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Hydrogen RD&D Collaboration Opportunities: India

As at 18 August 2022

Australian Government
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Acknowledgments

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Contents

Executive summary: India

With large energy demands and significant manufacturing capability, India is seeking to position itself as a global renewable hydrogen hub.

The *Hydrogen RD&D Collaboration Opportunities: India* chapter aims to enhance country-to-country engagement by providing an overview of India's hydrogen priorities and ecosystem. This report also includes a publication and intellectual property (IP) scan, identifying the key stakeholders in India actively undertaking hydrogen RD&D, both at the early research and commercialisation stage.

India's hydrogen strategy

India's hydrogen strategy will be articulated in its upcoming launch of the National Hydrogen Mission publication. The National Hydrogen Mission was announced by Prime Minister Narendra Modi in August 2021. Key elements of India's strategy included positioning India as a global hydrogen hub by facilitating the scale-up of renewable hydrogen production and utilisation, with a particular focus on fuel cells, and reforming the country's science and technology policies and regulations to align with global best practice. Phase 1 of the mission (2021-2024) will be focussed on providing an enabling environment for renewable hydrogen; this includes developing a policy and regulatory framework, establishing production and supply infrastructure, and conducting R&D and pilot projects. Phase 2 (2024-2030) will focus on utilisation and mass adoption of renewable hydrogen in various sectors.

India's hydrogen ambitions are driven by its need to achieve emissions reductions, seize opportunities for economic development and technology innovation and secure energy independence and security. Whilst not hydrogen specific, a reference paper prepared by the Ministry of New and Renewable Energy (MRNE) identified the following energy-related strategic priorities: industry decarbonisation; energy production; infrastructure and supply chain upgrades; pilot projects; development of technical codes and regulations; and hydrogen awareness. India is focussed on increased RD&D to accelerate the development and commercialisation of hydrogen technologies in support of these priorities.

India's targets and RD&D priorities

India's hydrogen-specific targets are yet to be announced. However, India's Hydrogen Mission has articulated preliminary hydrogen-specific targets, which include:[1]

- One million tonnes of hydrogen produced from renewables annually by 2030; and
- Fertiliser plants and oil refineries to use renewable hydrogen to meet 5% and 10%, respectively, of their total hydrogen requirements in 2023-2024, and increasing this to 20% and 25% respectively within five years.

[1] Ministry of Power (2021) Ministry of Power notifies Green Hydrogen / Green Ammonia Policy. <https://pib.gov.in/PressReleasePage.aspx?PRID=1799067>.

To achieve these goals, India is investing in RD&D in the following areas.

Production
Electrolysis: polymer electrolyte membrane, alkaline, emerging
Fossil fuel conversion: CCS, methane reforming
Biological
Biomass and waste conversion
Thermal water splitting
Photochemical/photocatalytic

Storage and distribution
Compression and liquefaction: pressurised storage
Chemical: hydrides, physisorption
Hydrides
Physisorption
Other: tube trailers and tank lorries

Utilisation
Gas blending: gas networks, appliances
Transport: fuel cells, refuelling stations
Electricity generation: fuel cells (polymer electrolyte membrane, solid oxide, emerging)
Industry processes: steel
Other: agriculture

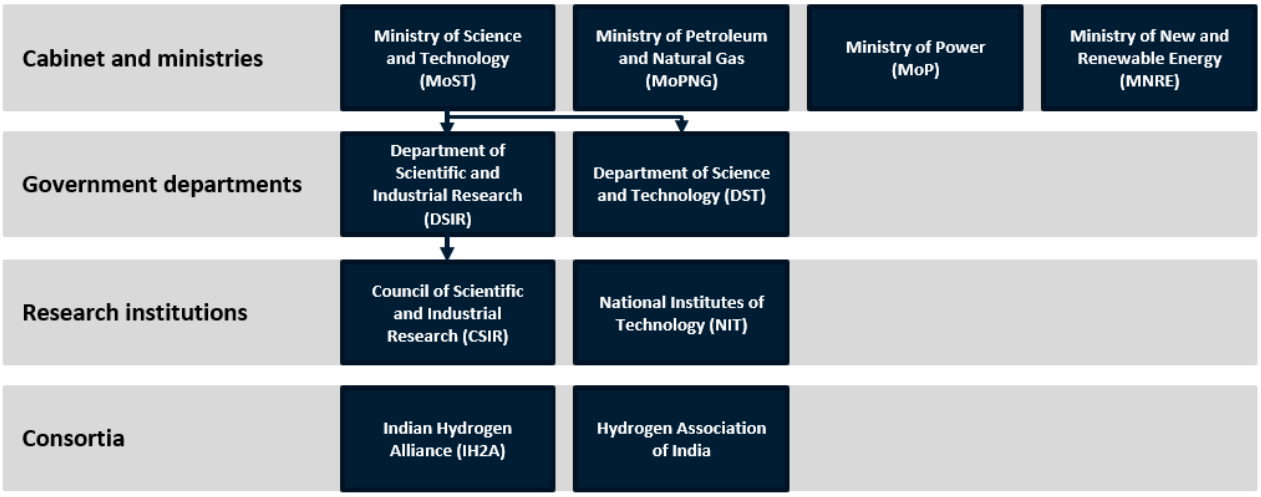
Cross-cutting
Modelling and analysis
Safety, regulation and policy

India's domestic hydrogen landscape

At the governmental level, there are several regulatory bodies that administer, promote and develop India's hydrogen policies. The primary government body driving India's hydrogen strategy and RD&D policies is the MNRE, which established the Hydrogen Energy and Fuel Cells Steering Committee to publish strategic documents and effect high-level strategic priorities. Other Indian ministries and departments support the implementation of these strategic priorities. For example, the Department of Science and Technology (DST) establishes mission-based programs, and the Ministry of Petroleum and Natural Gas (MoPNG) has oversight for hydrogen policies and demonstration projects which overlap with India's existing energy grid. Hydrogen RD&D funding sits across several departments with respect to their sector mandate. For example, the MoPNG's 'Hydrogen Corpus Fund' provides project funding relevant to the oil-industry whilst the DST's 'Advanced Hydrogen and Fuel Cell Programme' is focussed on hydrogen fuel cell, storage and electrolysis technologies and materials. Additionally, the MRNE's budget has allocated INR 20 Crore for hydrogen energy and fuel-cell R&D more broadly.

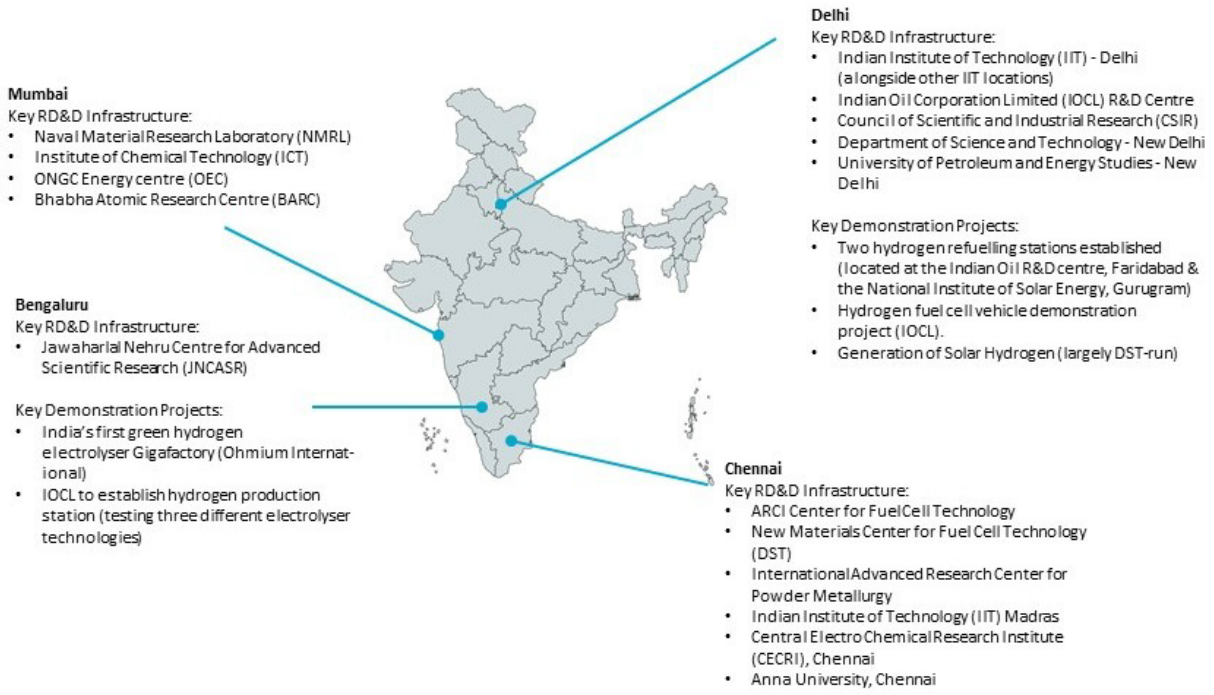
India also has active consortia and industry associations which support India's transition to a hydrogen economy, including the Indian Hydrogen Alliance (IH2A) and the Hydrogen Association of India. The IH2A is working with members to inform India's *National Hydrogen Policy Roadmap*.

Figure 1: India's hydrogen RD&D ecosystem



India aims to develop 'hydrogen valleys' (also known as clusters, hubs or ecosystems) across strategic locations with strong solar radiance, abundant water supply, and co-located industrial clusters. While no hydrogen valleys currently exist, several demonstration projects have already been carried out across India. Four areas where strong RD&D activity is occurring are Mumbai, Delhi, Bengaluru and Chennai.

Figure 2: Areas of high RD&D activity



IP and publications scan

Several universities, public research institutions and private companies are highly active in early-stage hydrogen research and late-stage technology commercialisation. This is reflected in hydrogen research publication output and patent output data.

Table 1: Top organisations active in early-stage and late-stage hydrogen RD&D

Rank	Top organisations (Research Publication Output)	Top organisations (Hydrogen Patent Output)
1	Council of Scientific and Industrial Research (CSIR)	Council of Scientific and Industrial Research (CSIR)
2	National Institute of Technology (NIT System)	Indian Oil
3	Academy of Scientific and Innovative Research (AcSIR)	Reliance Industries
4	Department of Science and Technology (India)	Hindustan Petroleum
5	Indian Institute of Technology (IIT) – Madras	Bharat Heavy Electricals; Tata Steel

International collaboration

India has signalled an intent to collaborate with international partners on hydrogen RD&D and commercialisation across the value chain. Key developments include the strategic partnership between the MNRE and the International Renewable Energy Agency (IRENA) announced in January 2022. The Indian government has reinforced its desire to collaborate internationally through existing partnerships and programs – including Mission Innovation, the Quadrilateral Strategic Dialogue and the International Organisation for Standardisation. Key areas of focus include the development of regulatory codes, technical specifications and market frameworks which are necessary to scale-up hydrogen utilisation.

India and Australia are also partners through a number of agreements: the Letter of Intent (LoI) on New and Renewable Energy Technology (February 2022); the India-Australia Comprehensive Strategic Partnership (June 2020); and the Memorandum of Understanding (MoU) on New and Renewable Energy Cooperation (February 2010).

To date, industry has been playing a leading role in hydrogen RD&D collaboration, with Indian state-owned and private enterprises announcing expressions of interest for international private-sector companies to partner and establish pilot projects. The India Hydrogen Alliance (IH2A) has led this approach and now represents a coalition of industry partners – both in India and globally – that seek to accelerate hydrogen RD&D and commercialisation, with a particular focus on hydrogen production, storage, industrial clusters and end-use applications.

Activity levels for hydrogen and net-zero initiatives is high. While effort has been made to capture major announcements and key information as at 18 August 2022, the content is intended to provide a starting point for informing international engagement, particularly when used in conjunction with other reports in the series, and is non-exhaustive.

1 Country analysis: India

1.1 Introduction

India is a driving force in the global renewable energy economy. Having rapidly developed wind and solar power production capacity at scale, India is now focused on developing a hydrogen economy.[2] India's well-established clean energy research capabilities, strong manufacturing industry, skilled workforce, supportive policy environment and active private sector means India is well positioned to take advantage of new hydrogen technologies and quickly become a major hydrogen producer and consumer.[3] In 2021 the Indian Government launched the National Hydrogen Mission of India,[4] which aims to leverage India's strengths to establish itself as a global renewable hydrogen hub and produce 5 million tonnes of renewable hydrogen annually by 2030.[5] The National Hydrogen Mission is driven by India's desire to secure energy independence, emissions reductions, technology leadership and economic development.[6]

India is increasing funding for hydrogen research and the National Hydrogen Mission is predicted to establish additional funding mechanisms and research, development and demonstration (RD&D) programs. The Mission's budget (FY2021-2024) is expected to be INR 800 crore, with INR 25 crore to be allocated to RD&D on hydrogen conducted between 2021 and 2022.[7] The Mission's focus will primarily be on RD&D projects across the value chain, which are expected to be jointly-funded by government-owned corporations and industry.[8] In this way, India is adopting an 'industry-focused' approach to RD&D international collaboration, in which Indian industry and research institutions will lead hydrogen RD&D alongside international industry partners.[9] Key areas of high RD&D activity include Mumbai, Delhi, Bengaluru and Chennai. India has several hydrogen and energy-related partnerships with other countries, including with Australia that may facilitate increased collaboration on hydrogen RD&D.

The *Hydrogen RD&D Collaboration Opportunities: India* report presents an overview of the hydrogen RD&D landscape in India, starting from the national strategy level, down to activity in specific hydrogen technology areas.

[2] Birol F and Amitabh K (2022) India's clean energy transition is rapidly underway, benefiting the entire world https://www.iea.org/commentaries/india-s-clean-energy-transition-is-rapidly-underway-benefiting-the-entire-world

[3] Birol F and Amitabh K (2022) India's clean energy transition is rapidly underway, benefiting the entire world https://www.iea.org/commentaries/india-s-clean-energy-transition-is-rapidly-underway-benefiting-the-entire-world

[4] Prime Minister's Office (2021) PM's address from the Red Fort on 75th Independence Day. https://www.pmindia.gov.in/en/news_updates/pms-address-from-the-red-fort-on-75th-independence-day/?comment=disable&tag_term=pmspeech

[5] Priya L (2021) India's National Hydrogen Mission and Prospects for Cooperation with GCC, Manohar Prrikar Institute for Defence Studies and Analyses. Viewed 6 December 2021, https://www.idsa.in/issuebrief/india-national-hydrogen-mission-n-gcc-lpriya-270821#footnote1_c80n6n2

[6] FTI Consulting (2020) India's Energy Transition Towards a Green Hydrogen Economy: White Paper on Building a Green Hydrogen Economy and Policy Roadmap for India http://images.info.fticonsulting.com/Web/FTIConsultingInc/%7Ba15cdad1-1916-4f95-bad9-34cf950f842c%7D_FTI_Hydrogen_Green_Energy_Report_20201202.pdf

[7] Priya L (2021) India's National Hydrogen Mission and Prospects for Cooperation with GCC, Manohar Prrikar Institute for Defence Studies and Analyses. Viewed 6 December 2021, https://www.idsa.in/issuebrief/india-national-hydrogen-mission-n-gcc-lpriya-270821#footnote1_c80n6n2

[8] FE Bureau (2021) National Hydrogen Mission: An alternative to battery electric mobility, Financial Express, https://www.financialexpress.com/auto/electric-vehicles/national-hydrogen-mission-an-alternative-to-battery-electric-mobility/2332649/

[9] India Hydrogen Alliance (IH2A) (2021) About IH2A. Viewed 26 November 2021, https://ih2a.com/

1.2 India's hydrogen drivers, strategy and RD&D priorities

1.2.1 India's key drivers

India's hydrogen ambitions are driven by four key drivers, which include energy independence and security, emissions reductions, technology leadership, and economic development. The four drivers are outlined below: [10]

- **Energy independence and security**: In August 2021, Indian Prime Minister Narendra Modi announced that India will seek to transition to an energy-independent state by 2047.[11] Since the 2000s India has increased its reliance on fossil fuel imports (importing over 25%, 75% and 50% of its coal, oil and gas demand, respectively)[12]. Establishing domestic hydrogen production capacity will reduce India's import dependency whilst also creating export opportunities. Indian Prime Minister Modi has identified that hydrogen is central to achieving environmentally sustainable energy security.[13]
- **Emission reductions and energy targets**: In 2021, India committed to significant emissions reductions and energy-related targets, known as the 'five elixirs.' By 2030, India aims to increase its non-fossil fuel energy production capacity to 500GW; meet 50% of energy requirements from renewable energy sources; reduce total projected carbon dioxide equivalent (CO_2-e) emissions by 1 billion tonnes; reduce the carbon intensity of its economy by less than 45%; and finally by 2070, achieve net-zero emissions. The National Hydrogen Mission is key in achieving these clean energy targets.[14]
- **Technology leadership**: India seeks to accelerate renewable hydrogen technology innovation and R&D to become a global hub for renewable hydrogen production and export, which includes leading the development of related technologies. Prime Minister Modi signalled he intends India to become an 'inspiration for clean energy transition all over the world.'[15]
- **Economic development**: Renewable energy technology R&D, the creation of hydrogen hubs and potential hydrogen export opportunities are seen as important drivers for economic growth in India. Renewable energy technology development, particularly hydrogen technology, is at the forefront of India's economic strategy. Prime Minister Modi stated that the new Hydrogen Mission will serve to open up green growth opportunities and 'green jobs'.[16]

[10] Prime Minister's Office (2021) National Statement by Prime Minister Shri Narendra Modi at COP26 Summit in Glasgow https://pib.gov.in/PressReleasePage.aspx?PRID=1768712

[11] Prime Minister's Office (2021) PM's address from the Red Fort on 75th Independence Day. https://www.pmindia.gov.in/en/news_updates/pms-address-from-the-red-fort-on-75th-independence-day/?comment=disable&tag_term=pmspeech

[12] International Energy Agency (IEA) (2021) India Energy Outlook https://iea.blob.core.windows.net/assets/1de6d91e-e23f-4e02-b1fb-51fdd6283b22/India_Energy_Outlook_2021.pdf

[13] Ministry of Power (2021) Ministry of Power notifies Green Hydrogen / Green Ammonia Policy. https://pib.gov.in/PressReleasePage.aspx?PRID=1799067

[14] Prime Minister's Office (2021) National Statement by Prime Minister Shri Narendra Modi at COP26 Summit in Glasgow. https://pib.gov.in/PressReleseDetail.aspx?PRID=1768712

[15] Prime Minister's Office (2021) PM's address from the Red Fort on 75th Independence Day. https://www.pmindia.gov.in/en/news_updates/pms-address-from-the-red-fort-on-75th-independence-day/?comment=disable&tag_term=pmspeech

[16] Prime Minister's Office (2021) PM's address from the Red Fort on 75th Independence Day. https://www.pmindia.gov.in/en/news_updates/pms-address-from-the-red-fort-on-75th-independence-day/?comment=disable&tag_term=pmspeech

1.2.2 India's strategic hydrogen industry priorities

The National Hydrogen Mission aims to facilitate the scale up of renewable hydrogen production and utilisation, by supporting RD&D on hydrogen technology and establishing market and regulatory frameworks necessary to incubate a hydrogen economy. While details of the Mission are yet to be announced, the Indian Government is believed to have allocated INR 25 crore in the FY21-22 budget for hydrogen research and development (R&D).[17]

The Ministry of New and Renewable Energy (MRNE) has identified key areas for investment over the next three years, which include R&D, pilot projects, regulation and policy development and public outreach.[18] It also identifies the industries India will be targeting – steelmaking, oil refineries and fertiliser plants.[19]

India's hydrogen targets

India is yet to articulate specific hydrogen targets. However, the National Hydrogen Mission has articulated preliminary hydrogen-specific targets, which include:

- Five million tonnes of hydrogen produced from renewables per year by 2030;[20] and
- Fertiliser plants and oil refineries to use renewable hydrogen to meet 5% and 10%, respectively, of their total hydrogen requirements starting in 2023-2024, and ramping up to 20% and 25% within five years.[21]

Further details on India's Hydrogen Mission are expected to be announced.

India's current industrial activity and IEA modelling does indicate India's future demand for hydrogen and future production. Table 2 outlines current hydrogen production and demand, and projected 2030 demand based on India meeting its announced emissions pledges (net zero by 2070).[22]

[17] Priya L (2021) India's National Hydrogen Mission and Prospects for Cooperation with GCC, Manohar Parrikar Institute for Defence Studies and Analyses. Viewed 6 December 2021, https://www.idsa.in/issuebrief/india-national-hydrogen-mission-n-gcc-lpriya-270821#footnote1_c80n6n2

[18] Priya L (2021) India's National Hydrogen Mission and Prospects for Cooperation with GCC, Manohar Parrikar Institute for Defence Studies and Analyses. Viewed 6 December 2021, https://www.idsa.in/issuebrief/india-national-hydrogen-mission-n-gcc-lpriya-270821#footnote1_c80n6n2

[19] Bhaskar U (2021) Govt charts course for usage of new-age fuel, Livemint. Viewed 6 December 2021, https://www.livemint.com/industry/energy/govt-charts-course-for-usage-of-new-age-fuel-11625078901655.html

[20] Government of India (2022) Ministry of Power notifies Green Hydrogen/ Green Ammonia Policy. Viewed 23 February 2022, https://pib.gov.in/PressReleasePage.aspx?PRID=1799067

[21] IEA (2021) Global Hydrogen Review. https://iea.blob.core.windows.net/assets/5bd46d7b-906a-4429-abda-e9c507a62341/GlobalHydrogenReview2021.pdf

[22] IEA (2021) Global Hydrogen Review https://iea.blob.core.windows.net/assets/5bd46d7b-906a-4429-abda-e9c507a62341/GlobalHydrogenReview2021.pdf

Table 2: Current and projected hydrogen demand and production

	2020	2030 (Announced Pledges Scenario)
Total Demand	~7 Mt H_2	~11 Mt H_2
Refining	45%	-
Chemicals	35%	-
Iron & Steel	20%	Primary driver
Domestic Production	~7 Mt H_2	-
Natural gas	~75%	-
Coal	~15%	-
Refineries (by-product)	~10%	-
Renewables	-	Substantial potential to scale-up renewables and low-cost electrolysis (subject to projected cost reductions)

1.2.3 India's hydrogen RD&D priorities

India is yet to establish specific RD&D priorities, however hydrogen RD&D priorities and opportunities can be inferred from several policy documents and reports. This includes early policy documents related to the National Hydrogen Mission as well reports published by the Indian Department of Science and Technology (DST), specifically the 2020 *India Country Status on Hydrogen and Fuel Cells* report[23] and the 2016 Sub-Committee on Research, Development and Demonstration for Hydrogen Energy and the Steering Committee on Hydrogen Energy and Fuel Cells (from the MNRE).[24] These have been supplemented by RD&D priorities identified during consultations with in-country stakeholders.

Table 3: India's hydrogen RD&D priorities

Supply chain area	Sub-technology areas	Key RD&D priorities
Production	Electrolysis	Development and demonstration of water electrolysis using renewable energy. Development and demonstration of electrolysers with locally-derived acid-based solid polymer electrolyte and alternative alkaline membranes. Development and demonstration of a high-temperature steam electrolyser (1 Nm^3/h) and a solid polymer water electrolyser (5 Nm^3/h). Development and demonstration of efficient alkaline water electrolysis. Integration of large capacity electrolysers with wind/solar power units. Investigating strategies for seawater electrolysis.

[23] Department of Science and Technology (2020) India Country Status Report on Hydrogen and Fuel Cells. Viewed 6 December 2021, https://static.pib.gov.in/WriteReadData/userfiles/India%20Country%20Status%20Report%20on%20Hydrogen%20and%20Fuel%20Cell.pdf

[24] EQ International (2016) MNRE: Report on Hydrogen Energy and Fuel Cells in India A Way Forward. Viewed 16 December 2021, https://www.eqmagpro.com/mnre-report-on-hydrogen-energy-and-fuel-cells-in-india-a-way-forward/

Supply chain area	Sub-technology areas	Key RD&D priorities
		Catalyst and membrane development.
	Fossil fuel conversion	Production by auto-thermal reforming. Development and demonstration of methane pyrolysis and methanol reforming.
	Emerging hydrogen production methods	Technology development for production of syngas and hydrogen from reformation of natural gas using solar energy. Hydrogen production via solar-driven pyrolysis of hydrocarbons Production by non-thermal plasma assisted direct decomposition of hydrogen sulphide. Photocatalytic splitting of hydrogen sulphide, with priorities including reduction in energy consumption. Demonstration of thermochemical water splitting cycles. This includes iodine sulphur (I-S) open and closed loop process and copper chloride (Cu-Cl) cycle using solar/nuclear heat. Production by water splitting through photolysis using solar energy. Photocatalytic conversion of CO_2 and water into value-added products. Development and demonstration of biological hydrogen production from different kinds of waste.
	Biomass and waste conversion	Gasification of biomass including demonstration of technology at pilot scale. Reforming of bio-ethane and bio-methanol. Reforming of bio-oil obtained from fast pyrolysis of biomass. Reforming of biomethane using solar energy.
Storage and distribution	Solid storage	Development of solid-state storage devices and cartridges for small vehicles and stationary power packs. Manufacture of solid-state storage materials such as intermetallic and metal hydride systems at a large scale (including pilot plants for mischmetal- and magnesium- based hydrides, and advanced and complex hydrides).
	Compressed storage	Hydrogen tanks and cylinders. Design and development of locally sourced and manufactured type III and type IV carbon composite cylinders for compressed hydrogen storage.
	Novel storage methods	Synthesis and characterisation of novel storage materials and devices (including complex hydrides and MOFs), and the scale-up of material and device fabrication.
	Tube trailers	Allow high pressure hydrogen transportation through tube trailers.
	Gas cylinders	Development and on-field deployment of high-pressure gas cylinders (up to 700 bar).

Supply chain area	Sub-technology areas	Key RD&D priorities
		Establishing purification units and compression systems to fill cylinders, in order to utilise surplus hydrogen.
Utilisation	Gas networks	Introduction of hydrogen into gas networks.
	Fuel cells	Development of high- and low-temperature proton exchange membrane fuel cells (PEMFC) with heat combined cycle. Development of planar solid oxide fuel cells. Phosphoric acid fuel cells. Direct methanol/ethanol fuel cell research and development. Molten carbonate fuel cell research and development. Bio-fuel cell research and development. Basic research projects for other varieties of fuels including direct carbon and alkaline fuel cells. Design and development of 20kW low temperature PEM fuel cell with high indigenous content. Develop of novel catalysts and membranes. Develop of fuel cells for remote back-up power systems.
	Refuelling stations	Increase on-board storage pressure limit to 700 bar for hydrogen refuelling stations.
	Transport	Demonstration of hydrogen use in buses, commercial vehicles and railways. Design, development and demonstration of fleets operating on fuel cell technology. Design, development and demonstration of fleets (including buses) operating on a hydrogen internal combustion engine. Testing and certification of fuel cell stacks, fuel cell and hydrogen engine based vehicles, and hydrogen storage cylinders. Compressed natural gas fuelled bus demonstration in select city bus fleets. Demonstration of motorcycles and three wheelers using metal hydride and compressed hydrogen storage.
	Civilian applications	Development and demonstration of home cookers with a mix of LPG and hydrogen (going from 75% LPG, to 25% LPG, to 100% hydrogen).
	Industry	Green steel and green ammonia manufacturing.
Cross-cutting	Modelling and analysis	Well-to-wheel analyses of fuel cell and hydrogen internal combustion engine-based vehicles using hydrogen produced from different sources. Direct economic costs (capital and operational costs for new FCEVs and conversion cost for on-road vehicles) along with TCO analysis.

Supply chain area	Sub-technology areas	Key RD&D priorities
		Mapping & techno-economic analysis of hydrogen retail outlets for setting up supply and distribution infrastructure in metropolitan cities. Process simulation modelling for hydrogen utilisation in hard-to-abate industries. Creation of H_2 Atlas Map for RE resources and water.
	Safety, regulation and policy	Development of policy and regulatory frameworks for hydrogen. Environmental, safety, and health effects of hydrogen based internal combustion and fuel cell vehicles compared to conventional internal combustion engine vehicles. Safety, driveability, customer convenience and societal impacts of hydrogen transportation. Testing facilities, standards for performance and safety regulations.

1.3 India's hydrogen RD&D ecosystem

1.3.1 Public bodies and policy ecosystem

Overview of India's STI policy landscape

India has a well-structured science, technology and innovation (STI) policy landscape. Government ministries formulate and fund RD&D policy initiatives, which are then implemented and overseen by several different departments – including the Department of Scientific & Industrial Research (DSIR), DST, Department of Biotechnology (DBT), and the Defence Research Development Organisation (DRDO). In December 2020, India announced the New Science, Technology Policy (STIP) which identifies India's current STI policy focuses. STI policy in India will be guided by the following broad vision:

- To achieve technological self-reliance and position India among the top three scientific superpowers;
- To attract, nurture, strengthen and retain critical human capital through a 'people centric' STI ecosystem;
- To double the number of full-time equivalent researchers, gross domestic expenditure on R&D (GERD) and private sector contribution to GERD every 5 years; and
- To build individual and institutional excellence in STI with the aspiration to achieve the highest level of global recognition and awards in the 2020s.[25]

Overview of India's hydrogen policy landscape

The MRNE is responsible for hydrogen and energy-specific policy in India, having led the development of the *Hydrogen and Fuel Cell Roadmap* in 2006[26] and more recently the National Hydrogen Mission.[27] In 2016, the MRNE published several reports which assessed India's progress on RD&D and outlined efforts to

[25] Government of India (2020) Science, Technology, and Innovation Policy (Draft STIP 1.4), Department of Science and Technology. Viewed 6 December 2021, https://dst.gov.in/sites/default/files/STIP_Doc_1.4_Dec2020.pdf

[26] Ministry of New and Renewable Energy (2006) National Hydrogen Energy Road Map: Path Way for Transition to Hydrogen Energy for India, Government of India. Viewed 6 December 2021, http://164.100.94.214/sites/default/files/uploads/abridged-nherm.pdf

[27] Department of Science and Technology (2020) India Country Status Report on Hydrogen and Fuel Cells. Viewed 6 December 2021, https://static.pib.gov.in/WriteReadData/userfiles/India%20Country%20Status%20Report%20on%20Hydrogen%20and%20Fuel%20Cell.pdf

increase RD&D activity in respect of hydrogen and fuel cell technology (these priorities are captured above in Table 3).

The MRNE establishes high-level committees – such as the Sub-Committee on Research, Development & Demonstration for Hydrogen Energy and Fuel Cells and the Steering Committee on Hydrogen Energy and Fuel Cells – to formulate and implement policies. However, various ministerial departments, agencies and bodies have responsibility for implementing hydrogen policies relevant to their portfolios. For example, the DST establishes mission-based programs, and the Ministry of Petroleum and Natural Gas (MoPNG) has oversight for hydrogen policies and demonstration projects which overlap with India's existing energy grid.[28]

The key public bodies involved in India's hydrogen STI ecosystem are depicted in Figure 3. A more detailed description of their role in the overall Indian STI ecosystem and their hydrogen-specific activities and initiatives are outlined in Table 4.

Figure 3: Summary of India's hydrogen policy ecosystem

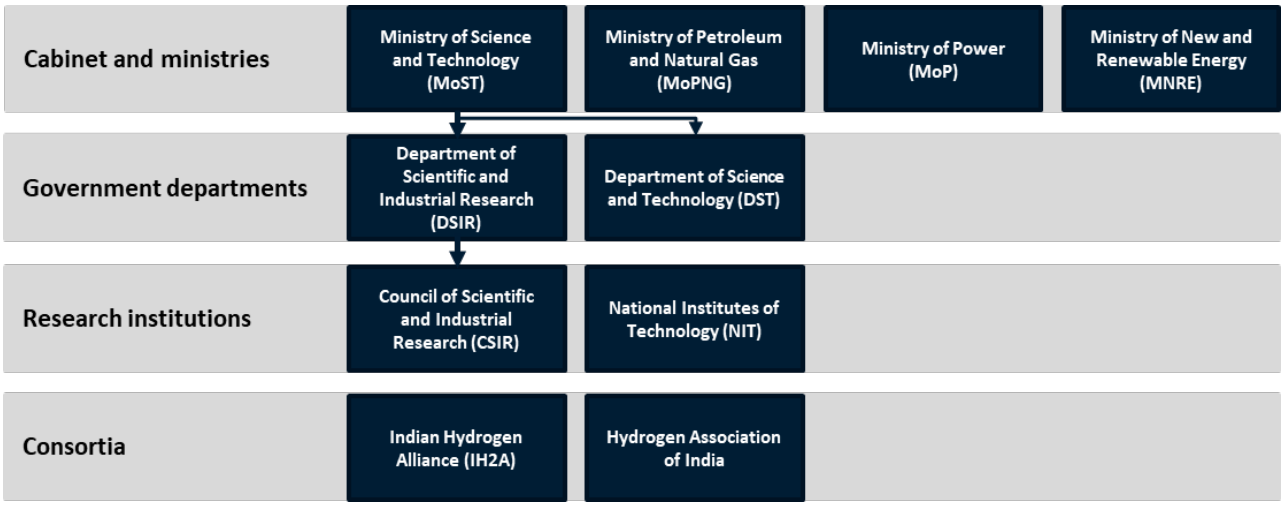


Table 4: Summary of key regulatory bodies

Body	Role in RD&D ecosystem	Hydrogen initiatives
MoST *Ministry of Science and Technology*	The MoST is responsible for policy, regulation and legislation across the science and technology portfolio in India. Within the MoST are three departments – the Department of Biotechnology, the Department of Scientific and Industrial Research, and the Department of Science and Technology.	See the DST and the DSIR below.
DST *Department of Science and Technology*	The DST aims to promote new areas of science and technology and to organise, coordinate and promote scientific and technological activities across the country. In addition, the DST provides funding and support for researchers and research	The DST has plans to establish a Hydrogen Valley Platform, which is an information sharing platform that brings together industry and policy makers to support the

[28] Department of Science and Technology (2020) India Country Status Report on Hydrogen and Fuel Cells. Viewed 6 December 2021, https://static.pib.gov.in/WriteReadData/userfiles/India%20Country%20Status%20Report%20on%20Hydrogen%20and%20Fuel%20Cell.pdf

Body	Role in RD&D ecosystem	Hydrogen initiatives
	projects. The DST has several scientific programs underway, including the Scientific and Engineering Research, Technology Development, and International S&T Cooperation Programmes.	development of hydrogen projects across the value chain.[29] The DST established the Hydrogen Research Initiative (HRI) which consists of two programs. The Hydrogen and Fuel Cell program focusses on the development of technologies to reduce the cost of hydrogen/fuel cell production, distribution and storage.[30] The Renewable and Clean Hydrogen program adopts an industry-directed approach toward R&D across public and private sectors.[31] The DST also established the Advanced Hydrogen and Fuel Cell Programme, which focusses on technologies and materials related to electrolysis, hydrogen storage vessels and fuel cells.[32]
MoPNG *Ministry of Petroleum and Natural Gas*	The MoPNG is responsible for the exploration, production, refining, distribution, marketing, import, export and conservation of petroleum, natural gas, petroleum products, and liquefied natural gas in India. This includes overseeing all public sector R&D projects related to petroleum products and liquefied natural gas in India.	The MoPNG undertakes several hydrogen initiatives. The first demonstration project was a grey hydrogen program, where hydrogen was blended with compressed natural gas for use as a transportation fuel.[33] The MoPNG has oversight for hydrogen policies and demonstration projects which overlap with India's existing energy grid. In addition, the MoPNG is planning five pilot projects related to renewable hydrogen in collaboration with industry, including hydrogen refuelling stations, pipeline injection in the City Gas Distribution network, and renewable hydrogen production plants/infrastructure.[34] The MoPNG funds hydrogen R&D projects led by the oil industry through the Hydrogen Corpus Fund.

[29] Department of Science and Technology (2020) India Country Status Report on Hydrogen and Fuel Cells. Viewed 23 November 2021, https://static.pib.gov.in/WriteReadData/userfiles/India%20Country%20Status%20Report%20on%20Hydrogen%20and%20Fuel%20Cell.pdf

[30] Department of Science and Technology (2021) Hydrogen Research Initiative. Viewed 6 December 2021, https://dst.gov.in/hydrogen-research-initiative-hri

[31] Department of Science and Technology (2021) Hydrogen Research Initiative. Viewed 6 December 2021, https://dst.gov.in/hydrogen-research-initiative-hri

[32] Department of Science and Technology (2021) General Information and Format for Submission of Project Proposals for Financial Assistance for Advanced Hydrogen and Fuel Cell Programme, Government of India. Viewed 6 December 2021, https://dst.gov.in/sites/default/files/Revised%20AHFC%20Call-2021.pdf

[33] Ministry of Petroleum and Natural Gas (2021) Hydrogen Mission, Government of India. Viewed 6 December 2021, https://mopng.gov.in/en/page/12

[34] Ministry of Petroleum and Natural Gas (2021) Hydrogen Mission, Government of India. Viewed 6 December 2021, https://mopng.gov.in/en/page/12

Body	Role in RD&D ecosystem	Hydrogen initiatives
		The MoPNG constituted an expert committee to study various techno-economical aspects of hydrogen production, storage and transportation.[35]
MoP *Ministry of Power*	The MoP is responsible for overseeing electricity production and infrastructure development. It oversees rural electrification projects and acts as a bridge between government and state electricity operations as well as the private sector.	Hydrogen related initiatives are limited, with the MoP more concerned with electric and hydro-electric power sectors. However, more generally, the MoP is responsible for general policy on all matters concerning energy conservation and energy efficiency.[36]
MNRE *Ministry of New and Renewable Energy*	The MNRE is responsible for research and development, Intellectual Property (IP) protection and international collaboration on renewable energy topics. This is performed to enable deployment of new and renewable energy in India.	The MNRE is responsible for devising the policy document for the upcoming National Hydrogen Mission. The ministry published the world's first hydrogen-specific roadmap. The 2006 National Hydrogen Energy Roadmap[37] identified technology gaps and challenges in introducing large-scale hydrogen to India. The ministry published several reports on India's hydrogen and fuel cell RD&D activity and recommendations for improving such activities.[38]
DSIR *Department of Scientific and Industrial Research*	The DSIR is a department within the MoST. The goal of the Department is to have India emerge as a global industrial research and innovation hub. This is achieved by catalysing industrial research through incentives and other measures; enabling and promoting the development and implementation of new innovations; and enhancing innovations through leveraging its resources and providing benefits.	The DSIR is a member of The Energy and Resources Institute (TERI), an initiative by the PhD Chamber of Commerce and Industry in collaboration with the Ministry of Environment, Forest and Climate Change, the Department of Science and Technology, and NITI Aayog. TERI engages in discussions on renewable hydrogen applications in India.[39] The DSIR organised the International Climate Summit 2021 in collaboration with other

[35] Ministry of Petroleum and Natural Gas (2021) Hydrogen Mission, Government of India. Viewed 6 December 2021, https://mopng.gov.in/en/page/12

[36] Ministry of Power (2021) About Us: Responsibilities, Government of India. Viewed 7 December 2021, https://powermin.gov.in/en/content/responsibilities

[37] Ministry of New and Renewable Energy (2006) National Hydrogen Energy Road Map: Path Way for Transition to Hydrogen Energy for India, Government of India. Viewed 6 December 2021, http://164.100.94.214/sites/default/files/uploads/abridged-nherm.pdf

[38] Ministry of New and Renewable Energy (2021) Annual Report 2020-21, Government of India. Viewed 7 December 2021, https://mnre.gov.in/img/documents/uploads/file_f-1618564141288.pdf

[39] TERI Web Desk (2021) India can become a leading hydrogen export hub: Cristian Valdes Carter, Director, Innovation Norway said at TERI's technical session at the International Climate Summit 2021, The Energy and Resource Institute. Viewed 6 December 2021, https://www.teriin.org/article/india-can-become-leading-hydrogen-export-hub-cristian-valdes-carter-director-innovation

Body	Role in RD&D ecosystem	Hydrogen initiatives
		bodies, which had the theme 'Powering India's Hydrogen Ecosystem'.[40]
NIT *National Institutes of Technology*	National Institutes of Technology (NIT) are public technical universities under the jurisdiction of the Ministry of Education. There are 31 NITs in total and are regulated by the NIT Council.	Several NITs engage in hydrogen RD&D. For example: • National Institute of Technology, Rourkela (hydrogen production). • National institute of Technology, Calicut, Kozhikode (hydrogen production). • National Institute of Technology, Tiruchirappalli (hydrogen storage).
CSIR *Council of Scientific & Industrial Research*	The CSIR is India's primary R&D organisation, and an autonomous body of DSIR.[41] The CSIR network is comprised of 37 national laboratories, 39 outreach centres, three innovation complexes, and over 4000 active scientists.[42]	CSIR Laboratories are a leading global organisation in hydrogen RD&D. The CSIR produces research across the hydrogen value chain and holds several patents across many hydrogen technology areas. CSIR laboratories relevant to hydrogen include: • **Central Institute of Mining and Fuel Research:** the Coal to Hydrogen Energy for Sustainable Solutions (CHESS) research group aims to develop new indigenous technologies for the production, separation and storage of hydrogen as part of the clean energy initiatives; • **National Chemical Laboratory:** the National Chemical Laboratory (NCL) performs hydrogen generation and storage research; and • **Central Electrochemical Research Institute:** performs research primarily related to fuel cells, electrolysis, and hydrogen storage. For a more comprehensive list, see *Section 1.4.1 Major domestic hydrogen RD&D projects.*

[40] Ians (2021) India has potential to meet global green hydrogen demand: Jitendra Singh, The Economic Times. Viewed 6 December 2021, https://economictimes.indiatimes.com/industry/renewables/india-has-potential-to-meet-global-green-hydrogen-demand-jitendra-singh/articleshow/85900025.cms?from=mdr

[41] CSIR (2021) About CSIR https://www.csir.res.in/about-us/about-csir

[42] Council of Scientific & Industrial Research (2021) About CSIR. Viewed 6 December 2021, https://www.csir.res.in/about-us/about-csir

1.3.2 Hydrogen consortia

India has several peak bodies and public-private-research consortia, which are outlined below in Table 5.

Table 5: Hydrogen consortia

Consortium	Description
IH2A *Indian Hydrogen Alliance*	An industry-led coalition which focuses on the commercialisation of hydrogen technology and systems to aid in India's decarbonisation efforts and net-zero carbon pathways. Members are all over the world and include the CSIR National Chemical Laboratory, FTI Consulting, JSW, TERI, Reliance Industries Ltd and Aberdeen Renewable Energy Group.[43]
Hydrogen Association of India	The Hydrogen Association of India is an industry-led body that conducts activities to: promote, encourage and develop the growth of hydrogen energy in the country; disseminate information concerning hydrogen energy developments; establish an active association of relevant individuals and organisations; and to provide advice to government and other commercial bodies related to hydrogen.[44] Members include the Federation of Indian Petroleum Industry, Indian Oil Corporation, and TVS Motor Company.[45]

1.3.3 Funding mechanisms

Overview of India's hydrogen public budget allocations

There are several regulatory bodies in India that provide funding for hydrogen RD&D. These include the MoST, CSIR Laboratories, MoPNG, DRDO, India Space Research Organisation, Oil & Gas companies, Department of Atomic Energy (DAE) and industry (often automobile manufacturers).[46]

Regarding fuel cell research, over the past decade (2010-2020):[47]

- MNRE spent approximately INR 25 Crore, with CSIR also spending a similar amount.
- The DST and DSIR contributed approximately INR 5 Crore each for a similar purpose.
- The DRDO has invested approximately INR 50 Crore and plans invest another INR 100 Crore in near future.
- Exact funding provided by DAE over the last 10 year is not publicly available, however it is expected to be in the order of approximately INR 50 Crore.[48]

This section is split into two sections: currently funded existing mechanisms (i.e. before the National Hydrogen Mission) and funding mechanisms planned under the National Hydrogen Mission in the near future.

[43] India Hydrogen Alliance (IH2A) (2021) About IH2A. Viewed 6 December 2021, https://ih2a.com/about-ih2a/

[44] Hydrogen Association of India (2021) About HAI. Viewed 6 December 2021, https://www.hai.org.in/about.php

[45] Hydrogen Association of India (2021) Office Bearers. Viewed 6 December 2021, https://www.hai.org.in/office_bearers.php

[46] Department of Science and Technology (2020) India Country Status Report on Hydrogen and Fuel Cells. Viewed 6 December 2021, https://static.pib.gov.in/WriteReadData/userfiles/India%20Country%20Status%20Report%20on%20Hydrogen%20and%20Fuel%20Cell.pdf

[47] Department of Science and Technology (2020) India Country Status Report on Hydrogen and Fuel Cells. Viewed 6 December 2021, https://static.pib.gov.in/WriteReadData/userfiles/India%20Country%20Status%20Report%20on%20Hydrogen%20and%20Fuel%20Cell.pdf

[48] Department of Science and Technology (2020) India Country Status Report on Hydrogen and Fuel Cells. Viewed 6 December 2021, https://static.pib.gov.in/WriteReadData/userfiles/India%20Country%20Status%20Report%20on%20Hydrogen%20and%20Fuel%20Cell.pdf

Public RD&D funding

Funding mechanism	Funding body	Description	Amount	International eligibility to participate
Hydrogen Corpus Fund	MoPNG	The Hydrogen Corpus Fund is delivered by the MoPNG and is focused on funding projects led by the oil industry.[49] Only INR 27 Crore out of the INR 100 Crore has been appropriated for 8 different projects.[50]	INR 100 Crore	*No data.*
Advanced Hydrogen and Fuel Cell Programme	DST	Funding is offered by DST through their Advanced Hydrogen and Fuel Cell Programme. In 2021, this funding was directed to promoting and supporting activities related to the indigenous development of new/existing material in large quantities, catalysts, membranes, components for fuel cells, electrolysers, hydrogen storage materials, materials for type IV cylinders and prototypes for implementation of various applications of hydrogen and fuel cells.[51] 10 Crore is available as a maximum amount per project proposal.[52] 11 proposals have been shortlisted for funding.	INR 10 Crore available per project. Total program budget for the 11 shortlisted proposals of INR 30 Crore.	Potentially. There may be opportunities an opportunity for industry or researchers holding a position at an Indian university or academic institution to partner.[53]
MNRE budget	MNRE	For the period 1 April 2020 to 31 March 2021, INR 200 million (USD 2.8 million) was allocated for hydrogen energy and fuel cell related activities in the MNRE budget.[54]	INR 20 Crore.	*No data.*

[49] Ministry of Petroleum and Natural Gas (2021) Hydrogen Mission. Viewed 6 December 2021, https://mopng.gov.in/en/page/12

[50] Oil Industry Development Board (2016) Hydrogen Corpus Fund, Ministry of Petroleum and Natural Gas. Viewed 6 December 2021, http://www.oidb.gov.in/index1.aspx?langid=1&lev=4&lsid=403&pid=36&lid=350

[51] Department of Science and Technology (2021) General Information and Format for Submission of Project Proposals for Financial Assistance for Advanced Hydrogen and Fuel Cell Programme, Government of India. Viewed 6 December 2021, https://dst.gov.in/sites/default/files/Revised%20AHFC%20Call-2021.pdf

[52] Department of Science and Technology (2021) General Information and Format for Submission of Project Proposals for Financial Assistance for Advanced Hydrogen and Fuel Cell Programme, Government of India. Viewed 6 December 2021, https://dst.gov.in/sites/default/files/Revised%20AHFC%20Call-2021.pdf

[53] Department of Science and Technology (2021) General Information and Format for Submission of Project Proposals for Financial Assistance for Advanced Hydrogen and Fuel Cell Programme, Government of India. https://dst.gov.in/sites/default/files/Revised%20AHFC%20Call-2021.pdf

[54] International Partnership for Hydrogen and Fuel Cells in the Economy (2021) INDIA. Viewed 6 December 2021, https://www.iphe.net/india

Planned funding

India has announced increased funding for hydrogen and fuel cell technology RD&D as part of the National Hydrogen Mission.[55] The National Hydrogen Mission's budget between 2021 and 2024 is expected to be INR 800 Crore over the next three years, with INR 25 crore allocated to R&D on hydrogen for FY21-22.[56] For 2022 the National Hydrogen Mission's will primarily focus on demonstration projects across the value chain, many of which are expected to be jointly-funded by government-owned corporations (such as Indian Oil).[57]

1.3.4 Other key hydrogen policies, regulation and legislation

India is yet to establish hydrogen-specific legislation and regulatory frameworks to support the scale up of a hydrogen economy. In the absence of a specific regulatory framework, hydrogen policies, RD&D programs and schemes implemented by government are supporting the commercialisation, deployment and uptake of hydrogen technologies. These policies include:

- **Production-linked Incentive Scheme:** In September 2021, India announced plans to implement subsidies for electrolyser manufacturers to incentivise hydrogen production from solar and wind. These subsidies, while yet to be finalised, may support up to 15 gigawatts of electrolysers.[58]
- **'Green Tariff' Policy:** In June 2021, India's MoP proposed a set of 'Draft Electricity Rules, 2021' to promote Renewable Energy throughout India, with these rules framing a 'green tariff' policy that would allow electricity distribution companies to supply green electricity at a more competitive rate compared to electricity generated through conventional fuel sources.[59]
- **Perform, Achieve, and Trade (PAT) Scheme**: The PAT was established by the National Mission for Enhanced Energy Efficiency as a regulatory instrument, based on the Cap-and-Trade mechanism, to reduce energy usage in energy intensive industries.[60] The scheme may be expanded to hydrogen once hydrogen utilisation is at scale.
- **General policies:** The Indian government has implemented various policies, programs and targets that seek to reduce anthropogenic CO_2-e emissions from the power, transport and industrial sectors. Key targets include establishing 450GW of renewable energy production capacity by 2030 and increasing the utilisation of electric vehicles across the public and private sector more generally. [61] The India government is yet to announce targets for the utilisation of hydrogen FCEVs.

[55] Priya L (2021) India's National Hydrogen Mission and Prospects for Cooperation with GCC, Manohar Parrikar Institute for Defence Studies and Analyses. Viewed 6 December 2021, https://www.idsa.in/issuebrief/india-national-hydrogen-mission-n-gcc-lpriya-270821#footnote1_c80n6n2

[56] Priya L (2021) India's National Hydrogen Mission and Prospects for Cooperation with GCC, Manohar Parrikar Institute for Defence Studies and Analyses. Viewed 6 December 2021, https://www.idsa.in/issuebrief/india-national-hydrogen-mission-n-gcc-lpriya-270821#footnote1_c80n6n2

[57] FE Bureau (2021) National Hydrogen Mission: An alternative to battery electric mobility, Financial Express, https://www.financialexpress.com/auto/electric-vehicles/national-hydrogen-mission-an-alternative-to-battery-electric-mobility/2332649/

[58] PTI (2021) Cabinet nod sought for setting green hydrogen purchase obligation for refineries, fertiliser plants: RK Singh, The Economic Times. Viewed 7 December 2021, https://economictimes.indiatimes.com/industry/renewables/cabinet-nod-sought-for-setting-green-hydrogen-purchase-obligation-for-refineries-fertiliser-plants-rk-singh/articleshow/86041929.cms?from=mdr

[59] PBNS (2021) Govt's new RE rules set to push Green Hydrogen in India, NewOnAIR. Viewed 7 December 2021, https://newsonair.com/2021/09/01/govts-new-re-rules-set-to-push-green-hydrogen-in-india/

[60] International Energy Agency (2021) Perform, Achieve, Trade (PAT) Scheme. Viewed 7 December 2021, https://www.iea.org/policies/1780-perform-achieve-trade-pat-scheme

[61] Biswas T, Yadav Deepak and Baskar AG (2020) A Green Hydrogen Economy for India: Policy and Technology Imperatives to Lower Production Costs [Policy Brief], Council on Energy, Environment and Water. Viewed 7 December 2021, https://shaktifoundation.in/wp-content/uploads/2020/12/A-Green-Hydrogen-Economy-for-India.pdf

Legislative change in the Oilfields Regulation and Development Act: In June 2021, the MoPNG released a draft amendment to *Oilfields Regulation and Development Act 1948* which is yet to be passed by the Indian Parliament. The draft amendment proposes to expand the definition of 'mineral oils' to include naturally occurring sources of hydrocarbons, which would therefore permit the Indian government to regulate hydrogen projects.[62]

Since the announcement of the National Hydrogen Mission, the MRNE has reportedly issued 3 draft policy documents. The documents are not yet publicly available, however it is expected the policy documents will:[63]

- **Set India's policy direction:** identify targeted short (4 year) and long-term (10 year) policy options to promote and develop a robust hydrogen supply chain, with the primary policy focus likely regarding hydrogen production and fuel cell technologies.
- **Establish hydrogen targets:** establish renewable hydrogen utilisation requirements in the fertiliser and petroleum refining industries. These targets may overlap with existing renewable energy purchasing obligations, which require energy distribution companies to buy a certain amount of renewable energy to reduce dependence on energy produced through conventional sources.
- **Streamline commercial supply:** aggregate and predict demand for renewable hydrogen across key industries and establish single procurement tender (known as a 'mega tender') to facilitate a cost-effective commercial supply of renewable hydrogen on an on-demand basis.

To further support the National Hydrogen Mission, the MoP announced the *Green Hydrogen / Green Ammonia Policy*.[64] The policy is designed to promote renewable energy generation and the provision of clean fuels throughout India. Key aspects of the policy include:

- The procurement and supply of renewable energy to manufacturers of renewable hydrogen and ammonia;
- The waiving of inter-state transmission charges over a 25-year period for manufacturers of renewable hydrogen and ammonia;
- Connectivity to India's power grid and interstate power transmission system (ISTS) for manufacturers of renewable hydrogen and ammonia; and
- The establishment of a portal by MNRE for general business activities.

[62] Arora P and Vaidialingam S (2021) Green Hydrogen in India: State of Play, BTG Legal. Viewed 7 December 2021, https://www.btg-legal.com/post/green-hydrogen-in-india-state-of-play

[63] Arora P and Vaidialingam S (2021) Green Hydrogen in India: State of Play, BTG Legal. Viewed 7 December 2021, https://www.btg-legal.com/post/green-hydrogen-in-india-state-of-play

[64] Ministry of Power (2022) Ministry of Power notifies Green Hydrogen/ Green Ammonia Policy: A Major Policy Enabler by Government for production of Green Hydrogen/ Green Ammonia using Renewable sources of energy. https://pib.gov.in/PressReleasePage.aspx?PRID=1799067

1.4 India's domestic hydrogen RD&D projects

1.4.1 Major domestic hydrogen RD&D projects

Projects led by Industry, Peak Bodies and Consortia

Several demonstration and research projects are being led by the private sector, largely in hydrogen production from renewables:

- India's JSW Energy has partnered with Australian-based Fortescue Future Industries on renewable hydrogen for industrial uses including steelmaking, green ammonia production, and hydrogen mobility.[65]
- In Mathura, Indian Oil is currently constructing India's first production plant for hydrogen produced from renewables.[66] Indian Oil will use the hydrogen produced at this facility to facilitate a second project to demonstrate buses fuelled by hydrogen blended compressed natural gas (H-CNG) in Delhi, which is expected to commence a pilot of 50 buses.[67]
- In Cuddalore, BGR Energy has partnered with Ireland's Fusion Fuel Green to establish a demonstration hydrogen production plant that produces cost-competitive renewable hydrogen.[68]
- In Rajasthan, ACME Group has commissioned the world's first integrated commercial-scale demonstration plant for hydrogen production from renewables.[69]
- In Indore, state gas utility GAIL (India) Ltd commenced India's commenced a pilot project to blend hydrogen into the natural gas network. The blended hydrogen will be distributed to households in Indore and also to support the retailing of H-CNG to automobiles and piped natural gas to households in Indore. The pilot project will initially blend hydrogen produced from fossil fuels, which will subsequently be replaced with renewable hydrogen.[70]
- A number of companies have also established the industry-led India Hydrogen Alliance, headed by Reliance Industries (see *1.3.2: Hydrogen consortia* above).[71]

Projects led by government bodies

Hydrogen and fuel cell RD&D projects in India are primarily led by three government bodies: the MoPNG, the DST, and the CSIR.

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[65] Fortescue (2021) Fortescue Future Industries to explore potential green hydrogen projects in India. Viewed 6 December 2021, https://www.fmgl.com.au/in-the-news/media-releases/2021/07/29/fortescue-future-industries-to-explore-potential-green-hydrogen-projects-in-india

[66] Gupta U (2021) Indian prime minister announces National Hydrogen Mission, PV Magazine. Viewed 6 December 2021, https://www.pv-magazine.com/2021/08/17/indian-prime-minister-announces-national-hydrogen-mission/

[67] Indian Oil (2020) 50 city buses to run on HCNG on trial, HCNG likely to achieve a significant reduction in vehicular emission [Press release]. Viewed at https://iocl.com/NewsDetails/58744

[68] Gupta U (2021) Indian-Irish partnership to produce green hydrogen, PV Magazine. Viewed 6 December 2021, https://www.pv-magazine.com/2021/03/08/indian-irish-partnership-to-produce-green-hydrogen/

[69] Gupta U (2021) Indian prime minister announces National Hydrogen Mission, PV Magazine. Viewed 6 December 2021, https://www.pv-magazine.com/2021/08/17/indian-prime-minister-announces-national-hydrogen-mission/

[70] The Economic Times (2022) GAIL starts India's maiden project of blending hydrogen into natural gas systems in Indore https://economictimes.indiatimes.com/industry/renewables/gail-starts-indias-maiden-project-of-blending-hydrogen-into-natural-gas-system-at-indore/articleshow/89249620.cms

[71] Gupta U (2021) Indian prime minister announces National Hydrogen Mission, PV Magazine. Viewed 6 December 2021, https://www.pv-magazine.com/2021/08/17/indian-prime-minister-announces-national-hydrogen-mission/

Ministry of Petroleum and Natural Gas

As part of the National Hydrogen mission, the MoPNG is undertaking several hydrogen initiatives and demonstration projects ultimately designed to achieve a greater use of hydrogen within India's energy sector. These projects are largely supported through the MoPNG's Hydrogen Corpus Fund. Major ongoing projects are outlined below:

Table 6: Projects led by the MoPNG

Project	Investment amount	Description	International eligibility to participate
Hydrogen CNG Initiative	One of the national hydrogen projects accessible to the Hydrogen Corpus Fund which offers INR 100 Crore per annum.	Hydrogen is blended with compressed natural gas to the extent of 18%, for use as transportation fuel at Rajghat Bus depot. Under this pilot, 50 buses in Delhi are running on blended hydrogen in compressed natural gas.[72]	*No data.*
Green hydrogen projects	Projects accessible to the Hydrogen Corpus Fund which offers INR 100 Crore per annum.	The MoPNG has announced/planned several pilot/demonstration projects on renewable hydrogen. These are: • Pilot projects for solar hydrogen refuelling stations at two locations for demonstration of fuel cell vehicles at tourist sites. • Pilot project of a renewable hydrogen plant to investigate the replacement of conventional hydrogen in refineries with hydrogen produced from renewables. • Pilot project for hydrogen production from renewables and its blending with compressed natural gas for dispensing at retail outlets. • Pilot project for renewable hydrogen infrastructure and pipeline injection of renewable hydrogen in the city gas distribution network.[73]	*No data.*
Multiple Pathways project	INR 296 Crore	The Multiple Pathways project is the first project in India that will investigate and address all aspects of the value chain for hydrogen-based mobility. Among the demonstrations will be 15 hydrogen fuel cell buses to conduct a 20,000 km field trial and four demonstration units of hydrogen production that will deliver 40 tonnes per day, where three of these units will be based on renewable sources such as	*No data.*

[72] Ministry of Petroleum and Natural Gas (2021) Hydrogen Mission. Viewed 6 December 2021, https://mopng.gov.in/en/page/12

[73] Ministry of Petroleum and Natural Gas (2021) Hydrogen Mission. Viewed 6 December 2021, https://mopng.gov.in/en/page/12

Project	Investment amount	Description	International eligibility to participate
		biomass gasification, reforming compressed biomethanol gas (CBG) and solar PV-based electrolysis.[74]	

Department of Science and Technology

The DST leads and/or funds several RD&D projects related to hydrogen and fuel cell technology. The Advanced Hydrogen and Fuel Cell Programme (2021) has shortlisted 11 projects on hydrogen production and utilisation technologies as well as cross-cutting policy frameworks. Major projects (defined as projects which receive funding equal to or greater than 1 crore from 2019-2020 are outlined in Table 7 below.

Table 7: Selection of projects led by the DST[75]

Project Description	Investment amount	Year
Development of Compressed Hydrogen-Fuel Cell Integrated System Suitable for Light Duty Vehicles	INR 4.7 Crore	2019-2020
Development of Micro Solid Oxide Fuel Cells (μ-SOFC) in Low Temperature Co-fired Ceramic (LTCC) Technology	INR 2.1 Crore	2019-2020
Demonstration and validation of hydrogen ecosystem for stationary power backup application for telecommunication towers	INR 3.9 Crore	2019-2020
Design, Development, Testing and Evaluation of a Lean Premixed Swirl Stabilized Gas Turbine Combustor for Stationary Power Generation using High-Hydrogen-Content Fuel	INR 2.6 Crore	2019-2020
Use of bio-hydrogen for PEM fuel stacks – Research and Demonstration	INR 3.7 Crore	2019-2020

Council of Scientific and Industrial Research

The CSIR, through its network of national laboratories, also establishes and coordinates hydrogen RD&D projects. Several current and completed projects are outlined in Table 8 below.

Table 8: Projects led by the CSIR[76]

Project title	Programme
Development of hydrogen standard in steel	Fast Track Translation / Fast Track Commercialisation – 1st tranche
Scale up and commercialisation of indigenously developed hydrogen standard in steel	Fast Track Translation / Fast Track Commercialisation – 2nd tranche

[74] Ministry of Petroleum and Natural Gas (2021) Hydrogen Mission. Viewed 6 December 2021, https://mopng.gov.in/en/page/12

[75] Department of Science & Technology (2021) Hydrogen Research Initiative https://dst.gov.in/hydrogen-research-initiative-hri

[76] CSIR (2020) Council of Scientific & industrial Research (CSIR) List of projects under various themes https://www.csir.res.in/rd-projects-csir-0

Project title	Programme
	Theme: mining, minerals, metals & materials
Energy efficient clean production of hydrogen	Fast Track Translation / Fast Track Commercialisation – 2nd tranche Theme: Energy (Conventional and Non-Conventional) and Energy Devices
Self-humidified Nafion based composite membranes for open cathode PEMFC stacks	Fast Track Translation / Fast Track Commercialisation – 2nd tranche Theme: Energy (Conventional and Non-Conventional) and Energy Devices
Development and demonstration of 1 kWe SOFC Stack with hydrogen & Air and 500 We SOFC Stack with reformed natural Gas and Air	New Millenium Indian Technology Leadership Initiative (NMITLI)
Demonstration and validation of a 5 kW HT-PEMFC based combined cooling and power system	CSIR-NMITLI projects
Demonstration and Validation of a LT-PEMFC system for automotive application	CSIR-NMITLI projects
Process/catalyst development for reduced hydrogen consumption for the hydrocracking of renewable oils (HLess-HCRO)	Ongoing Focussed Basic Research Projects Theme: Energy (Conventional and Non-Conventional) and Energy Devices
Protective conducting materials coating of La0.6Sr0.4Co0.2Fe0.8O3 (LSCF), MnCo2O4 and Mn1.5Co1.5O4 on SOFC interconnect Crofer 22 APU by Electrophoretic deposition to mitigate high temperature oxidation and degradation	Ongoing Focussed Basic Research Projects Theme: Energy (Conventional and Non-Conventional) and Energy Devices
Towards Large Scale Solar Hydrogen Production (SoHy)	Ongoing Niche Creating Projects Theme: Energy (Conventional and Non-Conventional) and Energy Devices

Generally, R&D hydrogen projects conducted by CSIR laboratories are aligned to three categories: Focused Basic Research, Niche Creating Projects, and Mission Mode Projects.[77] While the Green Hydrogen Mission is yet to be launched, hydrogen RD&D research is expected to be conducted across all three categories. Further detail on the three categories is outlined in Table 9.

[77] CSIR India (n.d.) CSIR India R&D Projects. https://csirprojects.anusandhan.net/

Table 9: CSIR research categories

Research category	Description	CSIR laboratories
Focused Basic Research	Targeted basic research for the development of hydrogen technologies	Central Mechanical Engineering Research Institute (CMERI), Advanced Materials and Process Research Institute (AMPRI), Institute of Minerals and Materials Technology (IMMT), Central Scientific Instruments Organisation (CSIO), National Chemical Laboratory (NCL), Central Electronics Engineering Research Institute (CEERI), and the Central Institute of Minish and Fuel Research (CIMFR).
Niche Creating Projects	Projects aimed to advance technology that can position India as a global hydrogen leader	NCL and National Institute for Interdisciplinary Science and Technology (NIIST).
Mission Mode Projects	Projects focused on addressing India's self-reliance, in this case largely addressing hydrogen production	NCL, CECRI, NIIST, Central Glass & Ceramic Research Institute (CGCRI), Institute of Minerals and Materials Technology (IMMT), and the Central Mechanical Engineering Research Institute (CMERI).
Green Hydrogen Mission	R&D across all areas of the hydrogen value chain, and associated technologies	NCL, CECRI, CGCRI, IMMT, CMERI, AMPRI, CSIO, CEERI, CIMFR, NIIST, National Metallurgical Laboratory (NML), Indian Institute of Petroleum (IIP), Central Salt and Marine Chemicals Research Centre (CSMCRI), National Environmental Engineering Research Institute (NEERI), Unit for research and Development of information (URDIP), and the National Institute of Science Communication and Policy Research (NIScPR).

Ministry of New and Renewable Energy (MNRE)

The MNRE, in collaboration with public sector entity NTPC Ltd., is preparing to commence a hydrogen fuel cell bus pilot project in Leh, Ladakh. In April 2020, NTPC announced a global expression of interest for the supply of these vehicles. Additionally, the MRNE has published a plan to establish 23GW worth of solar and transmission projects in the Ladakh region.[78]

1.4.2 Major domestic commercial hydrogen projects

The scope of this report is on RD&D projects. For information on commercial hydrogen projects, see *HyResource*, an online knowledge sharing platform across the hydrogen community led by CSIRO, Future Fuels CRC, NERA and the Australian Hydrogen Council.

HyResource provides a directory of publicly available databases and information sources on international projects:

- https://research.csiro.au/hyresource/projects/international/

[78] Anshul Joshi (2020) MNRE and NTPC to launch Hydrogen Fuel Cell Bus project in Leh: MNRE Secy, EnergyWorld. Viewed at https://energy.economictimes.indiatimes.com/news/renewable/mnre-and-ntpc-to-launch-hydrogen-fuel-cell-bus-project-in-leh-mnre-secy/74242771

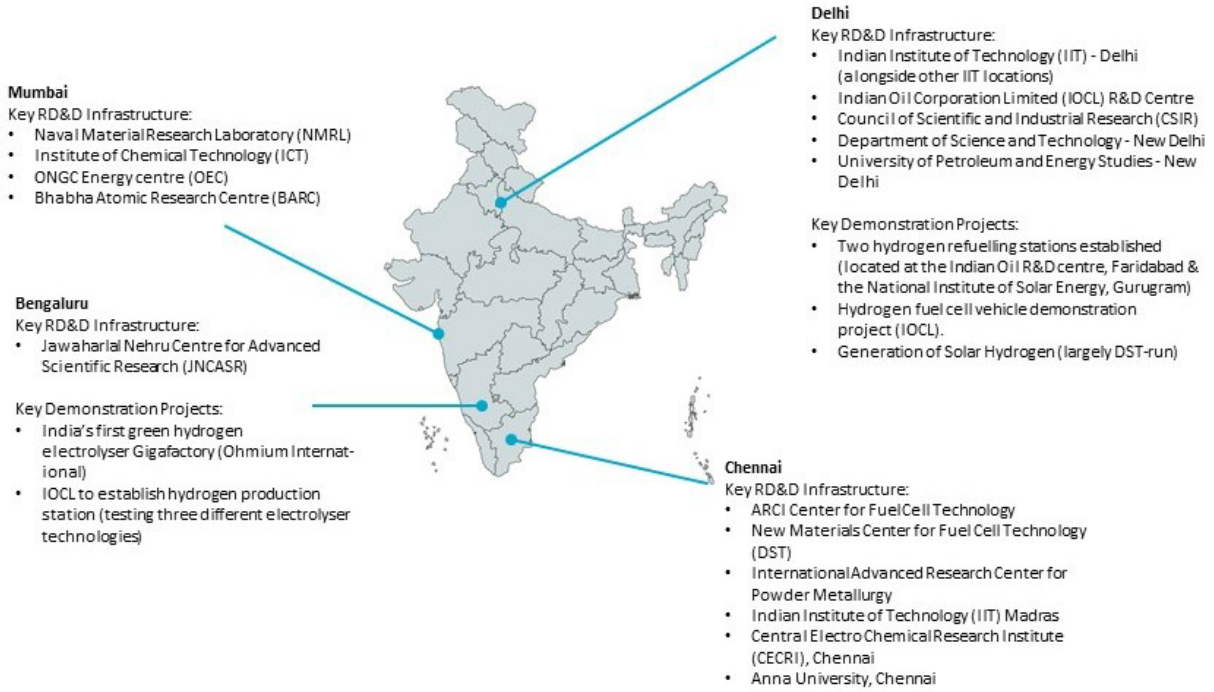
1.4.3 India's hydrogen RD&D clusters

Since the National Hydrogen Mission was launched, several large-scale projects have been announced in India across the public and private sector. India's approach to RD&D is based on local level partnerships between industry and research institutions across the country.[79] For example, the Indian Institute of Technology (IIT) has 23 locations that work on hydrogen RD&D and pilot projects, each working in a decentralised manner with local industry and other stakeholders on projects that align with regional strengths and strategic priorities. As of 2022, there are over 100 research groups focusing on fuel cell technology research in India, with other key research priorities including increasing the efficiency of water-splitting reactions and improving materials, catalysts and electrodes to accelerate these reactions.[80] Many academic and industry stakeholders operate within the Delhi region, which is considered to eb an area of high hydrogen RD&D activity.

Many pilot and demonstration projects are supported by private sector industry, often operating through a production linked incentive (PLI) scheme backed by government agencies or departments such as the MRNE to incentivise progress in a specific technology area.

Whilst hydrogen RD&D is largely decentralised, the DST has published plans to establish a 'Hydrogen Valley Platform' that brings together industry and policy makers to support the development of hydrogen projects across the value chain, with a view to establishing an integrated hydrogen ecosystem.[81]

Figure 4: Areas of high RD&D activity in India



[79] Department of Science and Technology (2020) India Country Status Report on Hydrogen and Fuel Cells. Viewed 23 November 2021, https://static.pib.gov.in/WriteReadData/userfiles/India%20Country%20Status%20Report%20on%20Hydrogen%20and%20Fuel%20Cell.pdf

[80] Manohar Parrikar Institutes for Defence Studies and Analyses (2021) IDSA Issue Briefs: India's National Hydrogen Mission and Prospects for Cooperation with GCC. Viewed 23 November 2021, https://www.idsa.in/issuebrief/india-national-hydrogen-mission-n-gcc-lpriya-270821#footnote1_c80n6n2

[81] Department of Science and Technology (2020) India Country Status Report on Hydrogen and Fuel Cells. Viewed 23 November 2021, https://static.pib.gov.in/WriteReadData/userfiles/India%20Country%20Status%20Report%20on%20Hydrogen%20and%20Fuel%20Cell.pdf

Table 10: Areas of high RD&D activity in India

City	Projects/Notes
Delhi	Key demonstration projects are focused on transportation and are supported by the MRNE and the DST. Corporations including the Indian Oil Corporation Limited (IOCL) RD&D Centre, the Mahindra Group and research institutions support the development of these project.[82] The hydrogen fuel station pilot project exists as part of the larger PLI scheme and was Centre of Excellence established.[83] Other key research stakeholders include Banaras Hindu University, the University of Petroleum and Energy Studies (UPES), CSIR laboratories, oil & gas companies, and a number of the IIT's locations - notably IIT Delhi. India places emphasis on a collaborative, multi-institutional approach to the design and development of projects. For example, the Generation of Solar Hydrogen project which aimed to develop scalable designs of solar hydrogen systems, was led by a consortium of research institutions (including IIT members), the Central Electro Chemical Research Institute and Bhabha Atomic Research Centre (BARC-Mumbai). Fostering collaboration between various industry stakeholders allows project teams to draw on the respective strengths of laboratories and institutes to achieve the most effective, efficient outcome.[84]
Mumbai	India's key scientific research bodies and academic institutes are concentrated in Mumbai. Key research projects include research on hydrogen production via Cu-Cl thermochemical pathways (conducted by OEC-ICT), SOFC (conducted by BARC) and research into hydrogen generation via autothermal reforming (conducted by NMRL).[85]
Bengaluru	Renewable start-up, American Ohmium International has recently launched India's first renewable hydrogen electrolyser Gigafactory in this area.[86] The Indian Institute of Science (IISc) and the IOCL have signed a Memorandum of Understanding (MoU) for the affordable generation of fuel cell-grade hydrogen from biomass without combustion.[87] With this, there are plans to establish a pilot hydrogen production station which will test three electrolyser technologies (PEM, alkaline electrolysis, and SOFC).[88]
Chennai	Several of India's research institutes and laboratories are located in Chennai. This includes the International Advanced Research Centre for Powder Metallurgy and New Materials Centre for Fuel

[82] The Ministry of New and Renewable Energy (2021) New Technologies: Hydrogen Energy. Viewed 23 November 2021, https://mnre.gov.in/new-technologies/hydrogen-energy

[83] Cabinet clears auto PLI scheme for EVs, hydrogen fuel cell vehicles, September 2021, Business Standard. Viewed 24 November 2021, https://www.business-standard.com/article/economy-policy/govt-approves-rs-26-058-crore-pli-scheme-for-auto-drone-sectors-121091500758_1.html; FIT Consulting Inc. (2020) India's Energy Transition Towards a Green Hydrogen Economy: WHITE PAPER ON BUILDING A GREEN HYDROGEN ECONOMY AND POLICY ROADMAP FOR INDIA. Viewed 23 November 2021, http://documents.jdsupra.com/af7b5c28-7b7a-43d6-b7d8-ab808f21125f.pdf

[84] Department of Science and Technology (2020) India Country Status Report on Hydrogen and Fuel Cells. Viewed 23 November 2021, p.12, https://static.pib.gov.in/WriteReadData/userfiles/India%20Country%20Status%20Report%20on%20Hydrogen%20and%20Fuel%20Cell.pdf

[85] Department of Science and Technology (2020) India Country Status Report on Hydrogen and Fuel Cells. Viewed 23 November 2021, https://static.pib.gov.in/WriteReadData/userfiles/India%20Country%20Status%20Report%20on%20Hydrogen%20and%20Fuel%20Cell.pdf

[86] US-Based Ohmium Launches India's Green Hydrogen Electrolyser Factory, August 2021, FuelCellWorks. Viewed 24 November 2021, https://fuelcellsworks.com/news/us-based-ohmium-launches-indias-green-hydrogen-electrolyzer-gigafactory/

[87] India takes step closer towards mass production of hydrogen fuel from biomass: IISc Bengaluru, (November 2021), The Indian Express. Viewed 23 November 2021, https://indianexpress.com/article/technology/science/hydrogen-fuel-from-biomass-iisc-bengaluru-6912372/

[88] Hall W, (2020) Make Hydrogen in India: Driving India towards the clean energy technology frontier [Policy Brief], The Energy and Resource Institute (TERI). Viewed 24 November 2021, https://www.teriin.org/sites/default/files/2020-06/Hydrogen-Policy-Brief.pdf

City	Projects/Notes
	Cell Technology (a DST R&D centre), IIT Madras, Anna University and the CSIR Centra Electrochemical Research Institute.[89]

1.5 International collaboration and joint RD&D projects

1.5.1 Overview of India's approach to international collaboration

India has signalled an intent to collaborate on hydrogen RD&D and joint projects. However, it must be noted that India's immediate strategic RD&D priorities appear to be focused on developing and scaling-up the technologies and infrastructure necessary to establish itself as a global renewable hydrogen production and export hub. As a result, potential areas of collaboration with India will likely be on hydrogen production and distribution technologies. More broadly, however, India is a member of several formalised hydrogen partnerships that each seek to facilitate increased collaboration to accelerate hydrogen RD&D and commercialisation and achieve decarbonisation ambition. In January 2022, the MNRE and the International Renewable Energy Agency (IRENA) signed a strategic partnership to strengthen collaboration on renewable energy. Under the strategic partnership, IRENA will support India's efforts to decarbonise by facilitating knowledge and technology sharing on scaling-up renewable and clean energy technologies, particularly hydrogen.[90] Key tracks of and priorities for international collaboration are outlined below:

- **Industry-led demonstrations:** India's approach to international collaboration is industry-focused with Indian state-owned and private companies submitting expressions of interest to partner with and establish pilot projects alongside global corporations. As a result, the number and scale of commercial RD&D projects that integrate research and technologies from industry partners is accelerating.[91] The India Hydrogen Alliance (IH2A) is key to India's approach to international collaboration.[92] The Alliance represents domestic and international industry leaders with the aim of commercialising hydrogen technologies and systems throughout India. Key areas of focus for the IH2A include the development of hydrogen production and storage solutions and the establishment of industrial clusters to facilitate decarbonisation of key industry sectors (including refineries, logistics and transport, and materials manufacturing.[93] The IH2A works alongside the Indian government to inform its National Hydrogen Policy Roadmap, develop a public-private H2 Taskforce and identify demonstration and pilot projects.[94]
- **Formalised industry agreements:** Memorandum of Understandings (MoUs) and agreements exist between non-member private industry (domestic and international) and state-owned corporations

[89] Department of Science and Technology (2020) India Country Status Report on Hydrogen and Fuel Cells. https://static.pib.gov.in/WriteReadData/userfiles/India%20Country%20Status%20Report%20on%20Hydrogen%20and%20Fuel%20Cell.pdf

[90] International Renewable Energy Agency (2022) India and IRENA Strengthen Ties as Country Plans Major Renewables and Hydrogen Push [Press Release]. https://irena.org/newsroom/pressreleases/2022/Jan/India-and-IRENA-Strengthen-Ties-as-Country-Plans-Major-Renewables-and-Hydrogen-Push

[91] India Hydrogen Alliance (IH2A) (2021) About IH2A. Viewed 26 November 2021, https://ih2a.com/

[92] India Hydrogen Alliance (IH2A) (2021) About IH2A. Viewed 26 November 2021, https://ih2a.com/

[93] India Hydrogen Alliance (IH2A) (2021) About IH2A. Viewed 26 November 2021, https://ih2a.com/; FuelCellsWorks (2021) India: Energy Transition Coalition 'India H2 Alliance' Formed by Industry Majors. Viewed 26 November 2021, https://fuelcellsworks.com/news/india-energy-transition-coalition-india-h2-alliance-formed-by-industry-majors/

[94] FuelCellsWorks (2021) India: Energy Transition Coalition 'India H2 Alliance' Formed by Industry Majors. Viewed 26 November 2021, https://fuelcellsworks.com/news/india-energy-transition-coalition-india-h2-alliance-formed-by-industry-majors/

such as the National Thermal Power Corporation Limited (NTPC) and the IOCL. These MoUs promote increased collaboration and knowledge sharing.

- **International Standards:** the Indian government has signalled its intent to collaborate internationally on the development of technical codes and regulations in respect of hydrogen, particularly through existing forums including Mission Innovation, the Quadrilateral Strategic Dialogue, the International Organisation for Standardisation (ISO) and the United Nations Economic Commission for Europe (UN-ECE).[95] In the 2020 *India Country Status Report on Hydrogen and Fuel Cells* report,[96] the DST highlighted that the immaturity of hydrogen codes and standards was a significant barrier to the commercialisation and uptake of hydrogen-based technologies.

1.5.2 India's bilateral hydrogen relationships

Other countries

India has several strong energy and hydrogen-related partnerships with other countries. Major relationships are detailed in Table 11.

Table 11: Formalised relationships with other countries

Country	Relationship	Description
UK	MoU	India and the UK have a strong energy and hydrogen-related partnership. In October 2021, UK Business and Energy Secretary Kwasi Kwarteng met with India's Minister for Power and New & Renewable Energy for the third UK-India Energy for Growth Dialogue. The Dialogue, which commenced in 2015, reiterated the importance of international collaboration and the need to develop a domestic renewable energy sector. The Dialogue solidified the nations' joint commitment to longer-term collaboration, particularly on renewable energy technology development and green finance. [97] In November 2015, India and UK signed a Memorandum of Understanding (MoU) on Cooperation in the Energy Sector. The purpose of the MoU is to facilitate greater collaboration across technical, policy, research and commercial aspects of the development of the energy sector. Key areas of collaboration include market and regulatory reform, new energy technologies and renewable energy deployment.[98]
US	MoU, G2G Agreement, and the Quad	India and the United States have a strong energy and hydrogen-related partnership. In April 2021, President Biden and Prime Minister Modi announced the US-India Climate and Clean Energy Agenda 2030 Partnership which seeks to strengthen collaboration and enhance progress toward shared energy goals. The Partnership

[95] Department of Science and Technology (2020) India Country Status Report on Hydrogen and Fuel Cells. Viewed 23 November 2021, https://static.pib.gov.in/WriteReadData/userfiles/India%20Country%20Status%20Report%20on%20Hydrogen%20and%20Fuel%20Cell.pdf

[96] Department of Science and Technology (2020) India Country Status Report on Hydrogen and Fuel Cells. Viewed 23 November 2021, https://static.pib.gov.in/WriteReadData/userfiles/India%20Country%20Status%20Report%20on%20Hydrogen%20and%20Fuel%20Cell.pdf

[97] India, UK agree joint plan on smart power, renewable energy (2021), The Economic Times. Viewed 25 November 2021, https://economictimes.indiatimes.com/industry/renewables/india-uk-agree-joint-plan-on-smart-power-renewable-energy/articleshow/86874319.cms?from=mdr; UK Government (2021) UK and India agree ambitious collaboration on clean energy https://www.gov.uk/government/news/uk-and-india-agree-ambitious-collaboration-on-clean-energy#:~:text=at%20the%2011th%20Economic%20and,450GW%20renewable%20energy%20by%202030

[98] MRNE (2015) Memorandum of Understanding between the Government of the Republic of India and the Government of the United Kingdom of Great Britain and Northern Ireland on Co-operation in the Energy Sector https://mnre.gov.in/img/documents/uploads/fe78eaff568147b09d47a8d8721e00e4.PDF

Country	Relationship	Description
		has two tracks of engagement: the Strategic Clean Energy Partnership (SCEP) and the Climate Action and Finance Mobilisation Dialogue. Focus areas for the FCEP include advancing the use of hydrogen in transport and industry and deploying CCUS technology.[99] In June 2021, the DOE and the Indian Ministry of New and Renewable Energy (MNRE), in collaboration with the US-India Strategic Partnership Forum, launched the US-India Hydrogen Task Force. The Task Force is a high level bi-lateral collaboration that brings together the industry, research and government sectors with the aim of accelerating RD&D on hydrogen technology.[100] The US and India continue to lead joint R&D programs, including the US-India Partnership to Advance Clean Energy Research (PACE-R) and the South Asia Group for Energy, both of which focus on RD&D on advanced clean technologies.[101] India is also a member of the Quadrilateral Security Dialogue's related Clean-Hydrogen Partnership.
Germany	Partnership	At the 2021 G20 Summit, Germany and India agreed to expand the scope of the India-Germany Strategic Partnership to facilitate increased collaboration on hydrogen production from renewables.
Japan	MoU, G2G Agreement, and the Quad	India and Japan carry out bilateral collaboration under various MoU's and joint agreements which facilitate increased collaboration. In 2019 a Joint statement was issued, reaffirming the 'Japan-India Energy Transition Cooperation Plan.'[102] There have been recent discussions surrounding collaboration in exploring hydrogen prospects and innovative technologies.[103] Japan is also a member country of 'the Quad' commitment to jointly pursuing sectoral decarbonisation efforts and the deployment of clean-hydrogen technologies.[104]
Australia	Letter of Intent	In February 2022, Australia and India signed a Letter of Intent (LoI) on New and Renewable Energy Technology. The partnership will focus on tangible actions to ensure low- and zero- emissions technologies are competitive against other energy alternatives. This includes scaling-up manufacturing and deployment of clean hydrogen technologies.[105] In September 2021, the Quadrilateral Security Dialogue (Quad) between Australia, Japan, India and the US, established the Clean-Hydrogen Partnership. The aims of a clean-hydrogen partnership revolve around reducing costs across the hydrogen value chain; promoting technological development and the scale-up of hydrogen

[99] DOE (2021) US-India Strategic Clean Energy Partnership: Responsible Oil and Gas Pillar (September 2021) https://www.energy.gov/sites/default/files/2021-09/SCEP%20Pillars_Accomplishments.pdf

[100] US-India Hydrogen Task Force (2022) US-India Hydrogen Task Force https://hydrogen-task-force.usispf.org/

[101] FuelCellWorks (2020) US-India Strategic Energy Partnership Launches Hydrogen Task Force https://fuelcellsworks.com/news/us-india-strategic-energy-partnership-launches-hydrogen-task-force/

[102] Joint Statement of 10th Japan-India Energy Dialogue (2019). Viewed 25 November, 20191210003-1.pdf (meti.go.jp)

[103] Press Information Bureau (2021), Ministry of Science and Technology, Experts from India & Japan discussed collaborations for innovations on Hydrogen based technologies. Viewed 25 November 2021, https://www.pib.gov.in/PressReleasePage.aspx?PRID=1712893

[104] The White House (2021) Joint Statement from Quad Leaders [Statements and Releases]. Viewed 26 November 2021, Joint Statement from Quad Leaders | The White House

[105] Minster for Industry, Energy and Emissions Reduction (2022) Australia enters into sixth bilateral low emissions technology partnership [Press release]. https://www.minister.industry.gov.au/ministers/taylor/media-releases/australia-enters-sixth-bilateral-low-emissions-technology-partnership#main-content

Country	Relationship	Description
		production; identifying and developing infrastructure to safely store, transport and utilise hydrogen across various end-use applications; and stimulating market demand across the Indo-pacific for hydrogen and hydrogen related technologies.[106] In June 2020 Australia and India established the India-Australia Comprehensive Strategic Partnership. The Partnership formalised an agreement to continue with a joint energy dialogue in order to facilitate increased cooperation on R&D and commercialisation of cost-effective battery technologies and hydrogen gasification. A new low-emissions technology partnership and low-cost solar program are also being considered.[107] The Australian Department of Foreign Affairs and Trade (DFAT) and Australia-India Council (AIC) holds an annual grant round to fund projects that foster collaboration and bilateral engagement in key priority areas. The 2021/22 round has flagged critical technology, critical minerals, energy and climate change. See *Section 1.3.3 Funding mechanisms* for funding details.[108] In February 2010, Australia's Department of Resources, Energy and Tourism and India's MNRE signed a Memorandum of Understanding (MoU) on New and Renewable Energy Cooperation. The MoU outlines a bilateral commitment to engage in the development, monitoring and evaluation of emerging technologies in areas including hydrogen fuel cells and clean energy services amongst other energy-related areas.[109]
Italy	MoU & Joint Statement	In 2021, India and Italy released a Joint Statement on the Italy-India Strategic Partnership in Energy.[110] The Statement declared both parties would expand the areas of cooperation originally agreed to in a previous MoU signed in 2017. [111] New areas of cooperation include supporting the development and deployment of renewable hydrogen and related technologies in India, smart cities and energy storage solutions and policy and regulatory frameworks (amongst other non-hydrogen related commitments).[112]
France	MoU	In 2020, the MRNE and the French Ministry for the Ecological Transition of the French Republic signed an MoU to facilitate the development of new and renewable energy technologies, including hydrogen. Key aspects of the MoU include the joint training of scientific and technical personnel; knowledge sharing of

[106] The White House (2021) Fact Sheet: Quad Leader's Summit [Statements and Releases]. Fact Sheet: Quad Leaders' Summit | The White House

[107] Department of Foreign Affairs and Trade (2020) Joint Statement on a Comprehensive Strategic Partnership between Republic of India and Australia. Viewed 26 November 2021, https://www.dfat.gov.au/geo/india/joint-statement-comprehensive-strategic-partnership-between-republic-india-and-australia

[108] Department of Foreign Affairs and Trade Australia (2021) International Relations Grants Program: Australia-India Council (AIC) 2021/22 Guidelines. https://www.dfat.gov.au/sites/default/files/australia-india-council-2021-grant-guidelines.pdf

[109] Ministry of New and Renewable Energy (2010) Memorandum of Understanding on New and Renewable Energy Cooperation. Viewed 6 December 2021, https://mnre.gov.in/img/documents/uploads/46115f9a4b0547698c45187921df992c.pdf

[110] Ministry of External Affairs (2021) Joint Statement on Italy-India Strategic Partnership in Energy Transition. Viewed 25 November 2021, https://mea.gov.in/bilateral-documents.htm?dtl/34447/Joint+Statement+on+ItalyIndia+Strategic+Partnership+in+Energy+Transition

[111] Ministry of External Affairs (2017) List of MoUs/Agreements signed during the visit of Prime Minister of Italy to India - October 30, 2017. Viewed 25 November 2021, https://www.mea.gov.in/bilateral-documents.htm?dtl/29067/List_of_MoUsAgreements_signed_during_the_visit_of_Prime_Minister_of_Italy_to_India_October_30_2017

[112] Ministry of External Affairs (2021) Joint Statement on Italy-India Strategic Partnership in Energy Transition. Viewed 25 November 2021, https://mea.gov.in/bilateral-documents.htm?dtl/34447/Joint+Statement+on+ItalyIndia+Strategic+Partnership+in+Energy+Transition

Country	Relationship	Description
		scientific and technological information; transfers of equipment and technology; and joint research and technological projects.[113] In 2018, the Commissariat a l'Energie Atomique et aux Energies Alternatives (CEA) of France and the National Institute of Solar Energy (NISE) of India signed a MoU (in 2018) of which the main area of work comprises of mutually identifying research/demonstration/pilot projects between the two institutes and working towards their implementation in International Solar Alliance (ISA) member countries. This includes operations in the evaluation of hydrogen technologies for storage.[114]
Saudi Arabia	MoU	In 2019, India and Saudi Arabia signed the Memorandum of Understanding (MoU) on Cooperation in the Field of Renewable Energy between Saudi Ministry of Energy and the MRNE. The purpose of the MoU is to increase collaboration between the two countries, with a particular focus on joint renewable energy projects, increasing RD&D on renewable energy, the development of complementary supply chains as well as the application and commercialisation of renewable energy technologies.[115]
Bahrain	MoU	In July 2018, India and Bahrain signed an MoU on Renewable Energy. The purpose of the MoU is to facilitate increased bilateral cooperation and knowledge sharing. India and Bahrain agreed to foster increased collaboration at a government and industry level, particularly in respect of solar, wind and clean hydrogen.[116]
Uzbekistan	MoU	This MoU seeks to identify research/demonstration/pilot projects between India's NISE and Uzbekistan's International Solar Energy Institute (ISEI) in mutually identified areas, including the evaluation of hydrogen technologies for storage. Based on mutual agreement, both parties would towards the implementation and deployment of pilot project in ISA member countries.[117]

1.5.3 India's joint international RD&D projects

The International S&T Affairs Directorate (ISTAD) maintains India's CSIR's collaborative relationship with other international scientific and technical agencies. CSIR has formal relationships with 46 international scientific bodies in 35 countries and openly welcomes collaboration on research projects.[118] For example, a RD&D project led by the International Advanced Research Centre (ACRI) for Powder Metallurgy and New

[113] Press Information Bureau (2021), Cabinet approves Memorandum of Understanding between India and France on Renewable Energy Cooperation. Viewed 25 November 2021, https://pib.gov.in/PressReleasePage.aspx?PRID=1702152; Ministry of New and Renewable Energy (2021) International relations Memorandums. Viewed 25 November 2021, MNRE - International Relation Memorandums

[114] Ministry of New and Renewable Energy (2021) International relations Memorandums. Viewed 25 November 2021, MNRE - International Relation Memorandums

[115] India, Saudi Arabia ink 12 agreements in sectors including renewable energy (2019), Economic Times. Viewed 25 November 2021, https://energy.economictimes.indiatimes.com/news/renewable/india-saudi-arabia-ink-12-agreements-including-renewable-energy/71813013; PV India (2019) Renewable energy MoU with Saudi Arabia gets cabinet nod < India, Saudi Arabia ink 12 agreements in sectors including renewable energy (2019), Economic Times. Viewed 25 November 2021, https://energy.economictimes.indiatimes.com/news/renewable/india-saudi-arabia-ink-12-agreements-including-renewable-energy/71813013

[116] Ministry of New and Renewable Energy (2021) 1st India-Bahrain Joint Working Group meeting in the field of Renewable Energy. Viewed 25 November 2021, https://pib.gov.in/PressReleasePage.aspx?PRID=1695346

[117] Ministry of New and Renewable Energy (2021) International relations Memorandums. Viewed 25 November 2021, MNRE - International Relation Memorandums

[118] Council of Scientific & Industrial Research (2017) International S&T Affairs Directorate (ISTAD), Ministry of Science and Technology. Viewed 25 November 2021, https://www.csir.res.in/divisions/international-st-affairs-directorate-istad

Materials on the 'Design and Development of 20kW Low Temperature Polymer Electrolyte Membrane Fuel Cell with high indigenous content' will be supported by international research institutes and laboratories.[119]

Country	Projects
US	Through the U.S.-India Strategic Energy Partnership, India and the US have launched a public-private U.S. Hydrogen Task Force on joint R&D – which specifically focuses on developing and scaling up the technologies necessary to produce hydrogen from renewable energies and fossil fuel sources, and reducing the costs of at-scale deployment.[120] India and the US also signed an MoU to collaborate on India's first Solar Decathlon which aims to educate students and apprentice builders on how energy efficiency buildings powered by renewables can be designed and constructed.
UK	The scope of the India-UK Joint Virtual Centre for Clean Energy includes advanced research on solar cells, fuel cells and distributed storage (amongst other things).[121] The Virtual Centre includes: • The INDIA-UK Centre for Education and Research in Clean Energy (IUCERCE). UK partners consist of SUPERGEN hubs which link to leading research centres in India (IIT – Bombay, Hyderabad, Kanpur; IIsc – Bangalore; CDAC) in key areas of solar and energy storage; and • The UK India Clean Energy Research Centre (UKICERI). A UK consortium is led by Loughborough University, with India partners including IIEST (Shibpur), MNIT (Jaipur), and the following IIT institutes: Kharagpur, Bangalore, Delhi, Kanpur, Madras, Bhubaneswar.
Australia	The Australia-India Strategic Research Fund (AISRF) supports scientists in Australia and India to collaborate on priority areas of research including clean energy technologies. This funding programme operates by linking cross-country research institutions working on strategically aligned areas of interest. This program is implemented by the Department of Industry, Science, Energy and Resources (DISER) and the DST or the Department of Biotechnology in India.[122]

1.5.4 India's joint international commercial projects

The scope of this report is on research, development and demonstration (RD&D) projects. For information on commercial hydrogen projects, see *HyResource*, an online knowledge sharing platform across the hydrogen community led by CSIRO, Future Fuels CRC, NERA and the Australian Hydrogen Council.

HyResource provides a directory of publicly available databases and information sources on international projects:

- https://research.csiro.au/hyresource/projects/international/

[119] Press Information Bureau (2021) Promotion of Hydrogen as automotive Fuel, Ministry of Science and Technology. Viewed 25 November 2021, https://pib.gov.in/PressReleasePage.aspx?PRID=1742793

[120] FuelCellsWorks (2020) US-India Strategic Energy Partnership Launches Hydrogen Task Force. Viewed 25 November 2021, https://fuelcellsworks.com/news/us-india-strategic-energy-partnership-launches-hydrogen-task-force/

[121] Mission Innovation. INDIA: Plans and Priorities. Viewed 25 November 2021, http://mission-innovation.net/our-members/india/plans-and-priorities/

[122] Department of Industry, Science, Energy and Resources (2021) Collaborating with India on science and research, Australian Government. Viewed 25 November 2021, https://www.industry.gov.au/policies-and-initiatives/increasing-international-collaboration/collaborating-with-india-on-science-and-research

Key commercial projects of note include:

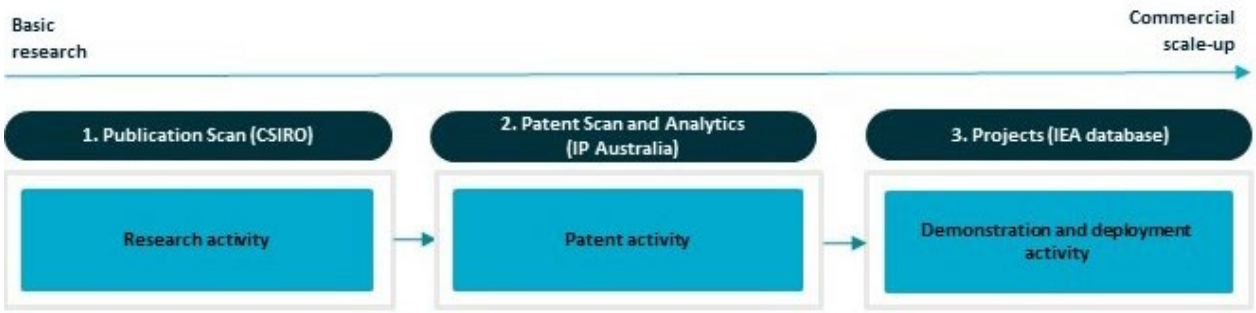
- Australian-based Fortescue Future Industries entered into a framework agreement with JSW Future Energy Ltd to explore development opportunities for hydrogen production and application in India. More specifically, the agreement relates to the identification of potential commercial-scale projects for hydrogen production and end-use application in industrial sectors (including steel fabrication, ammonia production and hydrogen mobility).[123]
- Indian BGR Energy Systems launched a partnership with Ireland's Fusion Fuel Green to establish a demonstrator plant for cost-competitive hydrogen production from renewables in Tamil Nadu, India.[124]
- India's largest solar power developer, Acme Group, entered into an agreement with the Government of Oman to establish a renewable hydrogen and ammonia production facility at the Port of Duqm. Once operational by the end of 2022, the facility is expected to export hydrogen and ammonia to Europe and Asia.[125]
- Several international entities are involved in the development of hydrogen-related infrastructure (particularly storage and distribution) in India. Key companies include Linde (a global member of the Hydrogen council), Air Liquid (France), H2Scan (US), ITM Power (UK), and Inox (an Indo-US joint venture).[126] These projects align with India's ambition to rapidly commercialise hydrogen technology.

1.6 Data insights: India's hydrogen RD&D activity

The following section provides data-driven insights on India's RD&D activity in hydrogen technologies. Research publication data, patent data, and commercial project data has been used to understand hydrogen related activity. While limitations exist with such an approach, these data sources do provide an opportunity to consider activity across the innovation spectrum from basic research to demonstration. It also aims to help identify technology areas that have received significant focus in each country and key organisations to support international collaboration efforts.

The data for this section was sourced from the CSIRO's publications team, CSIRO's IP team, IP Australia, and the IEA's hydrogen projects database.

Figure 5: Hydrogen innovation activity data



[123] Fortescue (2021) Fortescue Future Industries to explore potential green hydrogen projects in India. Viewed 25 November 2021, https://www.fmgl.com.au/in-the-news/media-releases/2021/07/29/fortescue-future-industries-to-explore-potential-green-hydrogen-projects-in-india

[124] Gupta U (2021) Indian-Irish partnership to produce green hydrogen, Pv Magazine. Viewed 25 November 2021, https://www.pv-magazine.com/2021/03/08/indian-irish-partnership-to-produce-green-hydrogen/

[125] Rai-Roche S (2021) ACME to set up 3.5GW green hydrogen facility in Oman in US $3.5bn deal, PV-Tech. Viewed 25 November 2021, https://www.pv-tech.org/acme-to-set-up-3-5gw-green-hydrogen-facility-in-oman-in-us3-5bn-deal/

[126] Department of Science and Technology (2020) India Country Status Report on Hydrogen and Fuel Cells. Viewed 25 November 2021, https://static.pib.gov.in/WriteReadData/userfiles/India%20Country%20Status%20Report%20on%20Hydrogen%20and%20Fuel%20Cell.pdf

1.6.1 Research publication data

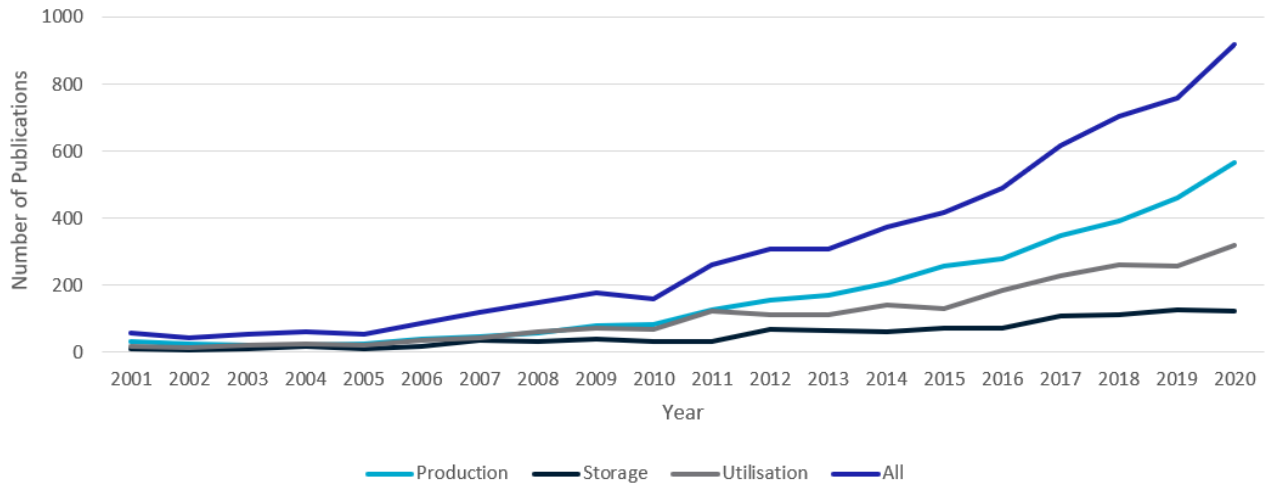
Research publications in hydrogen are an indicator of basic and applied research activity. CSIRO's publications team has conducted a research publication scan to identify Indian organisations conducting research across the hydrogen value chain. The publications search approach was developed in 2019 to support the report *Hydrogen Research, Development and Demonstration: Priorities and opportunities for Australia*. This search approach was applied in 2021 to provide an updated dataset for this report. The details of the search approach can be found in the *National Hydrogen Research, Development and Demonstration (RD&D): Technical Repository*.[127]

Figure 6 shows Indian institutions ranked in terms of publication output across hydrogen production, storage and distribution, and utilisation from 2016-2020. Figure 7 shows India's country-wide research publication output trends across the hydrogen value chain.

Figure 6: Top institutions by publication output (2016-2020)

Domestic Ranking	Production	Storage and Distribution	Utilisation	Overall
	3rd Global Rank	*5th Global Rank*	*5th Global Rank*	*3rd Global Rank*
1st	Council of Scientific and Industrial Research (CSIR)	Council of Scientific and Industrial Research (CSIR)	Council of Scientific and Industrial Research (CSIR)	Council of Scientific and Industrial Research (CSIR)
2nd	National Institute of Technology (NIT System)	Bhabha Atomic Research Centre (BARC)	National Institute of Technology (NIT System)	National Institute of Technology (NIT System)
3rd	Academy of Scientific and Innovative Research (AcSIR)	National Institute of Technology (NIT System)	Indian Institute of Technology (IIT) - Madras	Academy of Scientific and Innovative Research (AcSIR)
4th	Department of Science and Technology (India)	Department of Science and Technology (India)	Academy of Scientific and Innovative Research (AcSIR)	Department of Science and Technology (India)
5th	Indian Institute of Technology (IIT) - Delhi	Indian Institute of Technology (IIT) - Bombay	Indian Institute of Technology (IIT) - Delhi	Indian Institute of Technology (IIT) - Madras

Figure 7: India's hydrogen-related publication output (2001-2020)



[127] CSIRO (2019) National Hydrogen Research, Development and Demonstration (RD&D): Technical Repository. Available at https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/csiro-futures/futures-reports/hydrogen-research

1.6.2 Patent data

Patent activity in hydrogen is an indicator of applied R&D and innovation occurring across the value chain. This section draws on two different patent analytics approaches. CSIRO developed a search approach in 2019 to support the *Hydrogen Research, Development and Demonstration: Priorities and opportunities for Australia* report. CSIRO applied this approach to provide a patent landscape across the hydrogen value chain for each country. The details of the search approach and any limitations can be found in the *National Hydrogen Research, Development and Demonstration (RD&D): Technical Repository*.[128] The second approach, performed by IP Australia, builds on the hydrogen technology taxonomy developed in CSIRO's 2019 report to provide information on specific hydrogen technologies that sit within production, storage and utilisation. The full data visualisations, details of the search approach and any limitations can be found at *Patent analytics of hydrogen technologies: an interactive visualisation*.[129]

It should be noted that analysis of patent data is not necessarily representative of patent impact. As such, this data should be viewed holistically with the other data presented in this section, particularly project deployment.

Patent landscape of hydrogen value chain

Performed by the CSIRO, this patent landscape analyses patent family[130] filings across the hydrogen value chain. Figure 8 outlines patent filings over time across the areas of hydrogen production, storage/distribution and utilisation. Figure 9 shows the jurisdictions in which Indian patent applicants are filing patents, outside of India. This provides an indication of which global markets, or manufacturing/commercialisation destinations are of interest to Indian patent applicants or inventors.

Note that patent databases have a delay of roughly 18 months, therefore 2020 and 2021 have been omitted from the graphs below. Some patent filings may also be counted twice as the categories of production, storage and utilisation may not be mutually exclusive in all instances and some could relate to multiple areas of the hydrogen value chain.

[128] CSIRO (2019) National Hydrogen Research, Development and Demonstration (RD&D): Technical Repository. Available at https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/csiro-futures/futures-reports/hydrogen-research

[129] IP Australia (2021) Patent Analytics on Hydrogen Technology, Australian Government. Available at https://www.ipaustralia.gov.au/tools-resources/publications-reports/patent-analytics-hydrogen-technology

[130] Applications with the same priority, but filed in different jurisdictions, are known as patent families. Patent families enable us to analyse inventive activity regardless of the number of countries in which protection is sought. Patent families are used in analytics to represent a single invention.

Figure 8: Patent filings over time across production, storage/distribution and utilisation

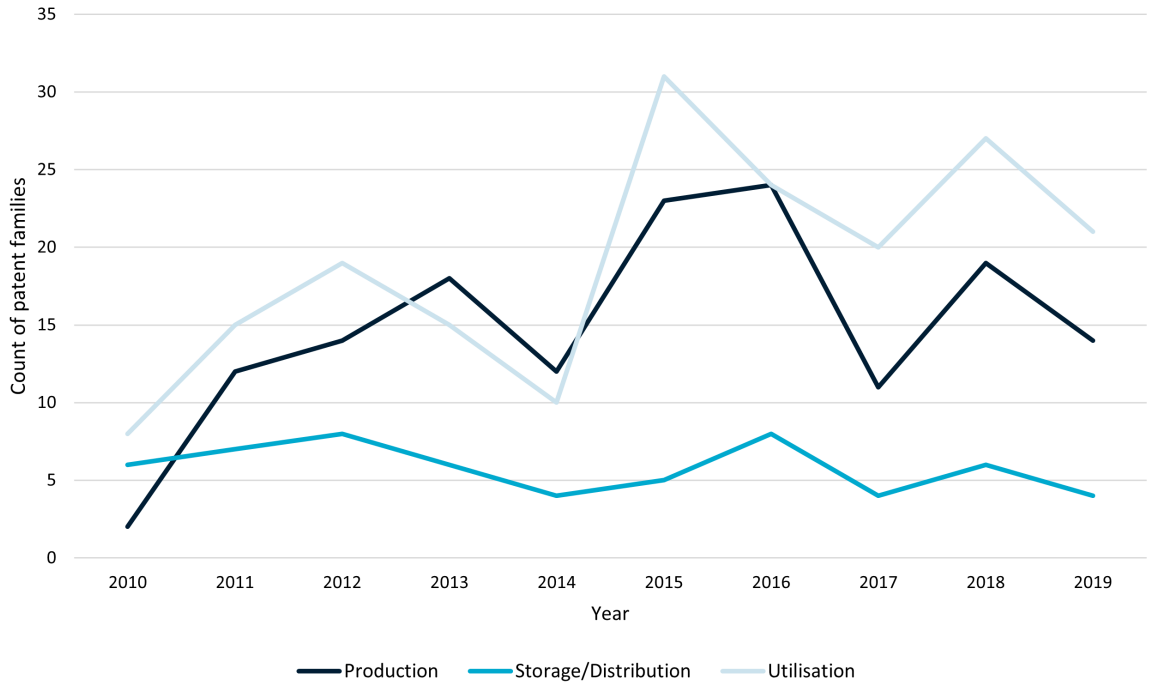
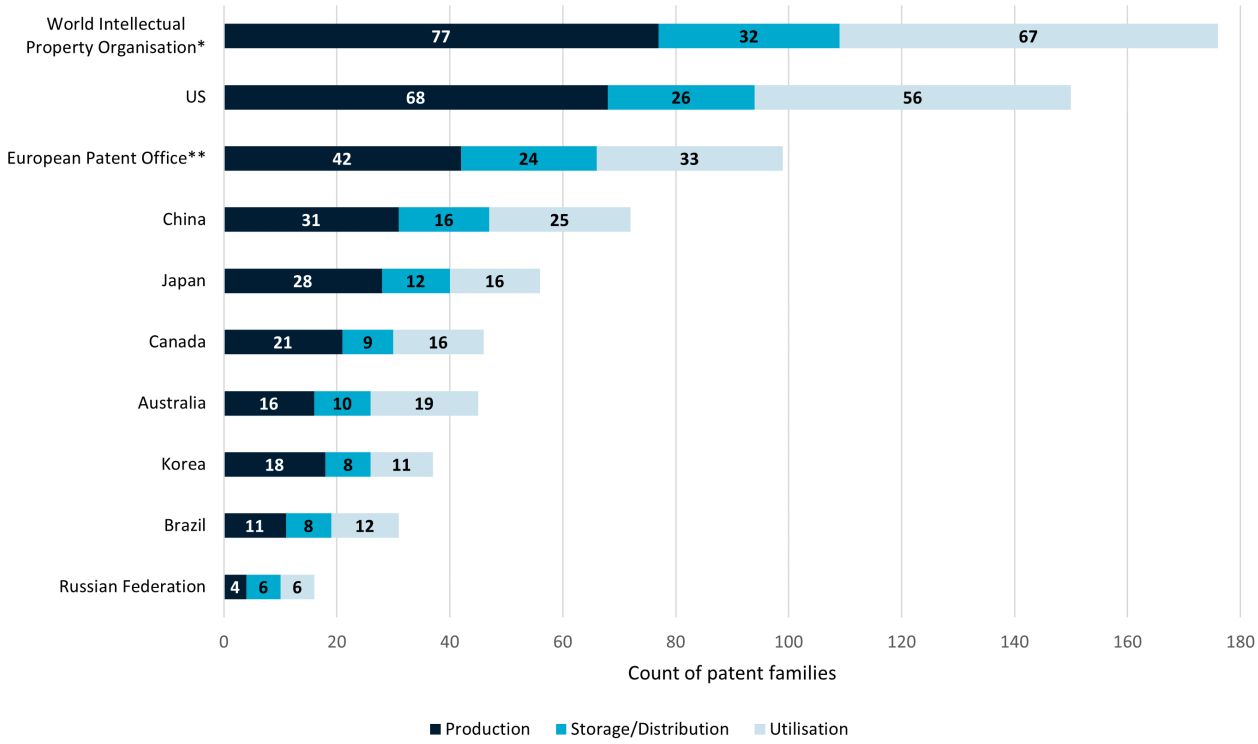


Figure 9: Location of patent filings by Indian patent applicants



*** The World Intellectual Property Organisation (WIPO) is an international organisation that promotes the protection of intellectual property and supervises administrative cooperation amongst the intellectual unions regarding protection of intellectual property. Patents filed in the WIPO enables applicants to obtain protection for their inventions in up to 153 of the parties to the Patent Cooperation Treaty.**

**** The European Patent Office enables investors, researchers and companies to obtain protection for their inventions in up to 44 countries, including all 27 EU member states.**

Patent analytics of specific hydrogen technologies

Data extracted from IP Australia's interactive visualisation provides an in-depth analysis of specific hydrogen technology developments. Figure 10 shows the number of patent families filed since 2010 for specific technology areas by Indian applicants.

Table 12 shows the number of patent families filed by Indian applicants since 2010 by sub-technology area, expressed as a percentage of total global patent family filings. Table 12 also shows the top organisations in India filing patents in each technology area. It should be noted that the majority of fuel cell technologies are categorised under the 'electricity generation' category.

Figure 10: India's patent family output by sub-technology area (2010-2020)

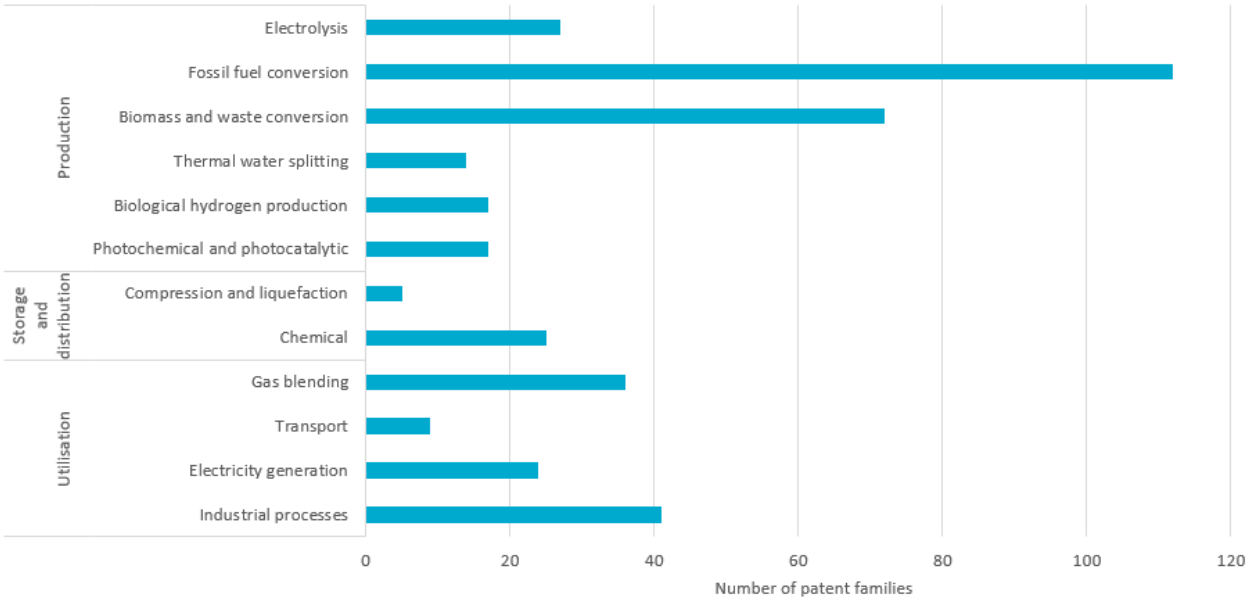


Table 12: India's IP output (number of patent families filed by Indian applicants) by sub-technology area from 2010-2020

Technology area		IP output (% of global)	Leading companies	Leading non-profits and universities
Production	Electrolysis	0.3%	Xh20 Solutions Private	Institute of Chemical Technology, ONGC, Council of Scientific and Industrial Research
	Fossil fuel conversion	1.8%	Indian Oil, Hindustan Petroleum, Reliance Industries, Bharat Petroleum	Council of Scientific and Industrial Research
	Biomass and waste conversion	2.4%	Indian Oil, Reliance Industries, Centre for High Technology, Bharat Petroleum, Hindustan Petroleum	Council of Scientific and Industrial Research, Institute of Chemical Technology, Centre for High Technology (CHT), ONGC
	Thermal water splitting	1.9%	Indian Oil	Council of Scientific and Industrial Research, Indian Institute of Science Education and Research, Indian Institute

Technology area		IP output (% of global)	Leading companies	Leading non-profits and universities
				of Technology, Jodhpur, Indian Educational and Research Institute
	Biological	0.7%	Megafine Pharma (P), Swasa Agro Solutions Private, Hindustan Petroleum, Centre for High Technology, Sphaera Pharma	Council of Scientific and Industrial Research, the Energy and Resources Institute, Jamia Hamdard
	Photochemical and photocatalytic	0.9%	N/A	Council of Scientific and Industrial Research, Indian Institute of Technology, Jodhpur, Indian Institute of Technology, Guwahati
Storage and distribution	Compression and liquefaction	0.7%	Tata Motors	N/A
	Chemical storage	1.0%	Thermax (Zhejiang) Cooling & Heating Engineering, Bharat Petroleum Corporation Limited (BPCL)	Council of Scientific and Industrial Research
Utilisation	Gas blending	2.5%	Indian Oil, Hindustan Petroleum	Council of Scientific and Industrial Research
	Transport	0.4%	N/A	N/A
	Electricity generation	0.6%	H2E Power Systems	N/A
	Industrial processes	0.9%	Indian Oil, Nagaarjuna Shubho Green Technologies, Shubho-Tech, Reliance Industries, Solara Active Pharma Sciences	Council of Scientific and Industrial Research, Indian Institute of Technology, Guwahati

IP Australia patent analytics on hydrogen technology

IP Australia has developed an interactive visualisation tool to provide hydrogen insights to researchers, academics, business and policy sectors. For more hydrogen IP statistics including key destination markets, origin profiles, applicant profiles, collaborations and specific patent searches, refer to IP Australia's Hydrogen Patent Landscape tool:

- https://www.ipaustralia.gov.au/tools-resources/publications-reports/patent-analytics-hydrogen-technology

1.6.3 Project data

Data from the IEA Hydrogen Projects Database (as at October 2021)[131] provides insight on clean hydrogen technology value chains deployed at pilot and commercial scale across India. Note that the following limitations should be taken into account:

- The database does not indicate whether the technologies used are indigenous or purchased from an overseas provider. While many countries often deploy their own technologies at scale, many countries purchase technologies from overseas to deploy locally. As such the database indicates deployment activity, but not necessarily the ability to translate indigenous R&D into commercial scale-up.
- This dataset counts only low-carbon hydrogen projects and their associated value chains. As such hydrogen production projects from gas, coal and oil without CCS are not included. Similarly, utilisation projects not related to a clean hydrogen project source are not included.
- The dataset reflects only projects occurring domestically, and therefore does not count projects undertaken by Indian companies outside of India. As such, the table may understate India's activity, particularly its contribution to international supply chain development. This data should therefore be considered holistically with the rest of this report.
- Any limitations stated in the data collection methodology, definitions and assumptions should be taken into account (see IEA Hydrogen Projects Database for details).

For the purposes of this report, the dataset has been filtered to include only projects from 2010 through to projects expected to be operational by 2030 as this timespan best reflects current activities. Projects without a specified date have been excluded from the table below. Further, only projects that are at feasibility study, final investment decision, demonstration, or operational stage are included. Projects at the 'concept' stage are not included. It should be noted that the majority of projects listed span production, storage and multiple end-uses, and as such can be counted in more than one technology category.

Table 13: India's domestic clean hydrogen project data

Technology	Sub-technology		Domestic project count	% of global
Production	Electrolysis	PEM	1	0.5
		Alkaline	1	0.9
		SOE	-	-
		Other or unspecified	4	1.6
	Fossil fuel conversion	Coal gasification with CCS	-	-
		Natural gas with CCS	-	-
		Oil with CCS	-	-
		Methane pyrolysis	-	-

[131] IEA (2021) Hydrogen Projects Database. Available at https://www.iea.org/data-and-statistics/data-product/hydrogen-projects-database

Technology	Sub-technology		Domestic project count	% of global
	Biomass and waste conversion		1	6.7
	Photochemical and photocatalytic		-	-
	Biological production		-	-
	Thermal water splitting		-	-
Storage and distribution	Compression and liquefaction		7	1.4
	Chemical carriers	Ammonia	-	-
		Methane	-	-
		Methanol	-	-
		Synfuels	-	-
Utilisation	Gas blending		-	-
	Transport		2	0.8
	Electricity generation		4	3.0
	Industrial processes	Refining	-	-
		Ammonia	-	-
		Methane	-	-
		Iron and steel	-	-
		Biofuels	-	-
		Synfuel	-	-
		Other industry	-	-

IEA Hydrogen Projects Database

The latest version of the IEA Hydrogen Projects Database can be found at:

- https://www.iea.org/data-and-statistics/data-product/hydrogen-projects-database

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