL 9), ensuring ease of deployment in India's industrial landscape
- Biomass availability: Biomass gasification is particularly suitable for India, where agricultural and forestry residues like rice husk and wood chips are abundant. Utilizing this biomass as a feedstock enables hydrogen production while supporting rural economies
- Carbon capture potential: Biomass gasification paired with CCUS allows for carbon-neutral hydrogen production, which is advantageous for emissions-intensive industries like steel
- Less dependence on imported materials: Both technologies minimize reliance on noble metals, reducing dependency on costly and scarce materials like platinum and iridium, which are required for PEM electrolysis

Figure 1: Hydrogen production cost and TRLs



Source: EYP analysis

Courtesy:

This April 2025 report has been prepared by WWF-India with research and inputs from EY Parthenon, based on publicly available information and data gathered from different sources.

India's First Green Hydrogen R&D Conference Charts Innovation Path

With the National Green Hydrogen Mission (NGHM) aiming to make India a global leader in the production and use of green hydrogen, the country now faces the twin challenge of building domestic technological prowess while scaling deployment.

India's first Green Hydrogen R&D Conference, convened by the Ministry of New and Renewable Energy (MNRE) in New Delhi on 11–12 September 2025, sought to address this challenge and offered key insights on how the country can strengthen innovation, R&D, and technology development, alongside scaling deployment. The two-day event, supported by the Council on Energy, Environment and Water (CEEW) as knowledge partner, brought together more than 1,300 participants, 119 speakers, and 25 start-ups, creating a platform for rich discussions across government, industry, and academia.

Brainstorming panel discussion among senior leaders on 'India's Vision as an R&D and Innovation Leader in Green Hydrogen'. From left to right: Prof S Dasappa, IISc Bangalore; Dr Anita Gupta, Head of Scientific Divisions, Department of Science and Technology; Prof KK Pant, Director, IIT Roorkee; Dr Arunabha Ghosh, Founder and CEO, CEEW; Dr Parvinder Maini, Scientific Secretary, O/o PSA to Govt. of India; Prof Rangan Banerjee, Director, IIT Delhi; Dr Ashish Lele, Director, CSIR - National Chemical Laboratory, Pune; and Dr RK Malhotra, President, Hydrogen Association of India

While green hydrogen is widely seen as a fuel of the future, its success in India depends on advancing technology development to solve two critical challenges: reduction in production costs, and overcoming reliance on imported critical minerals and core technologies. A CEEW study has found that the cost of an electrolyser stack can be reduced by around 75 per cent if certain technology development targets are met. Further, the same study finds that India can readily indigenize around 80 per cent of electrolyser costs, but has to rely on imports of critical minerals and core proprietary components.

CEEW helped bring together diverse voices from industry, academia, and government to ensure the dialogue at the conference combined aspiration with actionable pathways to overcome these challenges.

Shri Pralhad Joshi, Honourable Union Cabinet Minister, MNRE inaugurated the Start-up Expo, featuring 25 green hydrogen start-ups at the conference, in the presence of Prof Ajay K Sood, Principal Scientific Adviser to the Govt. of India; Mr Santosh Sarangi, Secretary, MNRE; Mr Abhay Bakre, Mission Director - National Green Hydrogen Mission, MNRE; and Mr Mohammad Rihan, Director General, National Institute of Solar Energy.

The discussions explored specific technology development themes, pointing to promising directions for research and innovation in green hydrogen. Materials innovation was identified as vital for reducing India's dependence on scarce and expensive platinum group metals in electrolysers and fuel cells. Breakthroughs to reduce the cost of hydrogen storage and dispensation, and to enable retrofit changes to existing natural gas pipelines to allow them to transport hydrogen safely, are necessary. Artificial intelligence and automation were seen as powerful enablers for improving efficiency in hydrogen storage, transportation, and end-use applications. The discussions underscored the need for structured pathways to realize technological ambitions, and the following imperatives emerged to do so.

Structured Pathways

First, integrating research into commercial projects is essential, beyond just validating technologies under real-world conditions to build market confidence in them. This requires active engagement of industry from the earliest stages of the R&D process, ensuring innovations are developed with market applications in mind. Demonstration facilities and testbeds were highlighted as particularly valuable, offering spaces where companies can "touch, feel, and embrace" technologies before they reach the market.

Several panelists also called for outcome-oriented innovation challenge programs by the government, which could channel resources toward defined goals while catalyzing collaboration between academia and industry.

Second, India's start-up ecosystem has a growing potential to drive deep-tech innovation. The launch of a funding scheme for start-ups under the NGHM Pilot Project Scheme is an important milestone. While financial support is important, start-ups also require access to dedicated testing sandboxes to validate technologies, shared expertise and infrastructure from national laboratories, accelerator programs to connect innovators with investors, and pilot projects to demonstrate solutions at scale. When combined with funding, such measures could help start-ups progress towards commercial viability and play a stronger role in India's green hydrogen ecosystem.

Roundtable discussion on frontiers in fuel cell applications featuring sector experts

Conference participants interacting with green hydrogen start-ups at the Start-up Expo

Third, build robust R&D infrastructure and frameworks that are aligned with industry requirements. Participants repeatedly emphasized strengthening the testing infrastructure across the material, stack, and system levels. Equipping national laboratories to provide internationally recognized certifications would not only boost domestic confidence but also help Indian technologies compete globally. Rather than broad, one-size-fits-all grants, there must be more granular and goal-specific funding cycles suited to the realities of deep-tech innovation. To unlock these reforms, collaboration frameworks need to evolve beyond the traditional academia-government axis to include stronger industry-industry partnerships, with common and unambiguous intellectual property sharing models.

Conclusion

Taken together, these insights point to a broader reality: India's green hydrogen journey requires robust R&D infrastructure, innovators, and strong collaborations to achieve technological breakthroughs. The Green Hydrogen R&D Conference was a step towards aligning research with deployment ambitions by bringing together researchers, start-ups, industry, and policymakers. Sustaining the momentum from this conference could help India move from being just a green hydrogen market to becoming a green hydrogen innovation leader.

CEEW is currently conducting a survey on green hydrogen R&D activities in India. The survey seeks perspectives from researchers, industry, start-ups, students, and observers. Please voice your opinions by filling out the form linked to this QR code, which will take you around 10 minutes.

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Torrent Group Launches Uttar Pradesh's First Green Hydrogen Plant for Blending into CGD Network

In a landmark move towards sustainable energy, the Torrent Group inaugurated Uttar Pradesh's first Green Hydrogen plant in Gorakhpur, which is also India's largest Green Hydrogen and Natural Gas blending project in the City Gas Distribution (CGD) sector. The inauguration ceremony was graced by Shri Yogi Adityanath, Hon'ble Chief Minister of Uttar Pradesh, who hailed the initiative as a significant step in India's energy transition journey.

The project is a collaborative effort between Torrent Power and Torrent Gas, both entities under the Torrent Group umbrella. The newly commissioned plant boasts an annual production capacity of 72 tons per annum (TPA) of Green Hydrogen. This hydrogen will be blended with natural gas—up to a concentration of 2%—and distributed through Torrent Gas' existing CGD network in Gorakhpur.

Torrent Power's state-of-the-art Green Hydrogen Production Facility at Gorakhpur

The blended fuel will reach domestic households, CNG stations, and industrial units, leveraging the already laid natural gas pipeline infrastructure. This makes the Gorakhpur facility not only the first Green Hydrogen plant in the state, but also the largest hydrogen-natural gas blending project in India's CGD sector. Torrent Gas has been authorized by the Petroleum and Natural Gas Regulatory Board (PNGRB) to operate in Gorakhpur, Sant Kabirnagar, and Kushinagar districts. With 32 CNG stations, gas supply to 12,000+ households, and service to 73 industries and commercial establishments, the company is poised to expand its footprint significantly.

Green Hydrogen, produced via electrolysis using renewable energy sources like solar and wind, is a zero-emission alternative to conventional hydrogen. Its integration into the CGD network not only reduces carbon emissions, but also accelerates the adoption of hydrogen as a mainstream energy source.

Welcoming Hon'ble CM, Shri Yogi Adityanath Ji and Hon'ble MP of Gorakhpur Shri Ravi Kishan Ji by Vice Chairman & MD of Torrent Power, Shri Jinal Mehta

Speaking at the event, Chief Minister Yogi Adityanath emphasized the importance of Green Hydrogen in achieving the goals of the National Green Hydrogen Mission (NGHM) 2030. He stated:

"Sustainable production of Green Hydrogen in the country is a critical part of NGHM 2030. The State of Uttar Pradesh has a target of 1 mmtpa Green Hydrogen production for which it has set up a specific policy that will support potential investments in Uttar Pradesh. Greener and cleaner energy sources, with lower carbon emissions are critical for the progress of the country. With the inauguration of this plant, green hydrogen has become a part of the life of common people as it will directly reach their kitchens and vehicles."

He also mentioned that availability of PNG has brought great relief to the people of Gorakhpur, especially the housewives due to the convenience, safety and savings it offers. Increasing use of CNG as transportation fuel has helped battle pollution and save costs for the masses. Various industries and commercial establishments in Gorakhpur are also now using piped natural gas and reaping the benefits of cheaper and economical fuel.

Tree Plantation by Hon'ble CM, Shri Yogi Adityanath Ji

contd on pg 23

Accelerating India's Green Hydrogen: From Innovation to Global Leadership

India stands poised to transform its abundant renewable energy potential into a cornerstone for decarbonizing hard-to-abate sectors like steel, fertilizers, refining, and heavy transport. With solar tariffs as low as ₹2.20 per kWh and a projected green hydrogen production cost of $1.50–2.00/kg by 2030, India could emerge as a cost-competitive hub in a multi-billion global market. Yet, as outlined in the insights report 'Accelerating Green Hydrogen: Unlocking India's Technological Prowess' by Xynteo and the Indian Institute of Technology (IIT) Madras Energy Consortium, systemic barriers—spanning financing, infrastructure, regulation, coordination, and competitiveness—hinder the leap from lab innovation to commercial deployment. Drawing from a June 2025 workshop at IIT Madras, attended by technology leaders from government (Ministry of New and Renewable Energy or MNRE), industry (Adani, Shell, Chevron), startups (Hydrovert, Hylan Power), and academia, this article explores India's green hydrogen opportunity, the challenges stalling progress, and a bold proposal to catalyze ecosystem transformation.

Participants of the workshop 'Accelerating Green Hydrogen: Unlocking India's Technological Prowess', held on 25 June 2025 at IIT Madras

The Green Hydrogen Imperative

Green hydrogen, produced through electrolysis powered by renewable energy, is central to India's net-zero emissions goal by 2070. It offers a clean energy carrier and industrial feedstock, enabling decarbonization of sectors resistant to electrification. Beyond domestic needs, green hydrogen positions India for energy exports and leadership in a rapidly growing global market. The International Energy Agency (IEA) underscores India's structural advantages: low-cost renewable electricity, affordable engineering capabilities, and a burgeoning innovation ecosystem. The National Green Hydrogen Mission (NGHM), launched in 2023, targets 5 million metric tons (MMT) of annual production by 2030, supported by policies to boost electrolyser manufacturing and demand creation.

However, scaling indigenous deep-tech electrolysers, fuel cells, and storage systems remains challenging. India's reliance on imports, particularly from China, which controls over 70% of global electrolyser manufacturing, exposes it to supply chain risks and price volatility. A September 2024 Council on Energy, Environment and Water (CEEW) report highlights that over 80% of rare earth element (REE) processing and 50% of nickel processing are concentrated in China and Indonesia, underscoring the urgency for resilient domestic supply chains. The workshop at IIT Madras unpacked these challenges, focusing on two critical questions: How can India foster indigenous innovation? And how can promising technologies at Technology Readiness Levels (TRL) 3–5 scale to commercial viability?

Systemic Barriers to Scaling Innovation

The workshop revealed five interconnected barriers preventing India from translating its R&D pipeline into market-ready solutions, each demanding urgent action.

1. Capital & Commercialization Gaps

India's hydrogen startup ecosystem is vibrant, with technologies achieving lab validation and early pilots. Yet, the "valley of death" between TRL 6 and 9, where prototypes transition to commercial scale, remains a choke point. Hydrogen technologies are capital-intensive, requiring multi-year investment horizons and infrastructure for demonstration. Unlike software startups, which attract venture capital (VC) optimized for quick returns, deep-tech hardware faces a financing mismatch. VC models shy away from the high-CAPEX, long-gestation nature of electrolysers or fuel cells, leaving startups underfunded for certifications, pilot manufacturing, and safety compliance.

First-of-a-kind (FOAK) deployments face a "funding-demand deadlock." Investors demand long-term offtake commitments, while buyers hesitate without cost reductions from scale, which only deployment can achieve. The absence of viability gap funding, conditional offtake guarantees, or risk-sharing instruments, stalls progress. For instance, startups struggle to secure buyers for FOAK projects due to high initial costs, delaying market entry and IP development. The report emphasizes the need for blended, milestone-linked capital, grants, zero-interest loans, or equity, to bridge this gap and de-risk early deployments.

2. Infrastructure & Validation Gaps

Commercializing hydrogen technologies requires rigorous performance validation, safety testing, and real-world demonstration. However, India has limited certified hydrogen labs, modular testbeds, and "hydrogen-safe" demonstration zones. Startups often resort to costly overseas validation services, which delays market readiness and erodes investor confidence. Without domestic facilities to benchmark performance or ensure compliance, innovators struggle to gain customer trust. The absence of modular, technology-agnostic testbeds for alkaline, proton exchange membrane

(PEM), or solid oxide electrolysis cells (SOECs) further hampers iteration and durability testing.

Globally, Europe's Hydrogen Valleys Programme offers a model, providing co-located infrastructure for production, storage, and use, with shared safety protocols and permitting. India's nascent hydrogen valleys, like those in Kerala and Pune, are steps forward, but lack the scale and integration needed. The report calls for a network of certified labs and demonstration zones within national R&D institutions, equipped with fire safety, compliance monitoring, and emergency protocols to enable risk-mitigated piloting.

3. Regulatory Gaps & Standards Inertia

India's regulatory frameworks for hydrogen are fragmented and outdated, lacking TRL-specific standards or responsive amendment pathways. Startups developing novel storage or high-efficiency stacks face compliance uncertainty, as early-stage pilots are held to standards designed for mature technologies. Without regulatory sandboxes and flexible frameworks for controlled testing, innovators struggle to secure approvals, and procurers default to established, often imported, solutions. The absence of mechanisms for exemptions or fast-tracked code updates creates a risk-averse environment, stifling innovation.

For example, public procurers hesitate to issue pilot orders without clear certification, while industrial offtakers avoid untested systems due to liability concerns. The report advocates for TRL-based standards, regulatory sandboxes, and a structured interface for code reform to balance safety with innovation, fostering trust and accelerating market access.

4. Evolving Institutional Anchors & Ecosystem Coordination

India's green hydrogen ecosystem is fragmented, with startups, micro, small, and medium enterprises (MSMEs), academia, and industrial players pursuing parallel efforts. Unlike mature sectors like solar, hydrogen lacks a unified platform to aggregate demand, align stakeholders, or mandate public procurement. The NGHM and centers like IIT Madras drive research, but coordination across the value chain remains limited. Startups lack visibility into demand pipelines, while state agencies are unfamiliar with applications like fuel cell buses or backup power systems.

A central platform could streamline collaboration, reduce duplication, and institutionalize demand creation. Models like Germany's Fraunhofer Institute or the Indo-German Energy Forum demonstrate how coordinated platforms can support technology commercialization and global market access. The report proposes a mission hub to aggregate public sector undertaking (PSU) offtake, advocate for procurement mandates, and raise awareness of use cases, fostering trust and market maturity.

5. Industrial Competitiveness Constraints

Indian manufacturers face rising input costs, particularly volatile steel prices, and fierce competition from Chinese electrolysers, priced 20-30% lower due to subsidies and scale. Without localization targets or incentives, India risks import dependency, mirroring vulnerabilities in solar supply chains. The absence of domestic content requirements or phased manufacturing roadmaps discourages investment in local R&D and tooling. The report calls for localization-linked procurement, tariff protections, and production-linked incentive (PLI)-type schemes to bolster competitiveness and position India in global supply chains.

A Blueprint for Transformation

The workshop's key recommendation is a government-anchored, multi-stakeholder platform to accelerate commercial deployment of indigenous hydrogen technologies. This platform could integrate six core functions:

1. **Demand Aggregation:** Secure PSU and industrial offtake commitments through decarbonization mandates and procurement quotas, prioritizing domestic technologies.
2. **Structured Financing:** Offer milestone-based grants, loans, and equity for deep-tech hardware, with PLI schemes and FOAK funding to de-risk deployments.
3. **Regulatory Enablement:** Establish TRL-based standards, regulatory sandboxes, and a working group to streamline approvals and update codes.
4. **Shared Infrastructure:** Build certified testbeds and pilot plants via MoUs with Council of Scientific & Industrial Research (CSIR), IITs, and PSUs, using government-owned, private-operated models.
5. **Technology Qualification:** Implement a national TRL certification system, modelled on U.S. consortia like ElectroCat, to validate readiness and monitor progress.
6. **Knowledge Hub:** Launch an open-access portal for pilot case studies, deployment tracking, and tech transfer, empowering regional hydrogen hubs.

The Path Forward

Green hydrogen is not a distant ambition, but a critical lever for India's industrial decarbonization, energy security, and global competitiveness. By closing capital, infrastructure, regulatory, coordination, and competitiveness gaps, the proposed platform could unlock India's R&D pipeline, reduce import reliance, and secure global offtake agreements. With momentum building in hubs like Kerala and Pune, and MNRE's push for indigenization, India has a narrow window to shift from potential to leadership. This ecosystem transformation promises not just cleaner energy, but a strategic foothold in the multi-billion market, positioning India as a green hydrogen powerhouse by 2030.

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(*refer back page for company profile*)

Enabling India's SAF Roadmap for Aviation Decarbonization via Hydrogen

India's aviation sector has grown rapidly over the past decade, with domestic passenger numbers increasing from around 50 million in 2010 to approximately 230 million in 2024[1]. To address the sector's rising emissions, the Ministry of Petroleum & Natural Gas, Government of India, set an indicative target of blending 1% Sustainable Aviation Fuel (SAF) in Aviation Turbine Fuel (ATF) by 2027, increasing to 2% by 2028 and 5% by 2030 for international flights[2]. While modest compared to the European Union (EU)'s ReFuelEU mandate (2% by 2025, 20% by 2035), this step is ambitious in India's context, translating into around 140 million liters (112 kilo tons) of SAF annually[3,4]. Meeting even India's initial target will require a rapid scale-up in SAF production, but the availability of sustainable feedstocks remains a critical bottleneck.

India's Feedstock Dilemma

Major SAF technologies differ in their feedstock requirements. Hydro-processed Esters and Fatty Acids (HEFA) primarily rely on oils and fats, including plant oils, animal fats, and waste cooking oils. Alcohol-to-Jet (AtJ) uses alcohols derived from sugars or starches, while Fischer-Tropsch (FT) depends on gasified biomass[5]. Given India's immature supply chain coupled with infrastructural constraints for suitable oils, fats, and biomass, scaling aviation fuels remains challenging. This underscores the need to diversify into hydrogen-based Power-to-Liquids (PtL) as a complementary pathway, particularly if India aims to achieve even the initial 1% SAF blending target.

Hydrogen's Role in SAF Production

Hydrogen is not only a future aviation fuel in its own right, but also a critical enabler of SAF production across all major pathways. In the HEFA route, which produces most of today's SAF, hydrogen is used in hydrotreating to remove oxygen from oils/fats. In the PtL pathway, green hydrogen combines with captured CO_2 to create syngas that is converted into synthetic kerosene. In the AtJ pathway, hydrogen is required in the hydrogenation step to stabilize intermediates from ethanol or iso-butanol. Together, these pathways highlight hydrogen's critical role in producing aviation-ready fuels, making the alignment of India's SAF and hydrogen strategies essential[5].

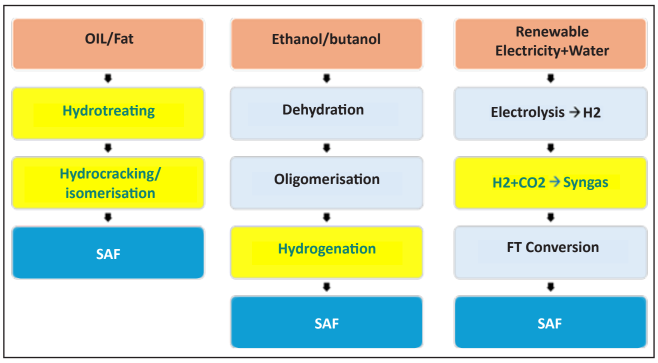


Fig. 1: Hydrogen utilization across SAF production pathways

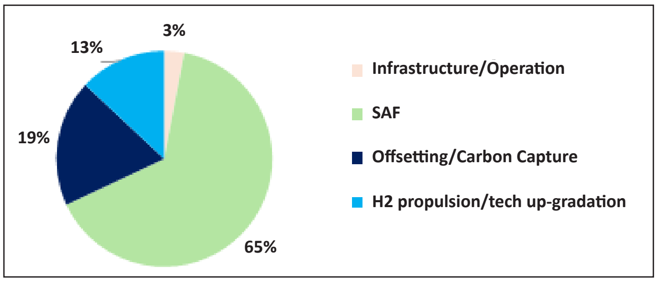


Fig. 2: Global aviation's net zero trajectory

Globally, the International Air Transport Association (IATA) expects SAF to contribute nearly 65% of aviation's emission reductions by 2050, with the remaining ~35% coming from hydrogen propulsion, efficiency gains, new aircraft technologies, etc[6].

Hydrogen-based PtL Fuels are Essential

The hydrogen requirement for SAF production varies significantly depending on the production pathway. **HEFA SAF** requires approximately 50 kg of hydrogen per ton to support hydrotreating, while **AtJ SAF** also consumes hydrogen during the hydrogenation step to stabilize alcohol-derived intermediates. In contrast, **PtL SAF**, produced from green hydrogen and captured CO_2, requires roughly 660 kg of hydrogen per ton of SAF[7].

To meet India's 1% SAF blending target (~112 kilotons of SAF), this translates to ~5.6 kilotons of hydrogen for HEFA/AtJ SAF and ~74 kilotons for PtL SAF. Looking further ahead to 2030, with an estimated 16 MMT of ATF consumption[8], achieving a 5% SAF blend (~800 kilotons) would require around 40 kilotons of hydrogen for conventional HEFA/AtJ SAF and roughly 528 kilotons for PtL SAF.

[1] https://www.pib.gov.in/PressNoteDetails.aspx?NoteId=154274&ModuleId=3; [2] https://www.pib.gov.in/PressReleasePage.aspx?PRID=1979705; [3] https://www.pib.gov.in/PressReleaseIframePage.aspx?PRID=1925417; [4] https://www.consilium.europa.eu/en/press/press-releases/2023/10/09/refueleu-aviation-initiative-council-adopts-new-law-to-decarbonise-the-aviation-sector/; [5] https://www.iata.org/contentassets/d13875e9ed784f75bac90f000760e998/saf-handbook.pdf; [6] https://www.iata.org/en/programs/sustainability/sustainable-aviation-fuels/; [7] https://rmi.org/the-five-dimensions-of-hydrogen/?utm; [8] https://www.hindustantimes.com/india-news/india-presents-feasibility-study-on-sustainable-aviation-fuel-101756840796284.html

This represents about 0.8% of India's projected 5 MMT (by 2030) green hydrogen target for HEFA/AtJ SAF and roughly 10.6% for PtL SAF, illustrating the substantially higher hydrogen demand for synthetic SAF production, and the critical role hydrogen will play in enabling scalable, sustainable aviation fuels in India.

Why Hydrogen Matters for India's SAF Roadmap

With India setting its SAF blending targets, the critical question is not just *how much* SAF is needed, but *how it will be produced at scale*. Hydrogen provides a unique lever here, not as a competing fuel, but as the backbone of synthetic SAF pathways that can complement limited bio-based options.

Hydrogen strengthens India's SAF strategy in several critical ways:

- **Feedstock security:** Relying on HEFA technology is not a sustainable long-term strategy for India, given its dependence on a weak and underdeveloped supply chain for oils and fats. These feedstocks are in limited supply and face high competition from the food and industrial sectors, placing additional stress on an already fragile system.
- **Scalability:** Unlike bio-based SAF, which is capped by land and feedstock availability, hydrogen-based PtL can scale in line with India's renewable energy expansion. With ambitious targets of 500 GW of renewables by 2030, India has the potential to anchor a robust PtL supply chain for aviation.
- **Policy alignment:** India has already launched four hydrogen valleys in Pune, Kerala, Odisha, and Rajasthan, as regional innovation clusters for hydrogen production, storage, and use. These could anchor future SAF production units by supplying hydrogen directly to airport-linked blending facilities.
- **Export opportunity:** Mandates in the EU (2% by 2025, 70% by 2050), the UK (10% by 2030, 22% by 2040), the US (3 billion gallons by 2030 under the SAF Grand Challenge), and Japan (10% by 2030 for international flights) will create sustained global demand for SAF[9]. By aligning its SAF and hydrogen strategies with these international targets, India can position itself as a reliable contributor to global supply chains while strengthening its own energy transition.

Roadblocks on India's Hydrogen-to-SAF Journey

While hydrogen offers a long-term solution for scalable SAF, its adoption faces significant economic, technological, and policy hurdles. Addressing these barriers is critical if India is to move beyond pilot projects and establish PtL as a viable pathway for aviation decarbonization.

- **High costs:** Green hydrogen in India today costs around **\$4–5/kg,** which translates into PtL SAF costs of **\$8–10/l**. This is far higher than the conventional process. For PtL SAF to be commercially viable, hydrogen prices need to fall closer to **\$2/kg**, a level not yet achieved.
- **Capital intensity and infrastructure needs:** PtL production requires investment in large-scale electrolysers, CO_2 capture systems, and Fischer–Tropsch or methanol-to-jet conversion units. Developing this infrastructure involves multi-billion-dollar outlays and long construction timelines, making financing difficult without strong policy support or long-term offtake agreements.
- **CO_2 supply chain:** PtL SAF depends on a steady stream of concentrated CO_2. In India, carbon capture and utilization infrastructure is still nascent, and transporting CO_2 from industrial clusters to SAF plants adds cost and complexity. Building reliable CO_2 logistics is therefore a major bottleneck.
- **Technology maturity:** Unlike HEFA and AtJ, which are already proven at or near commercial scale, PtL remains at **TRL 6–7 globally,** with only a handful of pilot and early demonstration plants in operation. India lacks experience with such projects, creating uncertainty over efficiency, yields, and integration with refinery or airport operations.

Overcoming these challenges will require coordinated policy support, technology demonstration, and investment signals, without which hydrogen's potential to anchor India's SAF roadmap will remain unrealized.

The Way Forward: Unlocking Hydrogen-enabled SAF

To translate ambition into action, India must create the right policy, financing, and infrastructure environment. Key priorities include:

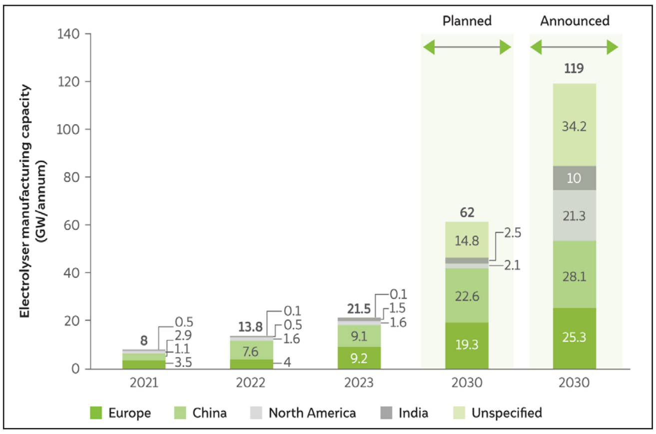
- **Policy integration:** Extend support under the National Green Hydrogen Mission (NGHM) to SAF projects, ensuring hydrogen use in aviation is explicitly recognized. This will align India's aviation decarbonization with its broader hydrogen strategy.
- **Demonstration at scale:** Fund and fast-track 1–2 PtL pilot projects (similar to Norsk e-Fuel in Norway or Atmosfair in Germany) to build local experience, validate technology performance, and de-risk investment.
- **Market creation:** Provide targeted incentives for airlines through viability gap funding and tradable carbon credits to offset the current cost premium of SAF and send a clear demand signal.
- **Hub development:** Position **refineries and major**

contd on pg 23

[9] https://xynteo.com/wp-content/uploads/SAF-Paper-1410.pdf

Removing the Bottleneck: AresTempoH$_2$™ Reimagines Electrolysers to Power India's Green Hydrogen Leap

Green hydrogen is widely seen as the cornerstone of a net-zero economy, but there's a less discussed truth holding back its scale-up: electrolysers themselves are the bottleneck. They are not only expensive, but also heavily dependent on imported membranes and critical minerals.



Global electrolyser manufacturing capacity

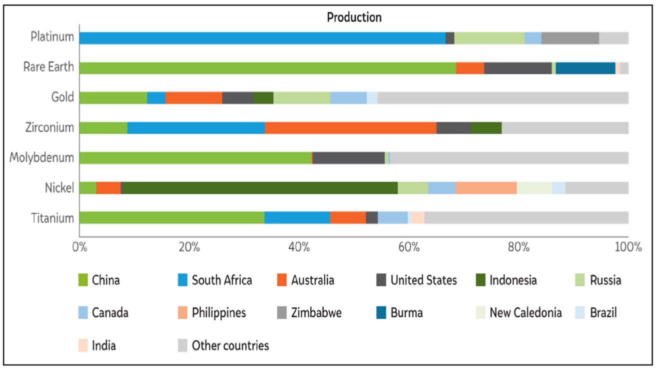
In India, where the National Green Hydrogen Mission (NGHM) targets 5 MMT of annual green hydrogen production by 2030, this challenge is particularly stark. Achieving that goal could require 60–80 GW of electrolysers, but today's supply chains remain dominated by foreign technologies and fragile mineral inputs. Without an indigenous solution, India risks swapping oil dependence for mineral dependence.

The Hidden Bottleneck in Green Hydrogen Scale-Up

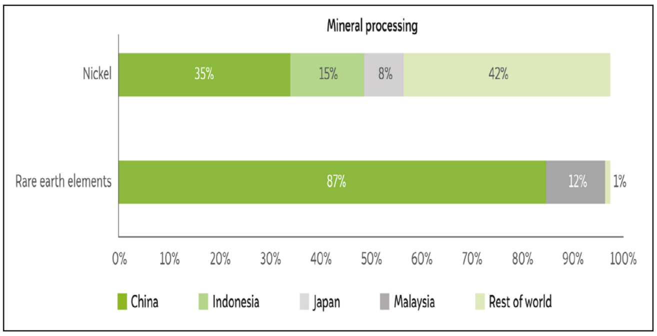
Electrolyser costs today remain daunting:

- Alkaline: \$800–1,000/kW, reliant on Zirfon™ membranes (Belgium) and porous nickel (65% imported from China).
- PEM: \$1,400–1,700/kW, dependent on Nafion™ membranes (U.S. monopoly) and platinum group metals like iridium (~80% sourced from South Africa and Russia).
- SOEC: \$1,100–1,300/kW, requiring rare earth elements like yttrium and lanthanum, ~80% controlled by China.

The challenge isn't just cost. Membrane failures, catalyst



Mineral production globally (Source: CEEW 2024)



Global mineral processing is dominated by China (Source: CEEW 2024)

degradation, and gas crossover reduce reliability and inflate operational expenses. Even as global prices fall, the true bottleneck is materials and supply chain fragility; not manufacturing scale.

India's electrolyser market alone is projected to reach 30 GW by 2030. At current designs, this could translate to \$30-40 billion of imports — a risk that is economical, technological, and geopolitical all at once.

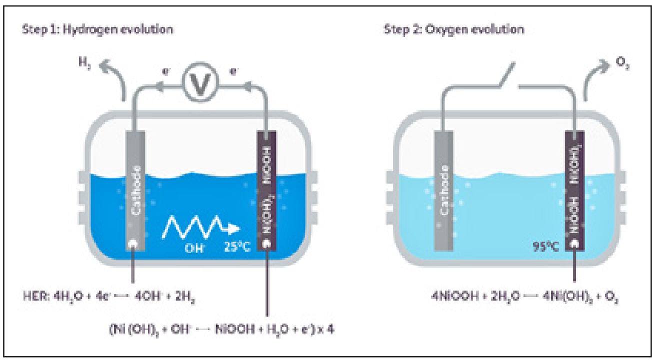
AresTempoH$_2$™: A Game-Changer for Green Hydrogen

At Ares Systems, we asked a simple question: what if the electrolyser itself could be reimagined to bypass these bottlenecks?

Our answer is AresTempoH$_2$™, a membrane-free, decoupled electrolyser that separates hydrogen and oxygen production in time and space.

- Step 1 – Hydrogen Evolution (25-60 ^{0}C): Water is reduced at the cathode, releasing hydrogen while hydroxide ions get deposited on customized anode, storing oxidative charge.
- Step 2 – Oxygen Evolution (95-135 ^{0}C): The anode regenerates spontaneously, releasing oxygen without external power input.

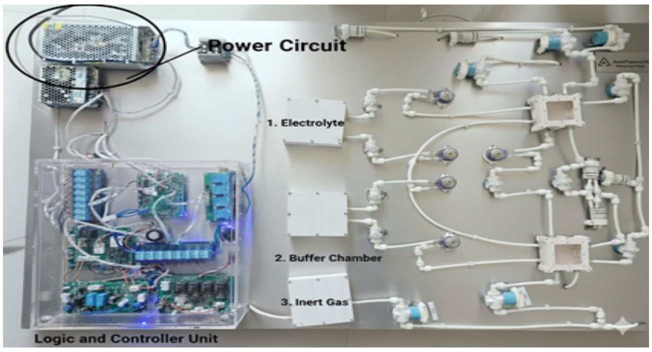
By decoupling these reactions through our proprietary electrodes, AresTempoH$_2$™ achieves safe operation without membranes or platinum-group metals. Proprietary



Decoupled Electrolysis: The Science Powering AresTempoH$_2$™

electrodes and inert gas purging enhance safety, efficiency, and durability; while eliminating reliance on scarce, import-heavy components.

Proprietary electrode powering AresTempoH_2; from concept to reality



Lab validated proof of concept: AresTempoH_2™

Why This Matters: Efficiency, Cost & Self-Reliance

Unlike conventional technologies, AresTempoH_2™ is built on abundantly available materials. This architecture achieves:

- >90% efficiency (HHV), outperforming conventional alkaline and PEM systems.
- CAPEX of $200–400/kW, compared to $800–1,700/kW for today's market technologies.
- 30–50% lower OPEX, thanks to minimal degradation and simplified operation.
- <45 kWh/kg H_2, energy consumption for hydrogen generation, the lowest when compared to conventional technologies.

Most importantly, there is no dependence on imported membranes or rare metals — enabling a fully indigenous, AtmaNirbhar Bharat electrolyser while delivering step-change improvements in cost and performance.

The Bigger Picture

India produced 125 Mt of steel in 2022. Transitioning even 20% of this through hydrogen-based direct reduced iron (DRI) could cut 40 MtCO_2 annually; equivalent to removing 9 million cars from the road. But with conventional electrolysers priced at $800–1,200/kW, the economics are daunting.

With AresTempoH_2™, projected at $200-400/kW, hydrogen steelmaking becomes viable. At scale, the potential is transformative:

- 10 GW of TempoH_2™ by 2035 could abate 20-30 MtCO_2 annually; equal to removing 6 million cars.
- Save $5–7 billion in imports of membranes and catalysts.
- Create 10,000+ skilled jobs in India's hydrogen manufacturing ecosystem.
- Position India as a global exporter of green steel and ammonia.

The Road Ahead

The journey toward scalable green hydrogen is already taking shape. Ares Systems has signed MoUs with Omega Seiki Mobility, a leading Indian electric vehicle manufacturer specializing in commercial electric three-wheelers for last-mile logistics and urban mobility solutions, to pilot AresTempoH_2™ for mobility applications. We also partnered with MatProp, which provides innovative engineering solutions for marine, industrial, and environmental applications with a focus on sustainable technologies for waterways and industrial propulsion systems, to advance hydrogen solutions in the marine and industrial sectors. Furthermore, we received a Letter of Interest from GPS Renewables, a pioneer in biogas and clean fuels technology specializing in industrial decarbonization, renewable energy integration, and sustainable waste-to-energy solutions, to explore collaborations in industrial hydrogen, decentralized energy systems, and integrating green hydrogen into renewable value chains.

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AresTempoH_2™ is a truly indigenous, IP-protected electrolyser technology backed by IIT Ropar and IIT Gandhinagar. Its modular, efficient, and durable design minimizes dependence on imported membranes and critical metals, addressing India's need to avoid mineral dependence while enabling local production at scale.

Beyond innovation in design, AresTempoH_2™ offers a pathway to self-reliant green hydrogen, helping reduce operational costs, and accelerate India's transition to a low-carbon energy future.

Green Ammonia Price Discovery in India: A Step Toward Sustainability

India's fertilizer industry, consuming 17–19 million tons of ammonia annually[1], is undergoing a transformative shift with the adoption of green ammonia under the National Green Hydrogen Mission (NGHM). In August 2025, the Solar Energy Corporation of India (SECI) announced a record-low price of ₹49.75 per kg ($569 per MT) for green ammonia under the Strategic Interventions for Green Hydrogen Transition (SIGHT) program, a significant drop from the 2024 H2Global auction's ₹100.28 per kg ($1,153 per MT)[2]. This milestone promises to reduce India's reliance on imported ammonia by 30% (~720,000 tons per annum).

This article examines the price discovery, auction winners, cost drivers, broader implications, including import substitution, export potential, market development, and associated risks and mitigants, along with a detailed table of the auction winners.

Record-Low Price and Auction Winners

SECI's first green ammonia auction awarded a contract to supply 75,000 metric tons per annum (MTPA) to Paradeep Phosphates Limited in Odisha, marking the start of 13 planned rounds targeting 724,000 MTPA. The winning bid of ₹49.75 per kg ($569/MT), secured by ACME Cleantech Solutions, narrows the cost gap with grey ammonia, priced at $515 per MT in March 2025[3], enhancing viability for phosphatic fertilizers, which do not require additional carbon dioxide for urea production.

Subsequent auctions saw successes from multiple companies, with tariffs ranging from ₹49.75 to ₹64.74 per kg. Below is a comprehensive table of all known winners, prices, quantities, and fertilizer companies based on available data from SECI's 13 auctions under Mode-2A-Tranche-I[4]:

Cost Drivers in Addition to Low-Cost Renewable Power

Policy Incentives

The SIGHT program, backed by ₹17,490 crore[5] under the NGHM, provides subsidies (₹8.82/kg in year one, decreasing

Winner	Tariff (₹/kg)	Tariff ($/MT)	Quantity (TPA)	Fertilizer Company	Location
ACME Cleantech Solutions	49.75	569	100,000	Indian Farmers Fertiliser Cooperative (IFFCO)	Paradeep, Odisha
ACME Cleantech Solutions	54.73	630	100,000	IFFCO	Kandla, Gujarat
ACME Cleantech Solutions	55.75	641	75,000	Paradeep Phosphates Limited	Paradeep, Odisha
ACME Cleantech Solutions	62.84	722	25,000	Paradeep Phosphates Limited	Zuarinagar, Goa
ACME Cleantech Solutions	64.74	738	20,000	Indorama India	Haldia, West Bengal
ACME Cleantech Solutions	51.89	596	50,000	Coromandel International Limited	Vishakhapatnam, Andhra Pradesh
NTPC Renewable Energy	51.80	591	70,000	Krishna Phoschem	Meghnagar, Madhya Pradesh
Jakson Green	50.75	580	85,000	Coromandel International Limited	Kakinada, Andhra Pradesh
Onix Renewables	52.25	600	50,000	Gujarat Narmada Valley Fertilizers & Chemicals	Bharuch, Gujarat
Oriana Power	52.50	603	60,000	Madhya Bharat Agro Products	Sagar, Madhya Pradesh
SCC Infrastructure	53.05	610	70,000	Madhya Bharat Agro Products-III	Dhule, Maharashtra
SCC Infrastructure & InSolare Energy	57.65	657	15,000	Mangalore Chemicals and Fertilisers	Mangalore, Karnataka
Suryam International	50.00	573	4,000	Madras Fertilizers Limited	Chennai, Tamil Nadu

***Notes**: • Tariffs are sourced from SECI auction results reported by Mercom India, Renewable Watch, and Solar Quarter. • The weighted average tariff across auctions is ₹53.27 per kg ($612 per MT). • ACME Cleantech Solutions secured the highest cumulative capacity (370,000 TPA) across six auctions. • Data for one auction (30,000 TPA) is missing, as SECI's total capacity is 724,000 TPA, but only 694,000 TPA is accounted for in available reports.*

[1] PIB [2] Mercom India [3] IMARC Group [4] SECI press release [5] 1 crore = 10 million

to ₹5.30/kg by year three). Central and state incentives include waived interstate transmission charges for 25 years and renewable power banking for 30 days, capital subsidies, duty waivers, surcharge waivers. State governments offer ₹5.05 lakh[6] crore ($61 billion) in support, per a 2025 Council on Energy, Environment and Water (CEEW) study[7]:

- **Odisha**: ₹1.25 lakh crore, including ₹3/unit power tariff rebates and 30% capital subsidies
- **Rajasthan**: 100% exemptions on electricity duty, transmission, and wheeling charges for 10–20 years
- **Uttar Pradesh**: Up to 40% capital subsidies (capped at ₹225 crore) and land allocation at 5 acres per MW.
- **Gujarat and Tamil Nadu**: Capital subsidies, state GST reimbursements, and duty exemptions.

Reducing Electrolyser System Costs

Electrolyser system costs are declining, with China's alkaline electrolysers at <$400 per kW compared to $800–1,200 per kW for Western models[8], reducing capital expenditure by more than 60%. India's manufacturers aim to lower costs to similar numbers as Chinese counterparts per kW, through domestic manufacturing and partnerships with Chinese suppliers, enhancing project economics.

Facilitative Green Hydrogen Certification Approach

India's certification, requiring 2 kg CO_2e/kg H_2 and renewable energy sourcing, is less stringent than the EU's hourly correlation and additionality rules, reducing compliance costs significantly. This flexibility accelerates deployment but may limit exports to stricter markets like the EU, necessitating future alignment.

Implications

Green Premium

The green premium, green ammonia's cost over grey ammonia ($515 per MT in March 2025), is $126 per MT (24.5%) at $641 per MT. SIGHT subsidies, state incentives, and low-cost renewables drive this reduction. For phosphatic fertilizers, the premium is nearly negligible, but urea production faces additional CO_2 capture costs, requiring further innovation to achieve cost parity. It is anticipated that government subsidies would largely absorb the premium, which could cumulatively cost ~1%-3% of current fertilizer subsidy outlay[9].

Import Substitution

Green ammonia significantly reduces India's reliance on imported ammonia, which constitutes a substantial portion of fertilizer production. In 2023, India imported ~2 million

https://fuelcellsworks.com/2024/10/01/green-hydrogen/hygenco-green-energies-launches-one-of-india-s-largest-renewable-energy-tender-for-green-ammonia-project

tons of anhydrous ammonia, valued at $1 billion, primarily from Saudi Arabia, Bahrain, Oman, Indonesia, and Qatar[10]. The planned 21 million tons of green ammonia capacity in the near term could fully substitute imports annually, saving $2-3 billion forex outflow.

Export Potential

India's low production costs position it as a potential exporter to Japan and South Korea, where green ammonia demand is projected to reach 8 million tons by 2030. Exports to the European Union require alignment with stricter certification standards, potentially increasing costs. Developing export infrastructure could unlock $4-6 billion in annual export revenue by 2030.

Market Development

The auctions foster a competitive market, attracting players like ACME, NTPC, and multiple other aspiring green ammonia suppliers. SECI has been effective in bringing together fertilizer companies to participate in the offtake, strengthening the green ammonia markets.

Annual ammonia demand growth of 1 million tons combined with an import substitution target of 1 million tons, in the near term, can provide stable demand outlook for suitable evolution of green ammonia market. This growth creates thousands of jobs by 2030 and encourages private investment and technology transfer, positioning India as a global green ammonia hub.

Challenges and Solutions

- **Contract Duration Mismatch**: SECI purchase contracts span 10 years, while projects last 25 years, creating financial uncertainty post-contract. Extending contracts to 20 years, as proposed by industry stakeholders, aligns with project lifespans, ensuring revenue stability and improving bankability.
- **Policy Stability**: Inconsistent policies could deter investment. State subsidies account for ₹5 lakh crore and many states that have announced incentives need

[6] 1 lakh = 100,000 [7] CEEW [8] Hydrogen Insights [9] Umagine, CEEW [10] World Bank

to provision 60% of the subsidy through already strained fiscal resources. Long-term frameworks with bipartisan support, backed by strong fiscal position, build investor confidence and reduce regulatory risks.

- **Renewable Energy Variability**: Variable solar and wind loads require reliable plant designs. Modular designs with battery storage or hybrid solar-wind systems, ensure consistent production, mitigating energy supply risks.
- **Learning Curve**: Developers face challenges handling gas molecules, especially new entrants. Partnerships with gas industry players are critical, and NGHM's focus on skill development should effectively bridge this skill and knowledge gap, enhancing operational expertise.
- **Financial Resilience**: Strong balance sheets are critical to absorb cost or policy shocks. Government-backed loan guarantees and risk-sharing mechanisms with original equipment manufacturers (OEMs) and project developers could be required to assure investors and enable sustainable scale-up of the sector.

Conclusion

The record-low green ammonia price of ₹49.75 per kg, driven by SIGHT and state incentives, advances India's fertilizer industry. Winners like ACME, Jakson Green, and others have leveraged policy incentives, access to favorable renewable energy resources, low-cost electrolysers, and enabling certification regime, to narrow green premium. Beyond subsidies, green ammonia enhances import substitution, export potential, market development, and supply chain maturity, saving billions in foreign exchange and positioning India as a global hub. Mitigating risks through extended offtake, robust project and plant designs, and training ensures scalability, decarbonizing agriculture and strengthening India's green hydrogen economy.

Author:
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Torrent Group Launches Uttar Pradesh's ......contd from pg 14

Jinal Mehta, Director of Torrent Group, echoed the sentiment, highlighting the company's commitment to India's energy transition:

"Torrent Group is committed to being a key player in Hon'ble Prime Minister Shri Narendra Modi's vision for India's Energy Transition and NGHM. The commissioning of Torrent Power's Green Hydrogen plant in Gorakhpur and its integration into Torrent Gas' CGD infrastructure in Gorakhpur, is a major milestone in this endeavor. It marks the culmination of the first initiative in our long-term vision of setting up large scale green hydrogen plants in the country for various use cases, including for blending with natural gas in the CGD network. Blending Green Hydrogen into Gorakhpur's gas grid is a step in achieving practical, scalable pathway to net-zero target of the country. It lowers emissions, builds demand for green molecules, and creates a platform for deeper de-carbonization in transport and industry. This initiative showcases how innovation, sustainability and collaboration can work together to deliver clean energy and pave the way for a more self-reliant future"

He also expressed gratitude to the Government of Uttar Pradesh and the Chief Minister for their support in promoting clean energy solutions.

For further information, please refer:
https://www.torrentpower.com &
https://www.torrentgas.com

Enabling India's SAF Roadmap ......contd from pg 18

airports as dual decarbonization hubs. Refineries bring hydrogen expertise and proximity to CO_2 sources, while airports can host SAF blending and hydrogen pilots with major hubs. Together, these can create integrated supply chains linking hydrogen, CO_2, and aviation fuel demand.

- **Global positioning:** Leverage India's potential for low-cost green hydrogen to tap into export opportunities. With the EU, UK, US, and Japan setting ambitious SAF mandates, India can position itself as a competitive supplier to meet the emerging demand gap.

Conclusion

India's aviation sector is at a pivotal moment in its energy transition. With surging domestic air travel and established SAF blending targets, the challenge lies not in ambition, but scale, and here hydrogen is the critical unlock. Conventional SAF routes like HEFA are constrained by weak and underdeveloped oil/fat supply chains, while AtJ depends on biomass, which is already stretched across other programs.

Hydrogen, by contrast, enables PtLs, a pathway independent of traditional biomass-based feedstocks, scalable with India's renewable energy growth, and capable of meeting both domestic and global SAF demand. By aligning SAF ambitions with the NGHM, and leveraging airports and refineries as decarbonization hubs, India can establish hydrogen as the cornerstone of a sustainable aviation future.

Author:
Bhaskar Jha, Consultant, Xynteo

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- Are you a venture capital or private equity investor or project financier, looking for opportunities to invest in clean hydrogen technologies and projects?
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