Towards a Green Hydrogen Economy

Identifying Externalities and Transition Challenges in Rajasthan

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Executive Summary

India aims to reduce carbon emissions significantly by 2030 and achieve net zero by 2070. The energy and industry sectors in India account for over 76% of its greenhouse gas emissions. In the light of India's ambitious climate goals with stringent timelines, green hydrogen holds potential as a crucial contributor in the country's decarbonisation efforts, particularly for hard-to-abate sectors.

Among the states, Rajasthan, with its substantial renewable energy potential and supportive policy framework, is well-positioned to become a key player in India's green hydrogen transition. This paper analyzes the green hydrogen ecosystem in Rajasthan within the context of the National Green Hydrogen Mission, 2023 and Rajasthan Green Hydrogen Policy, 2023. The state's Green Hydrogen Policy sets an ambitious target of producing 2000 kilo tonnes per annum (kTPA) of green hydrogen by 2030. This aligns with Rajasthan's impressive renewable energy capacity, at 24.7 GW as of December, 2023 with a year-on-year growth of 35% as of FY 2021-22, providing a strong foundation for green hydrogen production. The state's cumulative potential of 426 GW from solar and wind energy positions it as an ideal location for a green hydrogen ecosystem.

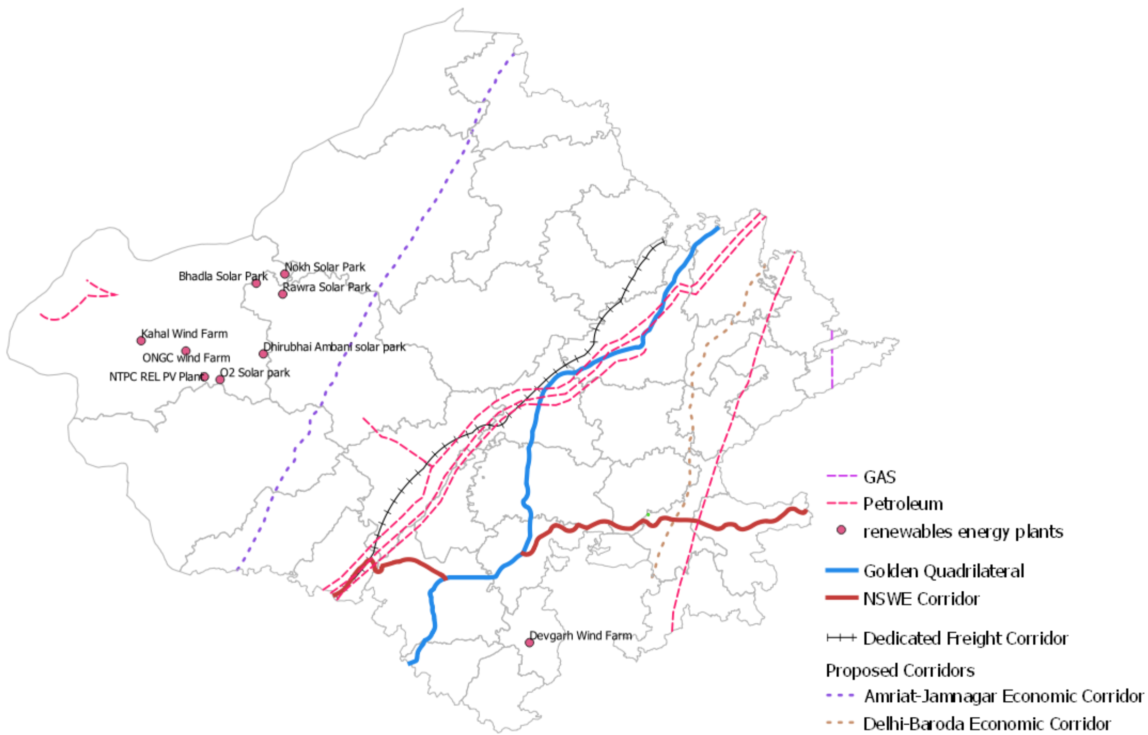
The paper highlights significant industrial interest in setting up green hydrogen production plants in Rajasthan. Notable projects include the world's first fully integrated green hydrogen production plant in Bikaner by the ACME Group and planned investments by companies like Inox Air Products, Jakson Green and Avaada Energy, indicating a robust pipeline of green hydrogen projects in the state.

However, the transition to a green hydrogen economy in Rajasthan faces several challenges. The high cost of production, primarily driven by electrolyser and electricity costs, remains a significant barrier. Water availability in the water-stressed state is another critical concern. The study highlights the need for re-evaluating the prescribed incentives in Rajasthan Green Hydrogen Policy and developing policy coherence with RIPS to attract investments in the green hydrogen value chain such as indigenisation of electrolyser manufacturing. These efforts may result in cost reduction of green hydrogen production.

On the demand side, Rajasthan currently ranks as the fourth-largest consumer of grey hydrogen in India, accounting for approximately 7% of the nation's total hydrogen consumption. The state's fertilizer industries and the upcoming HPCL refinery in Barmer present significant opportunities for green hydrogen adoption. However, the overall domestic demand

for green hydrogen is projected to be relatively low, emphasizing the need to focus on export markets to enable achievement of production targets.

The development of robust storage and transport infrastructure emerges as a crucial requirement for realizing Rajasthan's green hydrogen potential. The paper recommends considering dedicated hydrogen pipeline networks, repurposing existing natural gas pipelines, and deploying high-pressure tube trailers for road transport. Implementing stringent safety and regulatory frameworks is emphasized as vital for the safe handling of hydrogen.



To enable the green hydrogen transition, the paper examines the importance of both financial and non-financial enablers. It suggests leveraging a combination of public finance and private sector investments, innovative financing mechanisms such as PPPs, issuance of green bonds through SPVs and catalytic funding from multilateral agencies. Non-financial enablers, such as policy support focusing on indigenizing the green hydrogen value chain and market-driven approaches to encourage uptake and increase competitiveness in the entire landscape, are key determinants to decrease the levelized cost of hydrogen (LCOH) over time.

Key policy recommendations may include introducing a Green Hydrogen Purchase Obligation (HPO) for domestic industries to create a guaranteed market and blending mandates, requiring the mixing of green hydrogen with conventional hydrogen or natural gas in industries such as fertilizers and petroleum refining, to stimulate demand for green hydrogen while minimizing cost impacts of integrating green hydrogen in the feedstock for respective industries. The paper also emphasizes the importance of an export-oriented policy to facilitate the achievement of the state's green hydrogen production targets while contributing to the National Green Hydrogen Mission's objective of positioning India as a strategic player in the global green hydrogen value-chain.

In conclusion, while Rajasthan shows great promise in becoming a key player in India's green hydrogen economy, realizing this potential will require addressing significant challenges in production, demand, infrastructure, and financing. A coordinated effort involving policy interventions, technological advancements and strategic investments across the entire value chain will be crucial for the successful transition to a green hydrogen economy in Rajasthan and India as a whole. This transition not only aligns with India's climate commitments but also presents an opportunity for economic growth and energy security for the future generations.

1. Introduction

Decarbonizing India is essential for meeting the targets of reducing carbon emissions by one billion tons by 2030, cutting carbon intensity to below 45% by 2030, and achieving net zero by 2070 as laid down in the Updated Nationally Determined Contributions (NDCs). With the energy and industry sector accounting for over 76% of India's total greenhouse gas emissions[1], achieving these targets will require a significant addition of renewable energy to India's energy mix and an overhauling of industrial processes.

Green hydrogen presents a unique opportunity for India's decarbonization efforts as it is recognized as a clean energy carrier. 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 recognizes hydrogen's potential to decarbonize hard-to-abate sectors such as industry, transport, and power generation.

In addition to national efforts, six states have dedicated green hydrogen policies, while two states have integrated renewable energy policies. The state governments possess the context-specific knowledge required to tailor green hydrogen plans to local conditions and capitalize on varying resource endowments. Therefore, analyzing states' infrastructural, institutional, and technological capacities is crucial for supporting the widespread development of the green hydrogen ecosystem. Hence, this paper takes the typology of Rajasthan to explore state-level initiative and gain insights into the aforementioned domains.

The state introduced its Green Hydrogen Policy in 2023, setting an ambitious target to produce 2000 kilo tonnes per annum (kTPA) of green hydrogen by 2030[2]. With its substantial potential in renewable energy, Rajasthan is well-positioned to become a key player in the green hydrogen sector, promoting sustainable development and energy security. This paper aims to analyze the hydrogen ecosystem in Rajasthan, evaluate its key impacts and challenges, and outline a transition plan for the state.

2. Scope of Work

The paper's primary focus is Rajasthan, with a detailed analysis of the entire value chain of hydrogen, understanding various production and consumption hotspots, and identifying possible interlinkages within the ecosystem. This analysis will help in understanding the impact

1 India - Countries & Regions - IEA
2 Rajasthan Green Hydrogen Policy, 2023

of transitioning to green hydrogen on various stakeholders and identify the potential externalities impacting the transition.

Hydrogen generation, transmission, storage, and consumption are all evaluated, emphasizing the necessity of significant investment in infrastructure and technological upgradation. To guarantee a smooth and well-coordinated transition, any modifications to the administrative environment brought about by interdepartmental dependencies are also investigated. In light of the transition outcomes, the necessity for policy interventions is finally explored. The goal is to facilitate a smooth transition to a green hydrogen economy, ensuring sustainable and equitable growth for Rajasthan.

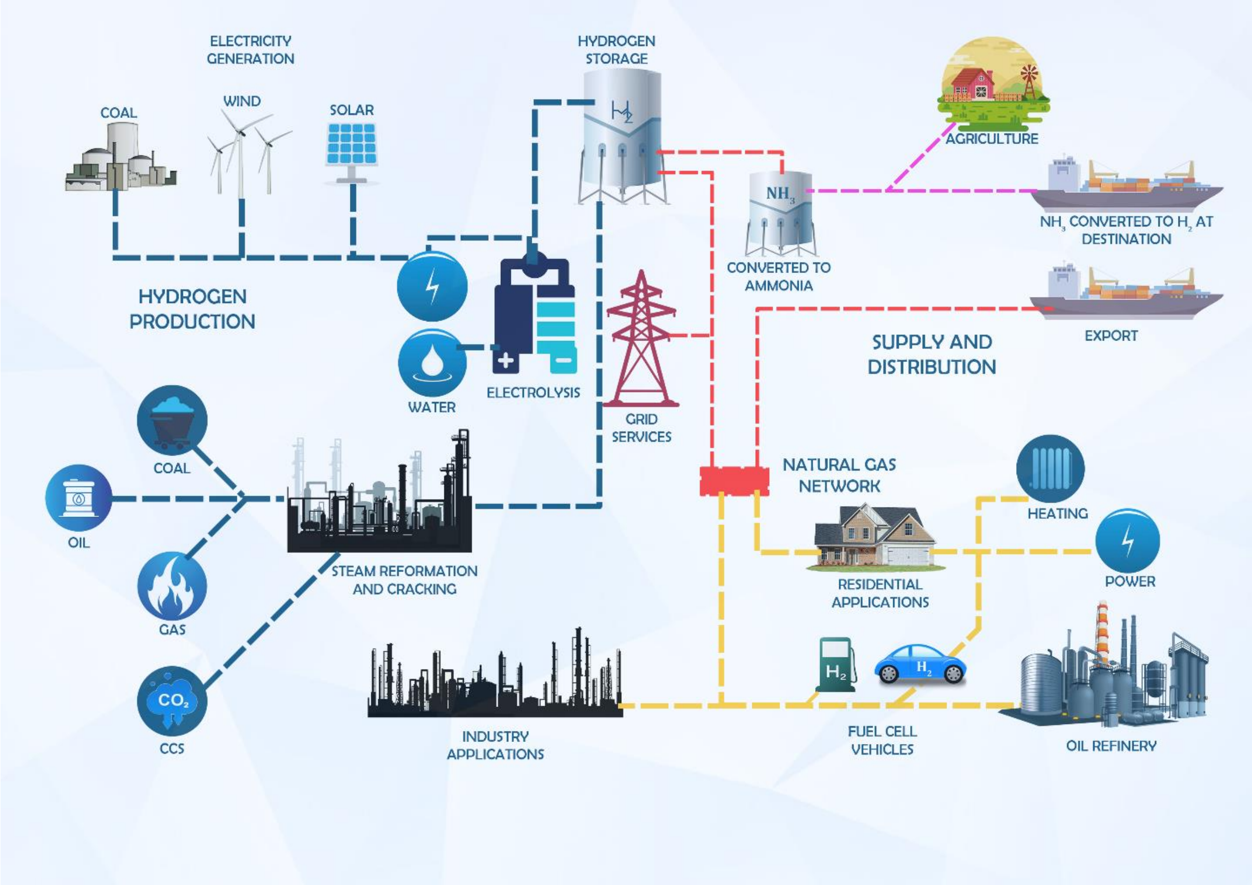


Figure 1. Green Hydrogen Ecosystem

3. Renewable Energy as Enabler

Renewable energy is the fundamental component that categorizes hydrogen production as 'green'. According to the standards issued by the Ministry of New and Renewable Energy (MNRE), 'Green Hydrogen' is defined as hydrogen produced using renewable energy sources[3],

3 MNRE, 2023

including but not limited to electrolysis powered by renewable electricity or the conversion of biomass. These renewable energy sources encompass a wide range of sources, such as solar, wind, hydro, pumped storage, tidal, and biomass.

The National Green Hydrogen Mission has set an ambitious target to produce 5 million metric tons (MMT) of green hydrogen, necessitating a renewable energy capacity of 125 gigawatts (GW)[4]. Using this national target as a reference, it is estimated that Rajasthan would require a renewable energy capacity of 50 GW to achieve its own target of producing 2 MMT of green hydrogen by 2030[5].

3.1. Current RE Capacity in Rajasthan

Rajasthan is leading the race in installing renewable energy capacity, having achieved 23.3 GW of RE capacity (Figure 2) [6,7] as of December 2023 and achieving year on year growth of 35.25% in FY 2021 – 22[8]. In addition to one of the highest installed capacities in the country, Rajasthan also possesses one of the highest renewable energy potentials in India, with a cumulative potential of 426 GW from solar and wind energy combined[9]. Rajasthan Renewable Energy Policy, 2023 targets to have installed capacity of 90,000 MW till 2030. This impressive potential positions Rajasthan as a frontrunner in renewable energy generation, making it a highly suitable state to produce green hydrogen.

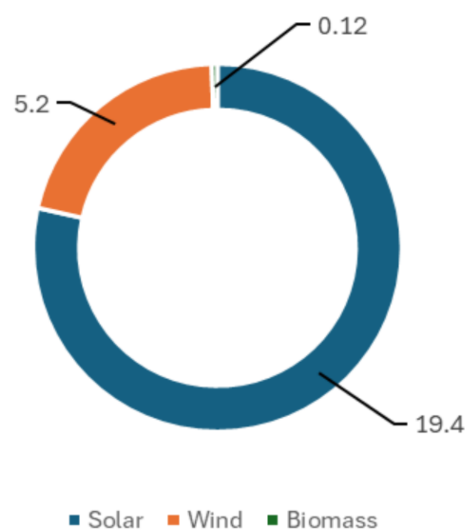


Figure 2. Installed Renewable Energy Capacity in Rajasthan as of 2023 (in GW)

4 National Green Hydrogen Mission, 2023 - Objectives
5 Rajasthan Green Hydrogen Mission, 2023 – Page 5
6 Press Release: Press Information Bureau (pib.gov.in)
7 India: Rajasthan installed renewable energy capacity | Statista
8 MoSPI – Energy Statistics 2023, Chapter 2
9 MoSPI – Energy Statistics 2024, Chapter 1

In addition to its renewable energy potential, Rajasthan's hydrogen policy includes several crucial incentives to boost green hydrogen production. These provisions include power banking, a 50% waiver on intra-state transmission and wheeling charges, and the waiver of additional surcharges and cross-subsidy charges for energy drawn from solar and wind energy plants within the state[10]. These incentives aim to reduce the overall cost of green hydrogen production, making it economically viable and attractive for investors and industries in Rajasthan.

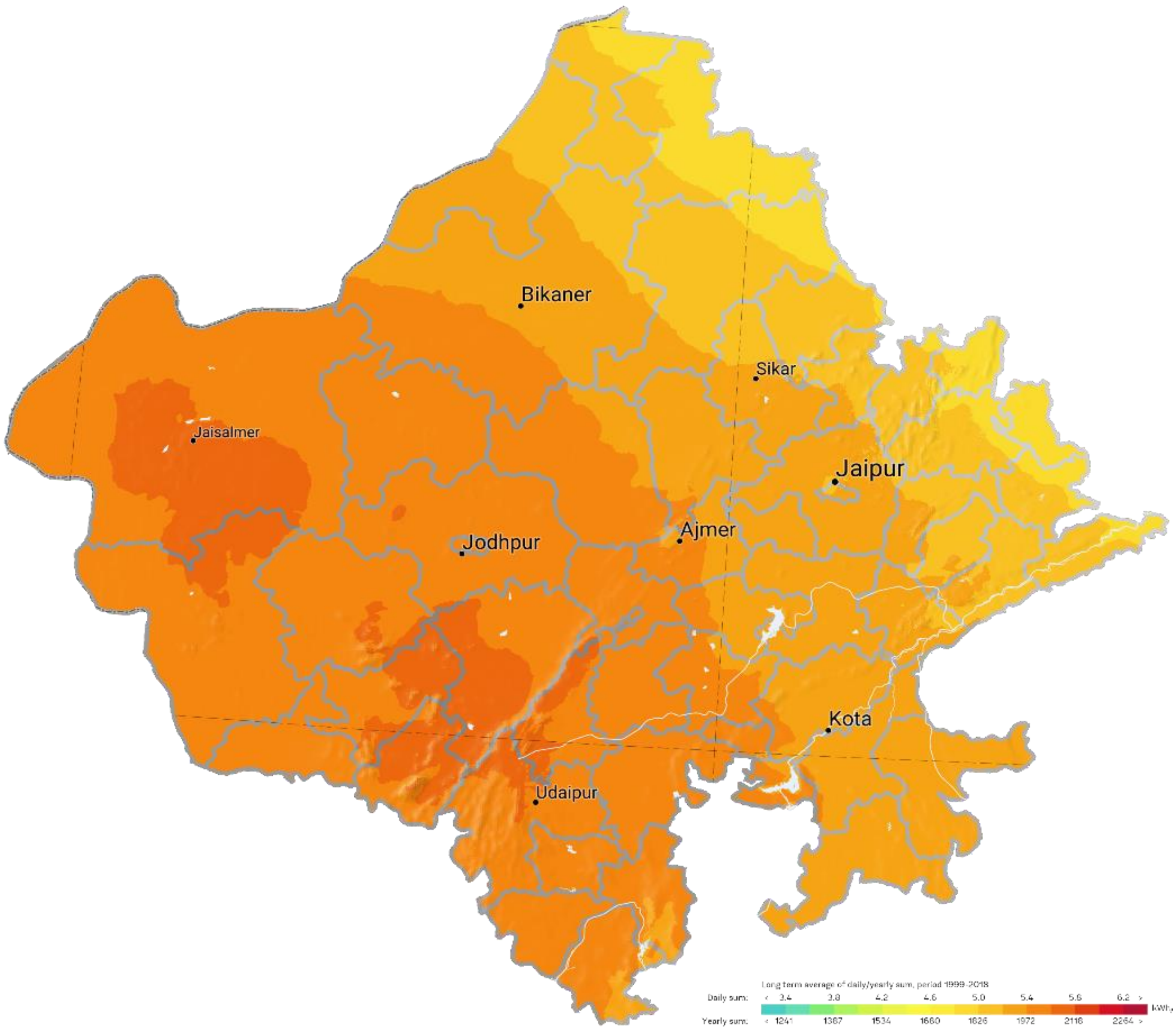


Figure 3. Solar Irradiation in Rajasthan (in kWh/m²)

Source – Global Solar Atlas

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10 Rajasthan Green Hydrogen Policy, 2023

3.2. Challenges

Despite having all the potential to provide renewable energy for production of green hydrogen, Rajasthan could face challenges specifically relating to incentives provided for sourcing RE for green hydrogen production. Rajasthan Green Hydrogen Policy has laid out capping on sourcing RE from different categories of sources (Table 1), thereby restricting the opportunities and associated incentives for sourcing RE from STU network (up to 500 kTPA). Apart from this, the policy has capped the special incentives (Figure 4) to 500 kTPA of green hydrogen production with individual green hydrogen plants eligible for availing incentives for capacities up to 50 kTPA. Even though the period of these incentives is 25 years, the ceiling on the total capacity for availing the incentives is underwhelming, especially in the case where other states are competing to attract investments of a similar nature.

Table 1: Categories of Green Hydrogen Projects as per RGHP

Category of Project	Capacity Allowed
CTU (PGCIL) Network within the state	No upper Cap
Co-located RE project	700 kTPA
Round the Clock RE Power Supply	800 kTPA
RE project at STU (RVPN) Network	500 kTPA

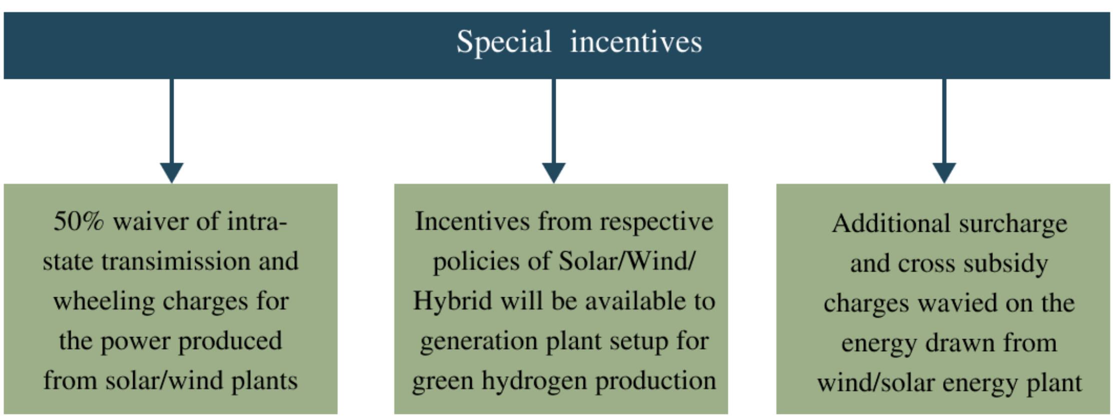


Figure 4. Special Incentives for RE sourcing as per RGHP

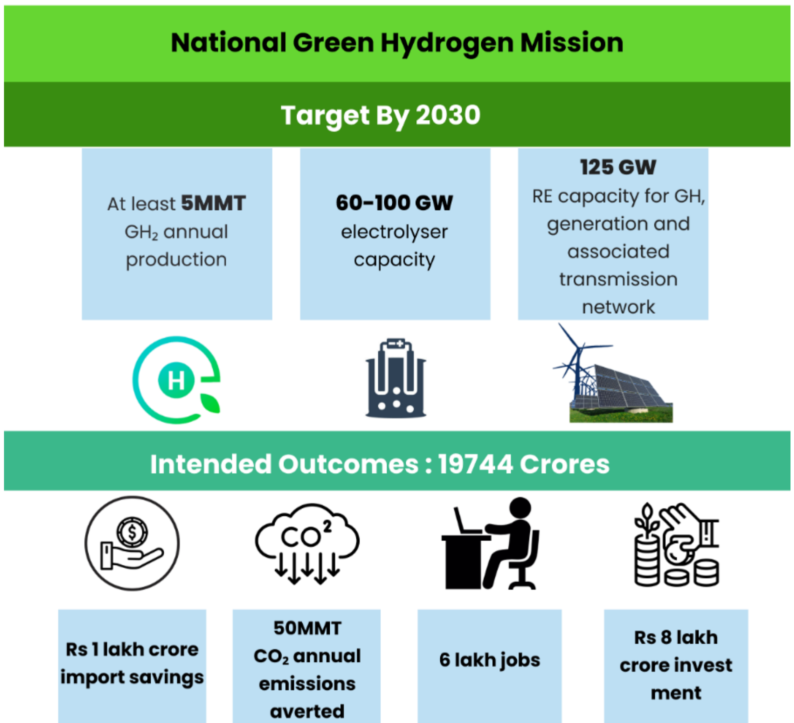
Table 2: RE Sourcing incentives of states with green hydrogen policy

States	Wheeling Charge	Inter/Intra state Transmission	Cross-subsidy surcharge	Distribution charge	Electricity Duty	Banked Energy
Rajasthan	50% exemption		100% exemption	–	50% exemption	Banking allowed for the period of 30 days
Uttar Pradesh	50% exemption		100% exemption	100% exemption	100% exemption (10 yrs.)	Banking allowed for the period of 30 days
Andhra Pradesh	–	25% exemption on intra-state transmission charges (5yrs, max INR 10 Lakhs/MW/year of installed electrolyser capacity)	100% reimbursed (5yrs)	–	100% exemption (5yrs)	–
Maharashtra	50% exemption (Standalone) 60% exemption (Hybrid)		–	–	100% exemption (10yrs.) (Standalone) 100% exemption (15 yrs.) (Hybrid)	Banking allowed for the period of 30 days
West Bengal	RE can be procured by WBSEDCL with applicable green tariff as determined by WBERC				100% exemption	Banking allowed for the period of 30 days
Punjab	50% exemption	50% exemption on Intra-state transmission 100 % waiver on Inter-state (25 yrs. if commissioned before 2030)	100% exemption	–	100% exemption during construction	charged for 10% of power banked, max 30% can be carried forward to next month

Source – Green Hydrogen Policy of Respective States

4. Green Hydrogen Production in Rajasthan – Current Status & Prospects

Since the announcement of the Rajasthan Green Hydrogen Policy, 2023, and the National Green Hydrogen Mission, there has been significant industrial interest in setting up green hydrogen production plants. This policy landscape, coupled with Rajasthan's renewable energy capacity, has catalyzed investment and development initiatives aimed at harnessing green hydrogen's potential.



Apart from the industrial investment for the production of green hydrogen, the state also gained ground in R&D. IIT Jodhpur has setup Hydrogen Valley Innovation Cluster under PPP Model and is advancing innovative methods to produce green hydrogen[11]. Leveraging the state's abundant solar energy, these initiatives aim to generate green hydrogen. Supported by an investment of ₹50 crore from the Union Government in the HVIC[12] under, these efforts will be aimed at utilizing electrolysers and biomass methods for green hydrogen production.

4.1. Current investments in Green Hydrogen Production

Rajasthan has received commitments from several major players in the hydrogen production sector (Table 2). Notably, the state hosts the world's first fully integrated green hydrogen production plant in Bikaner, established by the ACME Group, with a production capacity of 175

11 IIT Jodhpur – Press Release 2023
12 PIB – Financial and Technical Support to promote N&RE, 2024

tonnes per annum dedicated to ammonia production[13]. Additionally, investments aimed at future industry needs are also being directed towards Rajasthan. For instance, Inox Air Products plans to set up a green hydrogen production facility with a capacity of 190 tonnes per annum to supply clean energy to Asahi India Glass Limited (AIS) under a 20-year offtake agreement[14]. These developments highlight Rajasthan's potential to become a key state for green hydrogen production.

Table 3: Commissioned and announced green hydrogen project in Rajasthan

Project Name	Status	Location	End Use	Electrolyser Capacity (MW)	Project Capacity (Tons H2 P.A.)
ACME - Green Hydrogen and Green Ammonia Plant Rajasthan	Commissioned	Bikaner, Rajasthan	Fertilizers	2.1	314
IOCL - Jodhpur Refinery Green Hydrogen Production	Announced	Jodhpur, Rajasthan	TBA	TBA	TBA
Avaada Energy - Green Ammonia Plant	Announced	Kota, Rajasthan	Ammonia production	1,267.606	1,80,000
Jakson Green - Green Hydrogen and Ammonia	Announced	Rajasthan	Ammonia production	TBA	65,700
Aditya Birla - Renewables and Green Hydrogen	Announced	Rajasthan	TBA	TBA	TBA

4.2. Prospects and Challenges

Rajasthan has the potential to achieve its green hydrogen production target, provided the necessary investments amounting to ₹3,20,000 Crore (in line with the National Green Hydrogen Mission) are secured. However, these investments are contingent upon the availability of enabling infrastructure such as transport and storage facilities, proximity to renewable energy

13 ACME Group, 20222
14 INOX Air Products to set-up 190 tonne Green Hydrogen Project in Rajasthan, 2024

plants & industries and essential inputs for hydrogen production. The Rajasthan Green Hydrogen Policy addresses this need by proposing the development of green hydrogen valleys, hubs and clusters that offer plug-and-play facilities. This strategic approach aims to attract investors by ensuring that the foundational infrastructure required for green hydrogen production is readily available.

To foster a green hydrogen ecosystem, the Rajasthan Green Hydrogen Policy (RGHP) outlines plans to establish at least one gigafactory for electrolysers. These efforts aim to capture at least 20% of India's green hydrogen export market, including electrolysers[15]. The RGHP designates this sector as a Thrust Sector and offers incentives under the revised Rajasthan Investment Promotion Scheme (RIPS). However, the development of such enabling infrastructure presents its own set of challenges.

One such challenge is the high price of green hydrogen which is primarily influenced by the cost of electrolysers and electricity. The cost of electrolysers, which are crucial for the production process, currently ranges between USD 500 to USD 1,000 per kilowatt, depending on the technology and scale. Additionally, the cost of renewable electricity, which is around ₹2.5 to ₹3.5 per kWh, plays a crucial role in determining the overall price of green hydrogen[16,17]. Beyond these primary costs, operating expenses, transmission and distribution (T&D) costs, and wheeling charges further impact the pricing. For instance, T&D losses in India are approximately 20%, which can add to the overall cost burden. Taxes, such as the Goods and Services Tax (GST), also contribute to the final price, making the financial landscape for green hydrogen production quite complex.

The RGHP needs to be re-evaluated to identify potential areas to be incentivized which may enable reduction of the production costs of green hydrogen. While the policy includes important provisions of power banking, this alone is insufficient to increase utilization factor of electrolysers and lower production costs. Therefore, implementing a comprehensive incentive structure that includes waiving charges associated with open access can contribute to reducing the overall cost of green hydrogen production.

15 Rajasthan Green Hydrogen Policy, 2023 – Page 2
16 Bhattacharyya R, Singh KK, Bhanja K, Grover RB, 2022
17 Vartiainen, E., Breyer, C., Moser, D., Román, E., Busto, C., Masson, G., Bosch, E. and Jäger, A. 2022

Water availability is another major challenge in green hydrogen production, given the state's projected water stress in the year 2030 (Figure 5)[18]. The RGHP includes provisions to supply water from the Indira Gandhi Canal Project (IGNP), subject to availability. In cases where brine or treated water can be utilised for Green Hydrogen production/ maintenance of RE plants, allocation for the same will be prioritized. However, given the water stress in Rajasthan and provisions included for water availability in RGHP, there could be some degree of uncertainty in availability of water of the required standards to attain the green hydrogen production targets.

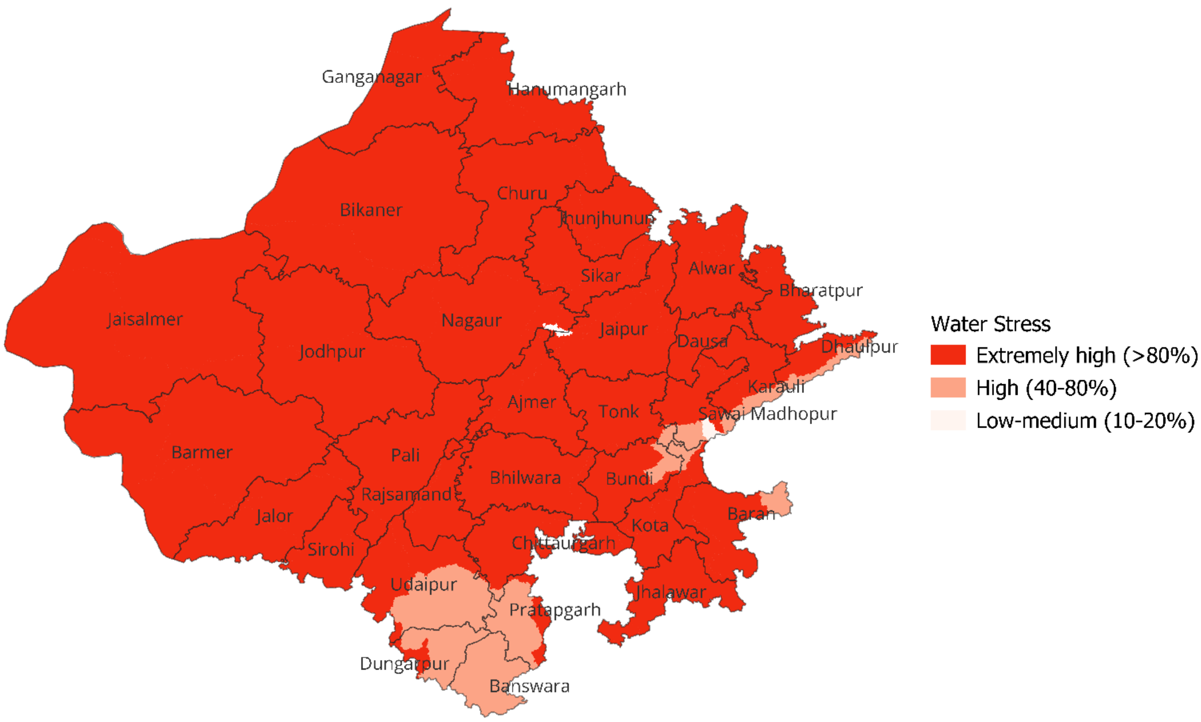


Figure 5. **Water Stress in Rajasthan in Pessimistic Scenario by 2030**

5. Rajasthan's potential as Green Hydrogen consumer

Currently, Rajasthan stands as the fourth largest consumer of grey hydrogen in India, accounting for approximately 7% of the nation's total hydrogen consumption[19]. This translates to roughly 0.42 million metric tons (MMT) of grey hydrogen per annum (Figure 6).

18 WRI Aqueduct

19 Financing Green Hydrogen in India – Bloomberg, 2024

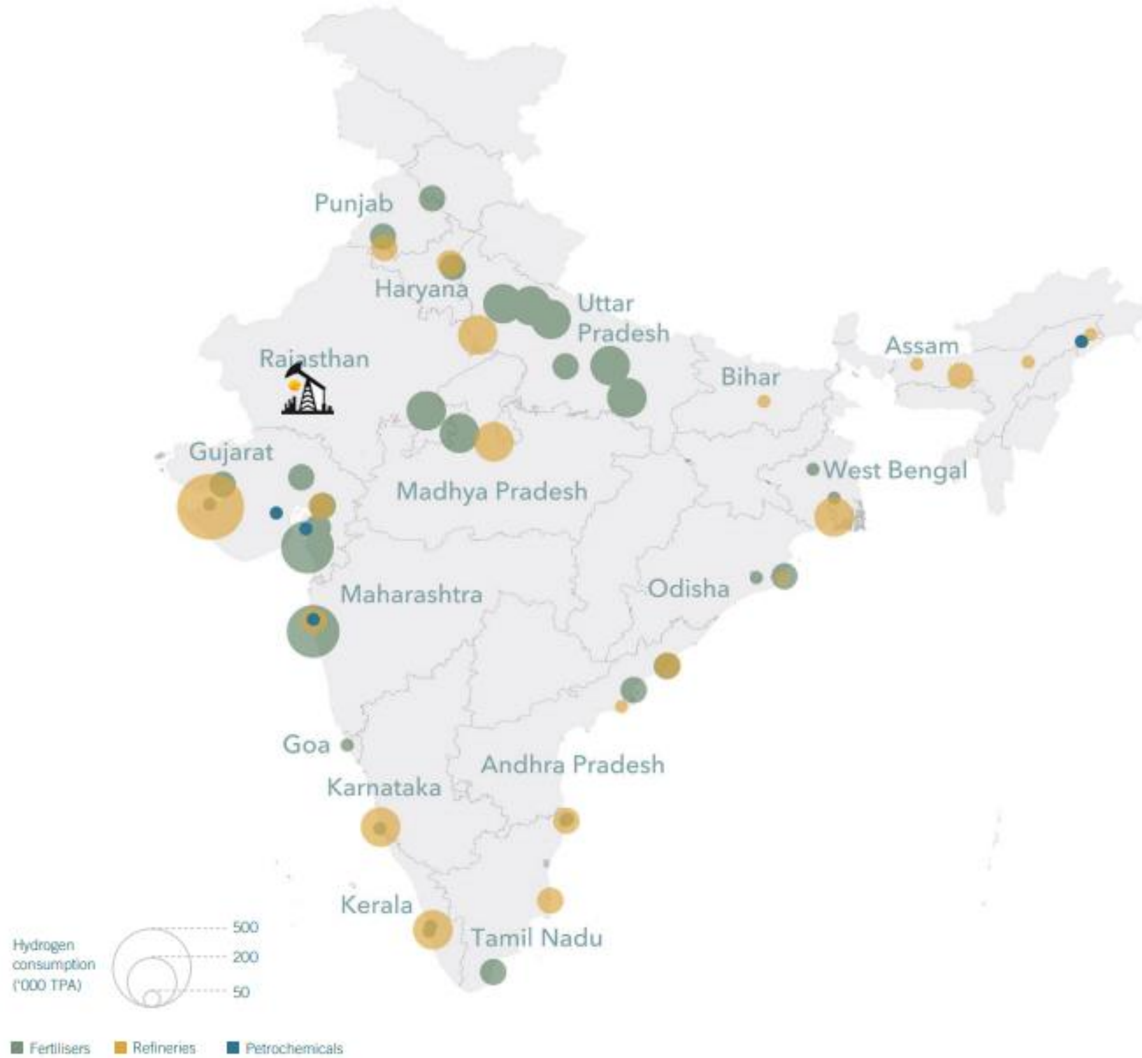


Figure 6. Hydrogen demand sites in India (FY 2020, in tonnes per annum (TPA))

Source – CEEW

In Phase 1 of the National Green Hydrogen Mission (FY 2023-2026), the focus sectors are refining, fertilizers, and city gas. Rajasthan's fertilizer industries, coupled with a new HPCL refinery in Barmer expected to operate at full capacity by 2027 can position the state as a key player in driving green hydrogen demand (Figure 7). This potential is underscored by the fact that the Indian fertilizer and refining industries currently consume 98% of the nation's grey hydrogen production, indicating a substantial opportunity for green hydrogen adoption within these sectors in the state[19].

Moreover, Phase 2 of the mission (post-FY 2026) will emphasize steel, mobility, and shipping as key drivers for green hydrogen. Rajasthan's steel industry can benefit from this shift, as green hydrogen provides a cleaner alternative to traditional coal-based steel production methods.

The mobility sector, particularly with Rajasthan's extensive road network and increasing focus on sustainable transport solutions, offers another avenue for green hydrogen application.

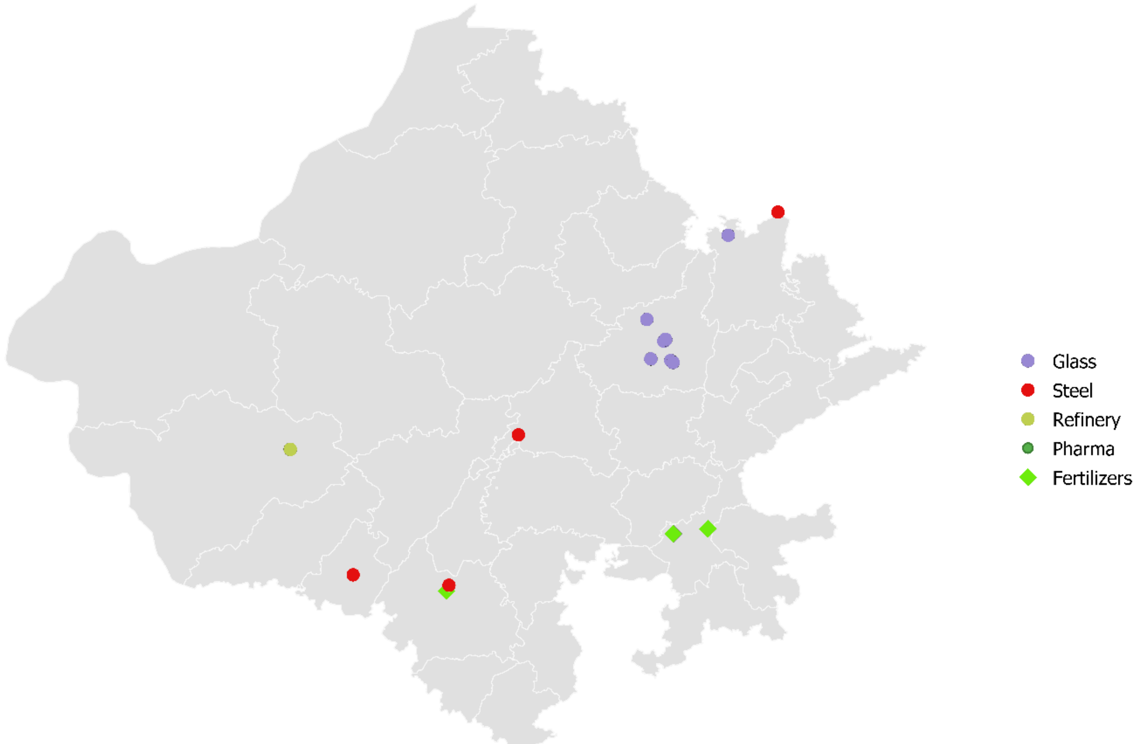


Figure 7. Industries in Rajasthan with potential of using green hydrogen

Source – Author's Analysis

5.1. Challenges in Green Hydrogen Uptake in Rajasthan

To encourage R&D and proof of concept for green hydrogen applications Union government under the National Green Hydrogen Mission (NGHM) has approved pilot projects in three key areas: steel, transport, and shipping. These projects aim to assess the potential of green hydrogen in these sectors. However, domestic demand for green hydrogen is projected to be relatively low, at approximately 2 MMT by 2030[19]. This limited demand is largely due to the high cost of green hydrogen, which is not expected to be as competitive as grey hydrogen in the near term.

Rajasthan will face similar challenges due to the limited presence of industries with high potential for green hydrogen uptake. Refineries are anticipated to be the primary drivers of green hydrogen demand in the state, as they are less sensitive to production costs compared to other sectors like fertilizers, where the cost of hydrogen production has high degree of impacts on overall production costs.

Given these challenges, the demand for green hydrogen in Rajasthan will be predominantly driven by the refining and fertilizer sectors. However, this demand is not expected to be high enough to be in sync with production capacities. Hence, to achieve production targets, demand from export markets will be crucial. Developing the necessary infrastructure to build export capacity for green hydrogen from Rajasthan will be key to tapping into these markets and ensuring the state's success in the green hydrogen economy.

6. Storage and Transport

To realize Rajasthan's potential as a green hydrogen economy, establishing robust infrastructure for the safe and efficient storage and transport of green hydrogen is essential. Given that Rajasthan is a landlocked state, efficient transport systems are key for distributing hydrogen from production sites to export hubs such as ports and to domestic end users. However, the Rajasthan Green Hydrogen Policy (RGHP) does not specifically address storage and transport infrastructure development.

Developing a dedicated hydrogen pipeline network or repurposing existing natural gas pipelines could be considered, which would involve upgrading pipeline materials to ensure compatibility with hydrogen's properties. Additionally, deploying high-pressure tube trailers for road transport is necessary, especially for areas not connected by pipelines (Table 3).

Alongside the development of transport and storage infrastructure, implementing stringent safety and regulatory frameworks is vital for the safe handling of hydrogen. Adopting international safety standards and training a skilled workforce to manage sophisticated infrastructure is crucial for ensuring compliance. Formulating clear policies and guidelines to facilitate the deployment of hydrogen infrastructure, including incentives for investments in hydrogen technologies, can accelerate this development.

Table 4: Storage and Transport methods for Green Hydrogen Economy

Method	Description	Advantages	Disadvantages	Deployment in Rajasthan
High-Pressure Gaseous Storage	Uses high-pressure vessels, such as carbon fiber-reinforced plastic composite, steel, or aluminum vessels.	Superior strength and impact resistance (composite vessels).	Higher cost (composite vessels).	Recommended to deploy carbon fiber-reinforced plastic composite vessels despite higher costs for superior strength and impact resistance. Steel and aluminum vessels for cost constraints.

Hydrogen Pipelines	Transport hydrogen via dedicated pipelines or repurposed natural gas pipelines.	Low-cost option for large volumes.	Requires high initial capital.	Repurposing natural gas pipelines for hydrogen transport with robust leak detection systems, regular inspections, and maintenance protocols.
Geological Storage	Uses geological formations like salt domes for large-scale, long-term hydrogen storage.	Stable and secure storage.	High initial setup costs.	Utilize salt domes for balancing the intermittency of solar and wind power.
Cryogenic Liquid Hydrogen Storage	Involves storing hydrogen as a cryogenic liquid in double-walled, insulated cryogenic tanks.	Suitable for large quantities and mid-range transport.	Energy-intensive.	Install double-walled, insulated cryogenic tanks at production sites and major consumption points. Develop a fleet of cryogenic tanker lorries and rail wagons, utilizing Rajasthan's rail network for long-distance transport.
Solid-State Storage	Uses metal hydrides and advanced materials like MOFs and porous carbon for hydrogen storage.	Safe and efficient storage.	Requires advanced research and development.	Invest in R&D of advanced materials, establish facilities for safe handling and processing of metal hydrides, implement temperature control systems, and manage charge-discharge cycles effectively.
Ammonia as a Hydrogen Carrier	Uses ammonia to store and transport hydrogen, with dehydrogenation plants for hydrogen release.	Creates synergies with existing agricultural industry.	Requires additional infrastructure for dehydrogenation.	Set up dehydrogenation plants, align with Rajasthan's existing agricultural industry for ammonia production and utilization.

6.1. Challenges

All these developments are desirable to achieve the objectives of the Rajasthan Green Hydrogen Policy (RGHP), but the major issue lies in the high capital cost of developing such infrastructure. The development of transport and storage infrastructure will need to occur in parallel with the growth of green hydrogen supply and demand to ensure synchronization.

A significant challenge is the need for dedicated hydrogen pipeline networks or the repurposing of existing natural gas pipelines. The cost and technical complexities of these upgrades are substantial. Moreover, for areas not connected by pipelines, deploying high-pressure tube trailers for road transport is necessary, adding to the logistical challenges and costs.

Another critical aspect is the implementation of stringent safety and regulatory frameworks. Hydrogen, being highly flammable, demands rigorous safety standards and protocols. Developing and maintaining such standards, along with training a skilled workforce to manage this sophisticated infrastructure, represents another layer of challenge and cost.

Additionally, as Rajasthan is a landlocked state, efficient transport systems are crucial for distributing hydrogen from production sites to export hubs such as ports and to domestic end users. Technological advancements hold a promise for reducing these costs. Innovations in materials science could lead to more durable and hydrogen-compatible pipeline materials, and advancements in hydrogen compression and liquefaction technologies could enhance storage efficiency and reduce transport costs. However, these technological solutions are still in development and require further research and investment before they become economically viable.

In summary, while the development of a robust hydrogen storage and transport infrastructure is essential for realizing the goals of the RGHP, it faces substantial challenges due to high capital costs, technical complexities, stringent safety requirements, and the need for technological advancements. Addressing these challenges will be crucial for the successful implementation of a green hydrogen economy in Rajasthan.

7. Enablers of Green Hydrogen Transition

7.1. Financial enablers

Financing the green hydrogen transition is key to realize sustainability to develop green hydrogen economy. A robust financing avenue will help in navigating high capital costs and leveraging a combination of public and private sector investments. While government initiatives such as the Rajasthan Green Hydrogen Policy (RGHP) and the National Green Hydrogen Mission provide financial support through grants, subsidies, and tax incentives, in parallel it is also important to attract private sector investments through innovative financing mechanisms such as green bonds and public-private partnerships, along with international funding from multilateral agencies, which can enhance the financial landscape for green hydrogen transition (Table 5).

Table 5: Financing Options for Developing Green Hydrogen Ecosystem

Financing Options	Description
Public Private Partnership	To foster private participation under NGHM, a PPP framework called Strategic Hydrogen Innovation Partnership (SHIP) is formulated. An initiative under PPP model is the collaboration among HSBC India, IIT Bombay, and Shakti Sustainable Energy Foundation to foster R&D in green hydrogen
Government Subsidies and grants	Government support in the form of tax breaks, subsidies and grants to facilitate development of green hydrogen ecosystem. SIGHT Scheme, HVIC and waivers on sourcing RE are few examples of financial incentives to foster green hydrogen ecosystem
Low-cost Financing from multilateral agencies	Concessional loans from multilateral development banks are key to enable low-cost financing options in green hydrogen. Similar efforts are undertaken by World Bank by announcing USD 1.5 billion support for India to transition into low carbon economy, these funds will also be used develop green hydrogen economy in India
Carbon Financing and Carbon Credit	Monetizing carbon credits from emissions reductions can create a revenue stream for green hydrogen projects. Implementation of the Carbon Credit Trading Scheme (CCTS) would place a carbon price on hard-to-abate sectors, incentivizing these sectors to transition to green hydrogen
Special Purpose Vehicles (SPV) and Green Bonds	Establishing Special Purpose Vehicles (SPVs) or issuing Green Bonds (GB) dedicated to financing green hydrogen projects can attract capital from institutional investors interested in sustainable investments. Green Bonds provide investors the opportunity to support environmentally friendly projects while earning financial returns
Export Credit Agencies	Export Credit Agencies (ECAs) can offer financing and insurance solutions to support the export of green hydrogen technologies and equipment. This support helps to ensure the successful deployment and adoption of green hydrogen technology on a global scale

7.2. Non-financial enablers

Apart from having enabling financing options, non-financial enablers are crucial to decrease the LCOH of green hydrogen. State-level Policies should focus on indigenizing the green hydrogen value chain such as electrolyser manufacturing, reducing dependency on imports and lowering the production costs over time. Market-driven policies encouraging green hydrogen uptake can help in increasing the competitiveness in green hydrogen production, subsequently reducing overall production costs and can support the necessary distribution & storage infrastructure for green hydrogen.

7.2.1. Green Hydrogen Purchase Obligation (HPO)

Currently, India's green hydrogen ecosystem experiences a strong supply-side push but lacks the necessary demand-side pull. To address this, policies mandating green hydrogen purchase obligations for domestic industries should be implemented.

The Green Hydrogen Purchase Obligation (HPO) mandates specific sectors to use a minimum percentage of green hydrogen in their feedstock or energy mix. Similar to Renewable Purchase Obligations (RPOs), the HPO aims to create a guaranteed market for green hydrogen, encouraging its adoption. This policy tool is crucial for sectors such as fertilizers, refining, and steel production, which are major hydrogen consumers. Implementing HPOs will drive demand for green hydrogen, facilitating a transition to cleaner energy sources without direct financial incentives.

7.2.2. Blending Mandates

Blending mandates require the mixing of green hydrogen with conventional hydrogen or natural gas, particularly in industries like fertilizers and refining. This approach can stimulate demand while minimizing cost impacts by spreading the incremental expense over the total hydrogen volume. In Phase I of the National Green Hydrogen Mission, city gas distribution is a priority, but its potential to drive substantial green hydrogen demand is limited. To encourage uptake, the government can mandate blending requirements for hard-to-abate sectors as well, with periodic increments, ensuring a gradual transition to green hydrogen.

7.2.3. Export Oriented Policy

Finally, prioritizing export orientation is crucial for India to become a significant player in the global green hydrogen market. Promoting exports to markets interested in importing green hydrogen or green ammonia can generate demand, helping develop economies of scale and drive down the cost of green hydrogen. This requires dedicated infrastructure and administrative support from all levels to facilitate exports. Removing structural and regulatory barriers to trade will create a conducive market and aid channeling of the targeted produce of green hydrogen.