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A multilevel perspective

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CRediT: **IGES**: Conceptualisation of the whole paper, methodology, analysis, writing, review and editing; **WRI**: Case Study 1 and 2 (writing, methodology, analysis, review); **IISD**: Case Study 3 (writing, methodology, analysis, review).

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Abstract

India's national government has offered strong support for the development of green hydrogen as part of the clean energy transition. However, much of the actual progress in this transition will depend on subnational governments. This paper argues India's subnational governments have significant potential to capitalise on diverse natural resource endowments while creating jobs and growing the local economy when promoting green hydrogen. At the same time, the national government will need to offer direct and indirect support to address technological, financial, and institutional constraints at the subnational level. The paper therefore recommends a six-point agenda that can strengthen the multi-level collaboration needed to capture the full benefits of green hydrogen. That agenda consists of the following: 1) tailoring skill development programme to support the green hydrogen ecosystem; 2) closing infrastructure gaps; 3) incentivising off-takers; 4) attracting investment and encouraging public-private partnership; 5) encouraging research and development (R&D); 6) promoting co-innovation. These six points can help India realise the potential while addressing the attendant limitations needed to pull off the difficult multi-level balancing act required for a green hydrogen transition.

Introduction

India's National Green Hydrogen Mission (MNRE, 2023) holds promise to be of immense strategic importance as it aims to build support for green hydrogen and thereby drive a clean energy transition. The mission recognises hydrogen's potential to decarbonise hard-to-abate sectors such as industry, transport, and power generation. This underlines the country's interest in contributing to international decarbonisation efforts while fostering economic growth and innovation.

The country has made notable pronouncements and modest progress supporting the mission. For instance, India's Hydrogen Mission states that it aims to "make India the global hub for production, usage and export of Green Hydrogen and its derivatives" (Government of India, 2023b). To this end, India's union budget for 2023 has allocated an initial outlay of $2.3 billion for the Green Hydrogen Mission (PIB, 2023), which also witnessed a 102% increase in the 2024 budget (ET, 2024). While the mission presents an ambitious scenario that the country be a global supply hub, questions are often raised about the capacity of the green hydrogen industry to grow at both national and sub-national levels.

Many subnational governments have shown great interest in developing a *green* hydrogen ecosystem, however, the lack of adequate infrastructure, an established market, availability of off-takers, etc. can

affect the momentum. Research suggests that, if governments fail to prioritise environmentally friendly green hydrogen, they risk becoming trapped in the production of non-sustainable blue or grey outputs, posing potential long-term problems (Hermesmann and Müller, 2022).

The paper highlights the need for policy focus on the promotion of green hydrogen over other hydrogen production methods. It argues that state governments possess the context-specific knowledge required to tailor green hydrogen plans to local conditions and capitalise on varying resource endowments. The paper also contends that it will be critical to recognise that some states may lack the financial, institutional, and technological capacities to support the widespread development of hydrogen. As such, the national government will need to offer a mix of direct resource transfers (i.e. block grants) and indirect enabling reforms (i.e. tax incentives) that fill these gaps. Additionally, where there is a need for overseas technology support, the national governments may need to facilitate the same. Pulling off this delicate balancing act will be challenging; it will nonetheless be easier if one views the transition to green hydrogen through a multilevel lens.

Toward a Multilevel Perspective

The paper will use a multilevel perspective to help analyse the factors that can contribute to this transition. In so doing, it will draw loosely on ideas underpinning the multilevel perspectives in the sustainability transitions (specially in creating niche and supporting regime-level reforms) as well as multilevel governance literature (especially in stressing the collaboration between agencies with issue-specific and localities with context-specific knowledge) (Betsill and Bulkeley, 2006; Geels and Schot, 2007; Bulkeley and Betsill, 2013; Markard, Geels and Raven, 2020).

The general overview of the multilevel perspective can also illustrate some of the specific factors that will be needed in India. India is a democratic federalist polity wherein the central and state governments work together to improve social welfare. In practice, this necessitates that India's central, state and lower level governments share power as they cooperate in the delivery of a wide variety of public goods issues. To illustrate, health or education targets may be designed by both the central government and state governments, but much of the implementation happens below the national level (Moeko Saito-Jensen, 2015). These kinds of cooperative power sharing arrangements have indeed left their own variety of sustainability initiatives (NITI Aayog, 2018; Kandpal and Okitasari, 2023)

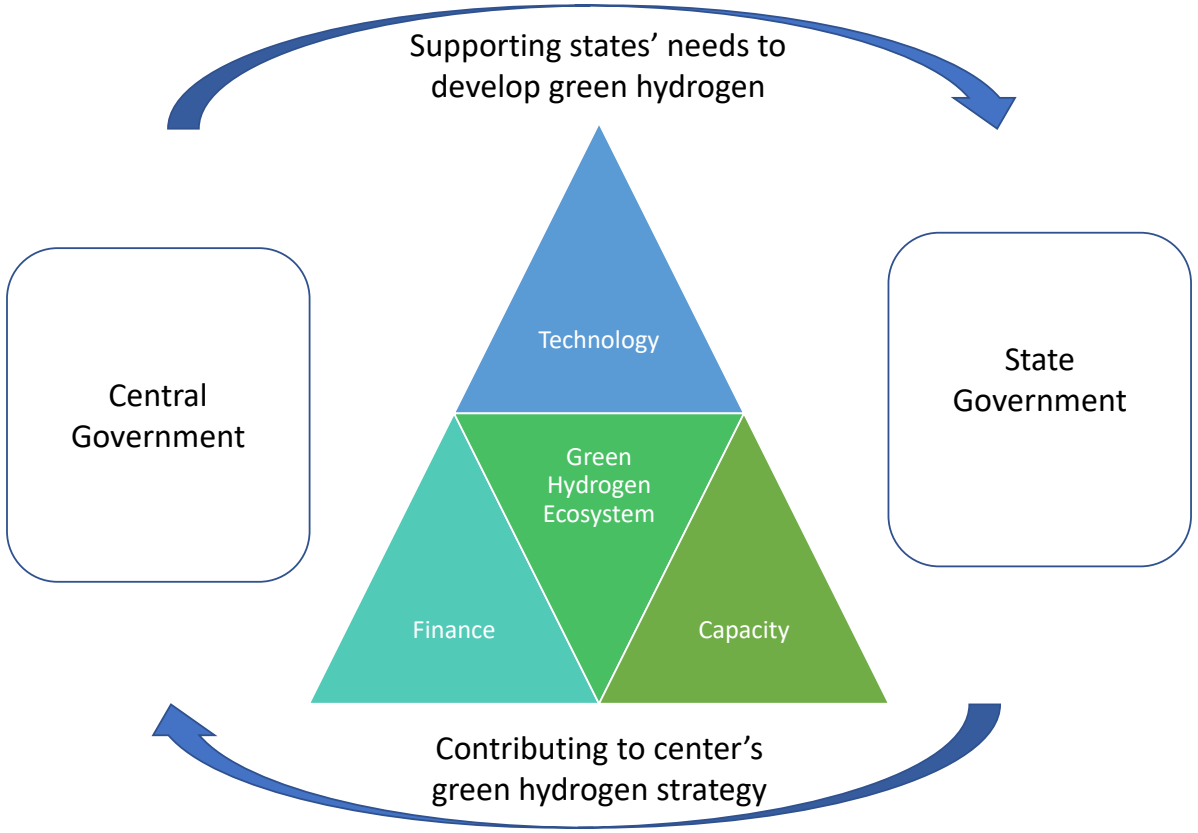
Past research has shown that a top-down climate agreement is unlikely to trigger the systemic changes needed for a 1.5^{o}C degree future (Osofsky, 2010). Fortunately, it has also become apparent that many of the transformative changes underlying such a future can be initiated from the bottom-up by subnational governments (C40 Cities, Sustainia and Realdania, 2017). Subnational governments often possess the knowledge and motivation to craft their climate solutions (C40 Cities, 2015). Further, they are also becoming adept at identifying linkages between climate solutions and local development benefits such as new jobs and industries (Rabe, 2007; Puppim de Oliveira *et al.*, 2013). At the same time, subnational governments may lack the essential capacities required to effectively implement climate solutions (Burch, 2010); they may further face limitations in spreading those solutions within and beyond the boundaries of their administrative area (Corfee-Morlot *et al.*, 2009).

For the sake of simplicity, however, the paper will narrow down its attention to a few central claims running through both sets of studies. Namely, it will stress that national and subnational governments need to work together to address the climate crisis. It will also highlight how subnational governments can be granted the autonomy to craft innovative and locally appropriate solutions. Finally, it will point

out that national governments provide the direct and indirect enabling support required to strengthen implementation and induce scaling (Corfee-Morlot *et al.*, 2009).

India will also need to craft an effective multilevel power sharing agreement to support a green hydrogen ecosystem (Figure 1). Though India's hydrogen plans are relatively new compared to renewable energy, it is possible to deduce several elements that are needed for this relationship to achieve the goals outlined in the hydrogen strategy. First, many states possess the natural resources needed to support the transition to green hydrogen. Second, the same states that tend to be rich in these resources may lack technological and financial resources to develop hydrogen, regardless of their renewable energy potential (Gupta, Kumar and Kumar, 2023; Abhyankar *et al.*, 2023)—these deficiencies are especially clear when it comes to building a hydrogen ecosystem necessary for production, consumption, or possible export. Third, it requires collaboration between the central and state (sub-national) governments (as well as cooperation among different sub-national governments). In sum, it is critical that national and subnational governments work together under a cooperative federalist structure for a successful green hydrogen transition (Dutt, 2023). State and central government are working together to build a hydrogen ecosystem, where technology, finance and capacity are necessary to build an active green hydrogen industry. While this joint initiative will contribute to strengthening the green hydrogen industry in the states, this also strengthens the national level green hydrogen development targets set by the central government.

Figure 1: Multilevel Governance for Green Hydrogen Ecosystem

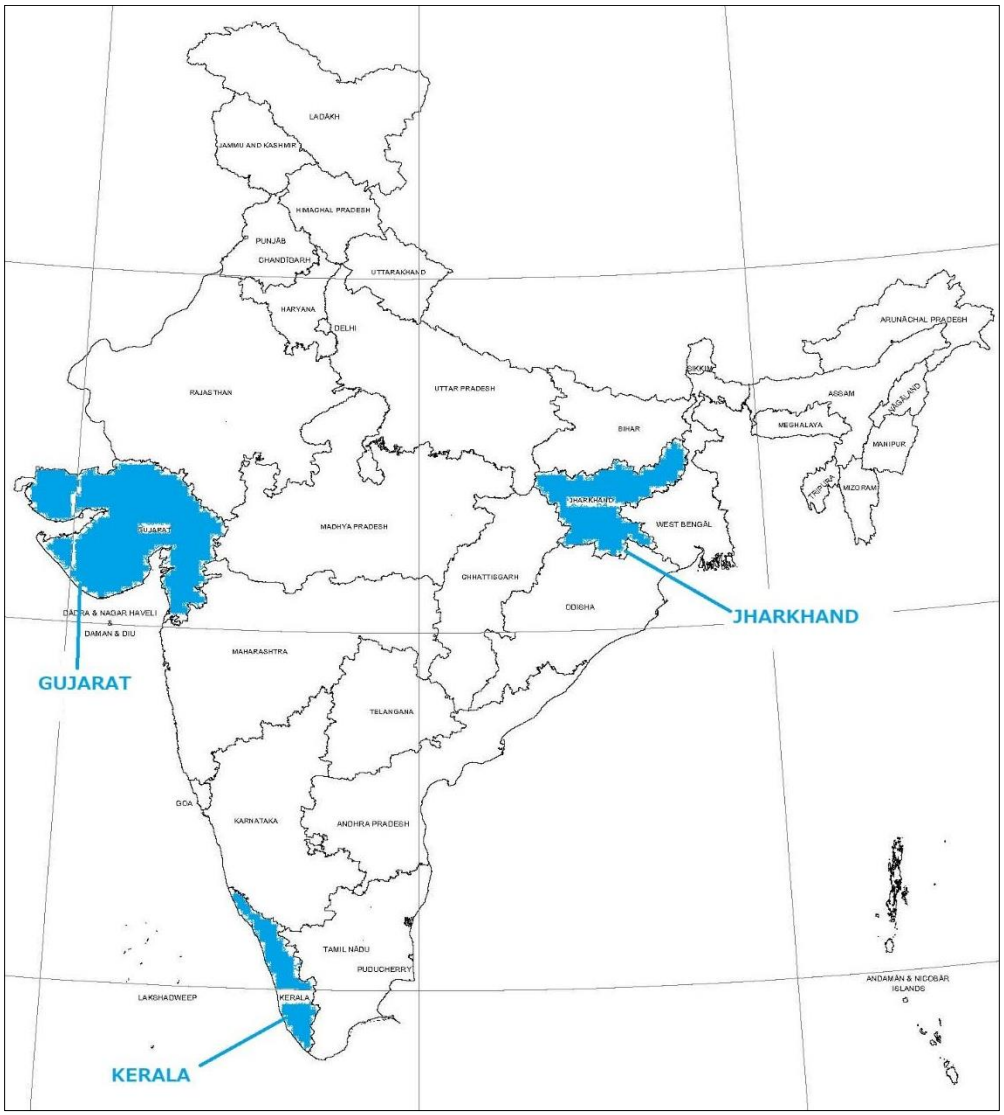


Source: Authors

Tracking Green Hydrogen Development Plans by the Indian States

The hydrogen market is witnessing growth due to government initiatives toward a clean energy transition. The country's ambitious renewable energy deployment plans are coupled with efforts to drive investment in the hydrogen sector as well. The transportation sector, particularly fuel cell vehicles and hydrogen-powered buses, shows promising growth prospects. Some states like Kerala have deployed demonstrative water transport options as well using hydrogen. Collaborations between public and private sectors are fostering innovation and expanding the hydrogen energy landscape in many states. Despite challenges like infrastructure development and cost, some states are set to emerge as major players in helping transition the country to a hydrogen economy.

Figure 2: Location of Indian States under Study



Source: Map from Government of India (Survey of India, 2023). Only for indicative purposes.

This section describes subnational initiatives and their alignment with India's National Hydrogen Mission. The green hydrogen development plans and the actual progress in three Indian states (see

figure 2): Gujarat, Jharkhand and Kerala have been studied here. The studies of the three states provide valuable insights into the unique circumstances and objectives, opportunities, and challenges experienced by sub-national governments, underscoring the broader transformation of India's energy landscape.

Methodology used: To conduct the studies, stakeholder interviews were conducted in Gujarat, Jharkhand and Kerala, in which major areas of the hydrogen ecosystem were covered. By addressing common pillars like policy alignment, business environment assessment, and state capacity evaluation, our interviews revealed a deeper understanding of each state's unique green hydrogen landscape. This approach used perspectives from diverse stakeholders including government authorities, academic/research institutions, and industry, helping understand the potential, challenges and innovative strategies that play pivotal roles in the development of green hydrogen initiatives.

The interviews in Gujarat provided invaluable insights from experts in key institutions such as Gujarat Energy Research and Management Institute, IIT Gandhinagar, and representatives from industry and the state government. Here, the focus was on exploring policy development and its impact on the business environment and gauging the state's capacity. In Jharkhand, we engaged in discussions with key institutions including the Jharkhand Renewable Energy Development Authority and the Central University of Jharkhand. The discussions centred around aligning initiatives of state policies with the state's capacity and business environment for green hydrogen initiatives. In the case of Kerala, interviews were conducted with policymakers, power utilities, and developers and helped us understand the ambitious green hydrogen goals, challenges and strategies to overcome those hurdles.

The assessment based on the case studies is structured into three key subsections: Estimated Potential, Challenges, and Strategies. The section on Estimated Potential evaluates each state's prowess, encompassing policy formulation, financial resources, technology capacity, and human resources availability. However, some states, from where the research team could not get adequate information, remain unexplored in this paper. Shifting the focus to the challenges, this section showcases the limitations in each state, ranging from renewable energy constraints to technological gaps and financial hurdles. Lastly, the section on Strategies provides an overview of the state's long-term and short-term policies, explaining their approaches to hydrogen development. Together, these sections offer a comprehensive insight into the landscape of green hydrogen evolution across the studied states.

Case Study 1: Overview of state-level developments in Green Hydrogen in Gujarat

Gujarat, one of the highly industrialised states in India, is targeting to produce 3 Million Tonnes per Annum (mtpa) of green hydrogen by 2030. It is the third most industrialised state in India after Maharashtra and Tamil Nadu. Gujarat is considered the petroleum capital of India due to the presence of a large refining capacity set up by private and public sector companies. The state government has shown keen interest and commitment to promoting green hydrogen production to achieve the net zero target. After the launch of the *National Hydrogen Mission* the Gujarat state released the draft Green Hydrogen Policy 2023, setting ambitious targets of producing 8 million tons per annum of green hydrogen by 2035 (Government of Gujarat, 2023a).

Gujarat is placing a strong emphasis on the importance of green hydrogen manufacturing, designating it as a priority sector. The state has identified both the demand and supply sides of green hydrogen,

with plans to establish a robust industrial base within the state for green hydrogen production facilities. It has also launched the Green Hydrogen Valley Project, aimed at developing a localised hydrogen value chain that can serve multiple end sectors and applications. This project is also expected to create local jobs, particularly within the Small and Medium Enterprises (SMEs) sector.

To facilitate and accelerate the green hydrogen ecosystem, Gujarat Urja Vikas Nigam Limited (GUVNL), the Energy and Petrochemical Department and the Gujarat Power Corporation Limited (GPCL) are identified as key nodal agencies. They are responsible for formulating the draft green hydrogen policy to promote and facilitate the development of projects in the state.

Estimated Potential

Gujarat's potential for green hydrogen is significant due to its abundant renewable energy resources, existing industrial base, environmental challenges, and the potential to create economic opportunities. As of March 2023, the state has about 21.6 GW of RE installed capacity (Government of Gujarat, 2023b). The RE policy further aims to develop 100 GW of installed capacity by 2030 (Government of Gujarat, 2023b), to expand its alternative energy production.

Concerning the hydrogen industry, private sector players are actively playing a role in the state. Leading energy industry players like Reliance Industries Limited (RIL) and Adani Group have been involved in setting up green hydrogen production infrastructure and are expected to generate over 99.8 GW of renewable power and approx. 4 million metric tonnes of green hydrogen production per annum by 2030. Other industry players like L&T are aiming to generate high purity of green hydrogen (99.99%) and oxygen for their captive consumption in manufacturing shops. This project also aims for 15% hydrogen blending with natural gas to be used as a fuel (LiveMint, 2023). The state government also signed agreements with Ocior Energy, a green hydrogen company, in February 2023 to build a new hydrogen production facility in the region of Kutch to generate 1 million tonnes of green hydrogen and ammonia per annum.

The state is actively involving the industry and taking various initiatives to overcome the complexities involved in green hydrogen development. The government of Gujarat is creating a comprehensive strategy to support the production of green hydrogen, such as land allocation and stakeholder consultation with key players for green hydrogen production. Green hydrogen can be exported to other states and countries, generating new revenue streams for Gujarat. This not only benefits the state's economy but also positions Gujarat as a leader in the emerging global green hydrogen market.

Challenges

The state also faces multiple challenges and obstacles in its path toward the development of a hydrogen economy. Most importantly, technological challenges due to the lack of adequate electrolysis capacity demand serious attention from policymakers both at the state and national levels. To facilitate the manufacture of green hydrogen, it is also crucial to expedite the installation of more renewable energy infrastructure and storage facilities. Despite these technical challenges, there is greater interest by developers as the government is encouraging public-private partnerships for green hydrogen projects. This optimistic outlook holds promise for future developments, ultimately benefiting off-takers, and showcasing the growing interest and potential in the green hydrogen sector.

A critical challenge the state faces is the lack of adequate capacity and the need for skilled human resources in the ever-evolving green hydrogen sectors. The officials must be aware of the various obstacles, environmental concerns, risk associations, etc with the production, storage, transportation, and end use of green hydrogen. Our research indicates that there is a need for regulators,

industrialists, developers, researchers, academicians, original equipment manufacturers (OEMs) and other industry participants to engage through a single platform to discuss and explore the obstacles, technology readiness level, cost optimisation and the gap in the existing landscape in this emerging sector.

Based on the insights from an interviewee from a government organisation, INR 8-10 lakh crore (roughly 100-120 billion USD) worth of investment is expected over the next 15 years in the green hydrogen sector in the state. However, there is a need for more investments in all sectors of the ecosystem including- industry as well as academia and research. It is noted that there is still less attention paid to the R&D of storage technologies, and the tender process is usually looking at projects that are high in readiness level. Hence, to increase the state's capacity for green hydrogen production, more focus is needed on infrastructure, demand creation, research and development, and capacity-building programs that can support a green hydrogen ecosystem.

Strategies

The state government is aiming to create an ecosystem for small and medium enterprises that could take part in all key value chains of green hydrogen. The research indicates that policies and schemes to incentivise SMEs (including a capital subsidy and a waiver of stamp duty) to be part of the green hydrogen ecosystem are being considered by the government. Insights from the industry association, academia, research and development bodies also confirm that the government has been continuously supporting the green hydrogen industry.

One of the key measures as part of supporting the hydrogen industry is the Gujarat government's readiness towards land allocation for setting up renewable energy green hydrogen production facilities. The Gujarat Power Corporation Limited (GPCL), which has been responsible for identifying and approving land has already conducted an allotment of 1,99,000 hectares of land, mostly wasteland, in the Kutch-Banaskantha border areas for green hydrogen production (Reliance New Energy Limited (74,750 ha), Adani New Industries Limited (84,486 ha), Torrent Power Limited (18,000 ha), ArcelorMittal Nippon Steel India Limited (14,393 ha) and Welspun Group (8,000 ha) (ToI, 2023).

The plan for developing a green hydrogen hub in the state is one of the important milestones. To achieve this, the government identified key players in the *production*, *storage*, *transportation* and *end usage*. Plans to establish electrolyser plants, development of storage facilities to bridge the supply-demand gap; initiatives towards building a network transportation infrastructure and policies to incentivise end users, etc are critical measures. It is expected that the industrial sectors like steel, fertilisers, and refineries within the state will be primary consumers of green hydrogen. This strategic initiative not only underscores Gujarat's commitment to cleaner energy but also aligns perfectly with the national targets.

Case Study 2: State-level Developments in Green Hydrogen in Jharkhand

Jharkhand is home to several major industries, such as iron and steel, cement, mining, transport vehicles, and fertilisers, which can be potential consumers and producers of green hydrogen. The state government has shown keen interest and commitment to promoting green hydrogen as a clean and sustainable energy source. The state has formed a task force and signed agreements for various green hydrogen projects and initiatives. The state of Jharkhand was the first in India to roll out a Green Hydrogen Task Force in March 2023, emphasising its proactive commitment. The task force is mandated to evaluate the current status of hydrogen utilisation, best practices around the world, and its applicability and suitability for the state. This will then be developed into a roadmap for implementing the mission in Jharkhand (Bisoee, 2023). The state aims to develop 5,000 MW solar

power capacity, which is more than double the Renewable Power Obligation (RPO) of 2,005 MW set by NITI Aayog and providing incentives for landowners to lease their land for solar farms, and for the generation and trading of green power (Deogharia, 2021).

Estimated Potential

Two key drivers underpinning Jharkhand's strategic promotion of green hydrogen are deployment and manufacturing. The deployment driver aims to stimulate demand for green hydrogen across diverse sectors, including transport, industry, power, and agriculture. Concurrently, the manufacturing driver seeks to position Jharkhand as a pivotal hub, fostering the establishment of green hydrogen production facilities and robust supply chains (The Pioneer, 2023). This dual focus not only addresses the imperative of creating demand but also aligns with the state's broader economic goals. Jharkhand, with its significant reserves of critical minerals such as graphite, has the potential to emerge as a promising manufacturing hub. Graphite, a key mineral for batteries, fuel cells, and high-tech applications, holds immense potential to complement the green hydrogen industry. This strategic alignment will contribute significantly to livelihoods, and job creation, and leverage the state's large renewable energy potential and industrial base.

The Jharkhand Task Force on the Green Hydrogen Mission, overseeing state-level initiatives. It comprises officials from the Energy and Forest departments, NTPC, CCL, and Tata Steel, collaborating with the technical partner CEED (Centre for Energy and Environment Development) to guide policy execution, ensure departmental coordination, and foster industry collaboration (CEED, 2023). The Department of Mines and Geology and the Department of Industries is actively contributing to green hydrogen efforts, focusing on sectors challenging decarbonisation. They are engaging in stakeholder consultations to develop Jharkhand's green hydrogen ecosystem. Simultaneously, the Department of Energy, led by the Additional Chief Secretary and chairing Jharkhand Renewable Energy Development Agency (JREDA), is serving as the nodal department for implementing renewable energy projects in the state.

The state has started engaging in dialogues with industries to collaboratively shape the plan and strategies for green hydrogen production and utilisation. A significant milestone in this endeavour is the formal approval of a major project, marking the inaugural of *the **"Hydrogen Fuel Project " in Jamshedpur***. The initial phase will witness the production of over 4,000 hydrogen internal combustion engines and more than 10,000 battery systems. Subsequent phases will include the manufacturing of advanced chemistry batteries, hydrogen fuel cells, and hydrogen fuel delivery systems. Under a pact with TCPL Green Energy Solutions Private Ltd (TGESPL), a collaborative venture between Tata Motors and Cummins Inc, USA, the state government is facilitating the establishment of this pioneering hydrogen fuel project (Ray, 2023).

Additionally, Tata Steel has embarked on a trial for the injection of a substantial volume of hydrogen gas—utilising 40% of the injection systems in the 'E' Blast Furnace at its Jamshedpur Works (Tata Steel, 2023). This trial signifies a pivotal milestone in the steel industry's progression toward sustainable and green steelmaking in India. The trial aims to address concerns and explore the viability of hydrogen as a fuel source, providing crucial insights for future endeavours in the green hydrogen landscape.

With several potential project developers and consumers present in the state's hard-to-abate sectors, Jharkhand presents possibilities for remarkable growth in the domestic hydrogen sector. Despite the nascent stage of green hydrogen initiatives, developments such as Tata Steel's hydrogen injection trial and involvement of TCPL Green Energy Solutions, indicate the potential for a surge in developers. The state also aims to attract developers by capitalising on its industrial strength. Positive sentiments

among developers, driven by collaborative efforts with industry leaders and recent trials, present a favourable outlook for future off-takers in the state. The state is also focused on creating a business-friendly environment, envisioning transparent rules and streamlined processes to facilitate the ease of doing business for green hydrogen projects.

Challenges

While Jharkhand ventures into the dynamic landscape of green hydrogen, it confronts challenges inherent to the nascent stage of this transformative industry. A pivotal challenge lies in cultivating a comprehensive and supportive ecosystem tailored to the state's unique context. It also grapples with establishing a resilient network of renewable energy sources crucial for powering the electrolysis process that produces green hydrogen. Ensuring access to cutting-edge electrolyser technology, optimising its efficiency, and potentially fostering local manufacturing capabilities are critical considerations for Jharkhand's sustainable green hydrogen journey.

Developing effective storage solutions for intermittent renewable energy sources and establishing a secure, efficient, and accessible hydrogen transportation network present a complex task. The state must also balance innovation, safety, and environmental sustainability while navigating complexities to create an environment that is conducive to innovation.

The state also emphasises the crucial position of research and development. It acknowledges the demand for ongoing innovation and the development of technologies tailored to its environment. For long-term success, it is essential to fund R&D initiatives that address the particular difficulties associated with producing green hydrogen within the state.

Strategies

Despite nascent developments, the green hydrogen task force envisions a pivotal role in shaping the future administrative landscape. The task force is poised to evolve into a linchpin, fostering collaboration among stakeholders. However, there is a need for a dynamic administrative framework that can adapt to the evolving green hydrogen landscape, integrating insights from industry, academia, and governmental bodies. Conversations with industrial stakeholders project a futuristic vision where administrative structures seamlessly integrate industry imperatives with green hydrogen goals. They anticipate a more robust collaboration with the state, with administrative mechanisms evolving to catalyse green hydrogen initiatives. The envisaged symbiotic relationship is expected to drive effective policy implementation in the future.

There is also an opportunity for Jharkhand to leverage the Eastern Zonal Council whose headquarters is in Ranchi, to become a pivotal hub for green hydrogen state trading. This could entail creating a coordinating body within the Council, fostering inter-state collaboration, joint projects, shared infrastructure, and standardised regulations. Jharkhand with its industrial strength positions as a leader in setting standards and ensuring fair trade practices. This strategic advantage for the state offers a unique opportunity for regional collaboration in the sustainable energy sector.

Jharkhand’s strategy reflects an understanding of the capital-intensive nature of green hydrogen initiatives and reflects Jharkhand's commitment to providing adequate financial resources. The recent pact for India’s first Hydrogen Fuel Project in Jamshedpur signifies the state's initial foray into this domain. The project's phased approach, spanning the production of hydrogen internal combustion engines, advanced chemistry batteries, hydrogen fuel cells, and delivery systems, lays the groundwork for scaled-up operations. The initial steps lay the groundwork for a future where budgetary allocations

and concrete plants for scale-up. Looking forward, Jharkhand envisions more robust budgetary allocations, aligning with its ambition to emerge as a key player in the green hydrogen landscape.

In its pursuit of advancing green hydrogen initiatives, Jharkhand has unveiled the "Solar Energy Policy 2022," aiming to achieve a cumulative solar power capacity of 4 GW by 2027 and fostering investor participation in the region (Government of Jharkhand, 2021). The comprehensive plan outlines the installation of 3 GW of utility-scale solar projects, including 700 MW from solar parks, 1 GW from non-solar parks, 900 MW from floating solar, and 400 MW from canal top solar projects (Government of Jharkhand, 2021). Encouraging private investors, the policy allows the establishment of solar parks with a minimum capacity of 20 GW, connected to the state transmission network, while non-park projects must have a minimum capacity of 2 MW. This strategic initiative supports Jharkhand's broader vision of clean energy development, integrating solar power advancements into its evolving green hydrogen landscape.

Case Study 3: Kerala's Green Hydrogen Development Strategy and Progress

The Kerala government views green hydrogen as an important lever in pursuing their goal of 100% renewable energy by 2040 and net-zero status by 2050 (Government of Kerala, 2023a). The state envisions green hydrogen's potential role in decarbonising multiple sectors – replacing grey hydrogen in refineries and the fertiliser industries, powering heavy transports and boats, blending with natural gas for heating applications, and opportunities in sustainable aviation fuel. The state believes that its abundant natural resources, including renewable energy potential and freshwater, and access to ports can help it to become a green hydrogen production centre.

Estimated Potential

Kerala plans to tap both domestic and export markets for green hydrogen. Although the state has a relatively low industrial base than many other states, it has a good presence of refinery and fertiliser units – the two 'low-hanging' sectors for green hydrogen adoption (NITI Aayog, 2022). For example, Fertilisers and Chemicals Travancore Limited (FACT) and Bharat Petroleum Corporation Limited (BPCL) Kochi Refinery had hydrogen demand of 70,000 tonnes and 175,000 tonnes approximately in the financial year 2021-22. Heavy transport, including buses and trucks, is the other sector the state is focusing on in the early-stage deployments. The government is also exploring other sectors, like energy storage, on an experimental basis.

Kochi, where both FACT and BPCL units are located along with other chemical industries, and is situated near the Cochin port, has significant potential to become a green hydrogen hub. The state government has partnered with India Hydrogen Alliance (IH2A), an industry association, to evaluate a proposal for Kochi Green Hydrogen Hub (KGH2), which includes building a green hydrogen plant with 60 tonnes per day capacity. The proposed project explores zero-emission transport options involving 60 hydrogen-engine-retrofitted bus fleets and a 60-tonne hydrogen liquefaction unit in the first phase. It plans to expand the infrastructure for large-scale industrial demand in the second phase (IH2A, 2022). The Cochin Shipyard, which recently signed a contract for building hydrogen-powered boats (Cochin Shipyard Limited, 2023), Kochi metro with its bus and boat fleets, and Cochin airport are all potential off-takers. The Travancore Cochin Chemicals (TCC) has also evinced interest in supplying Hydrogen to Kerala State Road Transport Corporation (KSRTC) for its hydrogen cell buses (T, 2021).

The export market is one of the important areas with tremendous opportunities. Many industrialised countries, particularly EU nations, have set ambitious green ammonia targets, with some Indian firms already securing supply contracts. The agreement signed by German energy player, Uniper with India's Greenko ZeroC to purchase 250,000 tonnes of Green Ammonia annually from the latter's facility in

Kakinada, India, is one such example (Uniper, 2023). The relatively cheaper renewables in India and the fully integrated national grid offer significant competitive advantages for domestically produced ammonia. Developers said that most large-scale projects currently in planning or development are targeting external markets. The state officials interviewed mentioned that the currently operationalised Vizhinjam port, India's first trans-shipment port, with advantages in terms of infrastructure and proximity to international shipping lanes, has the potential as an export-oriented green ammonia hub. The port authorities plan to set up green ammonia storage and logistic infrastructure in the coming months. The government of Kerala has already received proposals of INR 30,000 crore (~USD 3.75 billion) from two companies for setting up green Hydrogen and green ammonia production plants (Arushi Koundal, 2023). One of the companies is primarily targeting green ammonia exports to Germany.

According to industry experts, electricity accounts for more than 60% of the final cost of green hydrogen. Hence, the availability of cheap renewable electricity becomes a vital factor in attracting investments. Solar power along with pumped hydro offers the cheapest round-the-clock renewable energy making green hydrogen produced from them most cost competitive. Kerala aims to ramp up its renewable energy capacity in the next few years, primarily through floating solar plants and pumped hydro storage. The state estimates 5,000 MW and 1,500 MW floating solar capacity potential from its vast reservoirs and unproductive lands like saline water-logged areas. It is also banking on its estimated 11,000 MW pumped-hydro potential to support round-the-clock renewables. Further, there are several small hydro projects in the pipeline. Officials also highlighted the state's freshwater resources as an advantage in terms of resources.

Challenges

According to the interviewees, with green ammonia being almost three times costlier than grey ammonia, there is little bandwidth for fertiliser companies to absorb the cost escalation unless the union government announces explicit support for green ammonia procurement. Many studies have highlighted the importance of fertiliser and refinery industries in the early scale-up of green hydrogen (Kowtham Raj, Pranav Lakhina, 2022; Challa *et al.*, 2023). However, the interviewees flagged the constraints faced by fertiliser companies in exploring green ammonia options due to the political economy of fertiliser subsidies. The Union government regulates urea market price and compensates fertiliser companies for the revenue shortfall calculated based on fixed energy norms (Government of India, 2020).

The potential market among petroleum refineries also depends on government push as public sector undertakings dominate the sector. Interviewees reported that BPCL has shown interest in establishing green hydrogen production at the Kochi refinery, but no projects have been finalised yet. Developers emphasised the need to introduce hydrogen purchase obligations (HPO) to accelerate the green hydrogen market. Especially with refineries, this could open up a huge market for green hydrogen without significantly increasing the cost of their main product.

In the transport sector, Kerala is giving special attention to hydrogen internal combustion vehicles, due to the lower capital cost of retrofitting existing vehicles, compared to hydrogen fuel cell vehicles. However, the efficiency of the hydrogen combustion engine is much lower compared to fuel cells putting its cost-competitiveness in doubt. Further, Green hydrogen's role in sectors like heavy transport and energy storage is still unclear given there are alternative clean solutions like battery storage, which are currently cheaper. Unless the planned pilots can identify a specific use case where green hydrogen has a significant advantage, these sectors are unlikely to be significant markets for green hydrogen in the near future.

Another key issue is the lack of testing and certification facilities. Technology validation can significantly decrease the project risks and reduce the cost of financing. However, currently, there are very few testing facilities in India. According to consulted developers, this is an area where modest government investment can have a significant impact. It can also help to accelerate the local manufacturing of components, including electrolyser stacks.

The state also faces challenges in harnessing its renewable resources. Kerala currently imports about 76% of its electricity supply from other states and has low renewable penetration (the total renewable purchase as a share of total generation is below 14%, most of it from legacy small hydropower). According to consulted experts, much of the estimated renewable potential, including floating solar and small hydropower, lies within forest reserves. Developing projects in such areas may have negative environmental implications or may face delays in getting environmental clearances.

Developers consulted for this study highlighted two aspects related to renewable energy. Firstly, given the unified grid in the country, the green hydrogen projects can supplement renewable energy sourced within the state with wheeled power from other RE-rich states. However, this requires augmenting the state's transmission capacity and building evacuation infrastructure. The interviewees highlighted delays in past projects primarily due to challenges in land acquisition for laying transmission lines. If the state can designate sites for projects and plan transmission infrastructure in advance, including land acquisition and clearances for laying transmission lines, it will give a major boost to the state infrastructure prospects. Secondly, the state can also prioritise pumped hydro projects, which can significantly bring down round-the-clock renewable prices, giving a competitive advantage.

According to the interviewees, risk perception of green hydrogen projects among financiers has decreased significantly in recent years. Yet, it remains a challenge, especially for projects without secured purchase agreements from off-takers.

Strategies

According to the state officials consulted, Kerala is in the final stages of announcing a green hydrogen policy. A draft policy in circulation among policymakers outlines the key targets being envisaged for the state (The Hindu Daily, 2023). The policy could include 30% green hydrogen blending in the total hydrogen consumption by chemical, fertiliser and refinery units in the state by 2027. By 2030, the state targets to reduce Green Hydrogen cost to USD 1/kg, and by 2040 use 100% Green Hydrogen/Ammonia in all hydrogen applications (Government of Kerala, 2023b).

The state's strategy for scaling up Green Hydrogen includes developing Hydrogen hubs and small-scale projects dispersed across the states, including Green Hydrogen Valleys in Kochi and Thiruvananthapuram. The state envisages a private-investment-led growth model for the sector. To kick start the investments, Kerala allocated INR 200 crores (USD 24 Million) for green hydrogen development in 2023-24, becoming one of the first states to do so. This fund will support the deployment of green hydrogen through Viability Gap Funding (VGF), equity in projects and loans. The draft policy also highlights other potential incentives, including concessions in electricity duties, open access and transmission charges, and other non-monetary incentives like priority clearances of projects (RenewableWatch, 2023). The state officials said they are exploring financing options from multilateral lending agencies.

A high-level steering committee comprising ministers and secretaries guides the overall strategic direction of the scheme, with the Agency for New and Renewable Energy Research and Technology (ANERT) as the nodal agency for its implementation. ANERT has constituted (Aarushi Koundal, 2023)

a project management unit (PMU) to support the agency in investment promotion and project implementation support (Government of Kerala, 2016). It also aims to facilitate large-scale projects targeting refineries, fertilisers, exports, etc. and will aggregate demands from other sectors with a relatively lower potential to achieve better economies of scale. The state plans to implement a few pilots, using the union government's PLI scheme for green hydrogen pilots, to study the viability of this model at scale. Going forward, the state plans to create sector-specific roadmaps identifying and prioritising low-hanging sectors, prepare strategic investment plans using the allocated budget to facilitate private sector investments, expedite renewable energy project deployments and facilitate long-term technology and trade partnerships with national and international entities.

The States' Role in Accelerating a Green Hydrogen Transition

The case studies of Gujarat, Jharkhand, and Kerala underscore the pivotal role that Indian states play in contributing to the national hydrogen industry targets. The objective of the case studies is not to make a comparison among the states' capacity or potential to develop green hydrogen but to present a survey of the possible avenues the states may consider as part of the green hydrogen policies.

These studies demonstrate that the states have taken steps to develop comprehensive policies that align with India's national targets and provide a roadmap for the hydrogen sector's growth. Ensuring the effective implementation of these policies, alongside rigorous monitoring and enforcement, will be critical to meet India's national hydrogen mission objectives. The success in meeting national targets will depend on effectively addressing the common challenges of efficient hydrogen production, technological advancements, energy infrastructure development, and investment mobilisation. The states, as exemplars of diverse approaches, offer valuable models for the rest of India to follow as it advances towards a sustainable energy future. The below table presents an overview of the common elements in the potential, challenges and strategies observed in the Indian states.

Gujarat's emphasis on electrolysis-driven hydrogen, Jharkhand's manufacturing focus, and Kerala's ambitious green hydrogen targets align with the national objective of transitioning to a low-carbon economy. However, challenges lie in developing efficient and cost-effective production methods as well as overcoming technological and infrastructural barriers. While the states express their commitment to technological advancements, the practical implementation and successful integration of advanced hydrogen technologies remain a challenge. Considerable investments in research and development will be necessary to ensure that the domestic hydrogen sector remains technologically competitive.

With regard to the challenges associated with developing hydrogen, there could be some concerns. For instance, according to Kerala's State Electricity Board inadequacies in the distribution network are observed as a major hurdle in ensuring 100% supply availability to consumers (KSEB, 2019). It notes that outdated transmission infrastructure continues to pose a challenge, which in turn highlights the need for improved energy infrastructure and grid expansion to support an active hydrogen industry.

Table 1: Shared Potential, Common Challenges and Strategies

Potential	Challenges	Strategies
● Many Indian states have huge RE potential. ● Existing industrial bases in many states can help advance hydrogen production and create demand. ● The presence of industries will help states develop domestic and overseas partnerships. ● States in the coastal region could benefit from overseas export opportunities. ● Evolving policy and governance apparatus will help accelerate the hydrogen sector. ● States will need to work together to develop the hydrogen industry as they have specific competitive advantages in terms of resources – land, RE potential, water as well as technology and finance access	● Accessibility and affordability of advanced technology remain the key hurdles to states. ● The lack of testing and certification facilities is a common challenge across states. ● Need centre-state coordinated efforts to rope in off-takers. ● Production cost remains a key hurdle in attracting off-takers. ● Land acquisition for RE projects remains another major concern in many states. However, states like Gujarat have already shown significant progress. ● Clean water availability can be a concern in certain regions.	● There is an emphasis on public-private partnerships. ● Financial incentives continue to be the common element in strategies to attract investments ● Many states are progressing on green hydrogen policies and building nodal agencies/institutions. ● Efforts are seen to align policies with industries to develop a hydrogen ecosystem. ● States with geographic advantage and proximity to ports focus on becoming green hydrogen hubs.

Source: Based on assessment done by IISD and WRI researcher teams

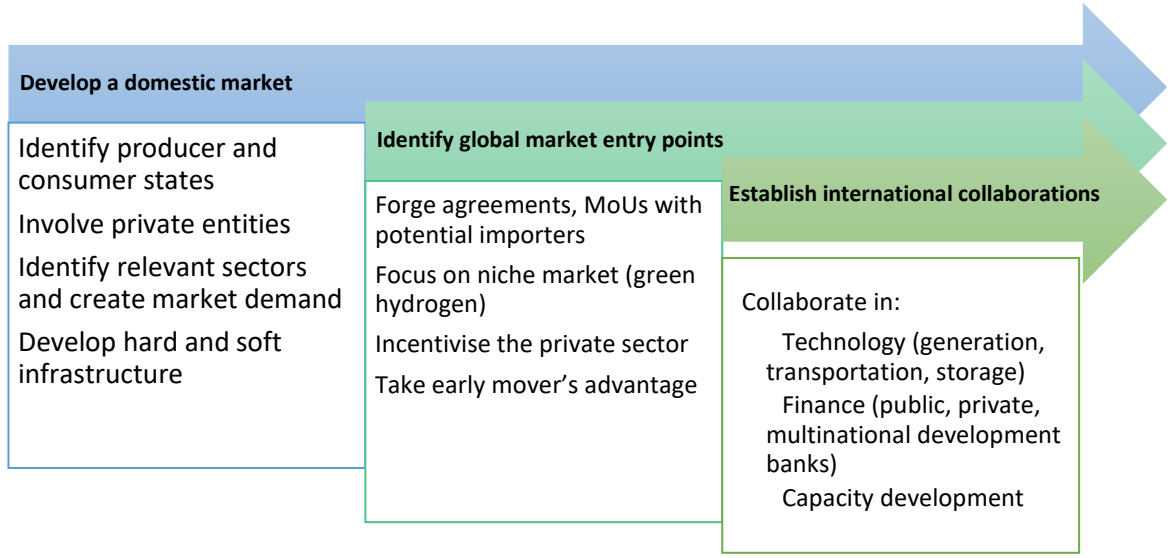
All three states are actively exploring various funding mechanisms, including international investments, public-private partnerships, and multilateral lending agencies, aligning with the national objective of securing the necessary capital for green hydrogen projects. However, convincing financiers to support these projects, especially those without secured purchase agreements from off-takers, may pose challenges. Clear and robust mechanisms to attract and retain investments are critical to meet India's national hydrogen industry targets.

The diversification of end-use sectors, as recognised by Gujarat, Jharkhand, and Kerala, resonates with India's national strategy. However, the challenge lies in harnessing the market potential, especially for sectors with low hydrogen demand. To address this, the states will need to find innovative solutions to aggregate demands and secure off-takers to achieve economies of scale and meet India's national hydrogen industry targets.

Prospects for International Collaboration in Accelerating Green Hydrogen Targets

The prospect of developing the green hydrogen industry in the state and thereby generating employment opportunities serves as a powerful incentive for policy formulation. However, the development of the hydrogen industry is rife with challenges and complexities. First and foremost, many Indian states are burdened by energy shortages and rely on cross-border electricity trade. For instance, Kerala heavily depends on power supplies from its neighbouring state, Tamil Nadu. This over-dependency on interstate power trade may prompt decision-makers to prioritise developing the domestic energy supply provisions over hydrogen (KSEB, 2020). Secondly, states must possess advanced technology and industrial manufacturing facilities for hydrogen production, including electrolysers and other necessary machinery. However, many states lack a mature industry in this regard, indicating that building such capacity might be time-consuming. Developing a domestic industry is crucial, given that over 50% of hydrogen production costs are attributed to power supply, water circulation, and hydrogen processing units (Kowtham Raj, Pranav Lakhina, 2022). Third, for India to thrive as a green hydrogen exporter, a focused approach to green hydrogen is essential. Indian states should aim to gain an early-mover advantage in the global green hydrogen market by prioritising green hydrogen. For example, the state of Kerala aims to overcome this challenge by developing floating solar power plants for the generation of renewable sources, which could potentially be used for hydrogen production (Jyothilal, 2023; TATA, 2023).

Figure 3: Areas of action to develop a green hydrogen exporting hub



Source: IGES

To address these challenges, international collaboration emerges as an effective strategy. States can play a crucial role in facilitating international collaborations by acting as intermediaries in the country. International collaboration can take shape in three key areas: technology, finance, and capacity

development. This involves sharing electrolyser technology, advancements in transport and storage solutions, and securing financial support from various sources.

First, the potential growth of the renewable energy sector in India in 2050, highlights the potential of the states. Second, as India's hydrogen production cost (including electricity and electrolyser costs) can be among the lowest in the world, trade with importing countries holds strong prospects.

Table 2: Determining Factors Influencing Green Hydrogen Export

Area of action	Key Factors	Narratives
Develop a domestic market	Supporting infrastructure	Trade in green hydrogen is contingent upon appropriate storage, transportation and distribution facilities.
	Enabling environment and regulatory/governance framework	To portray itself as a reliable source of green hydrogen, India will require creating an appropriate regulatory framework domestically and dealing with these issues internationally with its trading partners. This would include, among others, standards for ensuring hydrogen quality, safety regulations, and trade agreements.
	Innovation, research and development	For improving cost-competitiveness and enhancing efficiency, innovation and research are indispensable. Collaboration and partnership with other countries are also needed.
	Mobilising finance	Many of the factors mentioned above – infrastructure development, innovation and research for example – would require a significant volume of investments from both the public and private sectors.
Identify global market entry points	Understanding market demand	Green hydrogen demand in the importing countries is likely to be dependent upon those countries' clean energy transition plans, alternative energy sources, and the economic feasibility of using hydrogen across multiple sectors.
	Cost Competitiveness	As the longer-term cost range will become narrower across countries, India needs to ensure that its green hydrogen's cost – both production and transportation – is competitive with other suppliers.
Establish international collaborations	Agreements, partnerships and collaboration	Such partnerships can be in the form of bilateral agreements addressing issues such as pricing, volume, labelling rules and quality standards, and go beyond mere trade aspects and include issues such as technology, research and collaboration, co-innovation and so forth.
	Geopolitical factors	Geopolitics is likely to be the decisive factor in the global development of green hydrogen trade, which will necessitate building stronger trade ties through bilateral agreements.
	Climate change and environmental concerns	Most of the potential importers of India's green hydrogen i.e. Japan and the European countries, are likely to consider the production and transportation process of hydrogen, including the associated carbon footprint. Establishing itself as a major producer and supplier of green hydrogen, therefore, will be important for India.

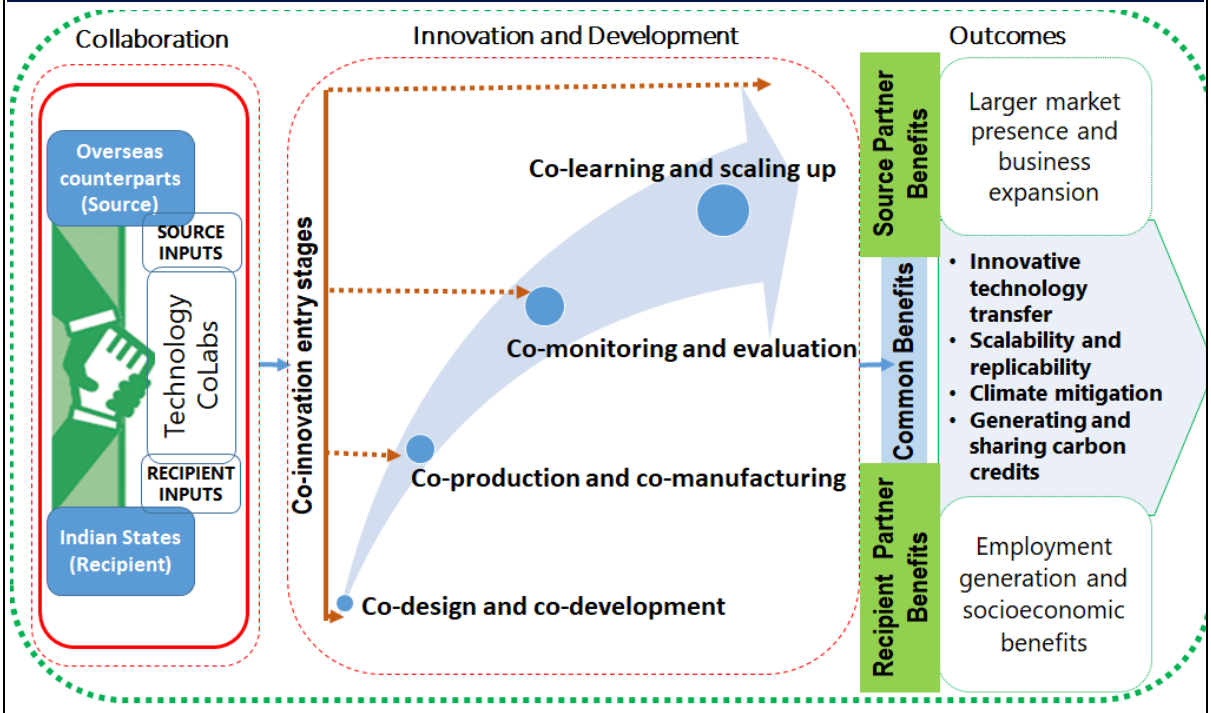
Source: IGES

The EU and Japan have already made some progress in making agreements with India. As the use of hydrogen features prominently in Japan's energy and climate change mitigation strategies, Indian

exports make it an attractive option. As Japan boasts a wealth of hydrogen technology patents (Ungria, Rodriguez and Burattini, 2023) it can offer an opportunity for India to access state-of-the-art technologies. India's agreement with Germany to establish an India-German hydrogen task force which would work to foster cooperation in production, utilisation and storage as well as trade in green hydrogen (Shetty, 2022). As several European Union countries have adopted their hydrogen strategies, green hydrogen from India could cater to the growing demand for green hydrogen in these European countries.

The environmental credentials of green hydrogen will play a significant role in attracting importing countries, especially those with high climate goals. However, it is important to note that the dynamics of the global energy market can change very rapidly and costs are not the only, or even a major factor, in defining trade partners. In particular, looking at the long-term scenario, as technologies become mature, the cost range for green hydrogen will narrow down, giving importers the option to import hydrogen from multiple sources and switch sources easily (IRENA, 2022). Geopolitics, supply security, bilateral relations, etc. could thus become deciding factors in trade.

Figure 4: Technology Co-innovation



Source: (Janardhanan *et al.*, 2021)

The significance of overseas stakeholders in India's hydrogen development initiatives is unquestionably substantial. Given that the advancement of green hydrogen necessitates a technology-driven approach, Indian states rich in renewable energy resources must incorporate cutting-edge technologies from these overseas players. Although the political framework bestows primary authority in foreign policy upon the central government, there is a growing emphasis placed by the national government on para-diplomacy – involving subnational entities in foreign policy. An institutionalised approach to foster collaboration through effective para-diplomacy is of paramount importance. In the realm of technology, finance, and capacity development, overseas collaboration by subnational entities can significantly enhance the state's green hydrogen initiatives. Utilising

mechanisms such as sister city partnerships and Exclusive Economic Zone (EEZ) ties can expedite para-diplomatic efforts to achieve the desired objectives.

The figure above reflects the co-innovation approach India may consider to strengthen cooperation with overseas partners. The traditional technology transfer (TT) mechanism has been more of a top-down, single product or service-oriented, subsidised sale of advanced technology-based equipment or machinery from the supplier to the recipient country. As the recipient developing countries lacked absorption capacity and have underdeveloped ecosystems or limited financial capacity, the transformative potential of TT has seldom been realised. Unlike traditional TT, co-innovation is transformational as it helps both developing and developed (recipient and supplier) countries to pool their financial, technological and human resources capacity to make advanced technology suitable to local contexts in recipient countries. Co-innovation also enables recipient countries to replicate and scale up technology applications and can thus make TT more transformational. Co-innovation is thus defined as 'a collaborative and iterative approach by two or more partners for jointly innovating, manufacturing and scaling up technologies'(Janardhanan *et al.*, 2022). Though co-innovation was originally discussed in the context of technology collaboration, it can have a wide range of applicability including joint investment, capacity development, etc.

As the development of the hydrogen ecosystem in Indian states demands greater collaboration with overseas investors and leading technology players co-innovation can be an effective approach. States that lack adequate technical know-how, have the potential to generate investment and will benefit from the collaboration from overseas players.

Table 3: Example of International Collaboration
Adani Total Gas Ltd (ATGL), a joint venture between Adani Group (India) and TotalEnergies (France), has unveiled plans for a green hydrogen production and blending project for city gas distribution, catering to over 4,000 residential and commercial customers in Ahmedabad in the State of Gujarat. The pilot project, which will commence in the fiscal year 2024-25, aims to incrementally raise the percentage of green hydrogen (GH2) in the blended gas to up to 8% or more, subject to regulatory approvals. Research indicates that incorporating up to 8% GH2 into natural gas can yield a 4% reduction in emissions. The initiative reflects a commitment to environmentally sustainable practices and contributes to India's target of achieving energy independence by 2047. The project also seeks collaboration with regulatory agencies and various stakeholders to establish an ecosystem around hydrogen blending in city gas distribution, with potential scalability and replication. This strategic partnership envisions a phased approach toward reducing the carbon footprint and fostering innovation in sustainable energy solutions.
Source: News reports

Conclusion and Recommendations

The case studies demonstrate the role of sub-national governments in advancing the objectives of the national green hydrogen mission. To advance the objectives of the national green hydrogen mission, a comprehensive strategy strengthening the capacity of the states to develop a hydrogen ecosystem is required. A set of six recommendations outlining specific actions to support 'capacity development, strengthening hard and soft infrastructure, incentivising off-takers, inviting more investment, strengthening technology and promoting international collaboration' is listed below:

1. ***Tailor skill development programme to suit the hydrogen ecosystem***: To strengthen the hydrogen ecosystem, a skilled workforce plays a key role. Programmes need to be in place to ensure that the workforce is capable of contributing to the design, operation, and maintenance of the green hydrogen ecosystem. In this endeavour, the support of the national government will be of great significance to the state governments.
2. ***Close the infrastructure gap***: As renewable energy production expands; transmission and distribution infrastructure will need to be strengthened on a priority basis. For example, the aggregate technical and commercial loss (which includes both loss due to theft and T&D loss due to infrastructure problems) in the power systems is about 44% of the generation in Jharkhand, about 15% in Gujarat and 16% in Kerala (Government of India, 2023a). Parallelly, states must also focus on strengthening the governance mechanism needed to support the transformation of the power sector infrastructure. There is also a need to ensure readiness domestic technologies, which requires building adequate testing facilities. Centre-state collaboration as well as engagement with overseas technology players will be pivotal in this regard.
3. ***Incentivise off-takers***: Implementing adequate financial mechanisms to incentivise off-takers will encourage the hydrogen industry's growth. The use of suitable subsidies and tax credits along with mechanisms similar to Renewable Purchase Obligations (RPO) (MNRE, 2010) to mandate hydrogen purchases for high-consuming sectors can help in this regard.
4. ***Attract investment, and encourage PPP***: States need to attract and facilitate investment from stakeholders in the hydrogen sector. This demands policies to encourage public-private partnerships as well as legal and governance structures.
5. ***Encourage R&D***: Lack of access to affordable technologies, in the production, transportation and storage of hydrogen, has been critical in many states. This demands specific initiatives to support research and development (R&D) to support the technology-intensive green hydrogen industry.
6. ***Promote co-innovation***: Opportunities for co-innovation - jointly innovating, manufacturing and scaling up technologies- with overseas players need to be supported with the necessary institutional mechanism. Where needed, the central government may consider promoting para-diplomatic engagement between Indian states and overseas counterparts through sister-city initiatives to help close the technology gap.

By focusing on these elements national and state governments together can overcome challenges and foster a vibrant green hydrogen ecosystem in India.

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Limitation: This paper largely confines its analysis to the information available until December 2023.

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Discussion Paper

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