Dalberg

Royal Academy of Engineering

Driving Green Hydrogen Growth: Opportunities for UK-India Collaborations

Royal Academy of Engineering & Indian National Academy of Engineering – Bilateral Green Hydrogen Exchange Report

March 2024

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1. EXECUTIVE SUMMARY

The insights provided are synthesised from various discussions held during the exchange and have been compiled by Dalberg Advisors for informational purposes only. The findings, and conclusions presented in this report do not officially represent the views of the Royal Academy of Engineering, His Majesty's government or delegate organisations affiliated with this report.

In the pursuit of global decarbonisation, collaborations between the UK and India on green hydrogen development hold immense promise. Both countries have ambitious goals and funding support to develop green hydrogen. The UK and India have expressed mutual interest in collaborating on industrial projects and research initiatives, and various collaborations between the two countries are already underway.

To explore how to deepen UK-India collaboration on green hydrogen, the Royal Academy of Engineering (Academy) and Indian National Academy of Engineering (INAE) jointly hosted a green hydrogen exchange programme on 31 January 2024 in Pune, India. The UK delegation comprised of 11 leading experts from across the green hydrogen research, innovation, and policy space. Over the visit the delegation engaged in panel discussions and one-on-one discussions with several Indian delegates who are the forefront of India's green hydrogen mission and visited various green hydrogen R&D labs in Pune (see annex for delegation list and agenda).

Delegates at the exchange highlighted substantial challenges in both the UK and India that slow the growth of green hydrogen in both countries. High production costs stemming from expensive electrolysers and renewable energy inputs hinder green hydrogen's scalability. Limited demand from end-use sectors, inadequate infrastructure, and a concentration of innovation efforts in the production stages of the value chain – with comparatively less attention on storage, transportation, and end-use stages – further hamper adoption. Additionally, both countries face unique hurdles: the UK grapples with investor reluctance due to high-risk perceptions, while India lacks cohesive state-level policies despite a national framework that prevents the harmonisation of efforts across states to advance green hydrogen.

Delegates are convinced that both nations can leverage their unique yet complementary strengths to overcome these challenges. India can benefit from the UK's world-leading expertise in renewable energy technology and energy transportation infrastructure. India on the other hand brings robust manufacturing expertise, cost-competitive renewable energy production as well as a strong interest in green hydrogen from its industrial conglomerates.

Thus, several opportunities for greater collaboration have emerged from the exchange – highlighted here in order of priority. Collaboration between both nations can help accelerate research on cost-effective technologies, support the prototyping and testing of such technologies at scale and help develop common standards and enablers that would facilitate greater exchanges between both countries. Doing so requires the following efforts:

- <u>#1 Align on key research questions</u>: identifying shared research gaps in green hydrogen development across the value chain is crucial to synchronise the R&D efforts of both countries, optimise resource allocation and maximise the impact of research endeavors.
- <u>#2 Enable prototyping and commercialisation:</u> consolidating funding and institutional focus for the prototyping and commercialisation stages of the value chain is essential to accelerate the transition green hydrogen technologies from the labs to the market.
- <u>#3 Localise production:</u> establishing local manufacturing capabilities for electrolysers and other essential equipment for green hydrogen production is essential to reduce costs.
- <u>#4 Demonstrate success at scale:</u> establishing hydrogen clusters/valleys is essential to showcase successful and profitable green hydrogen value chains to build trust among investors and end-users.

- #5 Codify knowledge: developing and disseminating successful case studies and best practices in green hydrogen development is essential to inspire confidence and stimulate demand and investments for new technologies.
- #6 Harmonise regulations: streamlining regulatory frameworks can facilitate cross-border trade and knowledge exchange and create a conducive environment for investment.
- #7 Develop a green hydrogen workforce: developing a training curriculum and implementing targeted skilling programmes in universities and technical training institutes is essential to create a green hydrogen workforce.

Driving progress on the opportunities identified above requires concerted efforts from various stakeholders, as outlined below:

- **Academicians and researchers** can lead technology development efforts, focusing on testing and validating cost-effective hydrogen technologies. They can develop case studies, best practices, and proof of concepts to build trust and acceptance for green hydrogen in the wider energy ecosystem.
- **Industry representatives** can play a key role in supporting the prototyping of emerging hydrogen technologies and facilitating their path to market readiness and commercialisation. Additionally, they can establish large-scale infrastructure to accelerate adoption across various end-use sectors.
- **Policymakers and multilateral bodies** can engage in multi-stakeholder discussions to understand regulatory bottlenecks across the value chain. Further, they can lead inter-governmental partnerships to enable cross-border knowledge exchange and trade.
- **National Academies of Engineering** can drive forward international collaboration on green energy through leveraging their vast networks of fellows. Their strong convening capabilities can accelerate collaborations among diverse stakeholders, propelling advancements in the clean energy space, including advancing green hydrogen technology.

India has a remarkable ambition to develop green hydrogen; now is the time to engage. India's ambition is evident both at the government level, as exemplified in India's National Green Hydrogen Mission, as well as at the industrial level with a strong willingness to invest in innovation and growth and move quickly. This creates a unique window of opportunity to build on this momentum and step-up UK–India collaboration efforts to build mutually beneficial low-carbon hydrogen solutions.

2. UK–India Green Hydrogen Landscape

2.1. UK and India governments' green hydrogen objectives

The UK and India share ambitious goals to position green hydrogen as a crucial pillar in their energy transition and economic growth strategies.

The UK and India aim to make green hydrogen a key part of their energy portfolios by 2030. The UK government is actively supporting the expansion of its hydrogen economy to facilitate the decarbonisation of various sectors including industry, power, transport, and potentially home heating. By 2030, the UK aims to achieve up to 10 GW of low-carbon hydrogen production capacity.[1] Similarly, given India's goal to become energy independent and achieve net zero by 2047, India aims to produce 5 million metric tonnes per annum (MMTPA) of green hydrogen and 125 GW of renewable energy capacity to support this production by 2030.[2]

The UK and India expect this growth to enable overall decarbonisation, create more jobs and enhance private investments across industries. Both countries aim to reduce carbon emissions by ~50 million metric tonnes (MMT) by 2030 through low carbon and green hydrogen adoption.[3] India wants to generate ~£80 billion investment and create 600,000 jobs, while the UK aims for ~£11 billion in private investment and 12,000 jobs.[4]

2.2. UK and India governments' green hydrogen policy and funding support

To realise these objectives, both nations have announced robust policies and substantial funding support.

The UK aims to bolster its domestic low-carbon hydrogen economy and India aims to become a global green hydrogen hub. In 2021, the UK launched its Hydrogen Strategy to support the production and use of low-carbon hydrogen across industries and end-use cases. It adopts a holistic systems approach, evaluating each aspect of the hydrogen value chain and proposing a range of policy support mechanisms, such as creating favourable regulatory frameworks, supporting innovative business models, increasing private investments and securing buy-ins from end-use industries. On the other hand, India launched its National Green Hydrogen Mission in 2023, aimed at enhancing the production, use and export of green hydrogen and its derivatives to position India as a global green hydrogen hub. It outlines a range of financial and non-financial support mechanisms for domestic manufacturing of electrolysers and boost production of green hydrogen. It also lays out an R&D roadmap to make green hydrogen more affordable over the next 15 years, among other provisions.

India's vision for green hydrogen is undeniably ambitious, underpinned by a skilled community of engineers and robust support from the private sector for the national mission. As the country sets its sights on developing cost-effective green hydrogen solutions over the next decade, the stage is set for significant progress. Now is the ideal moment for UK stakeholders to actively engage with India, leveraging this momentum to forge mutually beneficial partnerships and propel the advancement of low-carbon hydrogen technologies. By seizing the collaboration opportunities, both nations can chart a course towards a greener, more resilient future.

Each country has committed ~£2 billion to advance the green hydrogen transition up to 2030. The UK has earmarked funds to provide capital grants for private investments, support innovation competitions that help reduce costs, and encourage large-scale trials to

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[1] Government of the United Kingdom, Hydrogen Net Zero Investment Roadmap, 2023; Government of the United Kingdom, Press release - Major boost for hydrogen as UK unlocks new investment and jobs, 2023
[2] Government of India, National Green Hydrogen Mission, 2023
[3] Ibid.; Government of the United Kingdom, UK Hydrogen Strategy, 2021
[4] Government of India, National Green Hydrogen Mission, 2023; Government of the United Kingdom, Hydrogen Strategy Update to the Market, 2023

demonstrate success and inspire confidence among investors and end-use industries.[5] In parallel, India's funding is primarily offering subsidies for green hydrogen production and electrolyser manufacturing, supporting cost-reduction research initiatives, pilot testing and skill development programmes.[6]

Through various policy enablers, both governments are encouraging the growth of a green hydrogen ecosystem across four key areas:

Building infrastructure: in the UK, policy efforts are focused on providing funding support for large-scale deployment of low-carbon hydrogen production facilities, creating 'no regret' transport and storage business models, and establishing standards to ensure that quality and safety norms are upheld across the supply chain.[7] In parallel, India is keen to accelerate the development of large-scale infrastructure for green hydrogen production by providing financial incentives such as regulatory fast tracks for setting up green hydrogen industrial clusters (or green hydrogen valleys, as commonly referred to in India).[8] These are regions capable of supporting large-scale production and demonstrating end-to-end supply chains including pipelines, tankers, and distribution networks to enable end-use.

Stimulating demand: the UK is actively promoting the use of hydrogen in new industries and formulating targeted policies to facilitate its adoption across various end-use cases, such as blending hydrogen with existing fuels.[9] In contrast, India plans to impose purchase obligations on select hard-to-abate sectors.[10] It is also planning to create a certification framework for green hydrogen and its derivatives to build trust in the end product.

Supporting innovation: the UK is running innovation competitions, granting financial awards to collaborative innovation programmes between academia and industry, and inviting tenders from feasibility projects for support.[11] India has developed a public–private partnership framework, called the Strategic Hydrogen Innovation Partnership (SHIP), for collaborative hydrogen research. These initiatives aim to reduce the cost of production and accelerate the commercialisation of hydrogen technologies.

Simplifying business processes: to streamline regulatory processes related to hydrogen, the UK has created a Hydrogen Regulators Forum, tasked with identifying regulatory responsibilities and ensuring coherence between relevant regulatory frameworks.[12] India is developing a common portal to simplify compliance procedures for green hydrogen companies, thereby reducing administrative burdens and promoting investment in the industry.

2.3. Current green hydrogen production and consumption in India and the UK

Despite growing awareness and efforts to advance green hydrogen, the current production landscape in both countries is dominated by grey hydrogen.

The UK produces approximately 10 to 27 terawatt-hours (TWh) of hydrogen, while India produces around 6.5 MMTPA.[13] **Almost all this production consists of grey hydrogen, with only a few small-scale trials of green hydrogen production underway in both countries.**

[5] Government of the United Kingdom, Hydrogen Net Zero Investment Roadmap, 2023; Government of the United Kingdom, Press release - Major boost for hydrogen as UK unlocks new investment and jobs, 2023
[6] Government of India, National Green Hydrogen Mission, 2023
[7] Government of the United Kingdom, Hydrogen Strategy Update to the Market, 2023
[8] Government of India, National Green Hydrogen Mission, 2023
[9] Government of the United Kingdom, Hydrogen Strategy Update to the Market, 2023
[10] Ministry of New and Renewable Energy, Government of India, National Green Hydrogen Mission, 2023
[11] Government of the United Kingdom, UK Hydrogen Strategy, 2021
[12] Government of the United Kingdom, Hydrogen Strategy Update to the Market, 2023
[13] Government of the United Kingdom, UK Hydrogen Strategy, 2021; WEF, Green Hydrogen: Enabling Measures Roadmap, 2024

One of the primary barriers to the widespread adoption of low-carbon hydrogen, particularly green hydrogen, is its high production cost. In both the UK and India, the cost of green hydrogen can range from £3 to £8 per kilogram, depending on the technology and materials used.[14] This is nearly double the cost of grey hydrogen, making it economically less attractive for many applications today.

2.4. Primary assets of India and the UK for green hydrogen production

Both nations have distinct strengths in the green hydrogen domain, offering complementary advantages that can contribute to the overall potential of the green hydrogen sector.

The UK has unique strengths in renewable energy technology development and a robust transportation infrastructure. The UK is already a world leader in offshore wind energy, housing the second largest offshore wind (OSW) energy market in the world.[15] UK-based companies such Ceres Power, SGN, Intelligent Energy, Johnson Matthey, and ITM Power are developing unique fuel cell stack technologies for high-power applications and technologies for green hydrogen production at scale.[16] UK universities are also working on projects like hydrogen-powered trains and conducting advanced research on hydrogen energy systems.[17] The country also benefits from a wide gas transportation pipeline network, ~75% of which have been recently replaced, placing the UK in a strong position to transition to green hydrogen.[18]

India benefits from its manufacturing expertise, cost-competitive renewable energy production as well as a strong interest in green hydrogen from its industrial conglomerates. India houses a well-established and large-scale manufacturing expertise across sectors, which can accelerate the deployment of green hydrogen at scale. Renewable energy production costs in India are among the lowest globally, placing it in an advantageous position to become a global hub for green hydrogen production.[19] India's energy companies are already on the green hydrogen transition track. For instance, Hindustan Petroleum Corporation Limited (HPCL) is setting up a 370 tonne-per-annum green hydrogen plant, and Indian Oil plans to transition 50% of its total hydrogen usage to green hydrogen by 2030. Similarly, Reliance Industries has created a roadmap to reduce green hydrogen production costs to $1 per kilogram in one decade.

2.5. Key roadblocks to scaling green hydrogen in India and the UK

Despite their strengths, the growth of green hydrogen has been hindered in both countries by several shared challenges.

High production costs: the cost of producing green hydrogen remains prohibitively high in both countries, primarily as electrolysers and their components are expensive to manufacture and need many rare earth materials such as platinum, iridium, and titanium to function optimally[20]. For instance, the average cost of an alkaline electrolyser is in the range of $500/kW to $1400/kW[21]. Additionally, energy inputs to create green hydrogen, comprising mainly of renewable energy sources such as solar and wind energy, are also costly compared to fossil fuel sources such as coal and diesel.

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[14] NITI Aayog, Harnessing Green Hydrogen – Opportunities for Deep Decarbonisation in India, 2022
[15] Government of the United Kingdom, Offshore wind, Accessed February 2024
[16] Government of the United Kingdom, UK Hydrogen Strategy, 2021
[17] Ibid.
[18] ENA, Hydrogen Vision for UK, 2023
[19] NITI Aayog, Harnessing Green Hydrogen – Opportunities for Deep Decarbonisation in India, 2022; IEA, India Energy Outlook, 2021
[20] UK Govt, Hydrogen Production Costs, 2021; NITI Aayog, Harnessing Green Hydrogen – Opportunities for Deep Decarbonisation in India, 2022
[21] NITI Aayog, Harnessing Green Hydrogen – Opportunities for Deep Decarbonisation in India, 2022

Low demand across end-use cases: currently, demand for green hydrogen in hard-to-abate sectors is limited due to low awareness, high production costs, and storage challenges.[22] While industrial usage of hydrogen as feedstock is prevalent, expanding into new applications like transportation requires technological advancements and significant cost reductions.[23]

Uneven distribution of innovation efforts across the value chain: R&D efforts are predominantly focused on electrolyser manufacturing, fuel-cell development, and mobility applications, neglecting other vital aspects of the green hydrogen value chain such as storage, feedstock, transportation, and other end-use cases that might have varying needs and cost implications for green hydrogen use.[24]

Lack of infrastructure at scale: the green hydrogen value chain, from R&D to production to end-use, lacks sufficient infrastructure and technology to encourage investments and end-uses.[25] For instance, to enable mobility applications of green hydrogen, long-distance pipelines and refuelling stations need to be established. Critical funding gaps also persist in the prototyping and commercialisation stages, hindering the establishment of infrastructure at scale.[26]

Limited availability of low- and zero-carbon energy: green hydrogen production relies on carbon-free or renewable energy sources, which are currently insufficient in both countries. Additionally, renewable energy generation plants require a lot of physical space, and land stress is a critical issue in both the UK and India.[27] Optimal use of electrolysers also requires round-the-clock supply of renewable energy sources, and intermittency issues are inherent to sources like solar and wind energy, further affecting green hydrogen production.[28]

While there are shared issues, both countries are also facing unique challenges owing to their individual characteristics.

The UK is facing a significant challenge in attracting investments for green hydrogen projects, largely due to a high-risk perception among investors. These risks involve uncertainties regarding future demand, absence of proven business models at scale, substantial capital requirements, and a scarcity of skilled workers that can aid deployment among various end-use sectors.[29]

In India, while the National Green Hydrogen Mission (NGHM) provides a broad framework for green hydrogen growth, the absence of localised state-level policies poses a significant barrier. Currently, not all state governments across India have created targeted green hydrogen policies that aim to leverage the states' unique geographic profile, renewable energy penetration and locally available resources for green hydrogen growth. Coordinated action across state and central governments is critical to meet the country's net zero and decarbonisation targets.

2.6. Existing green hydrogen collaborations between the UK and India

The UK and India have begun collaborations to address the challenges associated with green hydrogen development, signalling a shared commitment to advancing low/zero carbon energy.

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[22] BCG, Clean Hydrogen Opportunity, 2022; Insights from the RAEng-INAE Bilateral Policy Exchange on Green Hydrogen, 2024
[23] KPMG, Assessing GH Production, 2022
[24] Insights from the RAEng-INAE Bilateral Policy Exchange on Green Hydrogen, 2024
[25] NITI Aayog, Harnessing Green Hydrogen – Opportunities for Deep Decarbonisation in India, 2022
[26] Insights from the RAEng-INAE Bilateral Policy Exchange on Green Hydrogen, 2024
[27] Ibid.
[28] Ibid.
[29] Government of the United Kingdom, Hydrogen Net Zero Investment Roadmap, 2023

The UK and India actively collaborate on energy and climate change. These collaborations have occurred through dialogues such as the India–UK Track II Dialogue on Climate Change and Energy 2024, and through platforms such as Mission Innovation in 2021, Hydrogen Breakthrough in 2022, and the India–UK NET Zero Innovation Virtual Centre in 2023 to enhance their science and technology cooperation.

Collaborations on green hydrogen are in the early stages but have gained momentum through joint research groups and pilot programmes in recent years. The UK–India Hydrogen Hub, launched in 2022, has facilitated networking and knowledge sharing between the two countries.[30] Similarly, several industry-led partnerships are also exploring pathways to advance green hydrogen. For instance, in 2023, Tata Steel and the UK government agreed to a joint proposal to enhance decarbonisation in the steel industry.[31]

Both countries want to deepen their partnership. In the 2030 Roadmap for India–UK future relations released in 2021, both countries agreed to collaborate on green hydrogen through knowledge exchanges, policy and regulation cooperation, and research and innovation initiatives.[32] Both countries have committed to strengthen collaboration to reduce the cost of clean energy technologies like green hydrogen, and jointly promote secure, affordable and sustainable supply of green hydrogen.

Thus, while both countries have laid the groundwork for collaboration, to fully realise the potential of these platforms and frameworks, it is imperative that they are adequately used and funded.

[30] UK India Hydrogen Hub, About, 2022
[31] Tata Steel, Press Release, 2023
[32] Government of the United Kingdom, Policy paper - 2030 Roadmap for India-UK future relations, 2021

3. Key Exchange Findings

3.1. Exchange objectives

The UK–India Bilateral Policy Exchange on Green Hydrogen was convened to provide a platform for researchers, industry leaders and policymakers to discuss opportunities for accelerating the green hydrogen transition in both countries.

The Academy and INAE jointly convened a bilateral policy exchange on 31 January at the National Chemical Laboratory in Pune, India, to aid cross-national learning and accelerate the green hydrogen transition in India and the UK. The exchange provided a platform for delegates from academia, industry, and government from both countries to discuss shared challenges and opportunities for potential collaborations to advance green hydrogen.

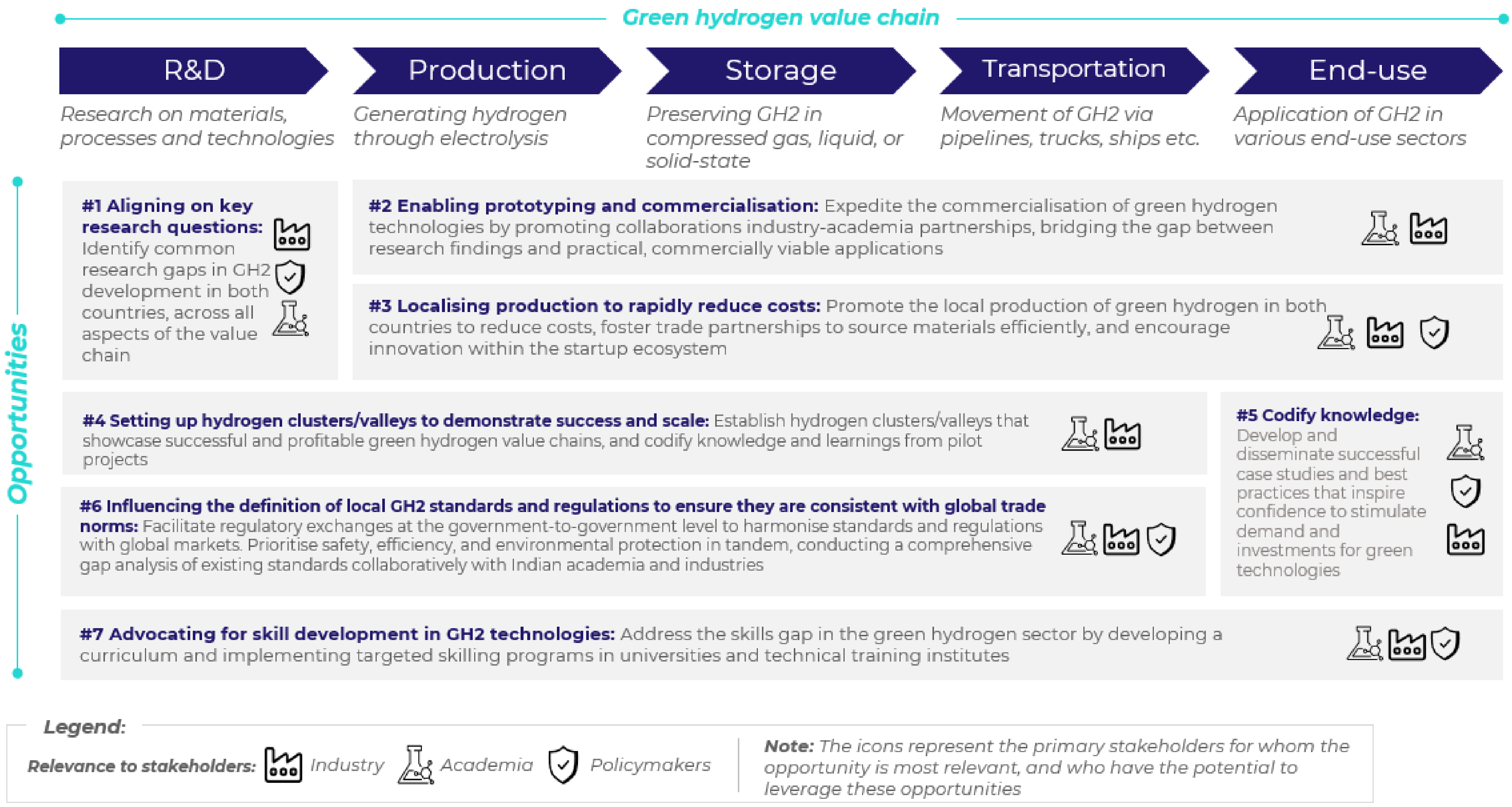
The exchange hosted various panel discussions around green hydrogen production technologies, critical infrastructure and innovation needed across the value chain, safety concerns, the need for standards and certifications, applications of green hydrogen in mobility, skills development to create a green hydrogen workforce, and major opportunities for collaboration across the value chain.

3.2. Major opportunities for collaboration

Several opportunities across the green hydrogen value chain were discussed at the exchange to leverage the complementary strengths of both the UK and India.

To provide a comprehensive overview of the opportunities within the green hydrogen value chain, the following illustration presents a condensed summary of the major collaborative avenues identified during the exchange. The opportunities are arranged based on the identified level of priority of next steps in both countries. Each opportunity box contains icons depicting the relevance of the opportunity to various stakeholders, indicating who is best positioned to lead engagements to seize the opportunities.

Figure 1: Illustrated collaboration opportunities across the green hydrogen value chain



Complementing the overarching view presented in the illustration above, the following table offers a breakdown of collaboration opportunities across each segment of the green hydrogen value chain. This analysis aims to provide deeper insights into specific areas for collaboration, ranging from research and development to production and beyond.

Figure 2: Detailed collaboration opportunities across the green hydrogen value chain

Opportunities in R&D:	Collaborative efforts to understand which sectors will drive green hydrogen demand; what kind of energy systems can facilitate green hydrogen growth; what are the common research gaps between the two countries; what technologies are required; and how both countries can catalyse commercialisation opportunities in R&D. Further, India's vast industrial base can help test and pilot new technologies that are being created in the UK.
Opportunities in production:	Promoting the localisation of green hydrogen production in both countries through materials research; trade and knowledge partnerships; innovation within the startup ecosystem, most importantly by building green hydrogen industrial clusters, which are critical opportunities to advance green hydrogen and build trust in the ecosystem, especially among investors.
Opportunities in storage:	Collaboration between storage technology developers and end-users to optimise storage solutions for different applications and environments, and joint initiatives to standardise regulations and safety protocols for the storage and handling of green hydrogen across borders can help create demand for industrial and mobility-related applications of green hydrogen.
Opportunities in transport:	Partnerships between gas and energy companies (that are successfully testing pipeline networks for green hydrogen) and transportation providers can integrate hydrogen-fueling infrastructure into existing transportation networks in both countries. Collaborations between automotive manufacturers and hydrogen suppliers can help develop, demonstrate, and deploy hydrogen-powered vehicles and refueling stations at scale.
Opportunities in end-use:	To enable the rapid adoption of green hydrogen, assessments that gauge the viability of green hydrogen for various end-use sectors, targeted incentive programmes and following advocacy initiatives that promote the adoption of green hydrogen technologies across various sectors can create demand among various industries and end uses.
Opportunities in harmonising regulations:	Regulatory exchanges at the government-to-government level to harmonise standards and regulations with global markets can create a supportive policy framework to enable cross-boundary exchange of technologies. In doing this, it will be essential to prioritise environmental protection and safety and efficiency of technologies by conducting a comprehensive gap analysis of existing standards and certifications collaboratively with academia and industries in both countries.
Opportunities in skill development:	Addressing the skills gap in the green hydrogen sector by developing curriculum for skills needed across the value chain, creating a workforce transition plan for people engaged in hard-to-abate sectors, and implementing targeted skilling programmes are critical opportunities to enable swift deployment of green hydrogen technologies.

3.3. Next steps and recommendations

The exchange emphasised the need for collaborative partnerships across three key themes to effectively address the identified challenges and opportunities. Multiple stakeholders can lead these initiatives.

In charting the course forward for collaborative efforts in the green hydrogen landscape, the following illustration outlines the key next steps identified during the deliberations at the exchange – namely technology development, accelerating deployment and harmonising regulations. Under each step, multiple collaboration ideas have been outlined, as voiced in various discussions at the exchange. The illustration outlines the immediate, near-term and long-term next steps for partnerships and highlights which stakeholders can potentially lead/drive/facilitate these engagements between the UK and India.

Figure 3: Next steps identified during the exchange and the stakeholders that can lead these initiatives to drive progress

Technology development

Unlocking research and innovation in top GH2 technologies across the value chain to reduce costs and catalyse growth

Next step	Time horizon	Potential leaders
Convene a challenge prioritisation workshop: Organise a workshop to shortlist the top 5-10 high priority research problems with potential for quick wins and scalability	Immediate	Academia, Industry, Policymakers
Organise a GH2 engineers exchange programme: Facilitate an exchange where engineers can learn from progress in both countries and identify transferable innovations	Immediate	Academia
Conduct pre-competitive scientific research studies: Find solutions for membranes for PEM electrolysers, electrolyser inefficiency, hydrogen blending in pipelines and cost reduction	Long term	Academia, Industry

Accelerating deployment

Accelerating the deployment of GH2 technologies through strategic partnerships that demonstrate viable business models and de-risk investments

Next step	Time horizon	Potential leaders
Prototyping and scaling: Collaborate with industry partners for prototyping and demonstrations of new green hydrogen technologies and their varying end-use cases	Near term	Industry, Academia
Codify learnings from GH2 clusters/valleys: Collaborate with researchers and industry players to establish GH2 clusters, showcasing successful applications	Long term	Industry, Academia
Create business models across the value chain: Develop viable business models across the value chain to minimise demand risk and build investor confidence in green hydrogen projects	Immediate	Industry, Policymakers

Harmonising regulations

Collaborating on policy and regulatory frameworks to harmonise standards and regulations across UK and India, facilitating technology and knowledge transfers

Next step	Time horizon	Potential leaders
Align on a common definition of low carbon hydrogen: Continue working towards a unified definition of low carbon to provide clarity and consistency in terminology	Near term	Policymakers, Industry, Academia
Align low carbon hydrogen standards and certifications: Streamline regulatory frameworks, standards, and certifications, ensuring consistency in trading and technological norms	Near term	Policymakers, Industry, Academia
Convene a policymakers working group: Facilitate dialogue among policymakers to identify exact policy enablers/levers needed to enhance cross-border collaboration for GH2	Immediate	Policymakers, Academia

Legend:

Time horizon: Immediate, Near term, Long term

Potential leaders: *Industry*, *Academia*, *Policymakers*

Technology development: both countries highlighted the nascency of critical green hydrogen technologies, such as fuel cells and electrolysers. Implementing a collaborative problem prioritisation workshop, organising exchange programmes for engineers, conducting lifecycle studies, or similar initiatives could help to unlock innovative, cost competitive and scalable green hydrogen technologies.

Accelerate deployment: given that sufficient testing of various green hydrogen technologies is key to enabling their rapid deployment at scale, promising areas for collaboration include establishing industrial partnerships for prototyping, creating industrial clusters to demonstrate successes at scale, and enhancing manufacturing efforts to diversify the applications of green hydrogen, while ensuring safety and efficiency of technologies.

Harmonise regulations: the UK is prioritising the use of 'low-carbon hydrogen' as the preferred terminology to enable interoperability of low-carbon hydrogen standards across borders. To further enable the transfer of technologies and trade between the UK and India, it is critical to align on common definitions, establish norms for IP sharing, harmonise standards and certifications, provide regulatory fast tracks to streamline processes and ensure consistency in regulations for the green hydrogen sector. Multilateral fora such as the International Energy Agency (IEA), Hydrogen Technology Collaboration Programme (H2 TCP), and International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE) can play a key role in driving progress in this segment.

3.4. Potential pitfalls to manage to ensure seamless collaboration

Cross-border partnerships to advance green hydrogen between India and the UK must adequately manage early questions around intellectual property sharing, regulatory alignment, and effective governance.

#1 Difficulties in IP sharing: intellectual property (IP) sharing presents a significant challenge for cross-border partnerships in green hydrogen initiatives between India and the UK. Issues may arise regarding the protection, licensing, and transfer of proprietary technologies, particularly if there are discrepancies in IP laws and regulations between the two countries. Failure to address these challenges could impede the exchange of critical knowledge and hinder the development and implementation of innovative green hydrogen solutions.

#2 Regulatory misalignment: divergent regulatory frameworks between the UK and India pose a risk to cross-border green hydrogen partnerships, potentially resulting in regulatory misalignment and bureaucratic hurdles. Inconsistencies in policies, standards, and certification requirements may create barriers to trade and investment, hindering the seamless integration of green hydrogen technologies and projects across the value chain.

#3 Effective governance: without effective mechanisms for coordination, communication, and decision-making, partnerships may struggle to maintain long-term collaboration and effectiveness. Establishing clear roles, responsibilities, and accountability mechanisms for participating stakeholders is essential to foster trust, transparency, and mutual respect.

Measures to address such pitfalls exist and could be further discussed in future dialogues. mitigation strategies could include establishing bilateral working groups to address IP sharing concerns through negotiated agreements, initiating regular policy dialogues between regulatory authorities to promote alignment and convergence of green hydrogen regulations, and developing comprehensive partnership frameworks with built-in mechanisms for monitoring, evaluation, and dispute resolution to enhance the sustainability and effectiveness of cross-border collaborations. By acknowledging these potential measures, stakeholders can proactively address challenges and work towards fostering successful and resilient partnerships in the green hydrogen landscape between India and the UK.

4. Annex

4.1. Details of the exchange

Agenda: Indian National Academy of Engineering x Royal Academy of Engineering Green Hydrogen Exchange Programme 30 January to 2 February 2024, Pune, India

Day 1: Tuesday 30 January 2024 | *Arrive in Pune, Dinner with Reliance Industries*

- **Dinner and presentation hosted by Reliance Industries:** Dr Anurag Pandey, Vice-President, New Energy Business, delivered a presentation on Reliance's New Energy Initiative. The event was attended by the UK delegation, INAE Staff and Reliance Industries' representatives.

Day 2: Wednesday 31 January 2024 | *One-day seminar event*

- **One-day seminar Royal Academy of Engineering – Indian National Academy of Engineering – Bilateral Policy Exchange on Green Hydrogen:** This one-day seminar was the flagship event of the UK delegation visit. The event hosted two main panel discussions and several keynote speakers.
    - **Panel discussion – I on green hydrogen: production, storage, mobility:** the panellists discussed the state of green hydrogen production, storage, and mobility in both countries, identified challenges and opportunities for growth, and discussed potential collaboration opportunities. The keynote speakers for this discussion were Professor RR Sonde FNAE, Department of Chemical Engineering, IIT Delhi, and formerly Executive Vice President, CTO and Member on Board of Executive Council, Thermax Ltd., and Mahesh Natarajan, Vice President, Low Carbon Pathway Innovation, BP. The panellists were: Dr Deepak Yadav, Programme Lead, Council on Energy, Environment and Water (CEEW); Dr Manas V More, Technical Expert-Business Development, Azista Composites Private Limited, Hyderabad; Deepesh Gujrathi, Senior System Architect, KPIT, Pune; Dr Marcus Walls-Bruck, Chief Engineer, Hydrogen Innovation Initiative, Professor Meysam Qadrdan, Professor of Energy Networks and Systems, Cardiff University; Dr Eugene McKenna, Senior Vice President Hydrogen & Sustainable Technologies, Johnson Matthey; and Celia Greaves, CEO/Founder, Hydrogen Energy Association. The session was moderated by Dr Ashish K Lele, Director, National Chemical Lab, Pune.
    - **Panel Discussion – II on standards, policies, hubs/valleys, industry use cases:** the panelists discussed critical areas for innovation, policy measures needed across the green hydrogen value chain, and highlighted the need for hydrogen industrial clusters/valleys and research on the cost economics for various end use-cases. The keynote speaker for this discussion was Antony Green FREng, Director – Future of Energy, SGN. The panellists were: Dr Reji Mathai, Director, Automotive Research Association of India (ARAI); Dr Anita Gupta, Head, Climate, Energy and Sustainable Technology (CEST) Division, Department of S&T (DST), Govt. of India; Dr Anurag Pandey, Vice-President, New Energy Business, Reliance Industry; Dr Frances Buckingham, Energy Engineer, Department for Energy Security and Net Zero, UK government; and Diana Raine, Managing Director, Smart Hydrogen Consulting Ltd. This session was moderated by Professor Nigel Brandon OBE FREng FRS, Dean of the Faculty of Engineering, Imperial College London.

Day 3: Thursday 1 February 2024 | Site visits

- **Site visit to National Chemical Lab (NCL) and the Automotive Research Association of India (ARAI):** the UK delegates visited the NCL to observe the various hydrogen technologies being developed under the Council of Scientific and Industrial Research's Hydrogen Technology Mission programme, such as PEM fuel cell, AEM electrolysers, and testing hubs for both. They also visited ARAI to learn about the scope of hydrogen standards research at ARAI, discuss opportunities for potential collaboration.

Day 4: Friday 2 February 2024 | *Site visits*

- **Site visit to KPIT Industries, ENPRO and H2E Power:** the UK delegates visited three private energy companies in Pune to observe how they are innovating for H2, which end-use applications they are exploring for green hydrogen, how they are managing international partnerships, and what the potential opportunities for collaboration are.

4.2. List of attendees

Delegates from the UK:

Professor Nigel Brandon FREng FRS, Dean, Faculty of Engineering, Imperial College London

Dr Frances Buckingham, Energy Engineer, Department for Energy Security and Net Zero

Cameron Davies, Senior Strategy Adviser, Department for Energy Security and Net Zero

Celia Greaves, CEO/Founder, Hydrogen Energy Association

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