ENVIRONMENT AND NATURAL RESOURCES PROGRAM &
SCIENCE TECHNOLOGY AND PUBLIC POLICY PROGRAM

India – The New Global Green Hydrogen Powerhouse?

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HARVARD Kennedy School
BELFER CENTER
50 YEARS OF RESEARCH, POLICY, AND LEADERSHIP

REPORT
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Environment and Natural Resources Program &
Science, Technology, and Public Policy Program
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A bus that runs on green hydrogen sits at a hydrogen plant at Oil India Limited in Jorhat, India, Thursday, Aug. 17, 2023.(AP Photo/Anupam Nath)

Executive Summary

India aims to become a leading powerhouse in green hydrogen production by the next decade as part of a broader industrial strategy to achieve a $5 trillion GDP economy by 2028. Hence, India must develop new approaches to produce vast amounts of green energy at affordable prices to support its economic development, growing population, and carbon reduction targets. Neither the public nor the private sectors can address these challenges alone, and technological innovation must increasingly play a role.

To achieve its ambitious goals, New Delhi must incentivize the creation of fully-fledged green hydrogen industrial value chains (such as fertilizers and steel), which includes scaling up domestic electrolyzer manufacturing capacity.[1] This strategy will avoid the inefficiencies and mistakes of the past, during which dependence on foreign manufacturing (i.e., Chinese solar technology) undermined the country's ability to deploy robust industrial clean technology value chains at scale. To accelerate the development and deployment of hydrogen value chains, the Indian Government must design appropriate incentives to drive adoption while supporting workforce development.

However, our research demonstrates how land availability, water scarcity, and infrastructure challenges could limit India's ability to become a green hydrogen export champion.[2] These factors would require India to produce hydrogen in less densely populated areas and efficiently transport it to demand or export centers. However, these regions also face higher infrastructure gaps.[3] Successfully tackling these hurdles while establishing a business-friendly regulatory framework - to mobilize the necessary private investments - would allow India to corner new green hydrogen markets connecting the Middle East, Europe, and other key countries in the Global South.

As witnessed during the G20 presidency, India could pioneer a new economic development model based on technological innovation, thereby side-stepping the carbon-intensive approaches of the past. Accelerating the transition to a low-carbon economy should not be perceived as a risk hindering growth but as an opportunity to reduce socioeconomic imbalances and achieve industrial leadership. Is India ready?

Introduction

Fossil fuels have paved the way for rapid industrialization and economic development for decades. Yet, with a growing and highly dense population of almost 1.5 billion people,[4] India's future is written in its demographics. In 2023, India overtook China as the world's most populous nation, with an almost three times higher population density (434 vs. 149 people per square kilometer, respectively).

India's growing population and fast-paced economy are skyrocketing demands for energy, enabling infrastructure, and new manufacturing capacity. Today, India is the world's third-largest carbon dioxide emitter after China and the United States. Continued reliance on fossil fuels would exacerbate existing socioeconomic imbalances, as worsening pollution and rising carbon emissions would severely impact the Indian populace through extreme events and pollution-related diseases, particularly among the most vulnerable; these events would also have significant adverse economic impacts.

Considering these circumstances, a critical question emerges: how can India balance sustaining growth and achieving prosperity for all while accelerating the transition to a low-carbon economy? The answer increasingly lies in technological innovation.

Green hydrogen could play a key role in balancing India's goals. Nevertheless, the transition from fossil-fuel-dominated energy systems to ones based on renewable energy and green molecules will dramatically impact existing regulatory and business models; these systems, in turn, must rapidly evolve to manage significant cost challenges and stakeholder interaction shifts. Neither the public nor the private sector can address these challenges alone.

Policy Stage and the Green Energy Challenge

India's twenty-nine states and seven union territories vary significantly in population, urbanization, economics, natural resources, and regulatory environments. A complex federal political system has given rise to distinct sub-national economies with unique growth drivers, investment climates, and reform strategies. As the Central Government's policy instruments – aimed at coordinating and driving the country's overall energy strategy – may collide with policies enacted by the autonomous State Governments, the risk of overlapping and increased competition should not be underestimated and could potentially hinder an efficient and effective transition to a low-carbon economy.

India's current goals (i.e., to become a $5 trillion economy by 2028, to achieve climate neutrality by 2070, and to become a global clean-tech manufacturing hub) are undeniably ambitious. Substantial capital investments will be required to deploy the needed clean technologies over a relatively short timeframe.[5] So far, India has advanced decarbonization opportunities by proactively subsidizing solar and wind.[6] Still, it remains to be seen whether New Delhi possesses the fiscal might needed to achieve the desired transition at scale.[7]

The International Monetary Fund (IMF) estimates that India's GDP grew by 6.3 percent in 2023 - the highest among the G20 countries.[8] According to estimates from the Organisation for Economic Co-operation and Development (OECD), India will continue to lead the race in 2024, with a projected GDP growth of 6.2 percent.[9] Against this thriving backdrop, however, many hurdles remain. The most pressing is the extensive infrastructure gap, which thwarts competitiveness and slows economic growth. Despite increasing infrastructure-related capital spending – mainly through the $1.8 trillion National Infrastructure Pipeline 2019-2025 Act[10] and the $549.5 billion 2023-2024 Union Budget[11] – infrastructure investments would need to be significantly higher for the foreseeable future, especially in the energy sector, to meet projected needs.[12]

Although facing increasing international competition, India strives to establish itself as a global leader in clean energy technologies, with an emphasis on green hydrogen.[13] New Delhi aims to become a global leader in hydrogen production,

aiming to supply 10 percent of global demand.[14] Still, our research shows that land and water availability and infrastructure challenges could limit the country's ability to become a green hydrogen export champion.[15] To succeed, India must produce hydrogen in less densely populated areas and efficiently transport it to demand or export centers. However, less densely populated areas face higher infrastructure gaps, further challenging deployment.[16]

To address these challenges, in early 2023, New Delhi launched the National Green Hydrogen Mission, which earmarked $2.3 billion to incentivize commercial green hydrogen production, make India a net exporter, and reach net-zero emissions by 2070.[17] Key strategic pillars include industrial competitiveness, energy security, energy affordability, clean transport, and climate targets. The strategy also aims to produce 5 million tons of green hydrogen by 2030,[18] deploy between 60 and 100 GW of electrolyzer capacity, avert more than 50 million tons of carbon dioxide emissions annually, and create more than 600,000 new jobs. India's hydrogen demand is expected to increase to 25 million tons by 2050,[19] driven primarily by the industrial and transportation sectors, which account for about 52 percent of this growth.[20] To rationalize investment efforts, the Central Government has identified 10 States where green hydrogen or ammonia clusters should be created.[21]

India's hydrogen strategy is part of a broader goal to achieve energy independence by 2047 – a true challenge considering that India currently imports over 40 percent of its primary energy demand at a cost of $90 billion annually. Today, India is the world's third-largest energy consumer, with fossil fuels accounting for more than 95 percent of primary energy supply (58.3 percent from coal, 29.7 percent from oil, and 7.7 percent from natural gas).[22]

With an installed capacity of 132 GW,[23] renewables comprise about 1.8 percent of India's energy mix (3.6 percent, including hydropower) and over 40 percent in the power sector.[24] Although installed capacity has grown at an average pace of 17.3 percent annually over the past few years,[25] it is estimated that India will require more than $500 billion in new investments to achieve its renewable targets by 2030, namely 500 GW of installed renewable energy (280 GW of solar and 140 GW of wind power).[26] This is a tall order considering that investments have averaged only $13-14 billion annually; inefficient authorization and land expropriation procedures further complicate matters.[27] Moreover, India's

renewable installed capacity would need to reach about 1,000 GW by 2040 to reach its net-zero goals.[28] Furthermore, to produce 5 million tons of green hydrogen a year, India would require between 100 and 125 GW of additional new renewables,[29] doubling today's installed capacity.[30] Therefore, the Central Government must be able to streamline decision-making across states and incentivize new infrastructure deployment by de-risking investments in order to achieve its goals.

But is New Delhi allocating enough financial resources to drive the desired transition at scale? A comparison with other decarbonization plans (such as the EU Fit for 55,[31] Net Zero Industry Act,[32] or RePowerEU[33] and the U.S. Inflation Reduction Act [IRA][34]) refutes this question, both in terms of infrastructure deployment and renewables capacity growth. Launched in August 2022, the IRA earmarked $370 billion over ten years to accelerate the transition to a low-carbon economy and stimulate industrial competitiveness in clean-technology sectors. The United States aims to reduce its dependency on Chinese clean-technology supply chains through subsidies, local content requirements, and diversification; India could play a pivotal role in this objective. Although India's hydrogen push lags, New Delhi can leverage some key competitive advantages, including one of the world's lowest renewable energy prices and a large, fast-growing domestic market; however, time is of the essence because the country faces competition from other Asian energy giants, such as China.[35] Financing from both the private sector and multinational banks will be crucial to bridging this investment gap. For example, in June 2023, the World Bank approved a $1.5 billion financing package for New Delhi to accelerate the development and deployment of low-carbon technologies focusing on renewable energy capacity growth, supporting green hydrogen adoption, and stimulating private investments.[36]

Water availability presents additional challenges in scaling green hydrogen. India is already one of the world's most water-stressed countries; furthermore, overall water demand is expected to exceed supply two-fold by 2030.[37] Producing one kilogram of green hydrogen via electrolysis requires about nine liters of fresh water; therefore, India would need about 45 million cubic meters a year to meet its green hydrogen targets alone. Addressing water scarcity concerns will, again, require supporting technology innovation and extensive investments in new infrastructure funded by public and private capital. Today, the direct use of seawater in electrolysis is hindered by its high salinity (as salts lead to corrosion).

However, researchers worldwide are developing processes that could make direct seawater electrolysis viable.[38] Additional innovations will also be necessary to boost electrolyzers' efficiency and lifespan while reducing their power and water requirements.[39]

Furthermore, India must also incentivize the creation of fully-fledged green hydrogen industrial value chains and scale up domestic electrolyzer manufacturing capacity.[40] These actions will avoid inefficiencies and mistakes of the past when dependence on foreign manufacturing (i.e., Chinese solar technologies) undermined the country's ability to deploy robust industrial clean technology value chains at scale. To accelerate hydrogen value chains' development and deployment, the Government must design appropriate incentives to drive green hydrogen adoption while supporting workforce skill development.[41]

According to the New Delhi Council for Energy, Environment and Water, green hydrogen costs fell from $4 to $3 per kilogram last year; the Government aims to reduce these prices to about $1 over the coming years, at which point green hydrogen would become competitive with coal.[42] To incentivize this process, the Indian government has earmarked $2.1 billion through a three-year incentive scheme to reduce electrolytic hydrogen production costs by 10 percent. Moreover, India's hydrogen policy also allows new producers to purchase renewable energy from the grid with no transmission costs for 25 years.[43]

India's Hydrogen Strategy

As discussed, current Indian green hydrogen production is marginal; the Ministry of New and Renewable Energy is supporting a 5 normal cubic meter per hour production plant powered by solar energy in Gurugram, Haryana, and a 6 kg per hour plant based on biomass gasification at IISc Bangalore, Karnataka.[44] Oil India, a State-owned enterprise, commissioned the first hydrogen pilot plant with an installed capacity of 10 kg per day at its Jorhat Pump Station in Assam in 2022. In January 2023, NTPC and Gujarat Gas started the first green hydrogen blending project in the natural gas network in Surat, Gujarat.[45]

India's green hydrogen strategy proposes a clear path for developing a robust national hydrogen industry by addressing the aforementioned challenges. The first phase (2022/23-2025/26) prioritizes demand and supply creation. On the

demand side, growth areas are expected in the refining, fertilizers, and city gas sectors thanks to the definition of green hydrogen standards, which require that a certain percentage of green hydrogen is used in a specific sector. On the supply side, growth will be based on incentivizing the creation of indigenous value chains through pilot projects and scaling up electrolyzer manufacturing capacity. Incentives will also be used to reduce green hydrogen production costs. If successful, by the second phase (2026/27-2029/30), green hydrogen is expected to become cost-competitive with fossil fuels, and commercialization efforts will focus on new sectors, such as steel, mobility, and shipping.

For example, by 2035, the Central Government aims to substitute all ammonia imports used for fertilizer production with domestic green ammonia. Green hydrogen and ammonia refueling hubs will be deployed in shipping and port operations, leveraging the Sagarmala Program to develop and modernize Indian ports.[46] The National Hydrogen Strategy mandates that green ammonia bunkers and refueling facilities be established in at least one port by 2025 and all major ports by 2035. Additionally, the Shipping Corporation of India must retrofit at least two ships to run on green hydrogen or other green hydrogen-derived fuels by 2027. Kandla Port on the west coast and Tuticorin Port on the east coast have been designated as India's first green hydrogen and green ammonia refueling hubs.[47]

Regarding pilot projects, economies of scale and infrastructure optimization will be developed by establishing green hydrogen hubs and cluster-based production. Regions with large-scale green hydrogen potential are being selected; for example, Gujarat has been chosen and will become the world's biggest green hydrogen hub.[48] Success will require an integrated and coordinated approach between the Central Government, the States, the Regional Government Agencies, and the private sector. Building on the positive experience of the Gati Shakti Program and the National Infrastructure Pipeline (i.e., the Indian Master Plan for connectivity and energy infrastructure in the country), the India Hydrogen Alliance exemplifies a successful cooperative model between industry, academia, and government to accelerate the transition to a low-carbon economy.[49]

India's Green Hydrogen Diplomacy

To help transform India into a green hydrogen export champion, Modi's government is pursuing "hydrogen diplomacy," a strategy to secure export markets for India's cost-competitive green hydrogen. During the recent G7 summit in Japan, New Delhi and Tokyo established a strategic partnership on green hydrogen focused on technology development.[50] In May, the Australia-India Green Hydrogen Taskforce[51] and the Quad – a strategic alliance between Australia, India, Japan, and the United States – were announced to create an integrated green hydrogen supply chain for the Indo-Pacific region, lower production costs, and accelerate technological innovation.[52]

Furthermore, India is pursuing partnerships with Gulf and Mediterranean countries to gain greater access to lucrative European markets. Major agreements were concluded with Gulf countries such as Oman[53] and the United Arab Emirates.[54] During the Middle East and North Africa (MENA) Climate Week in October 2023, a Memorandum of Understanding was signed with Saudi Arabia. The agreement established a general framework for cooperation on grid interconnecting and balancing, fostering renewables and green hydrogen co-development, and creating resilient supply chains for critical materials.[55] In Morocco, the Adani Group has committed to building up to 10 GW of solar and wind power dedicated to green hydrogen production for the European markets.[56]

New Delhi is also negotiating with the European Commission on a deal to supply up to 10 million tons per year of green hydrogen to the region;[57] this transaction will become a cornerstone of the broader EU-India Clean Energy and Climate Partnership, dating back to 2016.[58] In September 2022, the first EU-India Green Hydrogen Forum was held in New Delhi. Through this framework, India could play a pivotal role in supporting the overall goals of the EU Global Gateway strategy – a €300 billion connectivity, infrastructure, and sustainability plan launched in 2021 to counter China's Belt and Road Initiative (BRI);[59] the EU could leverage the plan to invest in green hydrogen capacity in India.

The BRI is a global infrastructure development strategy adopted by the Chinese Government in 2013; the strategy allows Beijing to gain geopolitical leverage by investing in more than 150 countries and international organizations.[60] With

investments of $965 billion ($366 billion of which is devoted to energy projects), the BRI is the world's most extensive infrastructure plan.[61] In 2022, the G7 established the Partnership for Global Infrastructure and Investment (PGII), a Western-led $600 billion global infrastructure investment plan, including the €300 billion Global Gateway. During the 2023 G20 Summit, New Delhi and G7 countries, under the PGII framework, agreed to create a new India-Middle East-Europe Economic Corridor (IMEC) to promote integration and connectivity between Europe and India through new railway and maritime trade routes. IMEC includes plans to export green hydrogen to the EU via pipelines between the UAE, Saudi Arabia, Jordan, and Israel, with shipping used for the remaining sections.[62] However, the Israel-Hamas war and the rising tensions in the region could delay the project.[63]

In June 2023, the EU-India Global Gateway Conference announced plans to deploy enabling infrastructure and increase renewable energy capacity in India. It reiterated the importance of creating shared Indo-Pacific value chains to accelerate the region's transition while improving integration with European programs and policies. The participants recognized that EU collaboration will be paramount to financing and providing technical assistance for deploying green technologies in the Himalayan States (such as Bhutan and Nepal) and Bangladesh. The first step of the partnership requires identifying 120 cleantech investment projects, including green hydrogen, starting from Northeast India.[64]

Finally, the European Investment Bank (EIB) signed a Memorandum of Understanding with the India Hydrogen Alliance to provide €1 billion to finance green hydrogen projects and spur the creation of large-scale hubs across India. Specifically, the EIB will develop a credit program to assist the Indian Government in financing critical public-sector green hydrogen projects, with increasing private-sector involvement.[65]

Europe and India are also close collaborators from a technology innovation perspective. In February 2023, the two regions launched the EU-India Trade and Technology Council (TTC), whose first meeting was held in May 2023 in Brussels. The TTC provides a crucial forum for deepening the partners' strategic partnership on trade and technology. It is a coordination platform to address key trade, trusted technology, and security challenges. In particular, the TTC established, among others, a working group on green and clean energy

technologies to bring new and sustainable technologies, including green hydrogen, to the market.[66] For example, Germany's Fraunhofer Institute for Solar Energy Systems and India's Government Department of Science and Technology established a long-term collaboration focusing on hydrogen and other clean technologies.[67]

These initiatives are vital pillars underpinning the broader EU Hydrogen Strategy and the REPowerEU energy plan, which require the EU to produce 10 million tonnes of renewable hydrogen domestically and import 10 million tonnes of renewable hydrogen in the EU by 2030. From this perspective, India could become a key green hydrogen export partner.

Conclusions and Policy Recommendations

To validate its geopolitical and economic leadership aspirations, India must navigate the delicate balance of sustaining economic growth while achieving prosperity for all. The case of hydrogen highlights how adopting new clean technologies can offer unique opportunities to accelerate the transition to a low-carbon economy. Still, deployment at scale faces significant challenges that neither the private nor the public sectors can address alone. Despite these challenges, India has an important opportunity to become a global leader in fighting climate change. Success is possible, but it will require a concerted effort to:

- Prioritize detailed analysis and planning now since the effects of policy choices made today will be felt decades in the future. As our research highlights, nations must consider their role in future low-carbon value chains from a geopolitical and market perspective.
- Support research and development efforts and public-private partnerships to accelerate innovation cycles - including training the needed workforce.
- Convene stakeholders across value chains and foster collaborations that address first-mover risks, strategic barriers, and opportunities. This will also require rationalizing responsibilities between the Central Government and States to streamline authorization procedures.
- Identify infrastructure bottlenecks and address financial gaps in specific sectors and applications. Synchronizing infrastructure investments with growth in supply and demand will be essential but challenging.
- Prioritize projects that can exploit economies of scale, including scaling up domestic electrolyzer manufacturing capacity. Pilot hydrogen facilities should be established in industrialized coastal areas with developed port infrastructure and high renewable energy potentials.
- Invest in electricity grid infrastructure to stabilize the Indian energy market and better match offers and demand across the country.
- Address the price gap between green and fossil-based hydrogen through active policy interventions. Such policies could include measures to

incentivize the value and use of green hydrogen, such as implementing clean hydrogen standards and carbon pricing.

- Leverage India's geopolitical multi-alignment approach to its global "hydrogen diplomacy" and drive market-aligning policies and production/safety standards to accelerate adoption and transnational trade.

As witnessed during the G20 presidency, India could pioneer a new economic development model based on technological innovation, side-stepping the carbon-intensive approaches of the past. But on the geopolitical and climate chessboard, great opportunities come with great challenges. Accelerating the transition to a low-carbon economy should not be perceived as a risk hindering growth but as an opportunity to reduce socioeconomic imbalances and achieve industrial leadership. Is India ready?

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