India's Emerging Green Hydrogen Transition

Ambitions, Barriers and Policy Directions

Author
Dwarkeshwar Dutt

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Summary

This discussion paper examines the domestic and global drivers of India's green hydrogen push and develops a contextualised understanding of India's green hydrogen initiatives and the challenges to realizing them. In India, green hydrogen has been positioned as a tool for decarbonization, energy security, industrial growth, and global leadership. The National Green Hydrogen Mission, launched in 2023, targets 5 million metric tons of annual production by 2030, deep integration into hard-to-abate sectors like fertilizers and steel, and exports capturing 10% of the global market. Domestically, green hydrogen aligns with India's renewable energy expansion, surplus energy utilization, and food security needs via green ammonia production. Globally, rising demand, recurring geopolitical shocks — including the Russia-Ukraine war and the more recent Iran war — and the EU's Carbon Border Adjustment Mechanism (CBAM) create both opportunities and pressures. India also seeks to build a strategic techno-economic niche through domestic electrolyzer manufacturing, R&D, and public-private partnerships. However, significant structural challenges persist: high production costs, water and land constraints, weak infrastructure, and limited R&D capacity. Of the roughly 6 million metric tons per annum of projects announced, only around 220,000 tonnes per annum have reached the final investment decision stage, underscoring the substantial gap between ambition and reality. The paper also cautions that North-South green hydrogen partnerships, while potentially beneficial, risk creating new forms of energy dependency if not carefully structured. To bridge the gap between ambition and execution, India should pursue stronger financial incentives, streamlined regulations, infrastructure investment, and demand-side mandates.

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1 Introduction

Hydrogen is a clean energy carrier that produces only water as a by-product when combusted. It is widely recognized as a versatile, source-independent energy carrier with a high energy value per unit mass compared to petroleum-based fuels (Qureshi et al., 2022). It is therefore unsurprising that green hydrogen is increasingly being considered a cornerstone of the global low-carbon transition.

India is the third-largest emitter of greenhouse gases (GHG), contributing 6.94% (2.299 gigatons) of global emissions, following China and the United States, which account for 28.6% and 14.57%, respectively (ibid.). Several experts argue that green hydrogen could play a significant role in India's energy transition. A range of converging forces—including climate imperatives, energy security concerns, the development of industrial capabilities, pressures to decarbonize industry, and shifting geopolitical dynamics—have brought green hydrogen into sharp focus within India's energy discourse. However, building a robust green hydrogen ecosystem in India remains a formidable challenge.

India is still in the early, yet decisive, stages of developing its green hydrogen sector. Decisions taken in the coming years will determine whether the country can capture early-mover advantages in a rapidly evolving global hydrogen economy or remain a follower. This paper explores the domestic and global drivers of India's green hydrogen ambitions and examines the challenges to realizing them. By situating these ambitions within a broader context, it aims to provide a comprehensive understanding of India's green hydrogen strategy and to identify potential policy directions.

2 Domestic drivers

2.1 Extension of India's broader and multi-dimensional RE narrative

Renewable energy (RE) was systematically integrated into India's broader development goals and energy policy with the launch of the National Solar Mission (NSM) in 2010. Prior to the NSM, most RE deployment—particularly solar—was largely confined to decentralized applications in rural areas (Maycock, 2005; Shrimali and Rohra, 2012). However, the launch of the NSM, which is widely regarded as India's first comprehensive solar programme, marked a significant shift towards utility-scale solar deployment, the development of domestic manufacturing capabilities, and the establishment of a complete solar value chain (Shrimali and Rohra, 2012).

The NSM was designed in three phases: Phase I lasted until 2013, Phase II from 2013 to 2017, and Phase III from 2017 to 2022. The mission initially set a target of 20 gigawatts (GW) of grid-connected solar capacity (including rooftop installations) to be achieved by the end of the third phase (Altenburg and Engelmeier, 2013; Behuria, 2020). In parallel, from the late 2000s onwards, the Indian private sector began to show increasing interest in Clean Development Mechanism (CDM) projects, viewing climate change mitigation as a potential business opportunity (Pulver, 2012). In 2014, the Government of India raised its solar deployment target from 20 GW to 100 GW by 2022; this target was later further expanded to 280 GW by 2030 (Aggarwal, 2021). By the end of 2022, India had installed an impressive 77.6 GW of solar capacity, although it fell short of its 2022 target (Gupta, 2023).

India's first comprehensive electric vehicle (EV) policy, the National Electric Mobility Mission Plan (NEMMP), was launched in 2013. The NEMMP aimed to promote hybrid and electric vehicles and set an ambitious target of achieving 6–7 million EV sales annually from 2020 onwards through a combination of fiscal and monetary incentives. It was followed by two major policy initiatives: the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) Phase I in 2015 and FAME Phase II in 2019 (PIB, 2019; PIB, 2023). The FAME schemes were introduced under the NEMMP to support the holistic development of the EV ecosystem, including demand creation, technology development, charging infrastructure, and demonstration projects (PIB, 2019a).

This brief overview of India's renewable energy (RE) initiatives—particularly in solar—highlights a clear shift from the pre-2010 period, when RE development was primarily aimed at addressing rural energy needs, to a more multi-dimensional policy approach. Today, RE policy in India seeks to address a range of objectives, including climate mitigation, net-zero targets, energy security, and energy access (especially rural access through off-grid solar) (Government of India, 2010). In parallel, India has sought to position itself as a global leader in the renewable energy domain. As part of this ambition, it co-founded the International Solar Alliance in collaboration with the Government of France to promote the global diffusion of solar technologies (Shidore and Busby, 2019).

India's ambitions regarding green hydrogen must be understood within this broader evolution of its RE policy framework, which increasingly integrates multiple objectives. As the country seeks to meet rising energy demand while pursuing its net-zero target by 2070, many experts argue that green hydrogen, much like solar energy, will play a critical role in India's sustainable energy strategy (Harichandan et al., 2023). Hydrogen is also expected to be central to advancing India's energy security, industrial development, global positioning, and overall decarbonization efforts (Singh et al., 2022; PIB, 2024a).

The Government of India launched the National Green Hydrogen Mission (NGHM) in 2023, envisaging a wide range of activities, including research and development, infrastructure creation, research collaborations, regulatory frameworks, standards-setting, pilot projects, and international cooperation (Singh and Bajpai, 2025; Athia et al., 2024) (see Table 1). The mission aims to establish a green hydrogen production capacity of at least 5 million metric tons (mmt) annually and to reduce emissions by around 50 mmt by 2030 (Athia et al., 2024). It has allocated approximately $2.3 billion to incentivize commercial green hydrogen production (Gili and De Blasio, 2024) and seeks to increase the share of green hydrogen in India's total hydrogen demand to 46% by 2030 (National Green Hydrogen Mission, n.d.). Another key objective is to position India as a global leader in the green hydrogen industry. To this end, the government has set a target of exporting around 10 mmt of green hydrogen and green ammonia annually by 2030, which would correspond to roughly a 10% share of the global market (Singh and Bajpai, 2025).

TABLE 1 KEY COMPONENTS OF INDIA'S NATIONAL GREEN HYDROGEN MISSION

S. no.	Component	Description
1	Strategic Interventions for Green Hydrogen Transition program (2023)	Incentives for electrolyser manufacturing
2	Pilot projects	Includes pilot projects on mobility, shipping, and low-carbon steel
3	R&D projects	Strategic Hydrogen Innovation Partnership (SHIP) – a public-private R&D partnership with a dedicated fund
4	Green hydrogen hubs	Setting up green hydrogen hubs in areas with refineries and fertilizer plants
5	Regulatory framework	Focuses on incentives like waiving interstate transmission charges and "renewable energy banking"[1]
6	Infrastructure	Developing robust transportation and distribution networks for green hydrogen
7	Skills development	Developing human resources in collaboration with the Ministry of Skill Development and Entrepreneurship

India's current hydrogen consumption is estimated at around 6 million metric tons per annum (mmtpa), with the majority used in oil refining and ammonia production, and the remainder consumed by the steel and chemical industries. This demand is expected to grow significantly, reaching approximately 12 mmtpa by 2030 (Anand, 2023). At present, most hydrogen in India is produced from natural gas, around 50% of which is imported. As a

[1] Renewable energy banking is a mechanism that allows green hydrogen producers to feed excess electricity into the grid during periods of peak generation and withdraw it later to power electrolyzers during non-solar hours. Under the Green Hydrogen Policy, this facility is typically limited to a 30-day cycle.

result, rising hydrogen demand could further increase India's already substantial energy import dependence, posing a challenge to energy security. Developing a domestic green hydrogen production ecosystem is therefore critical for advancing India's energy security and energy independence objectives.

India's renewable energy capacity is also expected to expand substantially, as the government aims to raise the share of renewables in total power generation to 50%, with solar energy playing a leading role in this transition (Balasubramanian and Balachandra, 2022). Surplus electricity—often subject to curtailment—could be harnessed for green hydrogen production, as excess renewable energy can be used to produce hydrogen on-site and subsequently transported for end use (Sontakke and Jaju, 2021; Sambasivam and Yuan, 2023).

2.2 Food security and fertilizer production

In many hard-to-abate sectors, including ammonia and fertilizer production, electrification remains challenging, and emissions reductions are difficult to achieve. However, as major carbon emitters, these sectors face increasing pressure to decarbonize (Das, 2023; Roy et al., 2024). Green hydrogen can play an important role in this process; indeed, the decarbonization of such hard-to-abate sectors is a key driver of its development both globally and in India (He et al., 2021). Among Indian industries, ammonia production is expected to be a major source of future green hydrogen demand. Even today, it is one of the largest consumers of hydrogen in the country (Midilli and Dincer, 2007). Moreover, ammonia and fertilizer production are not only a hard-to-abate sector but are also closely linked to India's food security.

India is home to the world's largest population (around 1.38 billion). Agriculture not only ensures food security for this vast population but also provides livelihoods for roughly 50% of it. Approximately 309 million tonnes (Mt) of food grains are currently required to meet India's food security needs, and this figure is expected to rise to 400 Mt by 2050 in line with population growth (Shukla et al., 2022). Food grain production in India has increased significantly over recent decades, driven in large part by rising fertilizer consumption (Fertiliser Association of India, 2021). Increased fertilizer use has thus enabled India to achieve self-sufficiency in food grain production and strengthen its food security (Government of India, 2023). Generous policies aimed at keeping fertilizers affordable have long been a central component of India's agricultural strategy; as a result, the country is now the world's second-largest consumer of fertilizers (Sapkota, 2025).

The manufacturing process for fertilizers, particularly nitrogen-based fertilizers, is energy- and emission-intensive, as it relies on natural gas to produce hydrogen for ammonia synthesis via the steam methane reforming (SMR) process. The resulting ammonia is then used to produce urea (a nitrogen-based fertilizer, or N-fertilizer) (Manna et al., 2021). In addition, greenhouse gas emissions arise during the application of N-fertilizers, particularly in the form of nitrous oxide (N_2O). Globally, around 6% of total anthropogenic GHG emissions originate from the production and application of N-fertilizers (Smith et al., 2008). In India, ammonia production accounted for approximately 25 mtpa of CO_2-equivalent emissions in 2022–23 (Patidar et al., 2024), while the chemicals and fertilizer sector more broadly contributed about 12% of the manufacturing sector's greenhouse gas emissions (Das, 2023). India consumed around 17–19 mmtpa of ammonia—both directly for fertilizer production and indirectly through fertilizer imports—in 2022–23, of which roughly 84% was used for urea production (Kothadiya et al., 2024).

The cost of natural gas constitutes a substantial share of urea production costs—around 90%—as the Indian fertilizer industry depends heavily on imported gas. Consequently, even minor fluctuations in global natural gas prices can significantly affect domestic gas and fertilizer prices. This import dependence exposes the fertilizer and agricultural sectors to economic and geopolitical risks (Das, 2023; Kothadiya et al., 2024) and makes India's fertilizer subsidy regime highly sensitive to volatility in international gas markets (Kothadiya et al., 2024).

With a growing population and the risk of declining crop yields due to climate change, the importance of fertilizers in Indian agriculture is likely to increase (Das, 2023). In this context, green ammonia (and subsequently green urea) production using green hydrogen is seen as a promising pathway to decarbonize the fertilizer sector while maintaining food security (Nayak-Luke et al., 2022). However, securing a reliable source of CO_2 for urea synthesis—potentially from industrial sources such as steel production—remains a key challenge for scaling up green ammonia production (Nallapaneni and Sood, 2023).

Several studies have highlighted India's potential for green ammonia production, driven by its substantial renewable energy resources (Nayak-Luke and Banares-Alcantara, 2020). With supportive policies and an enabling regulatory framework, the Energy and Resources Institute (TERI) estimates hydrogen demand in the fertilizer sector at around 3 million tonnes per annum (mta) (Hall et al., 2020). Moreover, domestically produced green ammonia could reduce India's dependence on natural gas imports, thereby enhancing energy security and resilience to volatile global energy prices (Harichandan et al., 2023).

A particularly encouraging development for green ammonia is the record-low tariff of US$ 594–774 per tonne discovered in recent auctions conducted under the National Green Hydrogen Mission (NGHM) by the Solar Energy Corporation of India Limited (SECI) in August and September 2025. This compares favourably with the US$ 1,160 per tonne awarded in the most recent European green ammonia auction for a project in Egypt. These developments suggest that green hydrogen in India may be approaching commercial viability relative to imported grey ammonia. A key feature of these auctions was the inclusion of a strong payment security mechanism (PSM), which reduces the risk of payment delays from fertilizer companies to producers (Kothadiya and Yadav, 2025).

The Government of India has adopted an ambitious target of substituting all ammonia imports used in fertilizer production with domestically produced green ammonia by 2035. If achieved, this could result in annual savings of approximately US$ 12 billion in fertilizer subsidies (Shah, 2022). The NGHM also mandates the establishment of green ammonia bunkering and refuelling facilities in at least one port by 2025 and in all major ports by 2035. Tuticorin Port on India's east coast has been designated as the country's first green ammonia refuelling hub (Gili and De Blasio, 2024).

Support from both central and state governments, including financial incentives and subsidies, has also helped generate private sector interest. A notable example is the US$ 4.3 billion investment by Sembcorp Industries in a state-of-the-art green hydrogen and green ammonia production facility in Tamil Nadu. The project will have an annual production capacity of 200,000 tonnes and is also intended to supply exports to Japan (Raizada, 2025). Similarly, Rashtriya Chemicals and Fertilizers (RCF) and Gas Authority of India Limited (GAIL) have formed a joint venture to establish a green hydrogen plant in Maharashtra, which will use solar and wind energy to produce hydrogen for green ammonia synthesis. The Avaada Group has also announced an investment of around US$ 1 billion in Gopalpur, Odisha, for green ammonia production. Located close to the deep-sea port at Gopalpur, the project—scheduled for completion by December 2026—also targets green hydrogen exports (Yadav, 2024).

One of the most high-profile green ammonia projects to reach the final investment decision (FID) stage is the facility in Kakinada, Andhra Pradesh, developed by AM Green Ammonia (a subsidiary of the AM Green Group). The plant is expected to begin production in the second half of 2026. Once operational, it will produce 1 million tonnes per annum (mtpa) of green ammonia initially, scaling up to 5 mtpa by 2030. At full capacity, it is expected to be among the largest facilities globally, with a majority of its output destined for export to Europe (NS Energy Business, 2024).

2.3 Developing a strategic techno-economic niche

In any emerging industry such as green hydrogen, countries tend to make substantial investments to create strategic industrial niches, stimulate economic growth, gain early-mover advantages, and position themselves as global leaders. Establishing a strong early presence can enable countries to capture market share, set industry standards, and influence future technological pathways. One of the key reasons India has strongly embraced green hydrogen is its ambition to position itself as a "global leader" in this space. Government officials and bureaucratic actors have repeatedly emphasized India's intention to leverage its resources to become a global leader in green hydrogen production and utilization (PIB, 2025).

Recent studies also support this framing. Singh and Ghosal (2024) argue that the NGHM should be understood as a strategic initiative aimed at positioning India at the forefront of global green hydrogen development. Similarly, Jayakumar et al. (2022) highlight that building domestic capabilities in electrolyzer manufacturing could significantly strengthen India's energy economy, enable active participation in the emerging global green hydrogen market, and help capture economic gains from the energy transition. Gili and De Blasio (2024) further note that India's ambition to become a global green hydrogen powerhouse by the next decade forms part of its broader industrial strategy to achieve a US$ 5 trillion economy by 2028, primarily through the development of indigenous manufacturing and R&D capabilities.

Manufacturing has long been a structural weakness in India's economy, and renewable energy in general is increasingly seen as an opportunity to strengthen domestic industrial capacity. In this context, green hydrogen is viewed as a potential lever for developing indigenous manufacturing. It is argued that India's flagship industrial initiative—Make in India—can be aligned with the development of industrial capabilities in the green hydrogen sector, particularly in electrolyzer manufacturing (Hall et al., 2020). The NGHM is also expected to attract investments of up to US$ 96 billion and create over 600,000 clean energy jobs (Raizada, 2025).

Creating a fully-fledged green hydrogen industrial value chain would help reduce dependence on foreign manufacturers, a pattern already observed in India's solar transition, which has been significantly driven by Chinese imports (Gili and De Blasio, 2024). The Indian government think tank NITI Aayog estimates that India's electrolyzer market could reach a valuation of US$ 5 billion by 2030 and US$ 31 billion by 2050 (Raj et al., 2022). The development of the electrolyzer industry is also expected to enhance the competitiveness of the Make in India manufacturing initiative (Barman et al., 2025).

Under the Strategic Interventions for Green Hydrogen Transition (SIGHT) programme, the government plans to develop domestic electrolyzer manufacturing capacity with an outlay of approximately US$ 2.1 billion up to 2029–30. Within this programme, US$ 176 million is allocated for pilot projects, US$ 48 million for research and development, and US$ 46 million for other mission components (Barman et al., 2025). The initiative is expected to significantly reduce green hydrogen production costs and support the establishment of a robust industrial value chain in India. As of April 2024, the government has awarded tenders for 1,500 MW of electrolyzer manufacturing capacity and 412,000 tonnes of green hydrogen production capacity (Sambasivam and Sarma, 2024). The state-owned National Thermal Power Corporation (NTPC) aims to reduce production costs below US$ 2/kg by 2025–26, which is considerably faster than most global projections (Shah, 2022).

The government has also introduced a phased R&D programme for green hydrogen development, structured across short (0–5 years), medium (0–8 years), and long-term (0–15 years) horizons, with a total outlay of approximately US$ 0.48 billion (Sambasivam and Sarma, 2024). Short-term projects focus on developing domestic modular electrolysers and compressed hydrogen storage tanks (Type 3 and Type 4). Medium-term projects aim to develop critical electrolyzer and fuel cell components, such as bipolar plates, while long-term objectives focus on building competitive advantage and generating global intellectual property for India's green hydrogen industry (National Green Hydrogen Mission, n.d.).

India's current electrolyzer capacity stands at less than 1 GW, but the government has set an ambitious target of 20 GW by 2030. The SIGHT programme—with an outlay of US$ 1.9 billion until FY2030—forms the central pillar of this expansion. Under this scheme, the Solar Energy Corporation of India (SECI) has already awarded 2.3 GW of electrolyzer manufacturing capacity (Anand, 2025).

TABLE 2 ELECTROLYZER MANUFACTURING AWARDS UNDER THE SIGHT PROGRAM

S. no.	Name of the bidder	Capacity (MW)	Electrolyzer type
1	Reliance Electrolyzer Manufacturing Limited	300	Alkaline
2	Ohmium Operations Private Limited	137	PEM
3	John Cockerill Greenko Hydrogen Solutions Private Limited	300	Alkaline
4	Advait Infratech Limited	100	Alkaline
5	L&T Electrolyzer Limited	300	Alkaline
6	Matrix Gas Renewables Limited	63	Alkaline
7	Homi Hydrogen Private Limited	101	AMSE/Solid Oxide
8	Adani New Industries Limited	198	Alkaline

A public–private partnership framework called SHIP (Strategic H2 Innovation Partnership), with dedicated funding, is also planned under the National Hydrogen Mission to identify and support Centres of Excellence (CoEs) and to foster technology innovation and development (Sambasivam and Sarma, 2024). To complement government initiatives, the private sector has also announced substantial investments in green hydrogen. For instance, Reliance Industries (RIL) aims to reduce the cost of green hydrogen to below US$ 1/kg within a decade (Shah, 2021). The company has also announced a capital outlay of US$ 10 billion to develop manufacturing capacity for clean energy technologies, including electrolysers, for green hydrogen production. Renewable energy developer ACME has already commissioned semi-commercial green hydrogen production capacity in Bikaner, Rajasthan (Shah, 2022) (see Table 2 for private sector initiatives in electrolyzer manufacturing).

3 Global drivers

3.1 Emerging global markets

In the coming years, estimates suggest that the global market for green hydrogen and its derivatives could exceed 100 mmt by 2030 and reach 528 mmt by 2050. Moreover, some countries are expected to emerge as major production hubs, while others will become key consumers (Ogino and Son, 2025; Madheswaran et al., 2024). Countries and regions that have traditionally been energy importers, such as South Korea, the EU, and Japan, are likely to fall into the latter category and have already begun exploring the prospects of importing green hydrogen in the form of liquefied hydrogen or ammonia (Kang et al., 2015). These potential importers are expected to generate global green hydrogen trade worth approximately US$ 24–36 billion by 2030 (Kamath, 2024).

A review of the energy transition roadmaps of the EU, Japan, and South Korea indicates that these actors largely envision themselves as future green hydrogen importers. Together, they are expected to import around 12 mmt of green hydrogen by 2030, creating an annual trade opportunity of US$ 24–36 billion for exporting countries (Energy Transitions Commission, 2021; Kamath, 2024). By contrast, the United States and China are expected to produce substantial volumes of green hydrogen, but primarily for domestic consumption rather than export (Kamath, 2024).

Against this backdrop, several experts argue that India, if it develops robust infrastructure and strategic international partnerships, could play an important role in meeting rising global demand for green hydrogen by leveraging its cost-competitive renewable energy base (Ogino and Son, 2025). The prospect of an expanding global green hydrogen market is therefore seen by some as a “once-in-a-lifetime opportunity” for India to engage more deeply in global energy and commodity trade (Madheswaran et al., 2024; Kamath, 2024).

This burgeoning global green hydrogen trade will provide an opportunity for Indian companies to enter export markets for green hydrogen and hydrogen-based low-carbon products such as green ammonia and green steel (Sadik-Zada, 2021). Kamath (2024) argues that the emergence of a global green hydrogen market provides a strong rationale for India to concentrate on developing its domestic green hydrogen infrastructure. By taking early and proactive steps, India could secure a larger share of this evolving global market. In addition, a significant share of green hydrogen trade is expected to take place through long-term contracts. As a result, importing countries are likely to prefer suppliers with robust infrastructure as well as stable enabling conditions, such as high political stability, strong trade relations, and reliable supply chains (ibid.).

However, becoming a green hydrogen export hub will require a robust transport ecosystem. In this context, India is exploring multiple strategies. One option is the liquefaction of hydrogen at -253°C for transport in specialized cryogenic tankers. While this approach is suitable for supplying high-purity hydrogen for industrial use, it requires significant technical expertise. The government is considering upgrading Kandla and Tuticorin ports to support this pathway (Kogekar et al., 2026). Another option involves chemically binding hydrogen to liquid carriers (such as toluene), which can then be transported using existing oil tanker infrastructure. Indian researchers are also working on developing liquid organic hydrogen carrier (LOHC) systems that enable hydrogen transport in stable liquid form without the need for extreme temperature or pressure conditions. However, at present, none of these transport options are cost-competitive.

Denmark and Japan have already expressed interest in developing a green hydrogen trade with India in the near future. In addition to promoting hydrogen trade, India and Japan are also exploring cooperation in joint research and development. Japan is actively engaged in R&D aimed at reducing electrolyzer costs, an area of high relevance for India (Otaki and Shaw, 2023). The NGHM aims to develop at least 5 mmt of green hydrogen production capacity annually by 2030, with the potential to scale up to 10 million metric tons to serve expanding export markets. To position India as a green hydrogen export hub, the mission also seeks to foster strategic international partnerships to facilitate exports of green hydrogen and its derivatives, with the broader ambition of capturing around 10% of the global green hydrogen market (Ogino and Son, 2025; Raizada, 2025).

A crucial factor in promoting green hydrogen exports is the adoption of global standards. In this context, the Ministry of New and Renewable Energy (MNRE) initiative Green Hydrogen Standards in India, which provides clarity on key parameters for green hydrogen, represents an important step toward ensuring safety while maintaining practicality. The standards define a well-to-gate emissions threshold of 2 kg CO_2 per kg of hydrogen, clarify permissible renewable energy inputs, and introduce rules for grid-connected production, among other provisions.

India's largest power utility, the National Thermal Power Corporation (NTPC) Limited, is among several prominent Indian companies that have expressed interest in entering the green hydrogen export market (Madheswaran et al., 2024). NTPC has recently signed a land lease agreement with the Andhra Pradesh Industrial Infrastructure Corporation (APIIC) for the development of an Integrated Green Hydrogen Hub, which includes the construction of India's largest green hydrogen production facility (1,200 tonnes per day) across 1,200 acres. The project is primarily aimed at export markets, with green hydrogen to be converted into derivatives such as green ammonia and green methanol (Nikhil et al., 2024).

India is also actively pursuing "hydrogen diplomacy" to secure export markets. As part of this strategy, it hosted the 41st Steering Committee meeting of the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) in New Delhi in 2024, attended by delegates from the European Commission, the United States, Japan, Germany, the UAE, France, the Netherlands, the United Kingdom, Austria, Singapore, Chile, and South Korea (National Green Hydrogen Mission, n.d.). In September 2022, the first EU–India Green Hydrogen Forum was also held in New Delhi to discuss the EU's plans to invest in green hydrogen capacity in India (Gili and De Blasio, 2024). India has further established a strategic partnership with Japan on green hydrogen technology development and recently announced the Australia–India Green Hydrogen Taskforce to develop an integrated hydrogen supply chain in the Indo-Pacific region, reduce production costs, and accelerate technological innovation (Kala, 2022). In addition, India is pursuing partnerships with Gulf and Mediterranean countries to gain access to European markets. For example, the Adani Group has announced plans to develop up to 10 GW of solar and wind capacity dedicated to green hydrogen production for European markets (Gili and De Blasio, 2024).

It is worth noting that global expectations surrounding green hydrogen have recently begun to moderate. In Europe and the United States, several planned projects have been cancelled or significantly delayed due to weak offtake, high costs, and policy uncertainty (Global Hydrogen Hub, 2025). Nevertheless, structural drivers for green hydrogen are still considered to be intact despite this slowdown in investment momentum (Collins, 2025). Overall, India continues to believe that its vast renewable energy potential provides a structural advantage in producing low-cost green hydrogen. As a result, it views green hydrogen both as an opportunity to decarbonize its economy and as a strategic pathway to position itself as a future low-cost exporter of green hydrogen and its derivatives (Gupta, 2025).

3.2 Geopolitical shocks

The development of a global green hydrogen trade has gained renewed urgency in the context of the Russia–Ukraine war. The conflict has significantly pushed up global energy prices, and with the war ongoing, prices are expected to remain high and volatile in the near future as well (Shah, 2022). Russia is also a major player in global fertilizer markets, being the second-largest producer of ammonia and urea, a leading producer of potash, and the fifth-largest producer of phosphatic fertilizers. It accounts for around 23% of global ammonia exports, 14% of urea exports, 21% of potash exports, and 10% of complex phosphate exports (Baxi, n.d.).

Gas prices, for instance, have shown extreme volatility due to disruptions caused by the war. They increased from around $10.75/MMBtu (million British thermal units) in January 2021 to $33.00/MMBtu in January 2022. This volatility has severely disrupted gas supply to Europe, raising concerns about the continent's energy security (Mazneva, 2022). Europe has historically been heavily dependent on Russian gas imports. Following the war, sanctions on Russia and the resulting disruption of gas flows led several EU member states to make emergency purchases on the global spot market. This is particularly evident in Germany, which is often seen as a frontrunner in the energy transition (Prys-Hansen and Kaack, 2023).

Natural gas is a key feedstock for fertilizer production, including in India, where it accounts for around 70–80% of production costs. In the aftermath of the war, global fertilizer prices have risen sharply due to high and volatile gas prices. Urea prices, for example, reached an all-time high of $794 per tonne in 2022 (Shah, 2022). India is import-dependent not only for fertilizers but also for key inputs and intermediates such as natural gas, sulphur, and ammonia. As the Ukraine crisis has disrupted global gas and fertilizer supply chains, many energy experts in India argue that it reinforces the need for greater energy security and reduced dependence on imported fossil fuels. In this context, green hydrogen is increasingly seen as a promising alternative pathway (Arun, 2022).

The Russia–Ukraine war has also triggered significant activity in the global hydrogen sector (Policy Circle Bureau, 2022). In its World Energy Outlook 2022, the IEA notes that the crisis is likely to accelerate investments in renewable energy, including green hydrogen, in the coming years. The report estimates that global clean energy investments could rise from around $1.3 trillion in 2022 to over $2 trillion annually by 2030, with a significant share expected to flow through bilateral and multilateral hydrogen partnerships (IEA, 2022).

An interesting outcome of the war has been that it has increased the cost of production of grey hydrogen and, by comparison, made green hydrogen relatively more cost-competitive (Shah, 2022). Thus, the Russia–Ukraine war is considered to have "turbocharged" the green hydrogen sector, which was already experiencing growth. It is estimated that the war will push up the cost of blue and grey hydrogen to around $8/kg and $14/kg, respectively, while bringing down the cost of green hydrogen to around $4/kg in some regions (Matich, 2022). Recent data on global gas prices show that they remained elevated throughout 2024, which has kept the cost of grey hydrogen relatively high. In contrast, green hydrogen costs have been declining in India (PTI, 2025). For instance, India discovered its lowest-ever green hydrogen price of approximately $3.08/kg in 2024 in a tender linked to Numaligarh Refinery Limited. The tender involves the supply of nearly 10,000 tonnes of green hydrogen annually (Shetty, 2026).

The war has also prompted countries to urgently look for alternatives to Russia as energy partners. India has emerged as a strong candidate for hydrogen cooperation with the EU in this context. An important indicator of the rising importance of India for the EU can be seen in the resumption of negotiations on a free trade agreement with India in June 2022, which had been stalled for some time. In September 2022, Energy Commissioner Kadri Simson travelled to Delhi to promote EU–India cooperation on green hydrogen under the EU–India Green Hydrogen Forum (European Commission, 2022). After extensive discussions, the India–EU Free Trade Agreement (FTA) was concluded and finalised in January 2026. The FTA is expected to increase market access, technology collaboration, and investment flows (around $10 billion) to India in green hydrogen. It will also help in the development of common standards and certification. Essentially, India is trying to strengthen its position as a potential reliable green hydrogen supplier to the EU (Das, 2026). Prys-Hansen and Kaack (2023) point out that the scale of diplomatic attention and financial resources that India is receiving from the EU in the wake of the Russia–Ukraine war is unparalleled.

Another indication of India's increasing importance is the engagement of the German foundation H2Global with non-EU countries such as India. The foundation aims to invest more than $4.3 billion to develop collaborations in the renewable energy space, including green hydrogen (Kurmayer, 2022). India and Germany also held consultations in May 2022 to deepen bilateral engagement on renewable energy, including the Indo-German Green Hydrogen Task Force. Following the establishment of the Task Force, both countries signed a $1.3 billion project in 2025 that aims to convert Mulapeta port in Andhra Pradesh into a global green hydrogen hub and export centre for clean ammonia by 2029. The project is expected to start with a capacity of 180,000 tonnes per year and increase later to 1 million tonnes (Mann, 2025).

Although the EU had begun expanding its green hydrogen partnerships with countries like India even prior to the Russia–Ukraine war, the war has undeniably accelerated these efforts (Prys-Hansen and Kaack, 2023). In her visit to India, European Commission President von der Leyen stated that the EU and India's partnership can be one of the defining partnerships of this century and identified clean hydrogen as an important component of this cooperation (European Commission, 2025).

Developing such partnerships may appear to be a win-win situation, where a country (often from the Global North) secures energy supply, while another country (often from the Global South) benefits from investments in sustainable energy. Here, Global South countries may also expand their own energy capacity through these partnerships. However, such arrangements may also create new Global North–Global South dependencies, especially if Global South partners are not able to secure their own energy security in parallel (Lindner, 2022).

Countries like India have been criticized in the past for not making sufficiently strong commitments to address climate change. However, the Ukraine war has provided India with both an opportunity and a rationale to invest more immediately in green technologies such as green hydrogen, as it now also makes strong economic sense (Prys-Hansen and Kaack, 2023). The Indian political class and bureaucracy are also hopeful that export markets for green hydrogen will develop and expand rapidly due to the Russia–Ukraine war. In fact, there is an argument in India that while green hydrogen may remain relatively expensive domestically, higher prices may not be as significant a constraint in Europe, especially in the wake of the Ukraine war. Therefore, India should begin developing its green hydrogen export capabilities with a clear focus on Europe (Pasricha, 2023).

The 2026 Iran war also underscores the complex relationship between geopolitical shocks, energy crises, and the need for energy security. Similar to the Russia–Ukraine war, the Iran war has disrupted supply chains of oil, gas, and fertilizers and created instability in already sensitive energy markets. In fact, experts believe that even if the war were to cease in the near future, its effects on energy and commodity prices would persist for a much longer time (Tangalakis-Lippert, 2026). Recurring geopolitical shocks highlight that the need for accelerated decarbonization is driven not only by environmental considerations but also increasingly by energy security concerns.

3.3 Complying with international standards: the case of the EU's CBAM

The Carbon Border Adjustment Mechanism (CBAM) is a regulatory measure introduced by the European Union that seeks to address the issue of carbon leakage, targeting highly carbon-intensive sectors such as steel, cement, aluminium, and fertilizers. Essentially, CBAM imposes a carbon price on imports of certain goods from countries that do not have comparable carbon pricing systems. This measure is intended to prevent the relocation of EU industries to regions with less stringent environmental regulations (European Commission, 2020). After an initial transitional phase focused on monitoring and reporting from 2023 to 2025, financial adjustments under CBAM have now come into effect as of 2026 (European Commission, n.d.).

The imposition of an additional carbon price through CBAM on exports of Indian industrial products affects their competitiveness in European markets (Sharma and Gupta, 2021). On the positive side, CBAM compliance may induce Indian companies to invest in cleaner technologies and practices, although this requires considerable capital investment and technological innovation (Gupta et al., 2024).

Although the CBAM initiative is undertaken by the EU, it may prove to be a significant factor in the decarbonization of hard-to-abate sectors in the EU's trade partners, including those in the Global South. It is often observed that the EU is able to transmit the effects of its regulation beyond its political borders without the intervention of international institutions or explicit cooperation with other countries. This phenomenon is referred to as the "Brussels Effect", under which market forces play a dominant role in the adoption of EU regulations by other countries (Bradford, 2012). CBAM is likely to induce a Brussels Effect on steel decarbonization in India. In fact, according to recent estimates in Das and Bandyopadhyay (2025), India is the third-most exposed country to the EU's CBAM initiative, after Zimbabwe and Ukraine.

However, it should be noted that the Brussels Effect on India's steel sector may be uneven. The impact is likely to be more pronounced for larger integrated steel producers, while it may be less significant for small and medium-sized enterprises (SMEs). Thus, larger players are likely to adapt more easily to the changes, whereas challenges for smaller players may be exacerbated.

The emissions intensity of steel production in India is around 2.54 tonnes of CO_2 per tonne of crude steel (tCO_2/tcs), which is considerably higher than the global average of 1.85 tCO_2/tcs. This indicates considerable scope for decarbonization (MoS, 2024). The steel sector is also significant for India's economy, contributing about 2% to India's gross domestic product (GDP). Steel is furthermore India's leading export, and the EU has been an important destination for Indian steel exports (MoS, 2023). Therefore, decarbonizing the steel sector can help prevent Indian steel exports to the EU from becoming cost-prohibitive.

Green hydrogen can play an important role in decarbonizing steel by replacing coal and natural gas in the production process. Steel production traditionally relies on coal-based blast furnaces, which emit CO_2. However, green hydrogen, produced using renewable electricity, can be used in Direct Reduced Iron (DRI) processes to reduce iron ore without emitting CO_2 (Mallett and Pal, 2022). Many integrated steel plants (ISPs) in India have already shown an inclination to take steps to ensure that their exports to the EU comply with CBAM requirements. Most of these ISPs operate multiple installations with different technologies; therefore, it is not expected to be very challenging for them to allocate production and direct lower-carbon output to the EU (Das and Bandyopadhyay, 2025). Globally, studies indicate that green hydrogen-based steel manufacturing is expected to become cost-competitive with conventional fossil fuel-based steel production by the 2030s (Nilsson et al., 2021).

Further, in India, steel can become a primary driver of green hydrogen consumption, replacing the need for coking coal, which is imported mainly from countries such as Indonesia, Australia, and South Africa (Mallett and Pal, 2022). The NGHM also acknowledges the importance of hydrogen in radically transforming the steel production process to meet its net-zero goals. The government has additionally prepared a roadmap through consultations with diverse stakeholders to better understand the steel sector's decarbonization pathways and the role of green hydrogen within them (MoS, 2022).

A recent think tank report also identifies green hydrogen as a promising candidate for decarbonizing India's growing domestic steel industry, with 100% green hydrogen-based direct reduced iron (DRI) operations becoming viable by 2050 (IEEFA, 2023). Some early mover companies such as Jindal Steel and Tata Steel have already undertaken initiatives to leverage green hydrogen for steel production. Jindal Steel has set up India's first green hydrogen plant in the stainless steel sector at Hisar, Haryana. It is also the world's first off-grid green hydrogen plant for stainless steel production and the world's first green hydrogen plant integrating rooftop and floating solar (Singh et al., 2024).

JSW Energy Limited has also commissioned India's largest green hydrogen manufacturing plant under Tranche I of the government's Production Linked Incentive Scheme. The plant is located adjacent to the JSW Steel facility at Vijayanagar, Karnataka, and will supply green hydrogen directly for low-carbon steel production (JSW Energy, 2025). Tata Steel has recently developed pipes for hydrogen transportation at its Khopoli plant using steel produced at its Kalinganagar facility. These pipes have passed the required tests, meet the necessary specifications and standards, and can be used for transporting 100% pure gaseous hydrogen under high pressure (up to 100 bar) (Tata Steel, 2025).

However, access to reasonably priced renewable energy will continue to be critical for steel decarbonization. In the short term, blending green hydrogen with conventional grey hydrogen could help smooth potential bottlenecks related to renewable energy availability (Yadav et al., 2021).

4 Challenges, trade-offs and policy directions

4.1 Cost

As with any novel technology, cost represents a significant obstacle to the development and deployment of green hydrogen, especially in a developing country like India, which has relatively limited financial resources compared to developed nations. Currently, the production cost of green hydrogen—around $7–8/kg—is higher than that of grey or blue hydrogen (Panchenko et al., 2023) (see Table 3 for cost comparison). The cost of green hydrogen is determined by several factors, including the cost of electrolyzers, energy used during production, operational expenditures, transmission and distribution (T&D) costs, and various taxes. Among these, electrolyzer costs and energy input are two of the most important components (Rohit et al., 2017; Bhattacharyya et al., 2022).

India has made considerable progress in renewable energy (RE) deployment over the years, with growth averaging 17.3% annually in recent years, resulting in a current installed capacity of 220 GW. Moreover, renewable energy costs in India have declined rapidly over the past decade. For instance, in the 2024 solar auctions, India achieved one of its lowest tariffs at $0.025/kWh (Hazarika, 2024). India is therefore considered to have a significant advantage, as it can leverage its rapidly expanding RE infrastructure for cost-effective green hydrogen production (Praveenkumar et al., 2022). Accordingly, India's ability to develop a robust and cost-effective green hydrogen ecosystem depends strongly on the realization of its renewable energy ambitions.

It is estimated that an investment of $500 billion will be required to achieve the Indian government's target of 500 GW of installed renewable capacity by 2030. This presents a major challenge, as recent investment levels in India's RE sector have been only in the range of $13–14 billion annually (Ahluwalia, 2023).

The central government's allocation of $2.3 billion under the NGHM for developing the green hydrogen ecosystem is also considered modest by several experts, given the scale of its ambitions. For comparison, although not specific to green hydrogen, the U.S. Inflation Reduction Act (IRA), launched in 2022, has earmarked $370 billion over ten years to accelerate its low-carbon transition and stimulate its clean technology industry (Gili and De Blasio, 2024).

There are also doubts as to whether the Indian government has the capacity to mobilize and effectively deploy the funds it has committed. Private sector investment will be required to supplement public financing; however, inducing the Indian private sector to invest in a nascent technological niche will not be easy, given the considerable investment risks associated with emerging technologies and the relatively low appetite of the Indian private sector for technology development (Singh and Bajpai, 2025).

TABLE 3 EMISSIONS INTENSITY AND PRICE OF DIFFERENT TYPES OF HYDROGEN

Hydrogen type	Emissions intensity (kg CO2 eq/kg H2	Price ($/kg)
Grey hydrogen	10-14	1.90-2.40
Blue hydrogen	5-8	2.70-3.40
Green hydrogen	0	5.30-6.70

Source: Sawhney, 2025

4.2 Ecological challenges

India's green hydrogen development also faces serious ecological and socio-environmental challenges, especially related to water and land availability. Land constraints are beginning to emerge as a major barrier to scaling renewable energy infrastructure, which is expected to play a critical role in green hydrogen production through electrolysis. Large utility-scale RE projects need vast tracts of (contiguous) land often leading to adverse effects on agriculture, biodiversity, and tribal habitats. This has led to conflicts and protests by local communities against such projects. In recent years, such land-use conflicts have frequently occurred in states with high renewable energy potential, such as Rajasthan and Gujarat, exacerbated by weak community engagement and poor data on land ownership (Yenneti et al, 2016). This challenge will likely intensify as green hydrogen clusters are developed in these same regions (Kar et al., 2023). A solution to this problem could be to develop green hydrogen projects in sparsely populated arid and semi-arid zones. However, such areas often have poor grid connectivity, limited pipeline and road networks, and water stress. These infrastructural deficits are likely to raise both the capital and operational costs of green hydrogen production and distribution (Sambasivam and Sarma, 2024).

Apart from land availability, water requirements represent another, and perhaps an even more formidable, ecological bottleneck for green hydrogen development in India. The electrolysis of water—the dominant production pathway for green hydrogen—requires approximately 9 litres of deionised water per kilogram of hydrogen produced (Beswick et al., 2021). If India were to replace its current consumption of around 6 million tonnes of grey hydrogen with green hydrogen, this would require between 132–192 million tonnes of water. Moreover, water requirements would increase significantly to meet the government's ambitious target of producing 10 million tonnes (mmt) of green hydrogen annually (Kumar, 2023a). The government has recently identified municipal and industrial wastewater as a potential feedstock for green hydrogen production. However, green hydrogen production requires demineralised or deionised water to ensure the optimal performance of electrolyzers.

Further, water is a State subject in India, and ensuring the availability of large quantities of deionised water would require Centre–State coordination as well as capacity building at the state level. Such interventions have often yielded unsatisfactory results (Kumar, 2023b). India's groundwater resources are among the most heavily overdrawn globally, and it is widely expected that water demand will increase substantially due to competing pressures from agriculture, domestic consumption, and industry. Deploying water-intensive green hydrogen production in a severely water-stressed country may therefore generate difficult trade-offs, potentially compromising food and water security (Mallya et al., 2024).

4.3 Poor R&D and infrastructural capacity

The government aims to build a strong R&D ecosystem across the green hydrogen value chain, including hydrogen production, storage, transport, and end-use applications, under the National Green Hydrogen Mission (NGHM) through its SIGHT programme (Kar et al., 2023). However, this presents multiple challenges, such as scaling electrolyser capacity and mobilizing capital investment across the green hydrogen value chain (Schmidt et al., 2017; Kar et al., 2023). Studies such as Trivedi et al. (2025) also show that weak R&D infrastructure and limited investment are significant barriers to developing India's green hydrogen ecosystem.

Estimates suggest that 11–13 gigawatts of electrolyser capacity are required to produce one million tonnes of green hydrogen. Accordingly, to achieve the NGHM target of 5 million metric tonnes per annum, an electrolyser capacity of approximately 55–65 gigawatts would be required. However, as things stand, India is expected to reach only about 8 gigawatts of electrolyser capacity by 2025, and as of September 2025, had installed only around 1.1 GW (The Times of India, 2023; Ojha, 2025).

Moreover, electrolyzers consume around 50 kWh of electricity to produce 1 kg of hydrogen, implying that India would require approximately 115 GW of electricity supply from renewable energy sources just to meet its target of 5 million tonnes of green hydrogen production via electrolysis. India's total current renewable energy (RE) capacity stands at around 226 GW (Krishnan, 2023).

Currently, there are over 100 research groups working on hydrogen technology development and commercialization across the country; however, this scale is not sufficient to realize India's green hydrogen ambitions (Hall et al., 2020). There is also very limited industry-sponsored or private-sector-funded research in India. Academic and research institutions rely heavily on public funding due to constrained budgets and limited alternative funding channels. As a result, a comprehensive and strategic long-term R&D vision for green hydrogen is not yet fully in place (Kar et al., 2023).

India's hydrogen infrastructure remains in its infancy, posing a significant challenge for policymakers. At present, there is no dedicated hydrogen pipeline network in the country and only a very limited number of hydrogen refuelling stations. This lack of infrastructure represents a major bottleneck for green hydrogen adoption. Existing natural gas pipelines may potentially be used for transporting hydrogen–natural gas blends; however, the impact of such blending on pipeline structural integrity requires thorough investigation (Kar et al., 2023).

Finally, the development of green hydrogen infrastructure—including hydrogen production plants, electrolyzers, storage facilities, and transportation systems such as pipelines, roads, and vehicles—can itself be a significant source of emissions. These emissions would scale with the extent of infrastructure expansion. The government must therefore ensure that net emissions associated with building India's green hydrogen infrastructure remain negative (Krishnan, 2023).

5 Policy recommendations

The challenges outlined above — cost barriers, ecological constraints, and weak R&D and infrastructural capacity — point to the need for a coordinated policy response. The following recommendations address four interconnected areas: financial support, regulatory reform, R&D and infrastructure development, and demand-side interventions. Taken together, they aim to narrow the gap between India's green hydrogen ambitions and the conditions necessary to achieve them.

Provide adequate financial support

There is a considerable need to increase direct financial support, such as capital subsidies for green hydrogen projects, especially those in the early stages. Avenues such as multilateral development banks need to be approached for low-cost financing instruments like interest-free or low-interest loans (Sambasivam and Sarma, 2024). Generous tax waivers would also be critical to inducing private sector interest — for instance, waiving inter-state transmission charges for the long term for renewable electricity used in green hydrogen production would make production considerably more lucrative (PIB, 2024b).

Streamline regulations

A long-standing issue in Indian bureaucracy is the processing time and tedious documentation associated with project approvals. The government must therefore take steps to streamline approvals through fast-track mechanisms and single-window clearance portals (PIB, 2024b). It should also establish clear definitions, standards, accreditation, and certifications for green hydrogen that are internationally acceptable — a prerequisite not only for domestic deployment but for the export credibility that the NGHM explicitly targets (Rodríguez, 2025).

Build a robust R&D and infrastructure ecosystem

India needs to invest significantly in R&D and infrastructure, particularly in electrolyser production. Fostering strong partnerships among industry, government, and academic institutions would help pool resources, develop indigenous technologies, and accelerate commercialization (Biswas et al., 2020). In parallel, the government should accelerate the development of efficient supply chains — including pipelines, tankers, intermediate storage facilities, and last-mile distribution networks — for both domestic consumption and export (Chaphekar and Sinha, 2024).

Focus on demand-side interventions

The government can introduce green hydrogen consumption mandates in industries with established hydrogen demand, such as fertilizers and petroleum refining, to create a tangible and assured demand baseline (Sawhney, 2025). Progressive blending targets for green hydrogen with natural gas in city gas distribution networks and other applications would further stimulate demand as the broader ecosystem matures (Anil and Rejikumar, 2025).

6 Conclusion

India's green hydrogen transition is unfolding at a moment of considerable global flux, shaped by intensifying climate imperatives, recurring geopolitical shocks, and the emergence of a new global clean energy trade order. India's NGHM firmly places green hydrogen within the country's energy and industrial policy framework in a strategic fashion, indicating that the importance of developing a green hydrogen ecosystem in India goes well beyond meeting climate goals. The analysis demonstrated that green hydrogen for India is simultaneously a tool for deep decarbonization, a lever for industrial transformation, a pathway to energy security, and a potential vehicle for energy diplomacy.

However, there are significant structural and operational challenges in realizing these goals. High production costs, land and water constraints, weak R&D and manufacturing capacity, and inadequate infrastructure could impede both domestic adoption and global competitiveness. The gap between ambition and execution is already visible: of around 6 mtpa worth of projects announced over the years, only projects amounting to 220,000 tonnes per annum have reached the final investment decision stage, underscoring the barriers project promoters are facing (Xynteo, 2025). India will therefore require targeted policy interventions — stronger financial incentives, streamlined regulations, demand-side mandates, and integrated supply chain development — to leverage the early-mover advantages it is eyeing. In short, green hydrogen represents a strategic pivot point, and through its development, India is attempting to shape its industrial competitiveness, trade positioning, and climate trajectory for decades to come. The challenge will be to ensure that this development is resilient, inclusive, and firmly anchored in the country's broader socio-economic and environmental priorities.

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Author

Dwarkeshwar Dutt

Dwarkeshwar Dutt is Marie Skłodowska-Curie Postdoctoral Fellow at the School of Global Studies, University of Sussex. His work broadly explores the interactions among policy, politics, and technology in the context of energy transitions by employing concepts and insights from policy studies, transition theory, political science, and science & technology studies (STS). His research focuses on comparative environmental and energy politics, policy evolution, design, and feedback, as well as just transitions.

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Contact:
Yana Zabanova: yana.zabanova@rifs-potsdam.de
Rainer Quitzow: rainer.quitzow@rifs-potsdam.de

Address:
Berliner Straße 130
14467 Potsdam
T: +49 (0) 331–28822–340
F: +49 (0) 331–28822–310
media@rifs-potsdam.de
www.rifs-potsdam.de

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