Financing Green Hydrogen in India

Private Sector Considerations to Strengthen India's Enabling Environment for a Competitive Green Hydrogen Economy

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Shri Pralhad Joshi,
Minister of New and Renewable Energy
Atal Akshaya Urja Bhawan,
CGO Complex, Lodhi Road
New Delhi – 110003, India

Dear Shri Pralhad Joshi *Ji*,

We are pleased to present this Climate Finance Leadership Initiative (CFLI) India report on *Financing Green Hydrogen in India* in support of the *National Green Hydrogen Mission* (*NGHM*) spearheaded by the Ministry of New and Renewable Energy (MNRE). The *NGHM* establishes an ambitious vision for the future of green hydrogen in India that builds on the country's trailblazing efforts to deploy renewable energy at scale. We look forward to working with the stakeholders of India's energy transition to help spur domestic demand and cement the country's position as a leading producer and, in time, a global export hub of green hydrogen.

CFLI India's Members, comprising 10 leading Indian and international financial institutions and corporates, with the objective of mobilising private capital towards the Government of India's climate priorities, are honoured to share a set of considerations that offer a private-sector view on the incentives deployed under the *NGHM*. These considerations, shared at the request of the MNRE, are informed by engagements with stakeholders from across the green hydrogen value chain. They focus on creating demand for green hydrogen, the enabling infrastructure that is needed, and suggest ways to reduce financing costs – in line with the policy's mission.

In the last year, India's hydrogen market has seen important developments and secured multiple investor commitments towards the manufacturing of green hydrogen and its derivatives, despite a challenging macro-environment and the uncertainties inherent to a sector still at an early stage. We believe that with proactive policies, partnerships between key private and public sector participants, and innovative financial solutions, India can become a global leader in green hydrogen.

On behalf of CFLI India, we thank you for your leadership and commitment to India's climate ambitions. Our Members look forward to working with you to advance India's green hydrogen transition.

Sincerely,

N. Chandrasekaran
CFLI India Co-Chair
Chairman
TATA

Shemara Wikramanayake
CFLI India Co-Chair
Managing Director & CEO
MACQUARIE

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Section 1. Preamble

In pursuit of sustainable growth, governments are turning to clean technologies to support their development. As countries raise ambition on climate and set 'net zero' targets to curtail emissions, decarbonising hard-to-abate sectors will be a critical means to this end. Green hydrogen – hydrogen produced through renewable energy – has sparked interest among policymakers, given its potential to contribute to a cleaner economic growth trajectory, especially in hard-to-abate sectors. To date, 53 countries have hydrogen strategies, and another 30 are developing similar policies to transition to it (BloombergNEF 2024).

As India assumes a prominent role in the global economy, the adoption of alternative fuels such as green hydrogen in its industries will be critical to mitigating global greenhouse gas emissions. Beyond mitigation, green hydrogen also provides a transition pathway for India to reduce its reliance on imported fossil fuels and establish export opportunities. To this end, the Government of India's Ministry of New and Renewable Energy (MNRE) launched the *National Green Hydrogen Mission* (*NGHM*) in 2023 aiming to promote demand for green hydrogen, facilitate an increase in production, and aid in developing key enablers for the sector. However, the economics of green hydrogen in India remain challenging due to significant capital costs, the nascency of the sector, the higher cost of renewable energy, and its intermittent nature. Therefore, public–private engagement will be essential to build on India's success in renewables and fuel its green hydrogen ambitions.

We – the Climate Finance Leadership Initiative (CFLI) India – offer a private sector view of practical next steps for consideration by the Government of India in deploying policy incentives to develop India's green hydrogen industry and realise its ambitions of becoming a global production and export hub.

Development and scope of the 'Financing Green Hydrogen in India' report

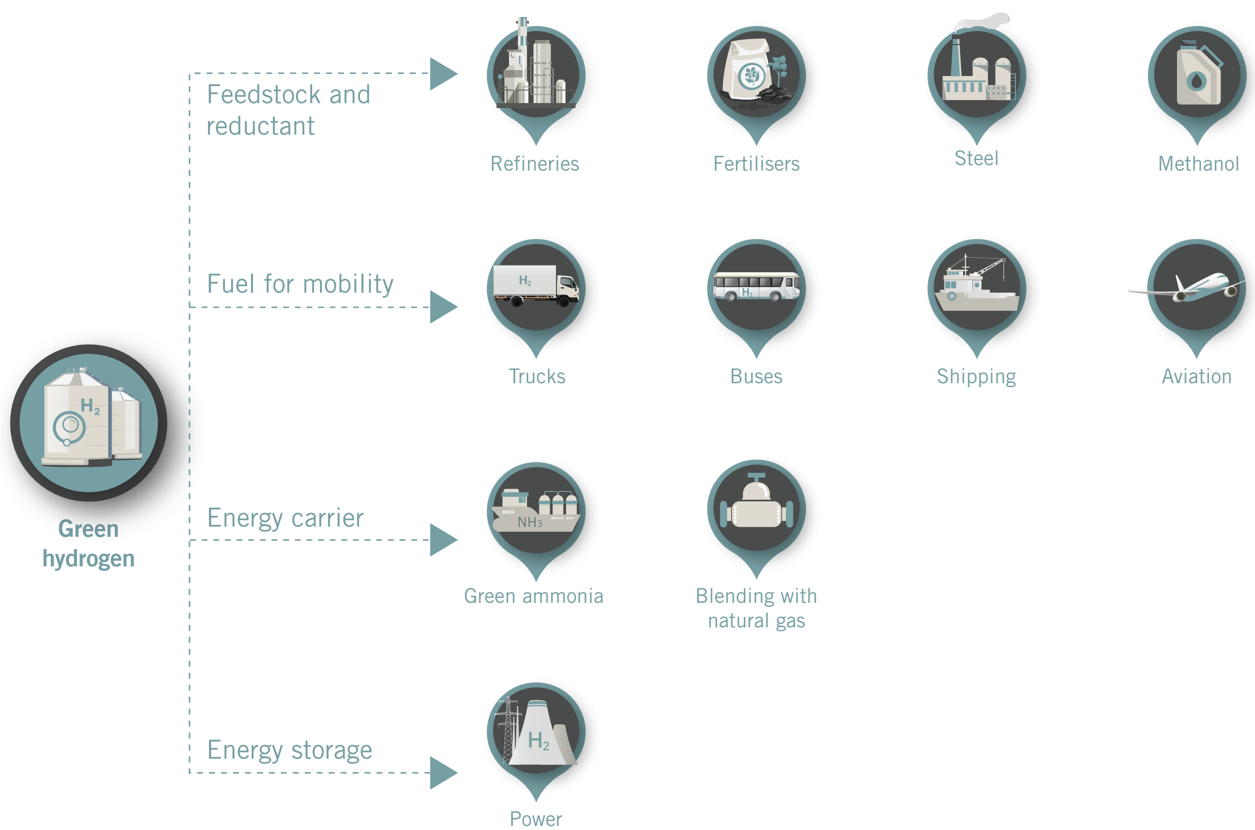
CFLI India engaged with the MNRE throughout 2023 to unlock finance for India's green hydrogen sector. At the ministry's request, we developed a set of working considerations to provide a private sector view on the deployment of incentives under the *NGHM*, given our expertise as financiers and developers. These working considerations were informed by stakeholders across the green hydrogen value chain, whose inputs were captured at a 'Financing Green Hydrogen' workshop held in March 2023 and were presented to the MNRE in June 2023. This report builds on those working considerations and offers additional analyses to support them. We would like to thank all who participated in the workshop and provided feedback to help ensure that the policy considerations represent a unified, private sector perspective on current challenges and learnings to strengthen India's enabling environment for a competitive green hydrogen economy. In addition, we would like to thank the Council on Energy, Environment and Water (CEEW) for their research and analysis that supports bringing to light the private sector considerations and financial learnings.

This CFLI India report presents actionable considerations for Indian policymakers at both the national and state levels to strengthen the enabling environment for green hydrogen uptake in India while also catalysing private sector investment into the industry. These considerations align with the MNRE's mission components – generating demand, incentivising supply, and developing key enablers – and are supported by estimated demand projections as well as a breakeven cost analysis.

The presented considerations, although tailored to the Indian context, may, in time, serve as an implementation blueprint for other international markets to promote green hydrogen. They are not intended to be a prescriptive set of policies, but rather, facilitate deeper public–private engagement on this topic.

FIGURE 1:

Use cases of green hydrogen as a decarbonisation tool



Source: CEEW analysis

What is green hydrogen?

Hydrogen can act as a fuel, industrial feedstock, reductant, and energy carrier and is produced through a variety of processes (Table 1). At present, most hydrogen used worldwide is grey – produced through natural gas reforming – a process that leads to significant greenhouse gas emissions. As countries seek to decarbonise their economy and reduce their dependence on fossil fuels, green hydrogen – produced using renewable energy – will be critical for them to achieve their energy transition goals.

TABLE 1:

The hydrogen colour spectrum

Colour of hydrogen	Hydrogen production technology	Feedstock or electricity source	GHG* footprint
Green	Water electrolysis	Wind, solar, small hydro, geothermal, and tidal	Minimal
Purple/pink	Water electrolysis	Nuclear	Minimal
Yellow	Water electrolysis	Mixed-origin grid electricity	Medium
Blue	Steam methane reforming (SMR)/coal gasification with carbon capture and sequestration	Natural gas and coal	Low
Turquoise	Pyrolysis	Natural gas	Low
Grey	SMR	Natural gas	Medium
Brown	Coal gasification	Brown coal (lignite)	High
Black	Coal gasification	Black coal	High

Source: (Prabhu, Mallya and Elango 2023) *GHG = greenhouse gas(es)

Note: Reference ranges for GHG footprint are considered as follows: minimal - less than 2kg CO_2eq. / kg H_2, low - 2-6kg CO_2eq. / kg H_2, medium - 6-15kg CO_2eq. / kg H_2, high - greater than 15kg CO_2eq. / kg H_2.

Decarbonising hydrogen will enable emissions reductions in several of India's core industries, given its many use cases (Figure 1):

- Feedstock and reductant:
  - Hydrogen is used to synthesise derivatives such as ammonia or methanol that can be used for fertiliser and chemical production.
  - Hydrogen can also act as a reductant in industrial processes, particularly in petroleum refining and steel production.
- Fuel for mobility:
  - Hydrogen can be used as a fuel in the mobility sector, especially for heavy road vehicles, ships, and aircraft, as its high-energy, density-per-unit mass enables it to power vehicles over long distances.
- Energy carrier:
  - Hydrogen can act as an energy carrier in the form of ammonia, which can be easily transported and traded.
  - Hydrogen can be blended with natural gas and used as a cooking fuel or as a fuel in similar applications.
- Energy storage:
  - Hydrogen can support grid stability in the power sector as an energy storage application.

Section 2. Key Trends and Emerging Opportunities for Green Hydrogen in India

Hydrogen is becoming increasingly critical as a fuel source for India's core industrial sectors: the country produces and consumes an estimated ~5.6 million tonnes per annum (MTPA) of grey hydrogen annually, amounting to nearly 6 per cent of global consumption (IEA 2021). To actualise India's aspirations of building a low-carbon and self-reliant economy, the Government of India has declared green hydrogen a sunrise sector (MNRE 2023) and enacted supportive policies to enable an industrial shift to achieve this vision by 2030. Furthermore, as countries around the world also look to transition to green hydrogen, Indian policymakers see an opportunity for the country to attract foreign investment, develop robust electrolyser manufacturing capabilities, and lead innovation in this sector.

This section highlights domestic policies, sectors, and trends that are shaping the contours of India's green hydrogen industry. In line with the national policies, our analysis forecasts that India's core grey hydrogen consuming sectors, including the fertiliser and refining industries, will drive initial demand for green hydrogen. As green hydrogen technology and its associated economics become increasingly viable, other applications of hydrogen in the steel, mobility and shipping sectors can materialise at scale. However, tapping into export opportunities and establishing a conducive enabling ecosystem will be critical to realising the government's targets and propelling this sector forward in the long term.

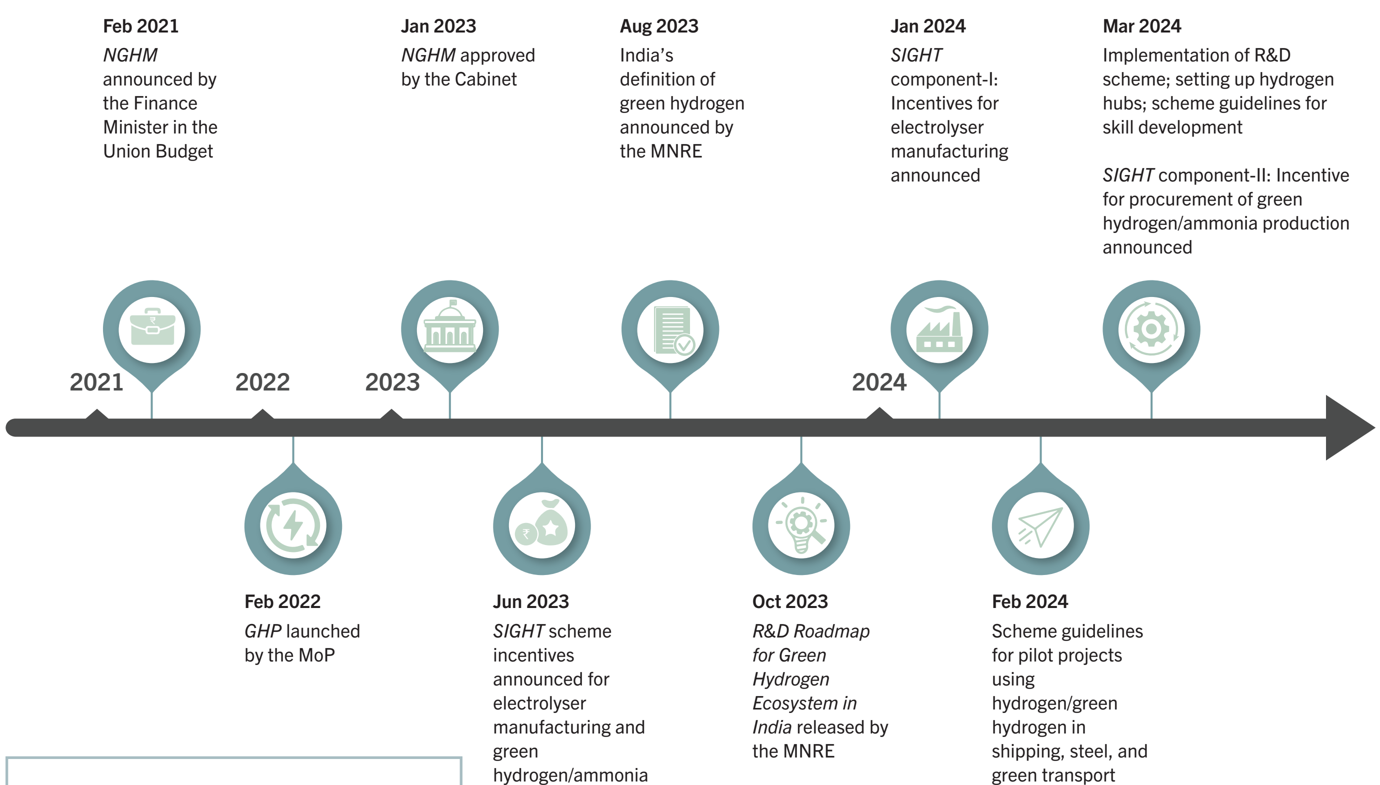
Policy support

The announcement of the *Green Hydrogen Policy* (*GHP*) in 2022, followed by the *National Green Hydrogen Mission* in 2023, underpin this emerging sector by defining green hydrogen, outlining a demand generation roadmap, and stating production capacity targets (Figure 2). Key targets outlined in the *NGHM* include a green hydrogen production capacity target of at least 5 MTPA by 2030, which extends to an ambitious export-inclusive target of 10 MTPA (MNRE 2023). To achieve these targets, the *NGHM* identifies critical ecosystem enablers such as infrastructure and supply chain, in addition to government incentives, policy interventions, and research and development (R&D) priorities (Appendix 3).

The country's national hydrogen policies provide an overarching direction for industry to move towards, along with a robust foundation for state governments to build on. As of March 2024, six Indian states including Maharashtra, Uttar Pradesh, Andhra Pradesh, Rajasthan, Odisha, and West Bengal have released green hydrogen policies. Madhya Pradesh and Karnataka have included provisions for green hydrogen in their renewable energy policies, while Punjab, Haryana, Gujarat, and Kerala have policies in the pipeline. These state government policies detail regional targets, offer incremental incentives for focus applications, and provide benefits for electricity provision, amongst other interventions, to attract investors and encourage the establishment of green hydrogen production units across Indian states.

FIGURE 2:

Green hydrogen related policy milestones



NGHM	*National Green Hydrogen Mission*
GHP	*Green Hydrogen Policy*
SIGHT	*Strategic Interventions for Green Hydrogen Transition*
SECI	Solar Energy Corporation of India
MNRE	Ministry of New and Renewable Energy
MoP	Ministry of Power
R&D	Research and Development

Source: CEEW compilation based on policy documents

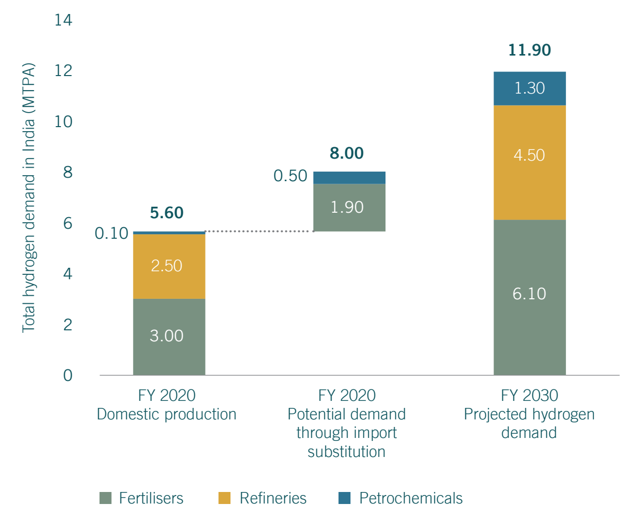
Current trends in India's grey hydrogen market

India's captive grey hydrogen market is estimated to be worth approximately USD 8.5-10 billion, based on production costs of USD 1.5-1.8 per kg (Biswas, Yadav and Guhan 2020). India's fertiliser and refining industries, where grey hydrogen functions as an intermediary and most production and consumption is in-house, together account for 98 per cent of domestic grey hydrogen production at 5.6 MTPA (Figure 3). The remaining share of grey hydrogen, produced as a by-product in certain industrial processes, is commercially traded and utilised for glass making, laboratory research, and pilot projects.

Given the demand dependence on the fertiliser and refining industries, India's grey hydrogen consumption has seen marginal growth in the last decade, attributed primarily to a low compound annual growth rate (CAGR) of approximately 1 per cent in these sectors since the financial year (FY) 2015. However, hydrogen consumption in the fertiliser and refining industries could double to nearly 10.6 MTPA by FY 2030 if the respective sectoral production capacity targets are met. In the case of the fertiliser industry, this includes increasing domestic production to offset imports as outlined by the Ministry of Chemicals and Fertilisers, while for the refining industry, the Ministry of Petroleum and Natural Gas (MoPNG) aims to increase capacity by setting up new refineries across the country. Similar increases can be expected in the petrochemicals sector, where consumption may grow to 1.3 MTPA for the same reasons. Together, these three sectors are anticipated to drive India's total grey hydrogen demand up from 5.6 MTPA in FY 2020 to 11.9 MTPA in FY 2030.

FIGURE 3:

Total hydrogen demand in India (MTPA)



Source: CEEW analysis; (Monna, et al. 2021)

Note 1: CEEW based its projections on announced capacity expansion plans for refineries and consumption trends from FY 2010 to FY 2020 for fertilisers, ammonia, and methanol.

Note 2: CEEW assumes completely indigenised production of fertilisers, ammonia, and methanol.

Emerging trends in India's green hydrogen market

Domestic demand creation

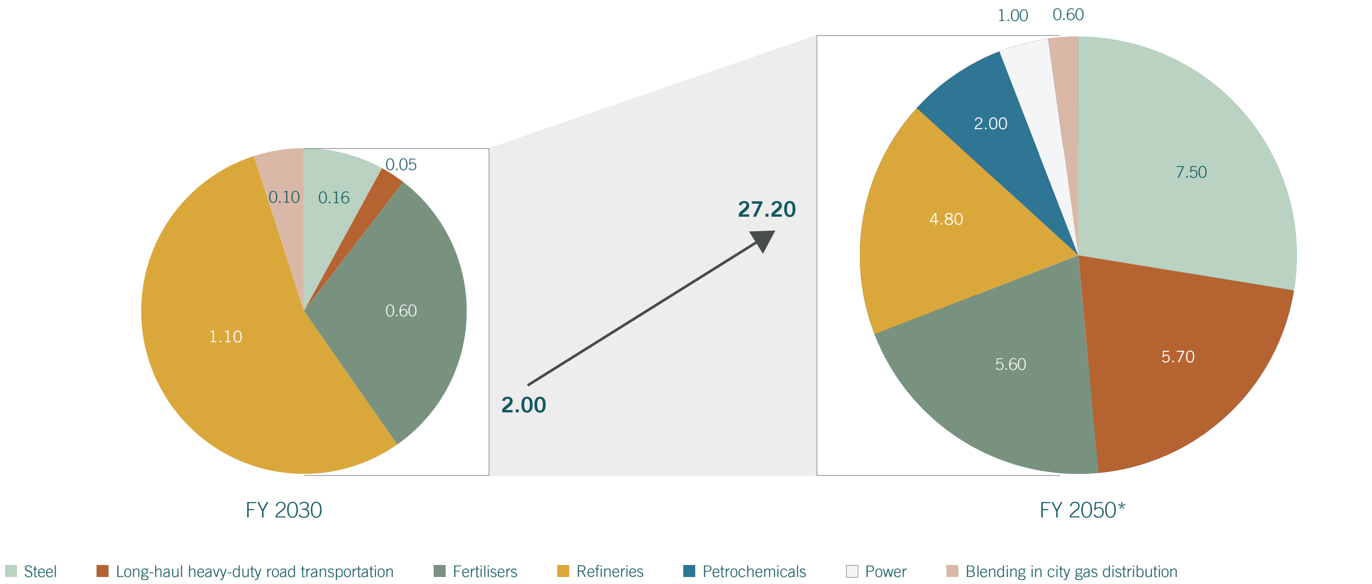
India's hydrogen demand and production are set to nearly double by FY 2030, led primarily by its core hydrogen-consuming sectors. However, only a fraction of this may be green. Phase I of the *NGHM*'s implementation roadmap posits refining, fertilisers, and the city gas sectors as leading India's green hydrogen transition from FY 2023-FY 2026, while Phase II identifies steel, mobility, and shipping as sectors that could explore green hydrogen uptake through FY 2026-FY 2030. However, despite this we note that the total domestic demand for green hydrogen in FY 2030 may be short of the *NGHM*'s 5 MTPA target, thus highlighting the role export opportunities could play in supporting growth of the sector in the near term.

Refining and fertiliser sectors to drive initial demand

In FY 2030, we project that the largest proportion of green hydrogen demand will come from the refining industry, which currently accounts for 44 per cent of India's grey hydrogen demand at 2.5 MTPA (Figure 3). Based on the government's targets for capacity addition (Prime Minister's Office, Government of India 2023), we estimate total demand to grow to 4.5 MTPA by FY 2030. The sector is a prime candidate for a transition to green hydrogen as it is comparatively less price-sensitive to production costs than other relevant sectors, which in turn cushions it against a green hydrogen premium. This is because the proportion of hydrogen input costs to overall production costs is smaller than it is for sectors such as fertilisers. According to NITI Aayog's estimates, around 24 per cent of the sector's hydrogen demand in FY 2030 can be met by green hydrogen (Raj, Lakhina and Stranger 2022). This contributes approximately 1.1 MTPA to India's projected total green hydrogen demand in 2030 (Figure 4).

FIGURE 4:

Projected green hydrogen demand in India by FY 2030 and FY 2050 (MTPA)



Source: CEEW analysis
*Statistics referred from (Raj, Lakhina and Stranger 2022)

Achieving these projections, however, necessitates updating existing refining units as well as integrating green hydrogen into refinery operations. After analysing plant designs of older refining units in India, we note that it may be more efficient for this sector to prioritise the structural integration of green hydrogen in upcoming units rather than retrofitting existing units at this stage. Multiple refineries in India have already announced green hydrogen pilot projects to support the sector's transition.

India's fertiliser industry is another priority sector for the transition to green hydrogen and is projected to significantly drive green hydrogen uptake. The sector currently consumes 3 MTPA of grey hydrogen, amounting to 54 per cent of the country's grey hydrogen demand (Figure 3). Based on the government's emphasis on localising imported fertiliser products and imported ammonia, in addition to the recent capacity expansion to the urea production sector (Ministry of Chemicals and Fertilizers 2022), we estimate that the sector's total hydrogen demand may grow to 6.1 MTPA by FY 2030.

However, the financials for substituting green hydrogen in fertiliser production are currently prohibitive. The cost of hydrogen production contributes substantially to overall production costs for fertilisers and, as a result, any premium associated with green hydrogen inputs could sharply inflate overall production costs for fertilisers. As a result, a blending mandate may be the most suited to unlock demand in this sector. However, the Government of India's already large subsidy expenditure for the fertiliser industry makes it challenging for it to bridge the viability gap any further. These barriers are compounded by aging domestic fertiliser plants, in addition to technical challenges, and factor into our green hydrogen demand projection for the sector (Figure 4). Based on these barriers, we expect that by FY 2030, only approximately 10 per cent of the fertiliser sector's 6.1 MTPA hydrogen demand (Figure 3) will employ green hydrogen. Non-urea fertilisers are likely to be the primary demand driver at this stage because of the input-specific lower premium non-urea fertilisers have, when compared to urea fertilisers, and due to fewer technical challenges in switching from grey to green ammonia.

Green hydrogen policy instruments for the fertiliser industry

Transitioning to green hydrogen in the fertiliser industry is also a key focus area for the United States, which has enacted tax credits under the *Inflation Reduction Act* of 2022. Under this act, starting in 2023, renewable energy and green hydrogen plants can receive a production tax credit of up to 2.75 cents per kilowatt-hour (kWh) (Hyde 2022) and up to USD 3 per kg of hydrogen (Department of Energy 2023), respectively, for the first 10 years of operation. Taking advantage of these credits, fertiliser manufacturer Atlas Agro Holding AG (Atlas Agro) aims to produce competitive, low-carbon nitrate fertilisers, locally, in agricultural regions that are dependent on fossil fuel-derived fertiliser imports with a significantly higher carbon footprint from both production and transportation. In 2023, Macquarie agreed to invest up to USD 325 million in Atlas Agro and affiliated entities to support the development of industrial-scale green nitrogen fertiliser plants in the United States and Latin America, which will utilise green hydrogen in the production process.

Steel and long-haul road transportation can also drive demand in the long-term

While the economics of switching from conventional fuel to green hydrogen in the *NGHM*'s Phase II sectors is currently prohibitive, existing analysis highlights pathways where technological innovations and economies of scale show meaningful green hydrogen demand from steel, mobility, and shipping in the long term (Figure 4).

However, due to the extended lead times for technology development, capacity deployment and infrastructure creation in these sectors, these pathways may not move from the margins to the mainstream until closer to FY 2050 in India. Demonstrating proof-of-concepts in Phase I of *NGHM* and developing infrastructure will be critical for green hydrogen demand to materialise in these sectors.

Other notable sectors

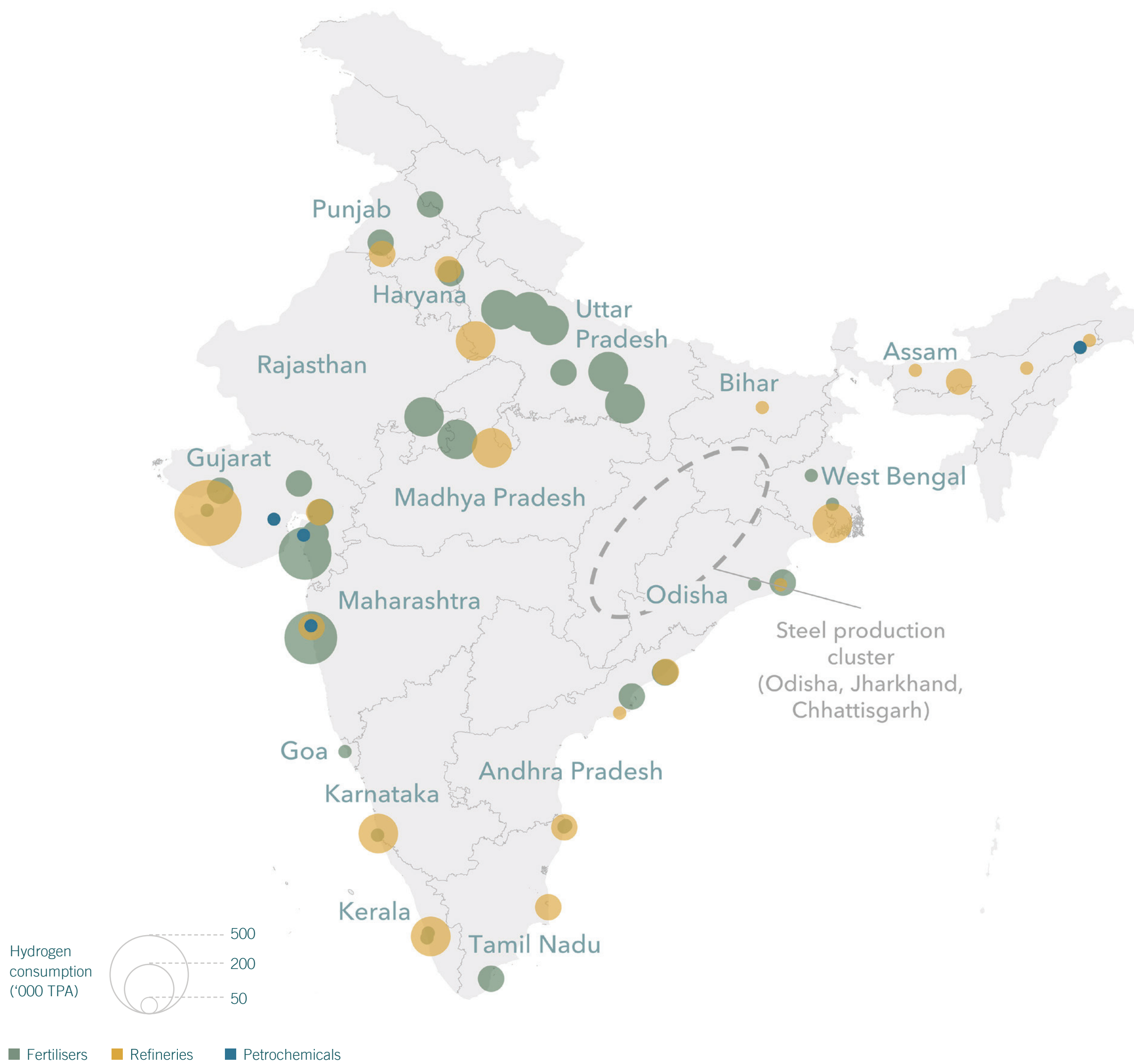
Although refining, fertilisers, steel, and long-haul road transportation sectors are projected to be the major demand drivers for green hydrogen, it is worth noting several additional applications. Phase I of the *NGHM* marks city gas distribution as a near-term priority sector. However, the sector is unlikely to contribute substantially to green hydrogen demand based on the blending parameters of initial pilot projects and the volumetric and energy requirements of the sector (MoP, GoI 2023). Niche sectors like railways and aviation, also mentioned in Phase II of the *NGHM*, are encouraged to undertake pilot projects to drive decarbonisation. By 2050, petrochemicals and the power sector may contribute to green hydrogen demand. However, this is based on the emergence of stable pathways for the use of green hydrogen in petrochemicals and improvements in the efficiency of electrolysers and fuel cells for the power sector. Other applications of green hydrogen in domestic and industrial heating are being explored globally, but current costs and better suitability of other decarbonisation solutions render them less cost competitive in the Indian context.

India's green hydrogen hotspots

Over and above sectoral demand and enabling policies, the geographical location of Indian industries will likely determine which regions drive domestic green hydrogen demand (Figure 5). Currently, Gujarat accounts for 30 per cent of India's grey hydrogen consumption, followed by Uttar Pradesh (17 per cent), Maharashtra (8 per cent), Rajasthan (7 per cent), and Madhya Pradesh (6 per cent). As mentioned, several of these states including Uttar Pradesh, Maharashtra, and Rajasthan are pursuing green hydrogen policies to stimulate demand, and combined these top five hydrogen-consuming states account for approximately two-thirds of the country's total grey hydrogen consumption. Existing demand from established industrial bases will continue to account for the majority of the country's emerging green hydrogen consumption. However, going forward, steel-producing states such as Jharkhand, Chhattisgarh, Odisha, and Karnataka may also emerge as large consumers of green hydrogen.

FIGURE 5:

Hydrogen demand sites in India (FY 2020, in tonnes per annum (TPA))



Source: CEEW analysis

Positioning India as a global contender

Given our projection of 2 MTPA of domestic green hydrogen demand by FY 2030, demand from export markets will be key to meeting India's green hydrogen production capacity target of 5 MTPA. Globally, the projected demand for hydrogen is expected to be around 150 MTPA by 2030, with green hydrogen projected to meet 51 MTPA of this demand (IEA 2023).

Several countries have already stated their intentions to import green hydrogen and its derivatives, such as ammonia, to support their decarbonisation goals. The European Union has committed to importing 10 million tonnes of green hydrogen by 2030 (European Commission n.d.). Similarly, East Asian countries such as Japan, Singapore, and South Korea have also expressed interest in importing green hydrogen and its derivatives to meet their climate commitments. India's geographical proximity to the potential East Asian importers will support India's export ambitions and help create a strong international supply chain. Multiple Indian firms are proactively exploring export opportunities with several export-oriented projects for green ammonia production already announced.

Export-focused green hydrogen hub

AM Green Ammonia (AMGA), a venture led by the founders of leading renewable energy company, Greenko Group, is building one of the world's largest green ammonia platforms at a brownfield site in Kakinada (an industrial base for India's oil and gas industry in Andhra Pradesh). Backed by global institutional investor GIC, the partnership, which spans multiple locations including Kakinada, aims to produce 5 million tons per annum of green ammonia by 2030. The facility will comprise 1,300 MW round-the-clock renewable energy power, enabled through a combination of renewable energy sources and long duration energy storage to be provided by Greenko. Electrolysers will be powered by renewable energy to produce green hydrogen that is then converted to green ammonia.

AMGA will set up the plant with an overall investment exceeding USD 1 billion and has secured an offtaker for 25 per cent of the facility's initial capacity. Utilising a build-own-operate model, the developer will sell green ammonia for the project's 25-30-year lifetime. For the first time in global markets, AMGA is offering short and medium-term contracts against the market standard of long-term only partnerships, enabling the creation of deeper and wider global green ammonia markets.

Developing an enabling ecosystem

In addition to spurring demand for green hydrogen, developing an enabling ecosystem, including critical infrastructure will play a pivotal role in supporting India's ambitions for this sector. Key enablers are a core component of the *NGHM*, which highlights the opportunity for India to lead on the manufacturing of electrolysers and renewable energy equipment, in addition to the customised infrastructure this sector requires for safe and efficient storage and transportation across offtake industries. The domestic production of electrolysers, renewable energy equipment, and other system components in sectors with emerging green hydrogen applications presents another opportunity for the country to reduce import reliance and assume market leadership in green hydrogen production.

Green hydrogen hubs will play a vital role establishing India as a frontrunner in the global transition to green hydrogen and are expected to emerge close to either domestic demand centres or major ports that can facilitate exports. The development of upstream component manufacturing industries can be centred around these areas. Green hydrogen hubs offer an opportunity to rationalise the storage and transportation infrastructure as production and consumption facilities are co-located. Coastal states with renewable energy potential and robust port infrastructure such as Odisha – which has already signed memorandums of understanding (MoU) to this effect – and others such as Tamil Nadu, Gujarat, and Maharashtra are likely contenders to develop these new hubs. They can build on the upcoming infrastructure by facilitating the participation of international stakeholders and may help broaden demand beyond the few Indian states where demand is currently concentrated.

While policy, both at the national and the state level, is essential to initiate an industrial transition towards India's emerging green hydrogen industry, adequate and affordable financing will also be key in supporting the industry's subsequent growth. To secure green hydrogen investments from developed countries, India has highlighted five activities that may involve the use or production of green hydrogen to be eligible for the trading of carbon credits per *Article 6.2 of the Paris Agreement* (Ministry of Environment, Forest and Climate Change 2023). While this is a step in the right direction, the active flow of private capital will be critical to achieving economies of scale for green hydrogen in India.

Developing a domestic electrolyser ecosystem

L&T Electrolysers Limited, a newly incorporated entity of L&T, is focused on manufacturing pressurised alkaline electrolysers using technology from McPhy Energy, France. L&T commissioned its first indigenously manufactured 1 MW hydrogen electrolyser at the green hydrogen plant at A M Naik Heavy Engineering Complex in Hazira, Gujarat. The company spearheaded the complete value chain, including the engineering and manufacturing of the electrolyser, in collaboration with Indian vendors and suppliers, thus setting a benchmark for 'Make in India' initiatives. L&T Electrolysers plans to leverage its upcoming giga-scale facility in Hazira to meet the growing demand for green hydrogen, maximise product localisation through an enhanced local supply chain, and automate for cost competitiveness.

Hydrogen hubs simplify supply chain development

Much like India, countries around the world are increasingly turning to hubs to bolster supply of green hydrogen and, in turn, create a reliable green hydrogen ecosystem. In October 2023, the United States launched the *Regional Clean Hydrogen Hubs Program* (H2Hubs) (Department of Energy n.d.). This initiative includes grants of up to USD 7 billion to establish 6-10 regional clean hydrogen hubs across the country. The programme requires that eligible projects be involved in the "production, processing, delivery, storage, and end-use of clean hydrogen" (Department of Energy n.d.). Seven hydrogen hubs have already been chosen (Jennifer L. 2023).

Section 3. Challenges to Scaling Green Hydrogen in India

This section presents the overarching barriers across the value chain – demand, supply, infrastructure, and financing – to deploying green hydrogen at scale in the Indian market. While these challenges are interrelated, incentivising demand remains at the heart of the commercial challenge. Green hydrogen will only command a higher share in industries' fuel and feedstock mix when it is competitively priced with grey hydrogen and other incumbent fossil fuels. Until then, the green hydrogen sector will have to rely on government mandates and external financial support for demand generation. Tackling the premium associated with green hydrogen over incumbent fuels is critical. Further, technology, policy, and financing solutions are of utmost importance in reducing the cost of green hydrogen, building an enabling ecosystem, and catalysing finance.

Challenge 1: Incentivising demand

Project developers and financing institutions struggle to identify sufficient demand in India to make green hydrogen projects viable at scale, creating commercial uncertainty and hindering investment in large-scale projects.

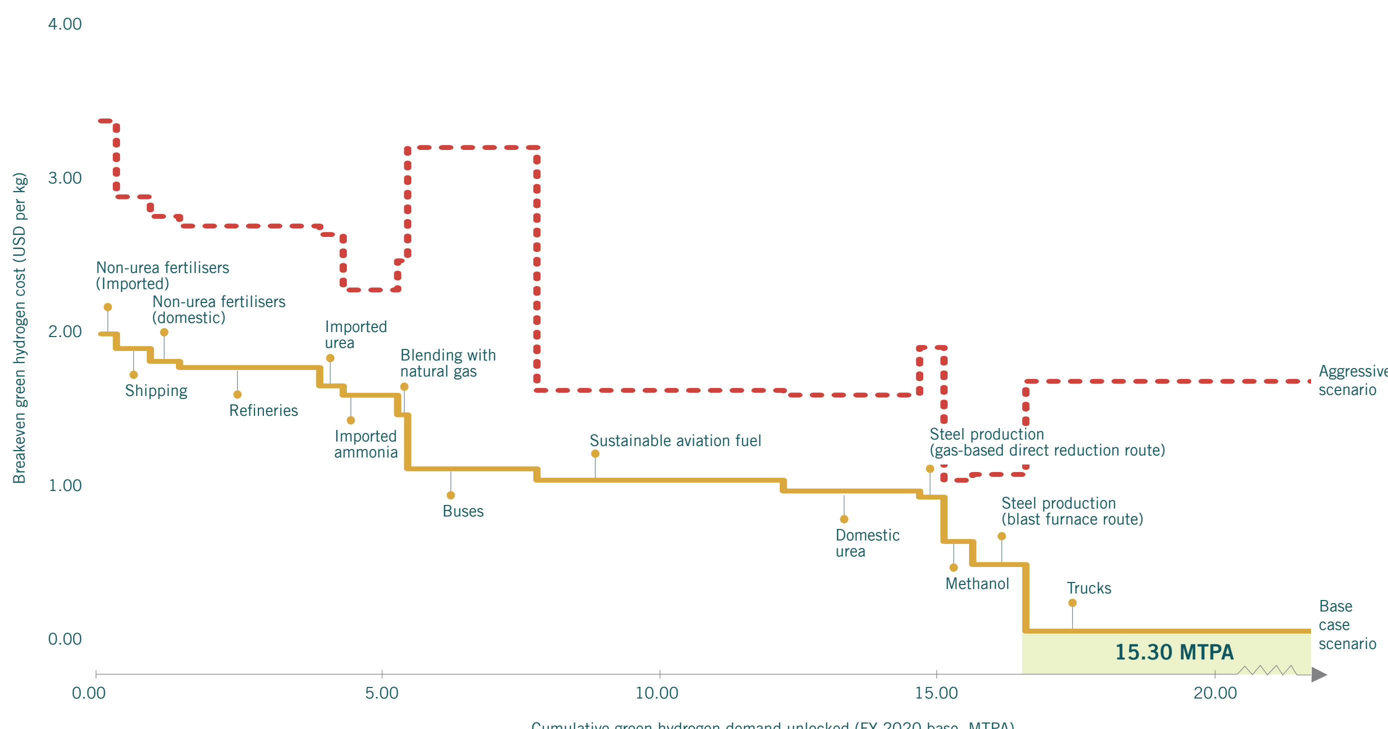
The cost of switching from grey to green hydrogen remains the largest impediment to the industrial uptake of green hydrogen. As per current industry estimates, green hydrogen costs USD 3.5-5 per kg, while breakeven costs for green hydrogen to replace conventional fuels in existing sectors are less than USD 2 per kg (Figure 6). Green hydrogen production costs may further increase due to cost overruns in projects if timelines and cost estimates are disrupted due to administrative or operational challenges. The incremental cost of green hydrogen renders it financially unviable without external support. While the *NGHM* does point to forthcoming consumption mandates, no timeline has been specified yet. As the Government of India is in the process of establishing the Indian carbon market, it is also unclear if, and when, carbon prices will be high enough to encourage demand sectors to switch to green hydrogen, especially given that other clean alternatives may have a lower cost of CO_2 abatement.

Challenging breakeven costs for green hydrogen versus incumbent fuels and commodities

The green hydrogen cost curve (Figure 6) plots the breakeven cost of green hydrogen production (USD per kg) against the theoretical potential of consumption (MTPA) that will be unlocked at the breakeven cost across various sectors of the economy. A base case scenario presents green hydrogen's cost competitiveness against incumbent fuels and commodities, at market prices. To present a forward-looking view, an aggressive scenario has also been depicted in Figure 6, which assumes higher prices of incumbent fuels. Furthermore, economised parameters have been considered in mobility applications. Comparing the green hydrogen production costs in India with the breakeven costs in both scenarios demonstrates that the use of green hydrogen will command a sharp premium. However, certain applications have a lower premium in the aggressive scenario.

FIGURE 6:

Green hydrogen cost curve



Source: CEEW analysis

Note 1: For assumptions of the cost curve see Appendix 2.
Note 2: CEEW has calculated breakeven costs for mobility applications only for long-haul transport. These costs correspond to the green hydrogen production cost after correcting for the estimated cost increase due to hydrogen refuelling stations, assumed at an optimum of USD 2 per kg (Reddi, et al. 2017).
Note 3: In charting the cost curve, pre-pandemic production values of various fuels and commodities are reflected, and the FY 2020 prices of incumbent fuels to negate the effect of price variability. With one exception for the mobility sector, where the 2023 diesel price has been considered to showcase the breakeven cost of green hydrogen due to volatile prices of the commodity.

The *NGHM*'s Phase I focus sectors for green hydrogen – fertiliser production (excluding urea) and refining – have the most achievable breakeven costs basis our analysis, ranging from USD 2.1-1.7 per kg. Cumulative demand unlocked in these sectors is estimated to be 4.7 MTPA, around half of which will originate from refining. Grey hydrogen – which currently relies on expensive imported fossil fuels – allows for a higher breakeven. Although shipping is a Phase II application area, its breakeven costs are comparable with those of the fertiliser and refining sectors due to high taxes on bunkering fuels. This sector could unlock an estimated 0.6 MTPA of green hydrogen demand in India.

The breakeven cost in urea production is much lower, at USD 1.03 per kg, albeit being a Phase I focus sector. This is because urea production in India receives high financial support through retail price subsidies. Furthermore, a transition from grey to green hydrogen use in urea production would necessitate procuring carbon dioxide externally, unlike the production of other fertilisers. This adds to the cost of transition which lowers the breakeven.

Hydrogen use in mobility applications is unlocked at a green hydrogen cost below USD 1.2 per kg. While the breakeven cost at the tank inlet for hydrogen-fuelled buses and trucks is around USD 2-3 per kg, the green hydrogen production cost must be significantly lower than this value to compensate for an increase due to hydrogen refuelling stations. The breakeven cost of hydrogen production for use in trucking is at a meagre USD 0.12 per kg, due to a high differential in the purchase cost and fuel economies of hydrogen-fuelled trucks and diesel trucks. These differentials will reduce over time, with economised production and technological improvements.

Other sectors – such as steel production, the green hydrogen–based methanol-to-jet-fuel pathway in aviation, and green hydrogen–based methanol production – are cost prohibitive, with breakeven costs of approximately USD 1 per kg or less.

Government incentives to catalyse demand by tackling production costs

The current incentives granted by the *NGHM* to provide viability gap funding for green hydrogen production and indigenise electrolyser manufacturing are intended to be catalytic. However, on a standalone basis, they will fall short of bridging the gap between green hydrogen production costs and the necessary breakeven costs. The subsidy for green hydrogen production (MNRE 2023), which is capped at USD 0.66 per kg in the first year and tapers down to USD 0.4 per kg by the third year, is insufficient for almost all sectors. The subsidy offered in the second tranche of the *Strategic Interventions for Green Hydrogen Transition* (*SIGHT*) scheme continues these rates for green hydrogen production (MNRE 2024) in

addition to offering an analogous subsidy for green ammonia production (MNRE 2024). Furthermore, the production-linked incentives (PLI) scheme for electrolyser manufacturing (MNRE 2023) with an allocation of approximately USD 560 million and an average incentive of USD 39.5 per kW, can only support around half of the electrolyser capacity needed to achieve India's 2030 green hydrogen goals. Therefore, financial institutions and green hydrogen sector participants must complement the government's efforts with innovative solutions to incentivise and unlock the demand for green hydrogen.

Challenge 2: Limited enabling infrastructure for green hydrogen deployment

Much like electricity and natural gas networks, deploying green hydrogen at scale relies on robust distribution and storage infrastructures to connect supply and demand nodes. However, green hydrogen supply chain infrastructure does not yet exist in India outside of several local industrial clusters that consume hydrogen. Moreover, power evacuation infrastructure closer to ports may also be insufficient to cater to export markets. This creates commercial uncertainty for project developers and financiers of green hydrogen, who must consider additional operational challenges. The added cost for developers to build the enabling infrastructure could also be prohibitive for new green hydrogen projects.

Medium-term applications that do not currently consume hydrogen, such as mobility, steel, and city gas distribution, will impose specific infrastructure requirements that must be built at scale from scratch. The production target of green hydrogen will need around 125 gigawatt (GW) of additional renewable energy capacity to be developed in India, beyond the country's ambition of 500 GW of renewable energy capacity by 2030 (MoP n.d.).

Developments in India aimed at building robust and enabling ecosystems

The central government's decision to offer a 25-year waiver on interstate transmission system (ISTS) charges for green hydrogen projects commissioned before 31 December 2030 through the *GHP* is a welcome incentive for the industry (MoP 2023). While state distribution company tariffs and state-level electricity duty on them may still be applicable, open access transmission charges would reduce because of the ISTS waiver. The *GHP* also maximises the use of existing infrastructure to connect renewable energy production areas with green hydrogen consumption nodes.

However, some states are unwilling to provide similar incentives on intrastate wheeling charges, which might impede the growth of the green hydrogen economy. The *NGHM* also mentions facilitating enabling infrastructure for two green hydrogen hubs by 2026. However, at present, limited details are available on the scale and type of public funding this would involve. Furthermore, assessing the cost-effectiveness of hydrogen hubs by comparing the costs of delivering renewable energy with the cost of transporting hydrogen/ammonia is necessary. The success of the *NGHM*'s integrated mission strategy (MNRE 2023) will be critical to ensuring coordinated and effective infrastructure development to support India's green hydrogen sector.

Challenge 3: High financing costs in emerging markets

Private investments in India carry a high cost of capital, particularly for capital expenditure-intensive projects in upcoming green sectors such as green hydrogen. The weighted average cost of capital (WACC) for green projects such as solar photo voltaic, natural gas and utility scale batteries in India ranges between 9 per cent and 11 per cent (IEA n.d.). High interest rates in advanced economies can also result in capital outflows from emerging markets such as India as the cost of borrowing increases. These challenges are often compounded by currency risk and macroeconomic volatility that dampen investor demand in unproven and upcoming sectors such as green hydrogen. Additionally, green hydrogen projects also face a substantial technology risk, especially for electrolysers, hydrogen storage, and fuel cells.

Slow progress on unlocking adequate financing for India's green hydrogen sector

Raising capital from private financial institutions is expensive for Indian green hydrogen producers. While domestic financial institutions have been working with the Government of India to develop financing frameworks for domestic green hydrogen projects including guidelines on credit appraisal, risk assessments, and concessionary finance to aid credit flow into green hydrogen projects, these innovative solutions are still at the early stages. Development finance institutions globally have been cautious and sparing in financing green hydrogen with concessional capital at scale due to the nascent development in the sector. Furthermore, given the nascency of this sector, financial institutions are at the early stages of developing innovative financing solutions such as first-loss equity, risk insurance, and subordinated debt. Incentives offered by developed countries to support their green hydrogen sectors will also deter capital flow to emerging economies such as India. Inadequate financing hinders the demonstration of green hydrogen technologies at scale, which causes uncertainties associated with the sector to remain unresolved, further discouraging financing.

Section 4. Private Sector Considerations for Policymakers

Considering the challenges that the domestic green hydrogen ecosystem faces, and learnings from emerging markets globally, in this section we offer working policy considerations for the Government of India. These multifaceted considerations aim to reduce green hydrogen production costs, generate sustainable demand for green hydrogen, and leverage critical enablers for building a thriving green hydrogen sector in India.

Consideration 1: Reducing green hydrogen production costs

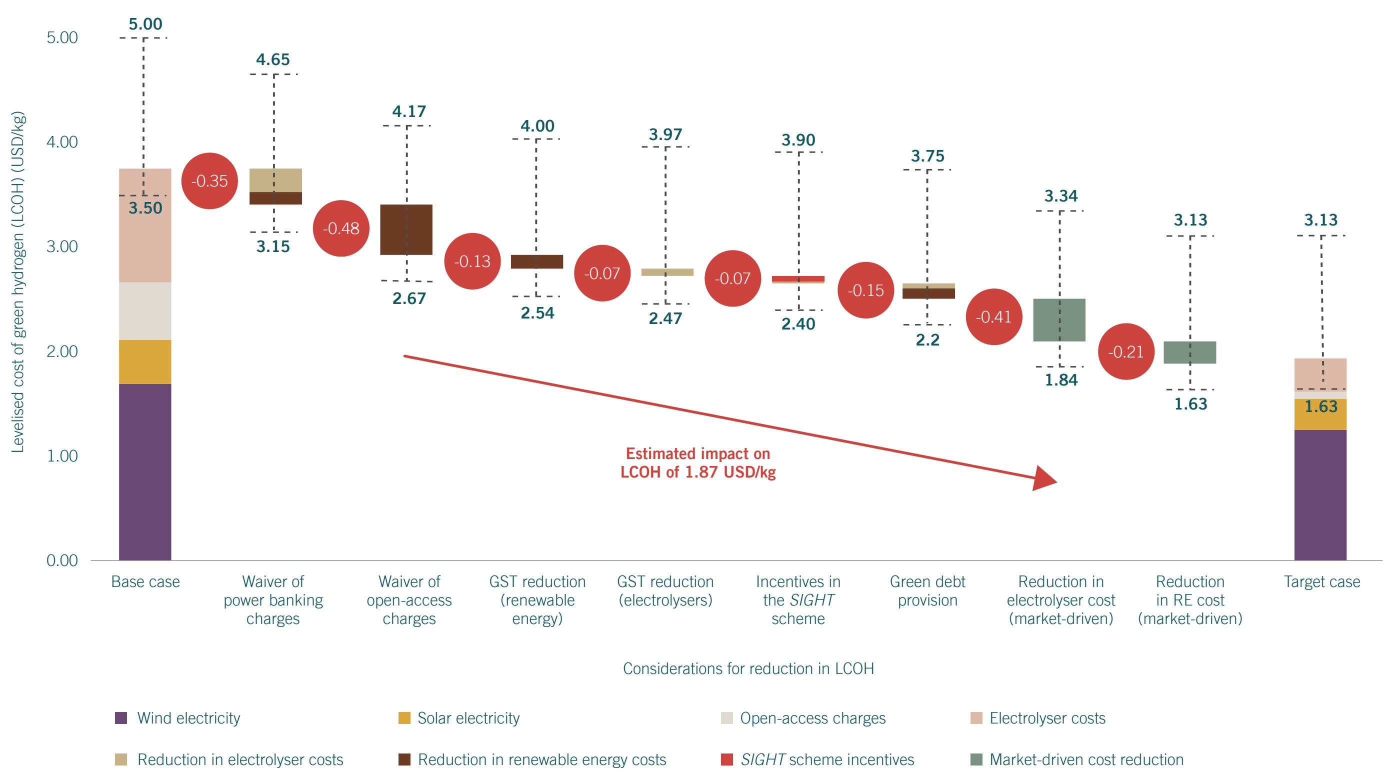
As per industry estimates, the levelised cost of green hydrogen (LCOH) in India in 2024 is estimated to range between USD 3.5-5 per kg. The variance in LCOH could be explained by the mix and type of renewable energy, capacity utilisation factor of renewable energy assets, plant load factor, power efficiency, assumed degradation, and contracted price of electrolysers.

In conjunction with the outlay granted by the *NGHM* to provide viability gap funding for green hydrogen production and to indigenise electrolyser manufacturing, several additional policy incentives could be considered to further decrease the LCOH. These incentives that lower the cost of renewable energy have an outsized impact on the LCOH, totalling as estimated reduction of USD 0.83 per kg of hydrogen (Figure 7). These include waiving power banking and open-access charges in addition to reducing the Goods and Services Tax (GST) on renewable energy components. Incentives such as a reduction in GST on electrolyser components; availing incentives under the *SIGHT* scheme for the production of electrolysers, green hydrogen, and green ammonia; and a decrease in capital costs through green debt access, that help drive down the cost of electrolysers have an estimated impact of USD 0.41 per kg. Waiver of power banking charges and green debt access would affect the cost of both the electrolyser and renewable energy as illustrated in Figure 7.

Market-driven innovations in electrolyser and renewable energy technologies could also support to lower the cost of electrolysers and renewable energy by an estimated USD 0.62 per kg. The cumulated impact of the aforementioned incentives along with potential innovations could lead to an estimated LCOH ranging between USD 1.63-3.13 per kg.

FIGURE 7:

Estimated impact of the policy considerations on green hydrogen production costs



Source: CEEW analysis

Note 1: The green hydrogen cost reduction trajectory has been estimated for the state of Gujarat, which is the largest industrial consumer of hydrogen in India, based on inputs pertaining to the cost economics in the state. A detailed description of the assumptions considered for the modelling can be found in Appendix 2.

Note 2: As per CEEW's cost build-up models for deriving the LCOH, the cost of procuring renewable energy accounts for 70 per cent of the LCOH in India, while the capital cost of electrolysers accounts for the rest. CEEW's LCOH model assumes optimised parameters for a wind-solar-hybrid (77 per cent wind, 23 per cent solar) renewable energy mix and economised costs of electrolysers. This optimised scenario results in a more competitive LCOH that may, under a bullish projection, be reflected in the market in the next 2-3 years as developers that currently utilise a solar-only procurement model incorporate wind energy into the mix.

Other important factors that can impact the cost of green hydrogen production include the efficiency of the electrolyser, scale of domestic production, and costs of supporting distribution and storage infrastructure.

Establishing a supportive power banking framework

Renewable energy banking could also be instrumental in reducing the cost of green hydrogen by increasing the utilisation of electrolysers. As per our models for a solar-only operation, electrolysers currently have a 33 per cent utilisation factor with 30 per cent oversizing of solar power plants. While the *GHP* already allows banking for a period of 30 days, hydrogen-consuming state governments could also make similar allowances for green hydrogen projects on a monthly basis, injected at any 15-minute time block. This would further improve the utilisation of electrolysers and reduce green hydrogen costs. There is already precedence for this given that several state governments allow up to 100 per cent (Gulia, Banga and Garg 2021) of their renewable energy to be banked at different terms, even monthly (Sharma 2022). To facilitate uniformity in renewable energy banking provisions, the MNRE could consider standardising and reducing the terms for power banking vis-à-vis green hydrogen projects across states.

Providing low-cost open-access electricity

Waivers on interstate open-access charges (MNRE 2023) could also support the provision of wheeling power between special economic zones, given that the production sites of green hydrogen and its derivatives may be located at a considerable distance from renewable assets and across state lines. Similar to the central government, states could provide waivers on ISTS charges. States such as Rajasthan, Andhra Pradesh, and Uttar Pradesh already provide waivers or have reduced the intrastate open-access charges in their respective green hydrogen policies.

Reducing goods and services tax

The Government of India could reduce the GST for components used in green hydrogen/green ammonia production (solar and wind-electricity generation modules), including during its sale as a final commodity. Under the existing GST structure, electrolysers are taxed at 18 per cent, and renewable energy setups at 13.8 per cent under a composite structure. The reduction in GST could be planned for a stipulated period until a 5 MTPA production capacity is established.

Reducing capital costs through green debt

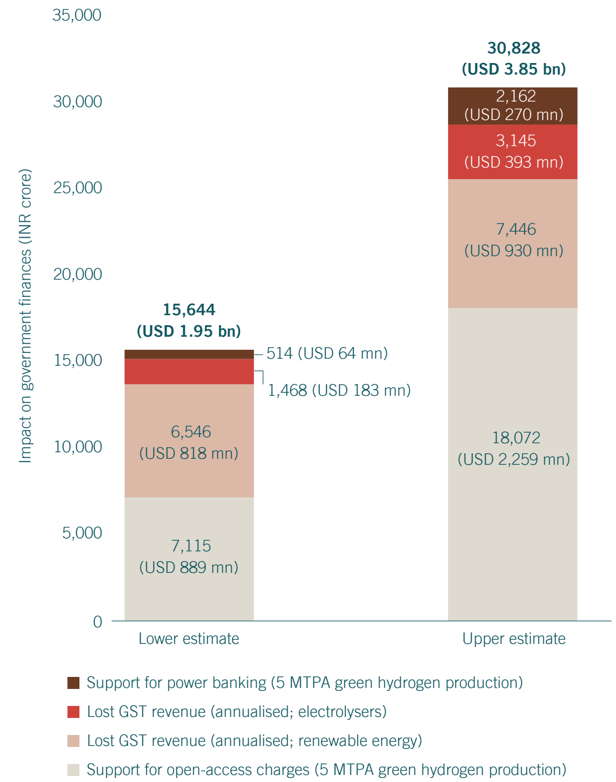
Central and state governments could consider providing direct fiscal support through low-cost loans, government-owned institutions, and other forms of financial assistance. The provision of low-cost green debt at rates commensurate with other green bonds or loans will be necessary to reduce the WACC for green hydrogen projects. This could help reduce green hydrogen production costs without significantly burdening government finances.

Projected budgetary outlay of the considerations

To implement the aforementioned considerations, direct financial support from the central and state governments will be essential. We estimate that waiving off open-access charges may have the largest impact on government finances (Figure 8). This impact, when annualised, could vary for each state, over a wide range of INR 7,115-18,072 crore (approximately USD 890 million to USD 2.2 billion). This is because the base components of the open-access tariffs are dictated by different policies across each state. Reducing GST on electrolysers and renewable energy will also incur a considerable loss of revenue for both the central and state governments. Until the capacity to produce 5 MTPA green hydrogen is established, the lost revenue due to the reduction in GST to 5 per cent may cost the government over a range of INR 8,015-10,593 crore (USD 1,068-1,412 million) per year. At a 5 MTPA green hydrogen production level, and by accounting for differences in state-level tariffs on power banking, the annualised impact on the governments for fully supporting power banking ranges between INR 515-2,163 crore (USD 69-288). These measures could complement the outlay in the *NGHM*, increasing the effectiveness of viability gap funding and PLI in the *NGHM*.

FIGURE 8:

Estimated impact of the considerations on finances of state and central governments (INR crore)



Source: CEEW analysis

Consideration 2: Catalysing sustainable demand for green hydrogen

Established and growing demand for green hydrogen will be instrumental in developing economies of scale, driving down the cost of green hydrogen, and creating a virtuous cycle. Mandated green hydrogen purchase obligations (HPO) for domestic industries can help initiate demand. Promoting exports to markets that have signalled intentions to import green hydrogen or green ammonia is another lever that can be employed to generate demand.

Stipulating green hydrogen purchase obligations

India's green hydrogen ecosystem is experiencing a supply-side push, but still lacks the necessary demand-side pull required to scale. Through the *Energy Conservation (Amendment) Act, 2022*, the central government could mandate the offtake of green hydrogen by instituting blending requirements in industrial units, such as in the fertilisers and refining industries. Blending mandates, with periodic upward revisions clearly outlined, may be needed in the early stages of this transition to help stimulate demand. A small blending proportion would spread the incremental cost of green hydrogen over the total volume of hydrogen used, thereby cushioning its impact on the financials. The MNRE has initiated discussions with stakeholders in the industry to outline a plan for green HPOs. Similar policies were successful in scaling India's renewable energy generation from 2003 onwards, when state electricity regulatory commissions set obligations for large commercial entities. While this may trigger an increase in the cost of industrial output, offtakers could eventually benefit from long-term stability in fuel costs and secured energy requirements due to reduced dependence on imported fossil fuels from volatile international markets.

In the initial phase, the refining and non-urea fertiliser industries could be brought under the ambit of HPOs, as the premium associated with green hydrogen is lower in these applications than in urea fertilisers. The price increase due to the blending of green hydrogen in refineries could be passed on to the end consumers if the cost of crude oil in the international market reduces to compensate for the increased prices. To minimise the impact on citizens, the government could consider reducing taxes on refinery products. Once the cost of green hydrogen has decreased significantly, urea plants could also be brought under the ambit of HPOs. A hydrogen blending mandate in urea fertiliser plants could be supported by the viability gap fund under the *SIGHT* scheme.

Facilitating a compliance carbon market

We welcome the Government of India's release of the *Carbon Credit Trading Scheme* (*CCTS*) (MoP 2023). Under this scheme, obligated entities in the fertiliser, refining, and steel sectors must comply with the set carbon targets. A carbon price on these obligated entities would incentivise the transition to green hydrogen in these sectors. The design of a compliance carbon market with allowances and carbon pricing aligned with the *Paris Agreement* goals, will be critical to successfully incentivising demand for green hydrogen without imposing exorbitant financial pressures on the obligated entities.

Providing financial assistance to the fertiliser industry for consuming green hydrogen

Given that the cost of fertiliser production in India is highly sensitive to the cost of fuel, any blending mandate for green hydrogen will significantly impact the financials of the fertiliser industry. Furthermore, it may be challenging for the government to increase the outlay for fertiliser subsidies, which exceeded USD 10 billion a year in FY 2021 and FY 2022. The total subsidy expenditure is heavily dependent on the volume of chemical fertilisers consumed, which the Indian government has already initiated efforts to rationalise through the *Prime Minister - Promotion of Alternate Nutrients for Agriculture Management Yojana (PM-PRANAM scheme)* (Ministry of Agriculture and Farmers Welfare 2023). This scheme aims to promote the use of alternate and organic fertilisers through a market development assistance subsidy, and incentives to states to reduce chemical fertiliser consumption. The subsidy expenditure that will be saved due to the reduced use of chemical fertilisers through these initiatives could support the fertiliser industry's green hydrogen consumption, either as support for capital expenses or as partial viability gap funding. The Department of Fertilisers, Ministry of Chemicals and Fertilisers, could consider making a provision to allocate a portion of the incentive amount to fertiliser plants located within the state where the reduction has occurred. This would also help states achieve their decarbonisation strategies within the *State Action Plans on Climate Change*.

Incentivising offtake in hard-to-abate sectors

Carbon prices in the *European Emissions Trading System* have nudged heavy industries in Europe to source green steel to lower their emission intensities. Green steel manufacturers that use green hydrogen in product manufacturing processes have successfully raised sufficient capital to initiate projects. Industrial buyers have issued advance purchase orders for green steel, thereby setting the sector on a self-sustaining path.

Promoting exports of green hydrogen and its derivatives

Through the *NGHM*, India envisions becoming not only a leading producer but also a major exporter of green hydrogen and its derivatives. Infrastructure and administrative support for export-oriented units could be prioritised to facilitate trade. Such units would need to be able to access incentives and other benefits of export-focused green hydrogen hubs. Port infrastructure should ensure adequate land availability and other resources for storing and handling green hydrogen derivatives. Further, through appropriate bilateral and multilateral agreements, India could remove structural and regulatory barriers to trade with key allied partners, facilitating a free international market for these fuels. India could also encourage initiatives that aim to leverage opportunities for collaboration with partners in allied countries to mutually enhance production capacities or develop technologies across the green hydrogen value chain.

Consideration 3: Leveraging critical enablers for a thriving ecosystem

Policy interventions to simplify project development processes, facilitate open trade and financing, and catalyse innovation in the green hydrogen ecosystem are critical. These interventions include establishing enablers to reduce transaction costs, removing structural bottlenecks for project development, developing standards and certification procedures, and investing in R&D.

Facilitating land and water allocation

Clear processes for land acquisition in manufacturing zones – for instance, on a long-term lease basis or land-for-sale – and streamlining the processes for obtaining various land use and zoning approvals for green hydrogen production, component manufacturing, distribution, and storage through a dedicated single-window clearance system, could be instrumental in facilitating growth in this sector. The transportation of green hydrogen will require the installation of pipeline infrastructure and obtaining a timely right-of-way would be paramount. To simplify right-of-way processes, the Government of India could introduce a law similar to that in the power transmission sector, where the licensee is given the right to build transmission lines under Section 164 of the *Electricity Act*.

State governments could consider replicating measures adopted by Uttar Pradesh, Andhra Pradesh, and Rajasthan to provide land and water at subsidised rates. States could also consider full or partial exemptions from land tax, local-body tax, land use conversion charges, non-agricultural tax, and industrial water consumption charges. While these measures may have a minimal impact on the overall cost of production of green hydrogen, they have the potential to be instrumental in improving the ease of doing business for developers.

Increasing research and development allocation

The proposed allocation of INR 400 crore (USD 49 million) under the *NGHM* is welcome; however, further investment may be required to reduce dependence on critical raw materials and promote 'Make in India'. The *R&D Roadmap for Green Hydrogen Ecosystem in India* (MNRE 2023) released by the MNRE outlines India's priorities along the green hydrogen value chain. Such a focused approach to R&D initiatives may be critical to the sector's progress. Further, R&D initiatives should be able to access provisions under the newly established Anusandhan National Research Foundation to augment the available resources. The government could float projects aimed at improving critical technology components in the public domain with clear eligibility criteria, project targets and milestones, and funding criteria. The results and methodology of such projects could be disclosed for public review, and the intellectual property could be published. Industrial stakeholders and start-ups, along with academia and other non-competing entities, could be eligible to undertake such projects and secure the associated funding.

Encouraging standardisation and certification to promote trade

While India has already released its definition of 'green hydrogen' (MNRE 2023), aligning with a global consensus on standards and certification norms will help create further interoperability and ensure smooth trade. Given India's ambitions for this sector, there is an opportunity for the country to lead efforts to establish a global rules-based cooperative framework for green hydrogen (Ghosh, et al. 2022.). Gaps in safety standards across the green hydrogen value chain should also be addressed (Sripathy, et al. 2023). Testing and certification facilities for all green hydrogen value chain components, with the involvement of premier research institutions and private stakeholders, can be facilitated with centralised institutional oversight to ensure quality control and project safety.

Fostering private sector participation in R&D

To pave the way for industrial green hydrogen adoption in India, HSBC India has partnered with the Shakti Sustainable Energy Foundation to support research on policy, technology, and finance solutions that can scale the real-world application of green hydrogen in industrial facilities. Technology pathways, business models, and complementing policy recommendations to scale the uptake of green hydrogen in high potential industrial clusters across Gujarat, Maharashtra, Jharkhand, and Chhattisgarh will aide in the industrial adoption of green hydrogen as a strategic alternate fuel and boost India's green hydrogen economy. HSBC India has also partnered with the Indian Institute of Technology (IIT) Bombay to launch the pan-IIT Innovation in Green Hydrogen programme to encourage researchers, scientists, and entrepreneurs to develop breakthrough technologies and solutions that address key challenges in green hydrogen production, storage, transportation, and utilisation.

Section 5. Initial Learnings on Green Hydrogen Financing

The policy considerations presented in the prior section represent a suite of high potential, near-term actions the government could pursue to accelerate private investment in domestic green hydrogen production. However, not all barriers to investment can be solved through government-led interventions. Private sector financial institutions, developers, and offtakers must partner with multilateral development banks, donors, and other development finance institutions to deploy innovative financing solutions at scale in the green hydrogen sector.

Financing green hydrogen and green ammonia projects remains a challenge, highlighted by the few projects that have secured sufficient financing to commence development. However, as demand increases, financiers must develop innovative financing solutions in response to market dynamics. In the meantime, existing projects that have received financing, as well as projects for proximate energy sources, such as renewables and liquefied natural gas, present valuable lessons.

To inform these considerations, we engaged in discussions with various stakeholders, including buyers, developers, lenders, private equity, and development finance institutions, to gather initial high-level learnings from early investments in this sector and present them in this section.

Learning 1: Standardise medium-term offtake agreements

Financial institutions could work with project developers to create standardised medium-term offtake agreements for green hydrogen, similar to the movement towards more standardised, bankable power purchase agreements in the renewable energy sector. A governmental nodal agency to facilitate such agreements would be critical. Financial institutions have indicated that 10-year offtake agreements would be sufficient, less than the typical project lifetime of 20-30 years. Since ammonia is a globally traded commodity with fluctuating prices, medium-term agreements can support developers and buyers, who need flexibility on pricing and volume.

Learning 2: Mitigate offtake risk with real options

Financial institutions could work with project developers and governments to design projects where renewable power generation capacity can be connected to the grid, providing an alternative revenue stream in case offtake risks make planned projects unviable. Although term-ahead and day-ahead markets in India have low trading volumes, they offer an avenue for project developers to sell excess power expeditiously. Purchase agreements should shield project developers from challenges in amortising capex in case of offtake risks. Finance professionals consider technology risks to be minimal, as most project costs will be related to proven technologies (e.g., solar, wind, and hydro-renewable power).

Learning 3: Manage currency risk with proven hedging products

Financial institutions could work with multilateral development banks and other organisations to develop currency hedging products for green hydrogen projects focused on export markets. Structuring contracts in USD rather than INR can also support to mitigate currency risks associated with investments in India.

Learning 4: Scale use of concessional capital, guarantees, and viability gap funding

Financial institutions and developers could work with multilateral development banks and donors to facilitate the investment of concessional capital in the green hydrogen sector in India. Guarantees and viability gap funding mechanisms should be encouraged to lower the cost of capital for projects and make Indian green hydrogen and ammonia production competitive in global markets.

Learning 5: Invest in project preparation and capacity building

Green hydrogen/green ammonia production and its supporting distribution and storage infrastructure require high upfront capital investment and considerable effort in designing, structuring, and financing projects. Significant project preparation funding will be needed to bring more projects into the pipeline and move them towards fundraising. However, project developers have also found that mainstream financial institutions currently do not have the capacity to evaluate hydrogen and ammonia projects, given their lack of experience and familiarity with the idiosyncrasies of these projects. Resources are therefore required to draw together investors from across commodities, infrastructure, and liquefied natural gas teams, all of which can play a role in transferring knowledge from their verticals to the green hydrogen sector and help in better evaluating green hydrogen and ammonia projects.

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Appendix 1: Abbreviations

CAGR	Compound annual growth rate
CCTS	*Carbon Credit Trading Scheme*
CCUS	Carbon capture, utilisation, and storage
FCEV	Fuel-cell electric vehicle
FY	Financial year
GHP	*Green Hydrogen Policy*
GST	Goods and Services Tax
GW	gigawatt
HGV	Heavy goods vehicle
HPO	Hydrogen purchase obligation
HRS	Hydrogen refuelling station
IIT	Indian Institute of Technology
ISTS	Interstate transmission system
kW	kilowatt
kWh	kilowatt-hour
LCOH	Levelised cost of (green) hydrogen
MGV	Medium goods vehicle
MMBtu	metric million British thermal unit
MMSCM	million metric standard cubic meter
MNRE	Ministry of New and Renewable Energy
MoEFCC	Ministry of Environment, Forest and Climate Change
MoP	Ministry of Power
MoPNG	Ministry of Petroleum and Natural Gas
MT	million tonnes
MTPA	million tonnes per annum
MW	megawatt
NGHM	*National Green Hydrogen Mission*
PLF	Plant load factor
PLI	Production-linked incentives
PM-PRANAM	*Prime Minister - Promotion of Alternate Nutrients for Agriculture Management Yojana*
R&D	Research and development
RE	Renewable energy
ROW	Right of way
SECI	Solar Energy Corporation of India
SEZ	Special economic zone
SIGHT	*Strategic Interventions for Green Hydrogen Transition*
TPA	tonnes per annum
WACC	Weighted average cost of capital

Appendix 2: Cost Curve Assumptions

Table A1 lists the assumptions for the cost curve across various end-use sectors of the economy. As discussed in the main manuscript, the cost curve uses pre-pandemic prices and consumption volumes to reflect the long-term breakeven price of green hydrogen across various sectors. The base case costs of incumbent fuels or commodities are compiled from various official government sources. The consumption values of incumbent fuels are compiled from reported literature or derived using appropriate conversion parameters.

TABLE A1:

Assumptions for the cost curve (excluding road mobility applications)

			Incumbent fuel/commodity cost			Consumption	
S.No.	End-use sector	Incumbent fuel/ commodity	Unit	Base case value	Aggressive case value	Unit	Value
1	Aviation	Jet fuel	USD/tonne	837.20	1,215	MTPA	15.20
2	Fertiliser production (urea)	Natural gas	USD/MMBtu	7.47	10.40	MMSCM	12,170
3	Fertiliser production (non-urea)	Natural gas	USD/MMBtu	10.10	14.80	MMSCM	2,717
4	Refining	Natural gas	USD/MMBtu	10.10	14.80	MMSCM	7,038
5.1	Shipping	High-speed diesel oil	INR/litre	64.96	96.50	'000 TPA	808
5.2		Light diesel oil	INR/litre	64.96	96.50	'000 TPA	2.20
5.3		Furnace oil	USD/tonne	399.85	445.25	'000 TPA	729
6.1	Steel: Hot metal production	Coke	USD/tonne	184.00	241.20	kg/tonne of product	13
6.2	Steel: Gas-based direct reduced iron (DRI) production	Natural gas	USD/MMBtu	7.47	14.80	kg/tonne of product	68
7	Methanol		USD/tonne	415	600	MTPA	2.46
8	Urea imports		USD/tonne	249	462	MTPA	10.29
9	Non-urea imports		USD/tonne	314	592	MTPA	6.64
10	Ammonia Imports		USD/tonne	303	462	MTPA	2.40

Sources: (i) Base case costs of incumbent fuels or commodities: jet fuel and shipping fuel prices (MoPNG 2022); delivered natural gas prices estimated on this basis of (Petroleum Planning and Analysis Cell 2023), (MoPNG 2015); cost of coking coal for steel production: (Ministry of Commerce n.d.); cost of imported methanol, urea, non-urea fertiliser and ammonia imports (Ministry of Commerce n.d.)

(ii) Consumption figures for incumbent fuels or commodities: jet fuel (MoPNG 2022); natural gas in fertilisers and refining (Petroleum Planning & Analysis Cell 2020); shipping fuels (MoPNG 2022); steel production figures (IBM 2023); coking coal in steel: imported methanol, urea, non-urea fertiliser, and ammonia imports (Ministry of Commerce n.d.)

Table A2 lists the assumptions used in calculating the breakeven cost for mobility applications.

TABLE A2:

Assumptions for the cost curve for road mobility applications

S.No.	Particular	Unit	Base case value	Aggressive case value	Source
	BUSES				
1	Average annual mileage by inter-city buses in India	km	65,000		(Soman, et al. 2020)
2	Number of inter-city buses in India	#	4,05,388		(SGA sustainable mobility solutions 2021)
3	Cost of diesel	INR/l	92		(MoPNG 2022)
4	Purchase cost of one 9 m diesel bus	INR million	4.00		CEEW research based on market rates
5	Purchase cost of one 12 m diesel bus	INR million	7.30		
6	Purchase cost of one 9 m fuel cell electric vehicle (FCEV) bus	INR million	10.80	4.80	
7	Purchase cost of one 12 m FCEV bus	INR million	13.80	8.80	
TRUCKS					
8	Average annual mileage of long-haul trucks in India	km	52,784		(Malik and Tiwari 2017)
9	Number of long-haul trucks in India	#	47,93,319		CEEW research
10	Cost of diesel	INR/l	92		(MoPNG 2022)
11	Purchase cost of one medium goods vehicle (MGV) diesel truck	INR million	2.00		CEEW research based on market rates
12	Purchase cost of one heavy goods vehicle (HGV) diesel truck	INR million	4.50		
13	Purchase cost of one MGV FCEV truck	INR million	5.50	2.60	
14	Purchase cost of one HGV FCEV truck	INR million	11.30	5.90	

Sources: (i) Base case costs of incumbent fuels or commodities: jet fuel and shipping fuel prices (MoPNG 2022); delivered natural gas prices estimated on the basis of (Petroleum Planning and Analysis Cell 2023), (MoPNG 2015); cost of coking coal for steel production: (Ministry of Commerce n.d.); cost of imported methanol, urea, non-urea fertiliser and ammonia imports (Ministry of Commerce n.d.)

(ii) Consumption figures for incumbent fuels or commodities: jet fuel (MoPNG 2022); natural gas in fertilisers and refining (Petroleum Planning & Analysis Cell 2020); shipping fuels (MoPNG 2022); steel production figures (IBM 2023); coking coal in steel: imported methanol, urea, non-urea fertiliser, and ammonia imports (Ministry of Commerce n.d.)

Table A3 lists all the modelling inputs considered for estimating the levelised cost of hydrogen (LCOH) in Figure 7. Estimation of LCOH across scenarios is done sequentially, as listed in the table. All considerations from a preceding scenario are carried forward, unless otherwise mentioned in the table.

TABLE A3:

Inputs for estimation of levelised cost of hydrogen (LCOH)

S.No.	Particular	Value	Unit	Source
BASE CASE				
1	Electrolyser plant load factor for wind-solar hybrid (WSH)	74%	%	Results from CEEW modelling
2	Specific power consumption in electrolyser	50	kWh/kg-H_2	
3	Surplus power consumption	6.10%	%	
4	Plant load factor - solar electricity	26%	%	
5	Plant load factor - wind electricity	34%	%	
6	Share of solar power	23%	%	
7	Share of wind power	77%	%	
8	Capex - electrolyser	750	USD/kW	CEEW research based on market rates and component build-ups
9	Capex - electrolyser stack	412.50	USD/kW	
10	Capex - electrolyser balance-of-plant	337.50	USD/kW	
11	Capex - solar electricity	625	USD/kW	
12	Capex - wind electricity	950	USD/kW	
13	Discount rate	10%	%	(IEA 2023)
14	Life of component - electrolyser stack	30	Years	Assumptions about plant operational parameters
15	Life of component - electrolyser balance-of-plant	8.50	Years	
16	Life of component - solar electricity module	25	Years	
17	Life of component - wind electricity module	25	Yeas	
18	Opex - electrolyser stack	5%	% of capex	
19	Opex - electrolyser balance-of-plant	5%	% of capex	
20	Opex - solar electricity	1.50%	% of capex	
21	Opex - wind electricity	2%	% of capex	
22	Exchange rate	75	INR/USD	Estimates
23	Open access rate: State transmission utility (STU) - solar electricity	0.99	INR/kWh	(CEEW-CEF 2023)
24	Open access rate (STU) - wind electricity	0.78	INR/kWh	

POWER BANKING PROVISION				
25	Electrolyser plant load factor for WSH	95%	%	Modelling results
26	Surplus power consumption	0	%	
OPEN-ACCESS PROVISION				
27	Open access rate: Central transmission utility (CTU) - Solar electricity	0.09	INR/kWh	(CEEW-CEF 2023)
28	Open access rate (CTU) - wind electricity	0.11	INR/kWh	
PARTIAL GST WAIVER (ELECTROLYSER)				
29	Existing GST rate	18	%	(Clear n.d.)
30	Proposed GST rate	5	%	
PARTIAL GST WAIVER (RENEWABLE ENERGY)				
31	Existing GST rate	13.80%	%	(Annapoorna M. 2022)
32	Proposed GST rate	5%	%	
BENEFITS DUE TO THE *STRATEGIC INTERVENTIONS FOR GREEN HYDROGEN TRANSITION* (*SIGHT*) INCENTIVES				
33	Year 1 base incentive under *SIGHT*	4,440	INR/kW	(SECI Limited 2023)
34	Year 2 base incentive under *SIGHT*	3,700	INR/kW	
35	Year 3 base incentive under *SIGHT*	2,960	INR/kW	
36	Year 4 base incentive under *SIGHT*	2,220	INR/kW	
37	Year 5 base incentive under *SIGHT*	1,480	INR/kW	
38	Performance quotient	1		
GREEN DEBT PROVISION				
39	Coupon rate under green debt provision	7.95%	%	(Shah and Mukherjee 2023)
40	Debt-to-equity ratio	4	–	Assumption
41	Discount rate	9.20%	%	Calculation
REDUCTION IN ELECTROLYSER COST				
42	Capex - electrolyser	350	USD/kW	Aggressive case assumption
REDUCTION IN COST OF RENEWABLE ENERGY COMPONENTS				
43	Capex - solar electricity	532	USD/kW	Aggressive case assumption
44	Capex - wind electricity	842	USD/kW	
45	Levelised cost of solar electricity	2.20	INR/kWh	
46	Levelised cost of wind electricity	2.75	INR/kWh	

Appendix 3: Major Policy Milestones

Key components	Features
	***Green Hydrogen Policy* (*GHP*) (Ministry of Power 2022)**
Implementing agency	Ministry of Power
Launch year	2022
General	Aims to facilitate the supply of renewable energy to the green hydrogen sector in an expedited, easy, and economical way
Definitions	Defines green hydrogen/ green ammonia as "produced by way of electrolysis of water using renewable energy, including renewables which has been banked and hydrogen or ammonia produced by biomass"
Renewable energy access	**To facilitate the supply of renewable energy, the *GHP* enables the following**: • A waiver on interstate transmission charges for 25 years on projects commissioned before 30 June 2025 • Granting open access to plants within 15 days of application • Provides guidelines on the banking of renewable energy, which is permitted for up to 30 days • Grants connectivity on a priority basis under the generation end for interstate transmission of renewable energy • Allows developers to set up bunkers near ports for green ammonia storage for exports
	***National Green Hydrogen Mission* (*NGHM*) (MNRE 2023)**
Implementing agency	Ministry of New and Renewable Energy
Launch year	2023
Objectives	• Make India a global hub for the production, usage and export of green hydrogen and its derivatives • Contribute to India becoming self-reliant through clean energy • Decarbonisation of the economy, reduced dependence on fossil fuel imports, and leadership in green hydrogen market and technology
Expected outcomes	**The expected outcomes by 2030 are as follows**: • Green hydrogen production capacity of at least 5 MTPA • Renewable energy capacity addition of ~125 GW • Total investments over INR 8 lakh crore • Create more than 6 lakh full-time jobs • CO_2 emissions mitigation of 50 MTPA

Two-phased approach	**The *NGHM* proposes a two-phased approach as follows:** Phase I (FY 2023 – FY 2026): Creating adequate and sustainable demand: • Incentives will target the indigenisation of a green hydrogen value chain through adequate domestic electrolyser manufacturing capacity • Encourage the utilisation of green hydrogen in key sectors such as refining, fertilisers, and city gas to create a sustained demand and attract investments • Lay the foundation for future transition in other hard-to-abate sectors such as steel, mobility, and shipping • Establish regulations and standards in line with international norms Phase II (FY 2026 – FY 2030): Enable a deep decarbonisation of the economy: • Commercial scaling of green hydrogen projects in steel, mobility, and shipping • Undertake pilots in other potential sectors such as railways, aviation, etc.
Mission components	**The *NGHM* consists of the following interventions:** • Demand creation through export markets, domestic markets, and import substitution • Incentivising supply through the *SIGHT* scheme • Key enablers through key resources such as finance; renewable energy, land, and water; R&D; ease of doing business; creating infrastructure and supply chain; regulations and standards; skill development; and public awareness *Strategic Interventions for Green Hydrogen Transition* (*SIGHT*) is a comprehensive incentive programme that facilitates a green hydrogen value chain. These incentives target: (i) domestic manufacturing of electrolysers through production-linked incentives under Component I (ii) production of green hydrogen and derivatives through viability gap funding under Component II of the scheme. As of March 2024, two tranches of the SIGHT scheme have been released that cumulatively provision incentives for 3,000 MW electrolyser capacity, 650 kTPA of green hydrogen production, and 550kTPA of green ammonia production.
Integrated mission strategy	**Calls on 13 central ministries and state governments to coordinate to achieve the outlined mission objectives. Some of these are as follows**: • Ministry of New and Renewable Energy: Overall coordination and implementation, formulation of schemes and financial incentives, etc. • Ministry of Power: Policies to facilitate the delivery of renewable energy • Ministry of Petroleum and Natural Gas: Policies to facilitate uptake in refining and city gas distribution sectors
Budgetary outlay	**Total outlay of INR 19,744 crore (~USD 2.4 billion), broken down as follows**: • *SIGHT*: INR 17,490 crore (~USD 2.2 billion) • Pilot projects: INR 1,466 crore (~USD 180 million) • R&D: INR 400 crore (~USD 49 million) • Others: INR 388 crore (~ USD 48 million)

Appendix 4: List of Figures and Table

Figures

Table

About the Climate Finance Leadership Initiative

The Climate Finance Leadership Initiative (CFLI) was formed in 2019 by Michael R. Bloomberg at the request of the United Nations Secretary-General, António Guterres, to lead a private sector initiative to "support a global mobilization of private capital in response to the challenge of climate change". CFLI aims to achieve that goal by bringing together leading institutions across the financial value chain, working alongside corporates, policymakers, and multilateral institutions to identify barriers to investment and support solutions that accelerate financing for low-carbon and climate-resilient projects in emerging markets.

CFLI India is Co-Chaired by N. Chandrasekaran, Chairman of Tata Sons, and Shemara Wikramanayake, Managing Director and Chief Executive Officer of Macquarie Group, and comprises 10 institutions namely GIC Private Ltd., Goldman Sachs India, HDFC Bank Ltd., HSBC India, Kotak Mahindra Bank Limited, Larsen & Toubro, Macquarie Group, NITI Aayog, State Bank of India, and Tata Sons. For more information, visit https://www.bloomberg.com/cfli.

About CEEW

The Council on Energy, Environment and Water (CEEW) is one of Asia's leading not-for-profit policy research institutions and among the world's top climate think tanks. The Council uses data, integrated analysis, and strategic outreach to explain — and change — the use, reuse, and misuse of resources. The Council addresses pressing global challenges through an integrated and internationally focused approach. It prides itself on the independence of its high-quality research, develops partnerships with public and private institutions, and engages with the wider public. CEEW has a footprint in over 20 Indian states and has repeatedly featured among the world's best managed and independent think tanks. Follow us on X (formerly Twitter) @CEEWIndia for the latest updates.

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