Towards a Clean Hydrogen Ecosystem: Opportunities for Indo–Dutch Cooperation

Netherlands Innovation Network

Kingdom of the Netherlands

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Suggested citation

The Energy and Resources Institute (TERI). 2022. *Towards a Clean Hydrogen Ecosystem: Opportunities for Indo–Dutch Cooperation*. New Delhi: TERI

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Foreword

Climate change is one of the biggest challenges of our times. With rising temperatures, shifting rainfall patterns, melting glaciers, droughts and wild fires happening all around us, it severely threatens human civilization and the natural world. The call to action has never been so urgent. It is the responsibility of all countries to address this issue as a national priority individually, but also in unison with others.

The Dutch government pledged to reduce greenhouse gas emissions by 55% by 2030, compared to 1990 levels, and achieve net-zero by 2050. To make this ambition a reality, government combined forces with Dutch stakeholders and committed to the National Energy and Climate Plan and the National Climate Agreement. The development and utilization of clean hydrogen will play an important role in this. Our government, therefore, recently launched a specific National Hydrogen Strategy, which entails policies, regulation, funding, and an international strategy to help meet hydrogen and energy transition goals.

With more than 150 hydrogen organizations, the Netherlands has a wide range of expertise, from green hydrogen production and storage to developing end applications for industries and society. Today, hydrogen production accounts for 10% of our total national gas consumption. We wish to increase this significantly in the years to come, and also transition towards a clean hydrogen ecosystem.

We, therefore, look beyond our borders and wish to establish research, trade and innovation partnerships with nations with expertise, talent and similar ambitions. India is a natural partner to work with, as we have strong ties collaborating in the field of trade, science, technology, and innovation. We very much welcome India's ambitions to achieve carbon net neutrality by 2070 and to become a global hub of green hydrogen production in the years to come.

The report in front of you is the outcome of such a collaboration. We worked together with TERI to organize round tables, do research and find potential opportunities for our countries to work together on clean hydrogen across the value chain. I invite you to read the report to learn more about the hydrogen ecosystems of both countries, and specifically to explore opportunities for international collaboration in the field of business, government, academia, and innovation. Together, I firmly believe, we can accomplish more than alone.

Marten van den Berg

Ambassador of the Kingdom of the Netherlands to India, Nepal and Bhutan

Preface

Climate change is a reality and realizing this the Government of India has announced its ambitious target of net-zero emissions by 2070 during COP26. The government is planning to do this through a multi-pronged strategy of enhancing renewable power generation, improving carbon sequestration efforts and switching to carbon neutral fuels. A major role is likely to be played by hydrogen as energy carrier, carbon free fuel and carbon substitute in industrial and chemical processes. The Government of India under the leadership of Hon'ble Prime Minister Mr Narendra Modi has announced National Hydrogen Mission, and various policy and regulatory initiatives are being planned to promote green hydrogen in India. TERI as a pioneering organisation in the sector has focused on developing the right kind of knowledge reports on the subject over the last couple of years.

In today's interconnected world, international cooperation and techno-economic collaborations are necessary to progress together on issues of common interest like climate change mitigation. In this context, we at TERI are happy to work together with the Dutch Embassy and bring out the joint report focusing on cooperation between the two countries in promoting clean hydrogen economy in India.

I hope you will find the report interesting and useful as a knowledge tool to identify the opportunities for developing joint programmes and business ventures between the organisations from both the countries in green and clean hydrogen sector. We at TERI are committed to working together to achieve the net-zero vision of the Government of India.

Dr Vibha Dhawan

Director General,
The Energy and Resources Institute (TERI)

Acknowledgements

We would like to extend our sincerest thanks to the Netherlands Innovation Network and The Embassy of the Kingdom of Netherlands in India. This work would not have been possible without their financial support and guidance. We would like to thank the following experts for their inputs:

» Mr K R Jyothilal, Principal Secretary, Transport, Government of Kerala

» Dr Sanjeev K Varshney, Head, International Cooperation, DST, Delhi, India

» Mr Han Feenstra, Senior Policy Officer, Ministry of Economic Affairs and Climate Policy

» Prof. R V Ravikrishna, Professor, Department of Mechanical Engineering, Indian Institute of Science, Bangalore, India

» Dr Avinash Kumar Agarwal, Professor, Department of Mechanical Engineering, Indian Institute of Technology Kanpur, India

» Dr R Balaji, Senior Scientist, International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI), India

» Prof. K P Karunakaran, Professor, ME Department, Indian Institute of Technology Bombay, India

» Prof. Dr PV Aravind, Professor of the Chair of Energy Conversion, University of Groningen, Netherlands

» Mr Lennart van der Burg, Program and Business Development Manager Green Hydrogen, TNO, Netherlands

» Mr Gerard Merkens, Regional Sales Manager, Xebec Asia, Netherlands

» Prof. Richard van de Sanden, Eindhoven Institute for Renewable Energy System, Netherlands

» Prof. Thijs Groot, Eindhoven Institute for Renewable Energy System, Netherlands,

» Mr Vijay Namjoshi, Chief-Generation, Tata Power, India

» Mr Debashisa Manasa Ranjan Panda, GM, NTPC Renewables, India

» Mr Vivek Singla, President New Business, ReNew Power, India

» Dr Renny Andrew, Chief Manager (R&D), Bharat Petroleum Corporation Ltd., India

» Dr N S Raman, Director, Centre for High Technology, India

» Mr Frank Wouters, Senior Vice President New Energy, Reliance Industries

» Mr Roel van de Pas, CCO, Nedstack fuel cell technology, Netherlands

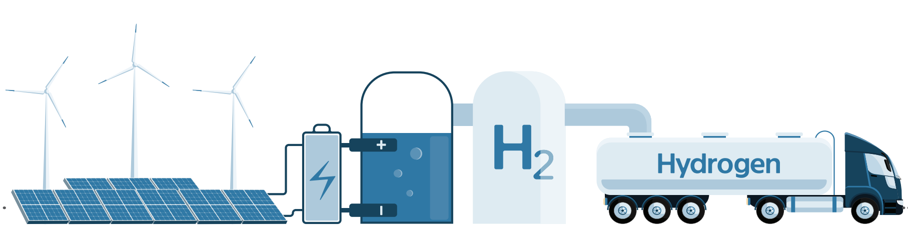
» Dr Matti M van Schooneveld, Business Development Manager, Magneto special anodes B.V., Netherlands

»   Mr Guido Dalessi, CEO Elestor BV, Netherlands

»   Mr Gerard Merkens, Regional Sales Manager, Xebec Asia, Netherlands

»   Mr Bart Biebuyck, Executive Director of Clean Hydrogen Partnership, Netherlands

Our thanks to TERI colleagues from the Industrial Energy Efficiency Division, Electricity and Fuels Division, and the Renewable Energy Technologies Division for their contribution. Thanks to TERI Press for their support with publishing of the report, and Ms Pooja Gulati for transcription and logistical support. We thank Mr Girish Sethi , Senior Director, TERI and Dr Vibha Dhawan, Director General, TERI for their support and guidance.



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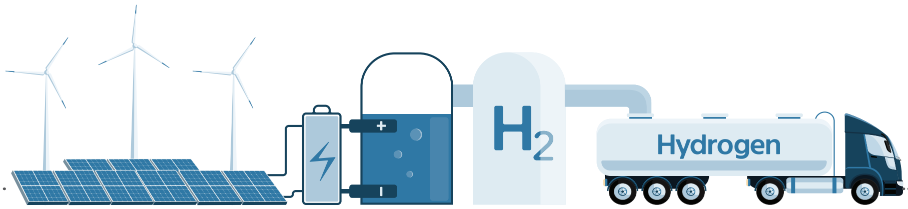

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Hydrogen

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Executive Summary

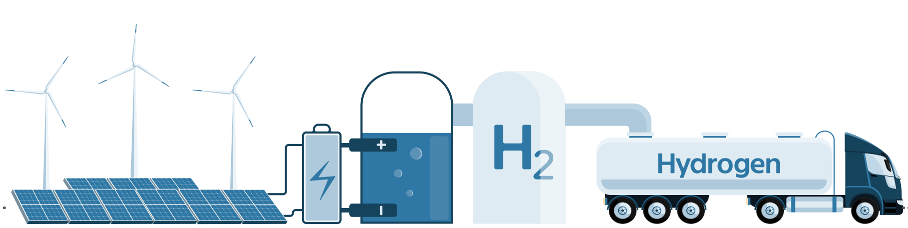
Climate change is one of the biggest threats to human civilisation. Collaborative actions at global levels are essential to intensify efforts in combating this threat. India has been an early advocate of the global fight against climate change. The Government of India has made aggressive commitments to the international community during the climate negotiations, i.e., by the year 2070, India will achieve the target of Net-Zero. In order to realise this goal, one of the key areas the government is focusing on is to maximise renewable energy (RE) generation. Hence, India has set a target to increase the non-fossil energy capacity to 500 GW by 2030. This is being complimented by announcement of Green Hydrogen Policy as this is seen as the main route for decarbonising hard-to-abate sectors like industries and transport. International collaborations and partnerships are going to play an important role in achieving these targets. Realising this, TERI and Netherlands Innovation Network developed this report, which maps the opportunities and challenges for Indo-Dutch collaborations in the clean hydrogen sector. Clean hydrogen hereby stands for hydrogen produced either using renewables (green hydrogen) or hydrogen produced using steam methane reformation processes with carbon capture utilisation and storage technologies (also known as blue hydrogen). This report provides a broad overview of the current and future scenario of generation, supply, storage & handling and demand for hydrogen in India. It covers the supply situation of hydrogen in India and also assesses the potential of generating hydrogen through various resources. The report then covers progress made by Dutch stakeholders in developing hydrogen-related technologies and projects. Finally, the report focuses on identifying the opportunities for collaborative work possible.

India currently consumes about 6.17 million tonnes (MT) hydrogen annually. It is projected that India's hydrogen consumption will grow to 28 MT per year by 2050. Currently, grey hydrogen is predominantly used in fertiliser and refinery sectors, however, hard-to-abate sectors such as cement, steel and transport can be potential hydrogen consuming sectors in the future. As of now, consumption is mainly "grey hydrogen", which is produced using steam methane reformation process using natural gas generated carbon dioxide (CO_2), a major greenhouse gas (GHG). Currently, grey hydrogen costs around \$2.12–2.65 per kg considering the natural gas input of \$10–12 per Metric Million British Thermal Unit (MMBtu). On the contrary, green hydrogen is produced by the electrolysis of water and is now 2–3 times costlier than grey hydrogen in the Indian market. As per TERI's report on the potential role of hydrogen in India, the cost of green hydrogen will be reduced by more than 50% by 2030 and will become competitive in comparison to grey hydrogen. These cost reductions would be driven by the decrease in the cost of renewables and electrolysers in India.

India's biggest industry giant Reliance Industries limited announced its plans to become one of the largest blue hydrogen producers by re-purposing its Jamnagar refinery. India has an estimated 500–1000 BT of the hydrogen storage potential in geological formations. As per the analysis by the International Energy Agency (IEA), some of the potential sites for carbon capture in India include parts of Gujarat, Madhya Pradesh, the Cauvery basin (Andhra Pradesh and Tamil Nadu), and the Assam Basin in the northeast regions of Nagaland, Manipur, and Tripura. In order to create an enabling environment, the Government of India has taken various research and demonstration projects to capture CO_2 for producing blue hydrogen engaging the corporate sector as well the public sector undertakings.

The project team engaged with key stakeholders to discuss research and business opportunities as well as bottlenecks in the Indian hydrogen sector. The discussions revolved around future price trends of green hydrogen, new focus sectors, enabling policies and incentives by the Government. There is an urgent need and a lot of potential for public-private partnership and cooperation between the two countries to build and strengthen the hydrogen ecosystem. It was asserted that a lower RE power tariff and large RE generation capacities in India provide an opportunity for Dutch technology transfer specific to the transport (heavy truck and shipping) sector and electrolyser technology where Dutch industries can play a major role to transform India into a green hydrogen hub. On the consumption side, potential sectors that can be targeted were identified as refineries, petrochemical, fertiliser, steel and cement industries, where grey hydrogen can be replaced with clean hydrogen. On the supply side, feedstocks for hydrogen generation through biomass gasification routes could be a potential area to be explored in India. The foreseen challenges by the Dutch industries to venture into the Indian market are the adoption of specific technology to meet the local conditions and markets, scaling-up hydrogen technology, development of the indigenous supply chain, and skill developments.

The study also identified possible areas of R&D collaboration like electrolyser manufacturing, research in materials for hydrogen storage devices, development of materials and subsystems, amongst others. A significant advantage is that India and the Netherlands already have strong industrial cooperation, with more than 200 Indian and Dutch companies working in respective countries, as well as existing research calls and funds. This can be leveraged for developing strong ties in the era of a hydrogen economy.



Research Recommendations	Business recommendations: Hydrogen Generation and Storage
» Explore university-to-university bilateral research collaboration agreements for funding joint research on hydrogen with industry participation. » Set up talent and expert exchange programs. » Utilize bilateral academic hydrogen infrastructure design consultancy. » Establish Indo-Dutch Centre of Excellence for carrying out pilot projects, training, and capacity building, testing and technology benchmarking infrastructures. » Explore bilateral relations in planning for hydrogen valleys in three regions. » Development of standards and safety regulations.	» Explore joint venture projects for offshore wind hydrogen production facility. » Set up CCUS and CCS studies for storage sites and CO_2 utilisation technologies. » Consider joint venture projects for electrolyser-manufacturing facilities with Indian industries. » Consulting opportunities for infrastructure development, especially hydrogen handling and storage facilities at both ports and generation plants. » Employ consulting opportunities in hydrogen pipeline infrastructure design, development, and installation.
Business recommendations: Hydrogen Utilisation	**Government Recommendations**
» Explore project development/ consulting in setting up hydrogen plants/facilities at refineries, fertiliser plants, steel plants, cement plants, and so on. » Create joint venture opportunities with Indian shipbuilding companies for hydrogen. » Set up joint projects with major public sector organisations for demonstration projects such as hydrogen fuel cell-powered buses, trucks, and fork lifts. » Fuel cell-manufacturing facilities in India. » Consider Indian investments in facilities in the Netherlands. » Joint projects with the state governments to plan and create integrated facilities based on hydrogen valley concept.	» The Ministry of New and Renewable Energy, Government of India, the nodal ministry for renewable energy and hydrogen development, and the Embassy of the Netherlands in Delhi can form a joint action group with members from other ministries and organisations including representatives from industry and think tanks. The group can then focus on developing road map for joint collaborations. » Design a separate call for research and development cooperation with NL and DST. The call could be industry-driven, focusing on transfer of technology. » “Seeing is believing.” A joint visit of Indian government, industry, and academia can be organised to the Netherlands to visit various projects and research facilities. This visit would be useful for mutually benefitting collaboration, and should be also organised for Dutch stakeholders to visit India. » State-level government-to-government collaborations can be explored with Indian state governments and state government-owned public sector units for infrastructure planning and development.

1. Introduction

Climate change is one of the biggest threats to human civilisation. Collaborative actions at global levels are essential to intensify the efforts in combating this threat. India has been an early advocate of global fight against climate change. Since 2008, India has stepped-up its efforts to decarbonise its economy by announcing its National Action Plan on Climate Change (NAPCC) in 2008. Further, India ratified Paris Agreement in October 2016[1] and announced its Nationally Determined Contributions (NDCs) under Paris Agreement. During the COP26 in 2021, India announced its five ambitious goals to address climate change, as given below:

1. India will increase its non-fossil energy capacity to 500 gigawatt by 2030.
2. India will meet 50% of its energy requirements till 2030 with renewable energy.
3. India will reduce its projected carbon emission by one billion tonnes by 2030.
4. India will reduce the carbon intensity of its economy by 45% by 2030.
5. India will achieve net-zero emissions of greenhouse gases (GHGs) by 2070.

Hydrogen produced in a clean way is fast emerging as a viable option to replace fossil fuels and carbon-based chemical processes in hard-to-abate industries such as steel, cement, fertilizers, refineries and sectors such as transport and power. This form of clean hydrogen is broadly defined as hydrogen produced from renewables or from natural gas/coal with carbon capture, storage and utilisation technologies. Thus, resulting in no or less emission of CO_2. As of now, 95% of hydrogen produced around the world is 'grey hydrogen', produced from fossil materials such as natural gas and coal. It is a global challenge, which requires efforts from government, academia, business and society, to scale up the production of clean hydrogen, produced from renewable energy sources.

Understanding that clean green hydrogen[2] is expected to play a key role in achieving the above mentioned targets, India launched its National Hydrogen Mission in August 2021, also publishing its Green Hydrogen Policy in February 2022,[3] as first initiative under the National Hydrogen Mission to promote production and utilisation of green hydrogen and green ammonia. A comprehensive National Hydrogen Mission document is also under preparation.

The Netherlands[4] has been at the forefront of advanced hydrogen research and development for the last few decades. Even though it is a small country, it is currently Europe's second largest hydrogen producer with an annual production of over 9 million m^3 of hydrogen. On 30 March, 2020, the Dutch

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[1] Details available at <https://pib.gov.in/newsite/PrintRelease.aspx?relid=151205>, last accessed on 3 June 2022.

[2] Green hydrogen is hydrogen produced using renewable energy and bio energy resources.

[3] Details available at <https://powermin.gov.in/sites/default/files/Green_Hydrogen_Policy.pdf>, last accessed on 10 March 2022.

[4] Also referred as the Dutch in the document

Government announced the Dutch National Hydrogen Strategy (DNHS) with a comprehensive policy agenda (Kamerstuk 32 813, nr. 485), based on the commitments made in the National Climate Agreement (Klimaatakkoord).[5] Apart from developing technologies for hydrogen generation, storage and utilisation, the country has developed innovative projects and concepts like PosHYdon[6] and the Green Hydrogen Valley.[7]

Together, India and the Netherlands have long history of bilateral relationship. There are over 200 Dutch companies present in India. At the same time, India has established more than 200 companies in the Netherlands. On 28 September 2020, NITI Aayog and the Embassy of the Netherlands in New Delhi signed a Statement of Intent (SoI) to support the decarbonisation and energy transition agenda for cleaner and more energy and sustainable growth.[8]

India and the Netherlands both see hydrogen as an important component to decarbonise hard-to-abate sectors and energy systems. Partnerships between India and the Netherlands can be valuable, given the Indian ambitions and market scale as well as Dutch experience and expertise across all areas of the hydrogen value chain. Collaborations will be necessary to meet future green hydrogen demand and support the rapid deployment of hydrogen technologies in the near term. Bringing together industry, academia and government stakeholders from both countries to build partnerships for co-innovation between India and the Netherlands will improve the chances of success.

Realising the immense potential for mutually beneficial association of the Indian and Dutch Government agencies, research institutes, academia and industry, the Netherlands Innovation Network in India and The Energy and Resources Institute (TERI) worked together to develop this report to map the road-ahead for clean hydrogen cooperation between the two countries.

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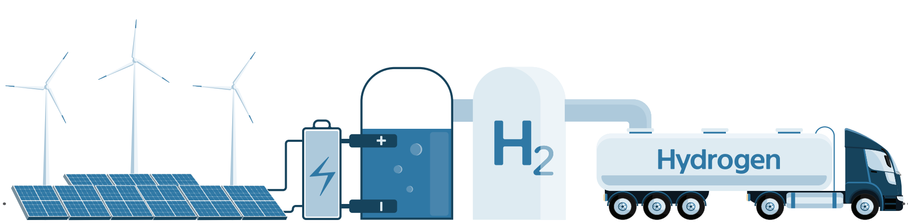
5 Details available at <https://www.cliffordchance.com/content/dam/cliffordchance/briefings/2021/03/focus-on-hydrogen_strategy-for-hydrogen-energy-in-the-netherlands_10.3.pdf>, last accessed on 15 March 2022.

6 Poshydon | Green Hydrogen Energy project aimed to generate hydrogen on an offshore platform using wind energy and seawater conversion

7 Hydrogen valley is broadly defined as geographical area where green hydrogen production, storage and utilisation facilities are concentrated

8 Details available at <https://mea.gov.in/Portal/ForeignRelation/Bilateral_Brief_April_2021.pdf>, last accessed on 3 June 2022.



Hydrogen Classification

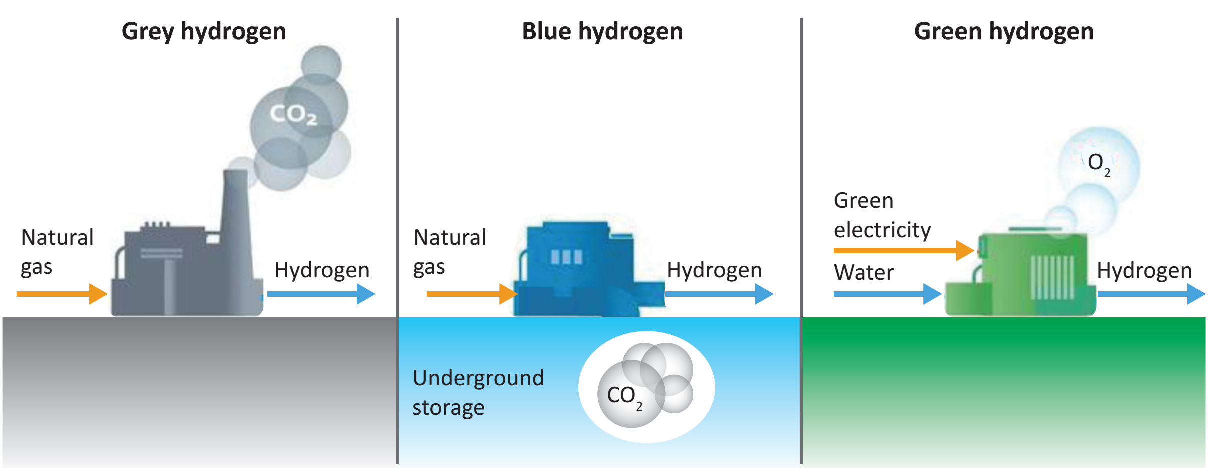
On the basis of generation method, the produced hydrogen is categorised as grey, brown, blue, and green hydrogen. Blue and green hydrogen together is termed as clean hydrogen.

» **Grey hydrogen** is produced using fossil fuels such as natural gas and coal without capturing the released carbon. It currently makes up the near totality of the hydrogen produced in India. The common method utilised for producing grey hydrogen from natural gas is steam methane reforming (SMR), where high-temperature steam (700–1000°C) is used to produce hydrogen from natural gas.

» Gasification of coal resources is another type of technology for producing **brown hydrogen**, which also releases carbon dioxide in the process. Owing to carbon emissions, it is named brown hydrogen.

» **Blue hydrogen** uses the same process as grey hydrogen (SMR and coal gasification), except in this case the emitted carbon is captured and stored. Grey hydrogen with carbon capture and storage (CCS) becomes more environmentally friendly, but is accompanied by high cost and added technical challenges. It can capture 90% of the CO_2 produced and CO_2 can be transported through pipelines and can be stored in deep underground, often in salt caverns or depleted oil and gas reservoirs. Captured CO_2 can be utilised for producing chemicals like methanol or in green houses for growing plants.

» **Green hydrogen** is produced with renewable or clean power instead of using fossil fuels. Green hydrogen is said to be the cleanest way for hydrogen production as it utilises renewable electricity for hydrogen generation and no GHG emissions are associated with the hydrogen generation. It is produced by splitting water through an electrolysis process. The electricity coming from renewable energy resources such as solar or wind energy resources powers the electrolyser for electrolysis, thus producing H_2 and O_2. Further hydrogen can be stored in form of gas or liquid and O_2 is released into the atmosphere without causing any carbon emissions. Hydrogen produced through biomass gasification or anaerobic digestion of biodegradable waste is also classified as green hydrogen.

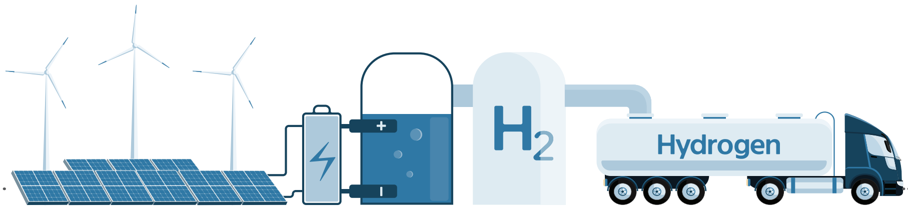


Objectives

The objectives of this report are multiple. The overall objective is to make a comprehensive documentation of the green hydrogen market and evolving ecosystem in India vis-à-vis Dutch green hydrogen sector with identification of mutually beneficial opportunities for joint collaborations in research, industries, and projects. It also aims to help the Dutch and Indian stakeholders from business, academia, and government understand the current state of the Indian hydrogen ecosystem, to help navigate the business and research sector by providing mappings of these sectors. The report takes a holistic view of India's hydrogen mission and Indian hydrogen sector covering policies, regulatory frameworks, mapping key research, academia and industry players and their activities, and so on. The report also analyses opportunities and barriers for Dutch players to work in India and assist them in developing their strategies and plans for Indian markets. Finally, it also includes recommendations on a way forward to create mutually beneficial ecosystems which would enable to work together in developing green hydrogen economy in India.

Approach and Methodology

The approach and methodology adopted for study is based on secondary data analysis and interactive sessions with important stakeholders from both countries. Two roundtables were organised in March 2022. One roundtable focused on business-to-business interactions while the second one was dedicated towards interaction between research institutes and academia from India and the Netherlands. Both these interactions were fruitful, had exchange of knowledge, and identified opportunities for mutual cooperation. The data compiled during the study has been analysed and presented here. This report is the final outcome of the project.



2. India's Hydrogen Policy and Regulations

India's hydrogen journey started in the early 2000s. In 2006, the Ministry of New and Renewable Energy (MNRE) released *National Hydrogen Energy Road Map: Vision 2020*, developing policy narratives and guidelines. The road map focuses on developing a hydrogen supply chain in India in several sectors. Under this road map, the MNRE identified the following two key important areas:

1. Initiatives for greening future transport vehicles by promoting hydrogen fuel cell-based vehicles.
2. Exploring possibilities for power generation through hydrogen fuels.

Infrastructure for developing hydrogen-based economy and exploring global collaboration opportunities was also highlighted in the road map. The road map also set target of green hydrogen production of 1 MT per annum by 2030.

A high-level committee was formed by the Government of India in 2016 to review the progress made under the National Hydrogen Mission Road Map and eminent Indian scientist Dr K Kasturirangan was appointed as a chairperson of the committee. The committee identified the following themes to develop hydrogen-based technologies:

» Developing novel hydrogen production technologies
» Hydrogen storage and transportation
» Developing awareness and safety standards
» Focus on developing hydrogen infrastructure through a public–private partnership

Based on recommendations from the committee for the development of the hydrogen value chain, the MNRE released a report in 2016 titled *Hydrogen Energy and Fuel Cells in India: the way forward report.*[9] The report highlighted the utilisation of hydrogen energy and fuel cells in the industries and transport sector, encouraging the production of hydrogen from renewable energy resources. It focused on exploring affordable technologies to be developed for the production, storage, and applications of hydrogen in the transportation sector as well as for portable and stationary power generation.

On 15 August 2021, Honourable Prime Minister of India, Shri Narendra Modi, announced the launch of Green Hydrogen Mission during his Independence Day speech. A high-level committee was then established to formulate the mission. The committee is currently working on the mission document. In a major step towards realising the mission and vision of the government, in February 2022, the Ministry of Power, Government of India announced National Green Hydrogen/Green Ammonia Policy. A snapshot of various activities in India related to hydrogen is depicted in Table 1.

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9 Details available at <https://www.eqmagpro.com/hydrogen-energy-and-fuel-cells-in-india-a-way-forward/>

Table 1: Hydrogen activity in India

Year and hydrogen-specific activity	Responsible agency
2006, National Hydrogen Energy Road Map: Vision 2020	Ministry of New and Renewable Energy, India
2016, Formation of Dr K Kasturirangan committee for fuel cells	Ministry of New and Renewable Energy, India
2016, Hydrogen Energy and Fuel Cells in India: the way forward report	Ministry of New and Renewable Energy, India
2020, India Country Status Report on Hydrogen and Fuel Cells	Department of Science and Technology, New Delhi
August 2021, Announcement of National Hydrogen Mission	Government of India, India
February 2022, Green Hydrogen Policy-2022, India	Ministry of Power
Paper by NITI Aayog in June 2022	NITI Aayog

Announcements at COP26

India's announcements on its ambitious commitments and deploying non-fossil fuel-based technologies to climate risk mitigation from COP26, held in Glasgow in November 2021, drew global attention. These commitments lead the pathway to India's big plan in becoming a net-zero country by 2070 (Fugure 1).

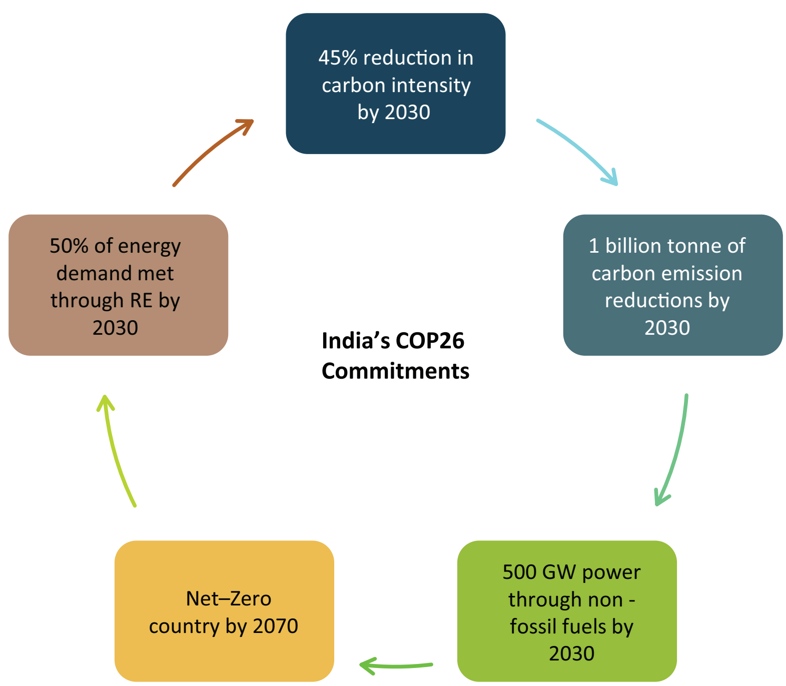
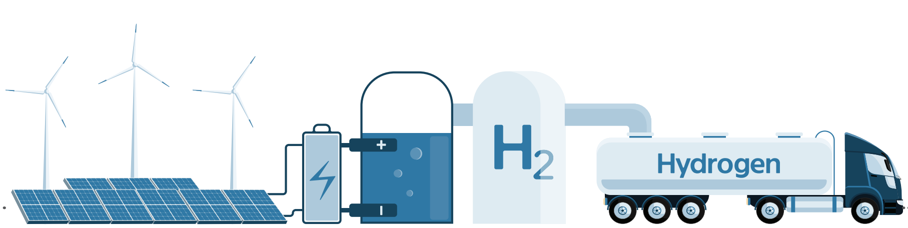


Figure 1: India's COP26 announcements

Source: Details available at <https://pib.gov.in/PressReleasePage.aspx?PRID=1768712>



Because the targets set at COP26 are quite bold, it requires comprehensive and persistent efforts. Apart from the immense support needed to overcome the challenges of new technology deployment, a complete transition to non-fossil fuel energy sources would be disruptive to the livelihoods of those employed in the fossil fuels sector. Presently, India's coal sector employs around 3.6 million people in direct and indirect ways.[10] Therefore, careful thinking and systematic planning become necessary to ensure a smooth and just transition wherein re-skilling human capital through capacity-building programmes for employment in other domains including renewable energy jobs is prioritised. On a government-to-government level the Netherlands, which has already embarked upon a clean hydrogen pathway, can share learnings and help Indian stakeholders in planning and strategizing the implementation of clean hydrogen projects. In addition, long-term strategies are needed for ascertaining sectoral priorities and actions to fulfil the net-zero targets. Emission mitigation schemes such as carbon pricing could be implemented in industries to accelerate decarbonisation. Carbon emission in India is expected to peak by 2040 and to support the net-zero goals there would be a demand for about 20 MT of blue hydrogen (with carbon capture). In this context, support from Dutch industries would be substantial in addressing technological barriers to generate hydrogen from clean energy resources.

Green Hydrogen Policy 2022

The Government of India issued the first part of the Green Hydrogen Policy[11] in February 2022, in alignment with National Hydrogen Mission and net-zero commitments declared at the COP26. The mission guidelines are designed to make India a green hydrogen hub and develop associated infrastructure to meet its climate targets. The green hydrogen policy targets to boost the production of hydrogen and ammonia using renewable energy resources. The key features of the first phase of Green Hydrogen Policy are given in Table 2.

Table 2: Key features of the Green Hydrogen Policy

S. No.	Key features of policy
1	**Waiver of inter-state transmissions charges for 25 years:** Charges for inter-state transmissions have been waived for the green hydrogen and green ammonia producers. Applicable for projects commissioned before 30 June 2025.
2	**Manufacture of green hydrogen from co-located plants or remotely located renewable energy plants and open access:** Green hydrogen/green ammonia can be manufactured by a developer by using renewable energy from a co-located renewable energy plant, or sourced from a remotely located renewable energy plant.
3	**Banking of renewable energy:** Banking of renewable energy to make green hydrogen/ green ammonia will be permitted for 30 days.
4	**Open access for sourcing of renewable energy**: Green hydrogen/green ammonia plants will be granted open access for sourcing of renewable energy within 5 days of receipt of application complete in all respects. The open access charges shall de under the rules as laid down.

Contd...

[10] Details available at <https://india.mongabay.com/2021/07/about-40-percent-of-indias-districts-have-some-form-of-coal-dependency/>

[11] Details available at <https://powermin.gov.in/sites/default/files/Green_Hydrogen_Policy.pdf>

Table 2: contd...

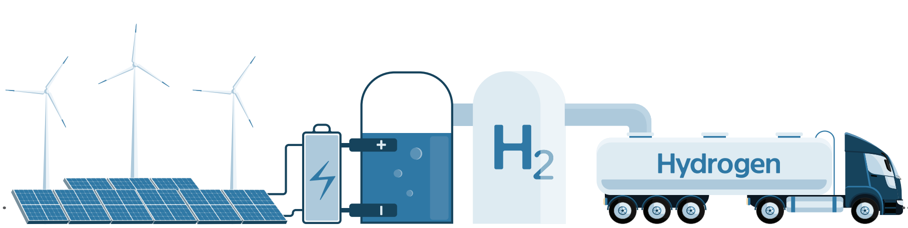
S. No.	Key features of policy
5	**Allocation of land in renewable energy parks**: Land in renewable energy parks can be allotted for the manufacture of green hydrogen/green ammonia.
6	Creation of manufacturing zones for green hydrogen/ green ammonia production.
7	**Permission to manufacturers for setting up of bunkers near ports for storage of green hydrogen/ green ammonia for export/ use in shipping:** The land for the storage purpose shall be provided by the respective port authorities at applicable charges.
8	Renewable energy consumed during the production of green hydrogen/green ammonia will count towards renewable purchase obligation (RPO) compliance of the consuming entity.
9	**Distribution licensees may procure and supply renewable energy to the manufacturers of green hydrogen/green ammonia in their states:** In this case, the distribution licensee shall only charge the cost of procurement as well as the wheeling charges and a small margin as determined by the state commission.
10	**The MNRE will establish a single portal for all statutory clearances and permissions required for the manufacture, transportation, storage, and distribution of green hydrogen / green ammonia.**
11	The MNRE may aggregate demand from different sectors and conduct consolidated bids for procurement of green hydrogen/green ammonia through designated implementing agencies.
12	**The banking charges shall be as fixed by the state commission:** Banking charges will not be more than the cost differential between the average tariff of renewable energy bought by the distribution licensee during the previous year and the average market clearing price (MCP) in the day-ahead market (DAM) during the month in which the renewable energy has been banked.

Source: Ministry of Power, Government of India (2022)

Further, as next step, the Government of India is planning to introduce a Green Hydrogen Consumption Obligation concept, similar to the Renewable Purchase Obligations (RPOs), for industries consuming hydrogen generated directly from fossil fuel resources. The idea is to create a demand for green hydrogen in fertiliser industries and refineries in a phased manner. The government is working on mandating the use of green hydrogen and ammonia up to 20%–25% in the next five years' time, in an attempt to help the Indian market to achieve parity with grey hydrogen.[12]

The Government of India is also promoting high efficiency manufacturing technologies and manufacturing in India through an initiative called production-linked incentive (PLI) scheme. The PLI schemes are already in place for solar PV and advanced chemistry batteries. The PLI scheme allocation for solar PV modules and cells manufacturing is INR 24,000 crore. Similar scheme is being discussed for electrolyser manufacturing. Government offers capital subsidy for setting up the manufacturing units. The subsidy is offered on certain criteria and is disbursed after meeting the criteria.

[12] Details available at <https://www.power-technology.com/comment/green-hydrogen-india-energy-security/#:~:text=Policy%20Attributes&text=Green%20hydrogen%20%2F%20ammonia%20manufacturers%20may,days%20of%20receipt%20of%20application>, last accessed on 1 May 2022.



3. India's Hydrogen Market Potential

India has three primary drivers for moving towards a green hydrogen economy. Hydrogen is expected to play an important role in achieving energy security by replacing imported oil and ammonia. India is the world's third-largest consumer of oil, 85% of its demands are met through imports. Ammonia is a vital input for fertiliser production and currently India is dependent on ammonia procured through imports. Second driver is decarbonisation of hard-to-abate sectors and carbon-based chemical processes in industries like steel, cement, refinery, transport, shipping, power, and others. The third important driver is the potential for export of green hydrogen.

Currently, India consumes about 6.17 million tonnes (MT) of hydrogen per annum.[13] Almost all of it is consumed in fertiliser and refinery industries. India's sector-wise hydrogen demand is depicted in Table 3.

Table 3: India's sector-wise hydrogen demand (MT)[14]

Sector	Current hydrogen demand
Urea	3.03
Refining	2.16
DAP	0.20
Chemicals	0.37
Steel	0.35
Total	**6.17**

Note: Numbers are approximate values.

The Government of India has announced a target of 5MT of green hydrogen production per year by 2030.[15] These are strong drivers for upcoming investments in hydrogen technology in India. To facilitate meaningful green hydrogen adoption in the country, investment to the tune of US$160 billion is to be required by 2030.[16]

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13 *Green Hydrogen for India: a finance and policy perspective.* May 2022. Anuraag Nallapaneni, Pawan Mulukutla and Soham Kshirsagar, WRI India Akhilesh Tilotia and Arindam Som, National Investment and Infrastructure Fund (NIIF)

14 *Green Hydrogen for India: a finance and policy perspective.* May 2022. Anuraag Nallapaneni, Pawan Mulukutla and Soham Kshirsagar - WRI India Akhilesh Tilotia and Arindam Som – National Investment and Infrastructure Fund (NIIF)

15 Details available at <https://pib.gov.in/PressReleasePage.aspx?PRID=1799067>, last accessed on 20 April 2022.

16 Green Hydrogen for India: a finance and policy perspective. May 2022 Anuraag Nallapaneni, Pawan Mulukutla and Soham Kshirsagar - WRI India Akhilesh Tilotia and Arindam Som – National Investment and Infrastructure Fund (NIIF)

This will open up avenues for Indo–Dutch cooperation in both the green and blue hydrogen sector. The Netherlands has technologies and projects in both the green and blue hydrogen areas. Thus opening opportunities for development of clean hydrogen sector.

NITI Aayog Report

According to the recently released report by the NITI Aayog titled, 'Harnessing Green Hydrogen Opportunities for deep Decarbonisation in India',[17] the following targets can be achieved by India:

1. The world's largest electrolysis (green hydrogen generation) capacity of over 60 GW/5 million tonnes by 2030 for domestic consumption. This will help India meet the 500 GW renewable energy target.
2. The world's largest production of green steel at 15–20million tonnes by 2030 — a pioneering effort to make green steel mainstream for the world. Harnessing Green Hydrogen www.niti.gov.in | www.rmi.org /7
3. The world's largest electrolyser annual manufacturing capacity of 25 GW by 2028 delivering affordable ones for India and the world.
4. The world's largest production of green ammonia for exports by 2030 helping India's allies to decarbonise. This may require up to 100 GW of green hydrogen.
5. $1 billion investment into hydrogen research and development to enable breakthrough technologies for the world at scale and the speed that is required.

Role of Renewable Power in India's Power Generation

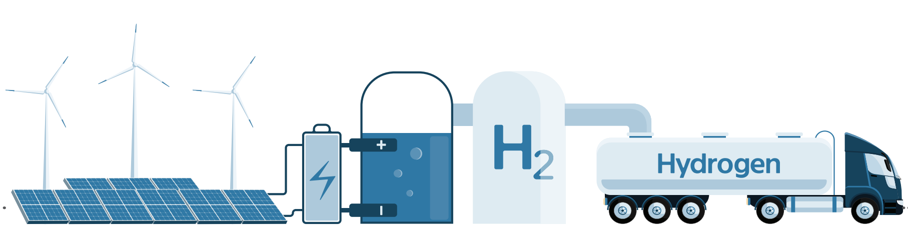
Development of renewable power is key to the success of green hydrogen economy. In this context, it is important to understand the role of renewable power in India's power generation capacity and its future growth targets. The following section focuses on the same.

India's renewable energy power generation potential is summarised in Table 4.

Table 4: India's renewable energy potential[18] (GW)

S. No.	Type of renewable energy source	Potential (GW)	Remarks
1	Solar energy	748	Assuming 3% of the waste land used for solar photovoltaic (PV) power plants
2	Onshore wind energy	302	At 100 m hub height of wind machines
3	Offshore wind energy	71	off the coast of Gujarat and Tamil Nadu
4	Small hydro power	21.13	Hydropower plants of 25 MW or less capacity
5	Biomass power	28	Assuming surplus biomass of 230 million metric tonnes

[17] Details available at https://www.niti.gov.in/sites/default/files/2022-06/Harnessing_Green_Hydrogen_V21_DIGITAL_29062022.pdf last accessed on 30/06/2022



The share of renewable power generation capacity as on 31 January 2022 is depicted in Figure 2. Renewable-based power generation installed capacity including large hydropower plants has crossed 37% in January 2022 (Figure 2). It is planned to increase the share to more than 50% by 2030 with the total installed capacity more than 500 MW (Figure 3).

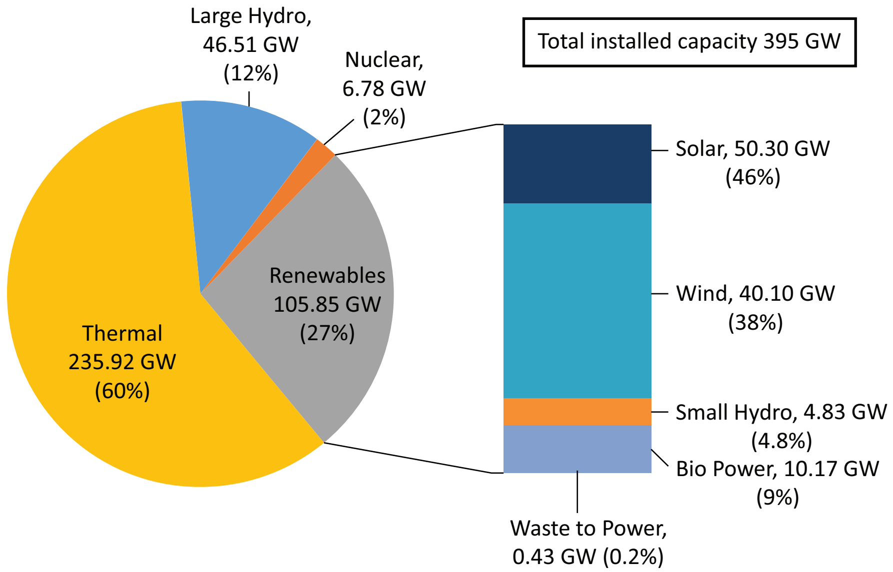


Figure 2: India's installed power generation capacity as on 31 January 2022

Source: CEA (2022)

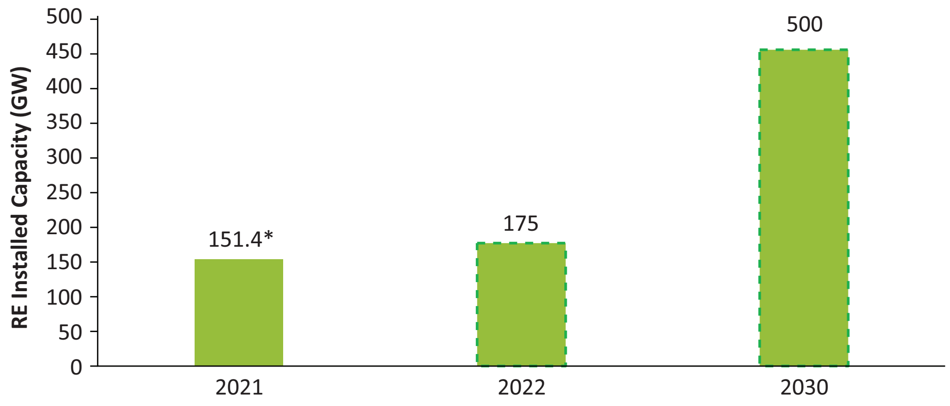
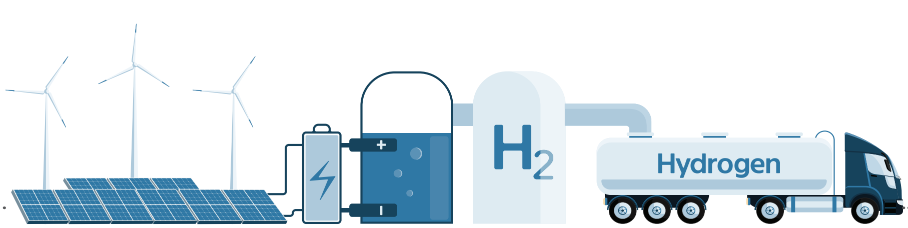


Figure 3: Renewable energy installed capacity and targets

Source: CEA

Note: Till 31 December 2021, including large hydro installed capacity.

Currently, renewable-based power generation capacity (excluding large hydro power capacity) is around 25% of the total installed capacity. However, in 2030 it is likely to go up between 40% and 50%.This increase in variable renewable power installed capacity would require grid balancing measures which also include green hydrogen production. Green hydrogen-generation systems can act as balancing load apart from hydrogen acting as a long-term storage. Moreover, large-scale green hydrogen production would need additional renewable energy production capacity.



4. Supply, Storage & Handling and Demand of Hydrogen in India

Ambitious announcements made by the Indian government to curb carbon emissions encouraged various industries to take steps to adopt clean hydrogen resources in energy-intensive industries such as cement, steel, and refinery. The steel industry for instance, is one of the biggest energy-intensive industries and contributes around 20% of industrial emissions.[19] Although in the present case, steel generation from RE is 60%–70% costlier than the conventional methods but even a small blending of 9% in the current hydrogen infrastructure could reduce the carbon emissions by 60%.[20] The acceleration in ongoing research activities, industries investments, and favourable policy frameworks would be key instruments in bringing down the cost of production. Followed by the government's recent Green Hydrogen Policy and Hydrogen Mission, several initiatives and investment announcements were made by Indian industries (See Annexures). In this chapter we analyse the current status of supply, storage & handling, and demand of hydrogen in India, and look forward towards potential future scenario's. We start off by analysing pricing trends.

Hydrogen Pricing Trends

Currently, the cost of hydrogen generation is generally high for green and blue hydrogen in comparison to grey/brown hydrogen. However, with rapid advancements in technology, the costs of green hydrogen production are expected to gradually decrease. The levelised cost of hydrogen production is summarised in Table 5.

Table 5: Cost trends of hydrogen production

H_2 production route	Cost of hydrogen production ($/kg)		
	2020	2030	2050
Grey hydrogen (SMR/ATR without CCUS)	1.59–2.24	1.56–2.21	1.48–2.15
Blue hydrogen (SMR/ATR with CCUS)	1.85–2.50	1.80–2.45	1.69–2.36
Green hydrogen (PEM/Alkaline)	4.11–5.45	2.03–4.07	1.11–3.18

Source: TERI analysis[21]

Note: Analysis is conducted for each hydrogen production route into two scenarios—high and low— for different methods. Steam methane reformation (SMR); auto-thermal reformation (ATR); proton exchange membrane (PEM) and carbon capture, usage, and storage (CCUS).

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19 Details available at <https://india.mongabay.com/2022/03/energy-intensive-steel-industry-looks-to-push-consumption-reduce-emissions/#:~:text=The%20average%20CO2%20emission,2.6%20T%2Ftcs%20by%202020.>

20 Details available at <https://www.ceew.in/blogs/ceew-explains-what-corporate-investments-mean-indias-green-hydrogen-export-manufacturing-market>

21 Details available at <https://www.teriin.org/sites/default/files/2021-07/Report_on_The_Potential_Role_of_%20Hydrogen_in_India.pdf>

Table 5 depicts that green hydrogen cost was more than twice the cost of the grey hydrogen.

Hydrogen Supply

This section covers the supply situation of hydrogen in India and also assesses the potential of generating hydrogen through various resources.

Status and Potential of Grey Hydrogen

Currently, hydrogen is produced using steam methane reforming route falling in the category of grey hydrogen. This would continue to play a pivotal role in meeting the industrial needs, however, India's focus on shifting towards green hydrogen could limit the long-term potential of grey hydrogen utilisation. Additionally, grey hydrogen is produced from imported liquefied natural gas (LNG) and other fossil fuels. Government of India's targets to reduce the dependency on imported fossil fuels may impact the expansion of grey hydrogen production and utilisation.

Grey hydrogen cost largely depends upon the price fluctuations in coal and natural gas prices. The grey hydrogen costs around \$ 2.12–2.65 per kg considering the natural gas input of \$ 10–12 per Metric Million British Thermal Unit (MMBtu).

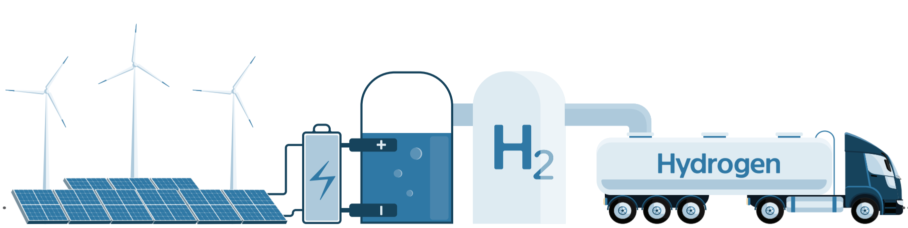
Status and Potential of Blue Hydrogen

Although green hydrogen is the cleanest form of hydrogen, other forms would also play a substantial role in addressing carbon emission goals. In blue hydrogen emitted carbon dioxide is captured and stored in geological formations through carbon capture and storage (CCS) or carbon capture utilisation and storage (CCUS) technologies. The CCUS is a technology that can capture and make effective use of the high concentrations of CO_2 emitted from combustion or industrial processes. The captured CO_2 can be transported via ships and pipelines to create valuable products such as polycarbonate,[22] high functional plastics, new concrete products, chemicals, and others. The captured CO_2 can also be stored in underground geological formations.

In India, industries like fertilisers and refineries, which are already utilising grey hydrogen and a few other carbon-emitting industries such as cement and steel can be the potential sectors for blue hydrogen utilisation. India's biggest industry giant—RIL—announced its plans to become one of the largest blue hydrogen producer by re-purposing its Jamnagar refinery.23 Although CCUS is in the early stages of development, significant carbon emissions from industry also provide an opportunity to explore blue hydrogen potential in India. India has an estimated 500–1000 billion tonnes (BT) of storage potential

[22] Details available at <https://www.meti.go.jp/english/policy/energy_environment/global_warming/roadmap/innovation/ccus.html#:~:text=Carbon%20Capture%2C%20Usage%20and%20Storage,challenge%20of%20global%20climate%20change>

[23] Details available at <https://www.businesstoday.in/latest/corporate/story/reliance-industries-targets-to-become-worlds-top-blue-hydrogen-maker-322392-2022-02-12>



in geological formations.[24] As per the analysis by the International Energy Agency (IEA), some of the potential sites for carbon capture in India include parts of Gujarat, Madhya Pradesh, Cauvery basin (Andhra Pradesh and Tamil Nadu), and Assam Basin in the northeast regions of Nagaland, Manipur, and Tripura (Figure 4). The storage potentials in deep saline aquifers and Deccan trap blastics rocks are 300–400 BT and 200–400 BT, respectively. These estimates of storage potentials were calculated using empirical equations on the basis of geographical, geochemical, and geological characteristics (Singh, *et al*. 2006).[25]

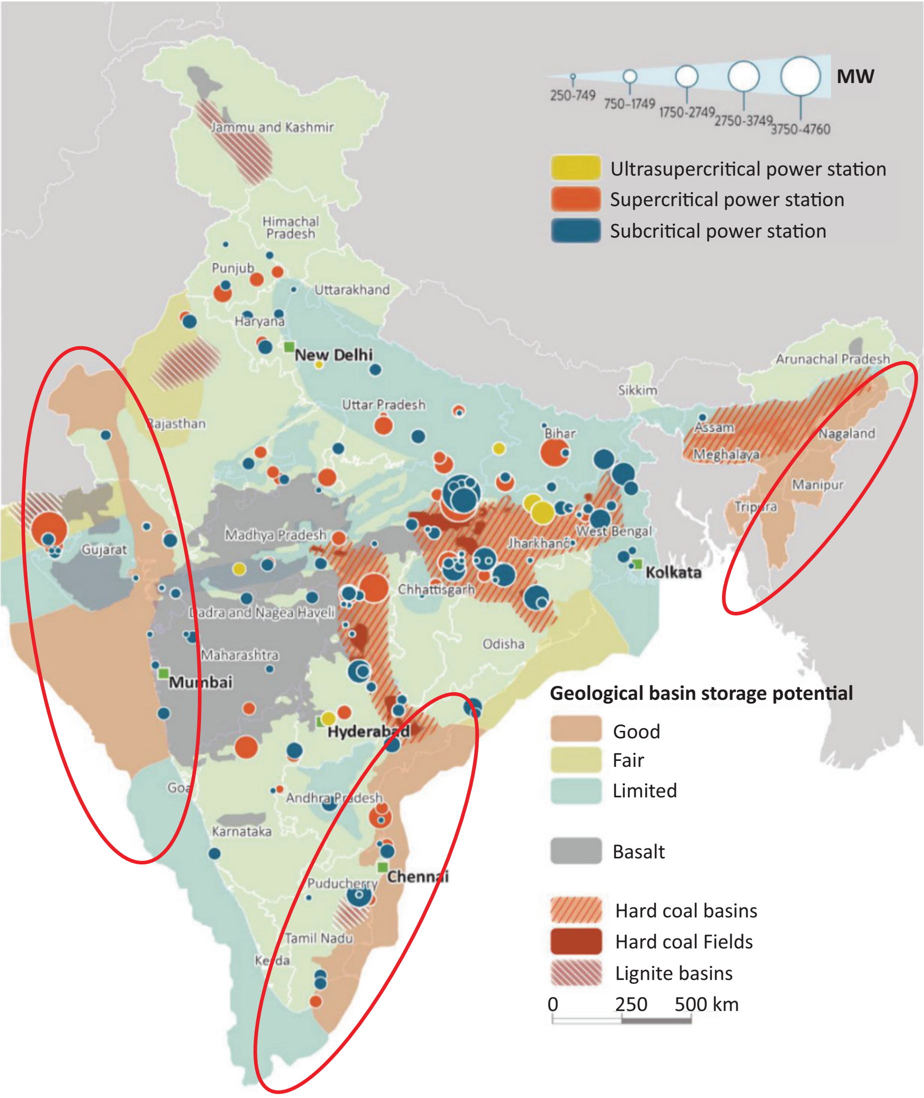


Figure 4: Potential sites for CCU/CCUS in India

Source: Clean Coal Centre, IEA

[24] Details available at <https://www.sciencedirect.com/science/article/pii/S2772656822000070>

[25] Details available at <https://www.researchgate.net/profile/Vinod-Mendhe/publication/315782860_CO2_sequestration_potential_of_geologic_formation_in_India/links/58e8fc63458515e30dccc63d/CO2-sequestration-potential-of-geologic-formation-in-India>

The Government of India has adopted three-pronged strategies to develop CCUS and CCS technologies (Figure 5):

a) It became part of Mission Innovation initiative under which Department of Science & Technology and Department of Biotechnology. funded research project on carbon capture projects,

b) Policy framework was developed to promote carbon capture while using oil and gas,

c) In 2020, National Programme on Carbon Dioxide storage to develop R&D and pilot projects was announced.

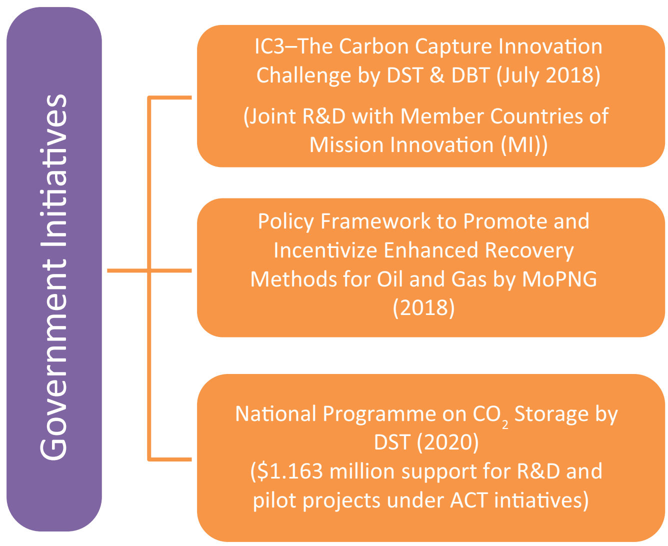
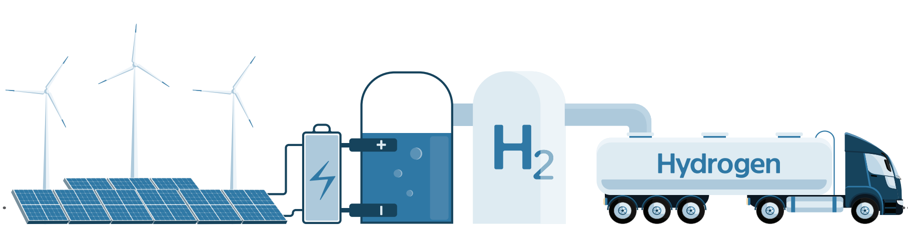


Figure 5: Initiatives on CCU/CCUS by the Indian government

Sources: DST, MoPNG, and DBT

The ministries under the Government of India have taken various research and demonstration project initiatives to capture CO_2 for producing blue hydrogen (Figure 6). Similarly, major industries have also initiated demonstration or pilot projects in CCS and CCUS.



Indian Oil Corporation Limited

- IOCL and ONGC plans to establish a pilot plant of CO_2 capture in Koyali refinery Gujarat.
- At IOCL's Gujarat refinery, a blue hydrogen plant is planned (Hydrogen generation with natural gas and carbon capture)

Relinace Industries limited

- To develop CCU technology as part of its net-zero commitment at its Jamnagar Refinery for blue hydrogen production

Tuticorin Alkali Chemicals & Fertilizers

- Running CO_2 CCU plant in Chennai unit
- Around 60,000 tonnes of CO_2 is captured per year and gets converted into soda ash.

Tata Steel

- At Jamshedpur steel plant CCU plant of 5 TPD. It extracts CO_2 directly from the Blast Furnace gas.
- Colloboration with The Council of Scientific & Industrial Research (CSIR) for CCUS.

NTPC

- NTPC, is setting up a CO_2 to Methanol demonstration plant at NTPC Vindhyachal, India.

Dalmia Bharat Cement

- Announced a large-scale CCUS facility of capacity 0.5 $MtCO_2$ per annum in a plant at Tamil Nadu, India

BHEL and NALCO

- NALCO and BHEL initiated the process of setting up CCUS facilities.

Figure 6: Initiatives on CCS/CCUS by Indian industries

Sources: TATA Steel, MoPNG, NTPC, RIL, and various media resources

Status and Potential of Green Hydrogen

Green hydrogen is produced by the electrolysis of water and currently green hydrogen is 2–3 times costlier in the Indian market. As per TERI's report on potential role of hydrogen in India,[26] the cost of green hydrogen will reduced by more than 50% by 2030 and will become competitive in comparison to grey hydrogen. These cost reductions would be driven by the decrease in the cost of renewables and electrolyser in India (Figure 7).

26 Details available at<https://www.teriin.org/sites/default/files/2021-07/Report_on_The_Potential_Role_of_%20Hydrogen_in_India.pdf>

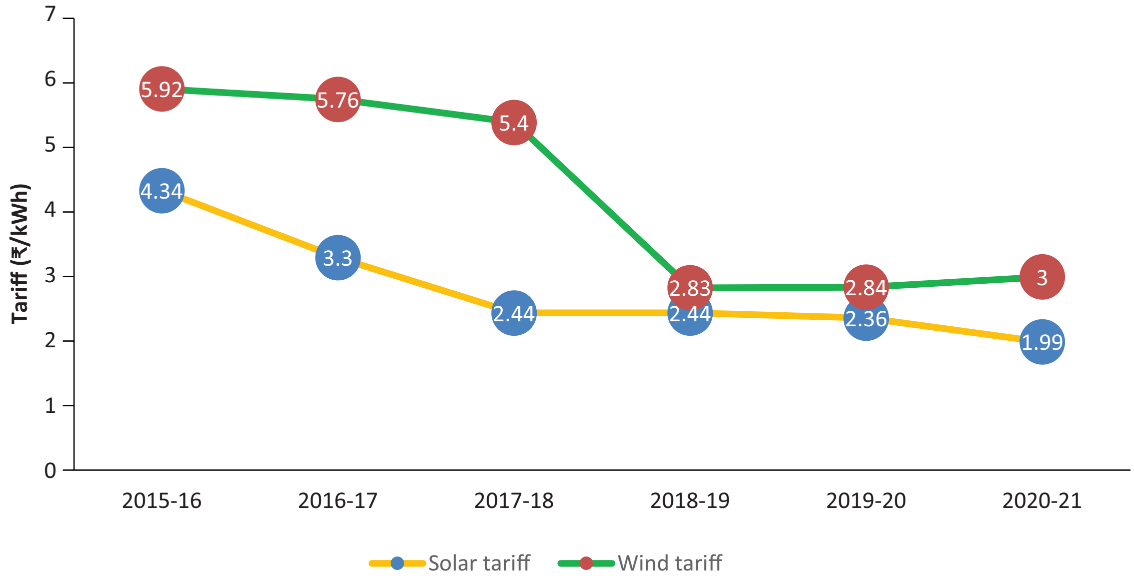


Figure 7: Falling renewable energy tariffs in India

Source: TERI analysis based on MNRE data

The trend of continually decreasing renewable energy costs is seen through examples like solar PV electricity reaching the lowest tariff of INR1.99/kWh in FY 2020/21 and the wind tariff decreasing by almost 50% in the last five years. Furthermore, the Production Linked Incentive (PLI) scheme launched by the Government of India for developing local manufacturing capabilities of solar PV modules in the country could further reduce the cost of solar projects in the coming decades.

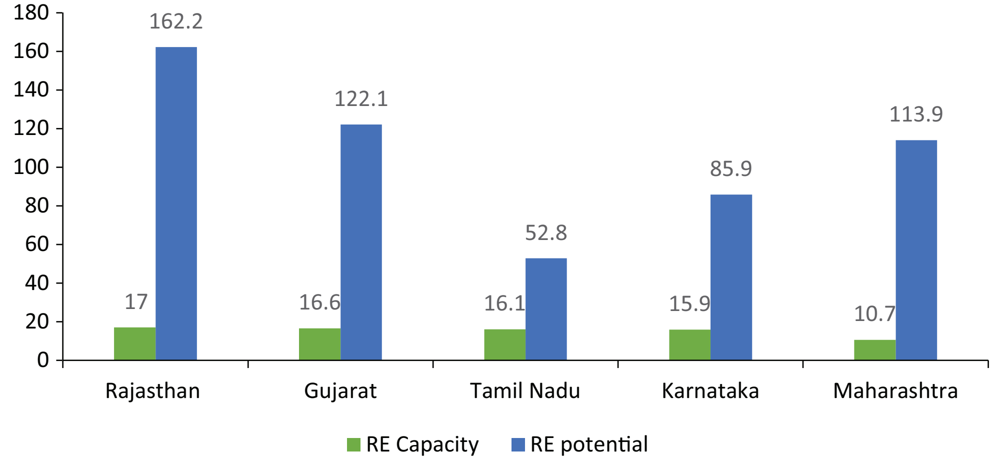


Figure 8: Top five states in RE deployments

Source: MNRE physical achievement (as on 31 March 2022)

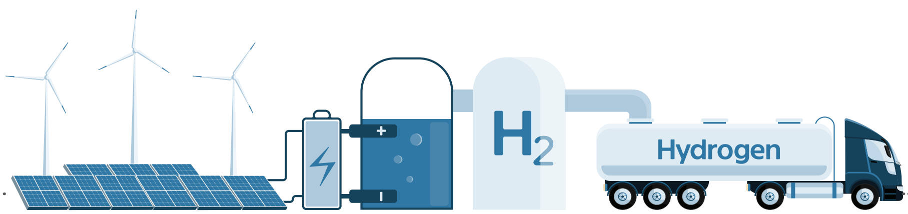


Figure 8 shows that Rajasthan, Gujarat, Tamil Nadu, Karnataka, and Maharashtra are the top five Indian states rich in RE resources, and have substantial potential for RE generation. These stated states could be ideal for establishing green hydrogen infrastructures. The benefits include the following:

- Strong renewable energy policy push
- State-level availability of land
- High GDP and industrial clusters
- Availability of cheap RE power for electrolysis

Dutch industries can focus on these states to start their business activities in green hydrogen generation, storage, and utilisation.

Hydrogen Generation at Offshore Wind Sites

India has identified offshore wind potential of 71 GW near the coasts of Gujarat and Tamil Nadu. These two states also have demand centres such as chemical factories, refineries, and cement factories for usage of hydrogen. A pilot offshore power plant of 1 GW capacity is planned in the near future. Dutch organisations are already developing offshore wind plants with integrated hydrogen generation facilities under project PosHYdon which is scheduled to be completed by 2024. It is timely to suggest similar concept for Indian offshore project as pilot project under the MNRE. This is a good opportunity for developing Indo–Dutch collaboration in offshore wind-based hydrogen-generation facility.

Hydrogen Generation Through Biomass Route (Bio-hydrogen)

Biomass accounts for around 32% of India's primary energy needs, with varied applications such as cooking, electricity, and heat generation. Biomass technologies also find potential use in the management of waste, given the alarming levels of waste generated by the population of India. In addition to green hydrogen, bio-hydrogen could be instrumental in supporting India's net-zero goals. A study by the MNRE shows the current biomass availability in the country stands at around 750 million metric tonnes per annum, and surplus biomass availability is around 230 million metric tonnes. Of this, around 7–8 million tonnes of dried biomass waste could potentially be used for hydrogen production. Furthermore, municipal solid waste also has the potential of producing around 1.8 million tonnes of hydrogen, annually.

Biomass gasification is another potential source of sustainable hydrogen generation. The process involves the thermo–chemical conversion of organic wastes in closed pressurised vessels at high temperatures (800–900°C). The syngas ($CO+H_2$) produced in the gasification process can be further treated to produce pure hydrogen (99.9%). Around 12–14 kg of dry biomass can generate 1 kg of hydrogen (Figure 9).

Hydrogen Production through Biomass Gasification

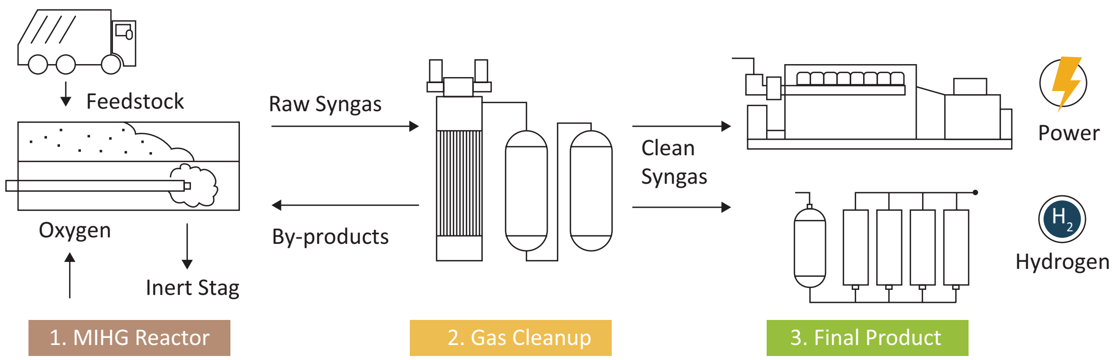


Figure 9: Hydrogen production through biomass gasification

Source: WRI India (2021)[27]

India's first commercial-scale biomass-based hydrogen plant is being developed by Watomo Energies Limited and Biezel Green Energy in Madhya Pradesh. The plant is expected to produce 1 tonne hydrogen per day by utilising 30 tonnes of biomass feedstock.[28]

Dutch industries which have experience of setting up bio-hydrogen plants can target the Indian market.

Hydrogen Storage and Handling

Hydrogen Storage

As the share of renewable energy increases in India's energy mix, hydrogen could provide inter-seasonal and inter-day storage to address the variability of the renewable energy systems. It could increase supply-side flexibility of the existing power system and compensate for variations in the supply of renewable energy. For short-term intra-day storage, hydrogen may not be able to compete with other forms of energy storage, such as li-ion batteries due to high capital costs and low round-trip efficiencies.[29]

TERI's analysis suggests that power–hydrogen–power route may become competitive for long-term seasonal storage applications, where the quantum of energy to be stored requires a dense energy carrier. India's high-quality solar photovoltaic (PV) resource and fairly constant annual electricity demand imply that intra-day storage is critical to enable high penetration of Variable Renewable Energy (VRE). Hydrogen may be necessary to push the transition of the remaining 10%–20% of

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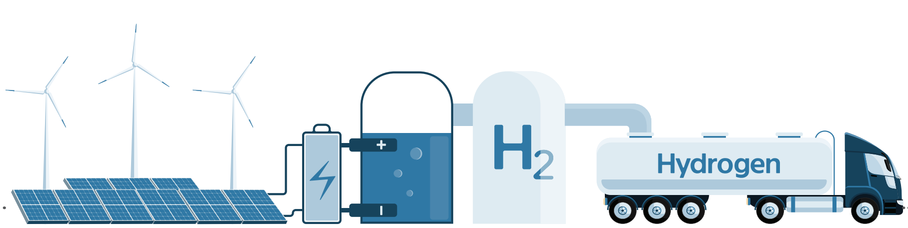
27 Details available at <https://wri-india.org/blog/biomass-gasification-circular-economy-enabler-hydrogen-production<

28 Details available at <https://www.thehindubusinessline.com/news/national/indias-first-biomass-based-hydrogen-plant-coming-up-in-mp/article64997164.ece#:~:text=The%20country's%20first%20commercial%2Dscale,also%20produce%20biochar%20and%20methane>

29 Details available at <https://www.sciencedirect.com/science/article/pii/S254243511830583X>



dispatchable fossil fuels used in power generation to a high VRE system. High penetration of wind and solar are likely to occur only in the 2040s, this increases the uncertainty about the role of power–hydrogen–power in the Indian energy system.

Hydrogen storage is possible either in gas or liquid forms. Storing hydrogen in gaseous forms in vehicles needs high pressure of 350–700 bar due to space constraints but for stationary applications hydrogen can be stored at lower pressures around 100 bar. Storage as a liquid requires cryogenic temperatures of –253˚C (TERI 2020).[30]

The most common types of hydrogen storage are geological and tank.

» **Geological storage:** One of the most cost-effective hydrogen storage options is geological storage. It can be stored in salt caverns, rock caverns, and depleted gas and oil fields. Storage costs are as low as $0.05/kg and $0.14/kg in salt and rock caverns, respectively. Unlike other countries, India does not have sufficient suitable salt deposits for this type of geological storage. Other geological storage options like rock cavern storage or reusing depleted gas & oil fields must be thoroughly investigated for India. A detailed survey of potential geological storage sites for assessing the feasibility of storage is required. Until then, India may have to rely on expensive steel tank storage. Dutch expertise in developing rock and salt cavern storages would be beneficial for India.

» **Steel tanks:** Steel tank hydrogen storage is commonly used but is the most expensive hydrogen storage method. Storing hydrogen in steel tanks costs about $0.65/kg for a 700 kg capacity. High-discharge rates and low-energy density of compressed liquid hydrogen make this type of storage suitable for small-scale applications. Ammonia has greater energy density, which reduces the need for large storage tanks but this advantage would have to be weighed against the energy losses and equipment for conversion and reconversion when end uses require pure hydrogen. Indian Oil Corporation Limited (IOCL) is also working on the development of a Type-3 High-Pressure Hydrogen Cylinder in collaboration with IIT Kharagpur. The cylinder increases the energy storage density over existing cylinders. They are also working on developing material-based hydrogen storage including metal-organic frameworks (MOFs). Their research is focused on producing high-energy density MOFs, which can be scaled up cost-effectively. Similar research is going on in the Netherlands. A collaborative approach to jointly develop the technology is recommended.

Taking note of the constraints of exploring the feasibility of geological storage for hydrogen storage, steel tanks would be preferable option for storage in India. The cost of storage is expected to decline from $0.64/kg in 2020 to $0.43/kg in 2050 (Table 6).

[30] Details available at <https://www.teriin.org/sites/default/files/2021-07/Report_on_The_Potential_Role_of_%20Hydrogen_in_India.pdf>

Table 6: Cost of hydrogen storage

Storage type	Year	Cost ($/Kg H_2)	Capacity
Salt cavern storage	2020	0.05	Salt cavern storage (20% vol.)
	2050	0.02	Salt cavern storage (20% vol.)
Rock cavern storage	2020	0.14	Rock cavern storage (20% vol.)
	2050	0.05	Rock cavern storage (20% vol.)
Steel tank	2020	0.65	700 kg capacity
	2050	0.54	1100 kg capacity

Source: BENF (2020)

Note: The analysis is for industrial clusters where hydrogen production facilities are located close to end-use consumers.

Storage and transportation of hydrogen could be a potential challenge for scaling up the hydrogen economy in India. Existing infrastructure is limited and could be insufficient to support the widespread use of hydrogen as an energy source. Globally, hydrogen is mostly transported in pipelines. However, pipelines need to be designed with higher specifications to minimize leakage and embrittlement. Alternatively, hydrogen can also be transported in the form of ammonia, methanol, and liquid organic hydrogen carriers (LOHCs).

In pure form, hydrogen is transported as a compressed gas (1000 bar pressure) or liquid (at -253°C), but this requires an extensive amount of energy and cost.

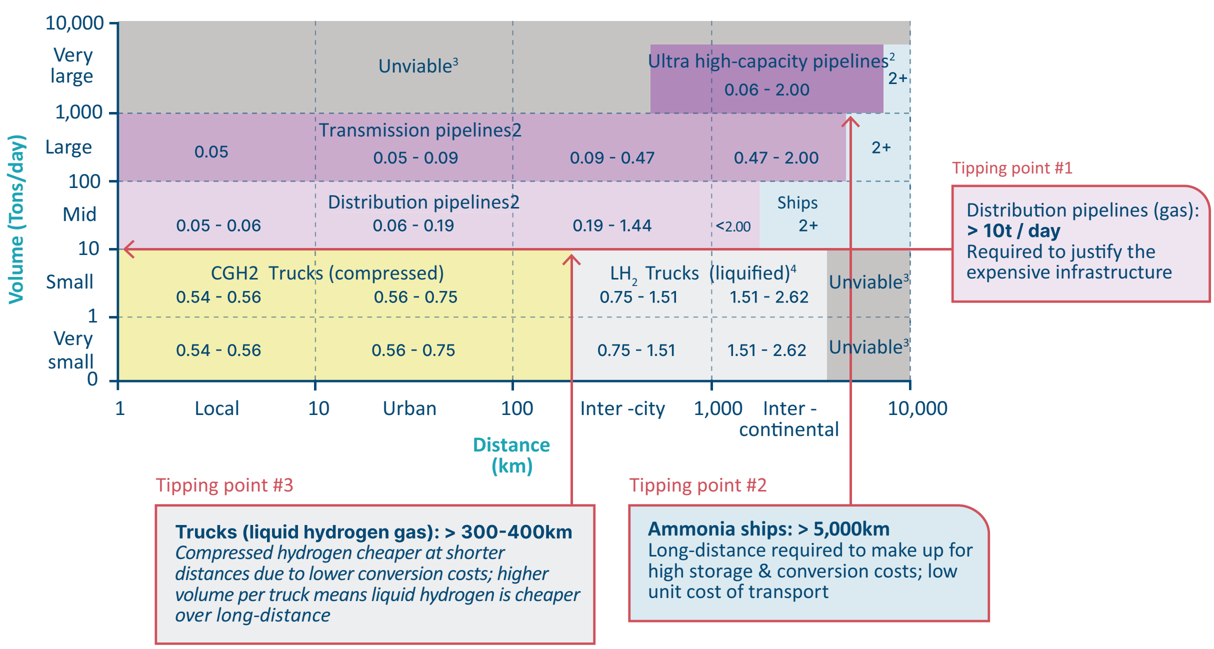
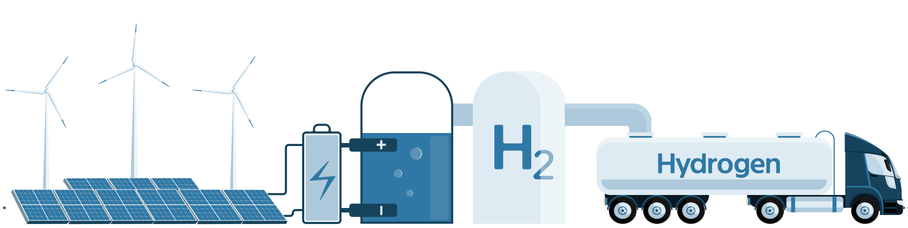


Figure 10: Lowest cost form of hydrogen transportation based on volume and distance

Source: Making the Hydrogen Economy Possible (report), Energy Transition Commission (ETC) (2021)[31]

[31] Details available at <https://energy-transitions.org/wp-content/uploads/2021/04/ETC-Global-Hydrogen-Report.pdf>



Notes: [1] Including conversion and storage; [2] Assumes salt cavern storage for pipelines; [3] Ammonia assumed unsuitable at small scale due to its toxicity; [4] While LOHC is cheaper than liquid hydrogen for long-distance trucking, it is unlikely to be used as it is not commercially developed.

Transportation of hydrogen can be done in three forms—pipelines, trucks, and shipping. As per an analysis by the Energy Transitions Commission (ETC), transporting hydrogen at lower volumes using trucks could be a viable option and for longer distances (> 5000 km), transporting in the form of ammonia could be an option (Figure 10).

For both green and grey hydrogen, the transportation of hydrogen is assumed to be through pipelines. As per TERI's analysis, based on BENF data, transportation costs through pipelines are expected to reduce from $0.03/kg in 2020 to $0.02/kg in 2050 (Table 7).

Table 7: Cost of hydrogen transportation

Technology	Year	Cost ($/kg H_2)	Description
Transmission pipeline	2020	0.03	50 km distance; 1000 tpd
	2050	0.02	50 km distance; 1000 tpd
Distribution pipeline	2020	0.09	50 km distance; 100 tpd
	2050	0.07	50 km distance; 100 tpd
Truck	2020	0.16	50 km distance; 700 kg capacity
	2050	0.54	50 km distance; 1100 kg capacity

Source: BENF (2020)

Note: The analysis is for industrial clusters where hydrogen production facilities are located close to end-use consumers.

Hydrogen Blending with Natural Gas

India is bestowed with a huge natural gas infrastructure of 32,559 km; spreading across various parts of the country. The total operational capacity of gas pipelines has reached around 17,000 km (Figure 11).

Another 15,500 km of pipelines are under construction. Though pipelines are the most suitable hydrogen transportation method, high initial capital costs for their construction can be a limiting factor. Moreover, there are some persistent technical concerns related to retrofitting existing pipelines for hydrogen transport, including the potential for hydrogen to brittle the steel, wherein hydrogen atoms are absorbed by steel, potentially leading to cracks in the pipe. This problem is well understood and several solutions exist, including lining steel pipes or using plastic pipes instead (for example, polyethylene). Up to 18% blending is safe for existing infrastructure of gas pipelines. Accordingly, up to 18% blending of H2 in CNG is planned.

Infrastructure development is very much required at various ports/refineries/fertiliser plants of India. The Dutch Government and industries have developed hydrogen infrastructure across the country, and have announced a national transport network of gas pipes to transport hydrogen, which is being developed by Gasunie and also includes import and storage facilitation. Both the Netherlands and India can benefit from collaborations on infrastructure development and share expertise in designing and installing hydrogen pipelines.

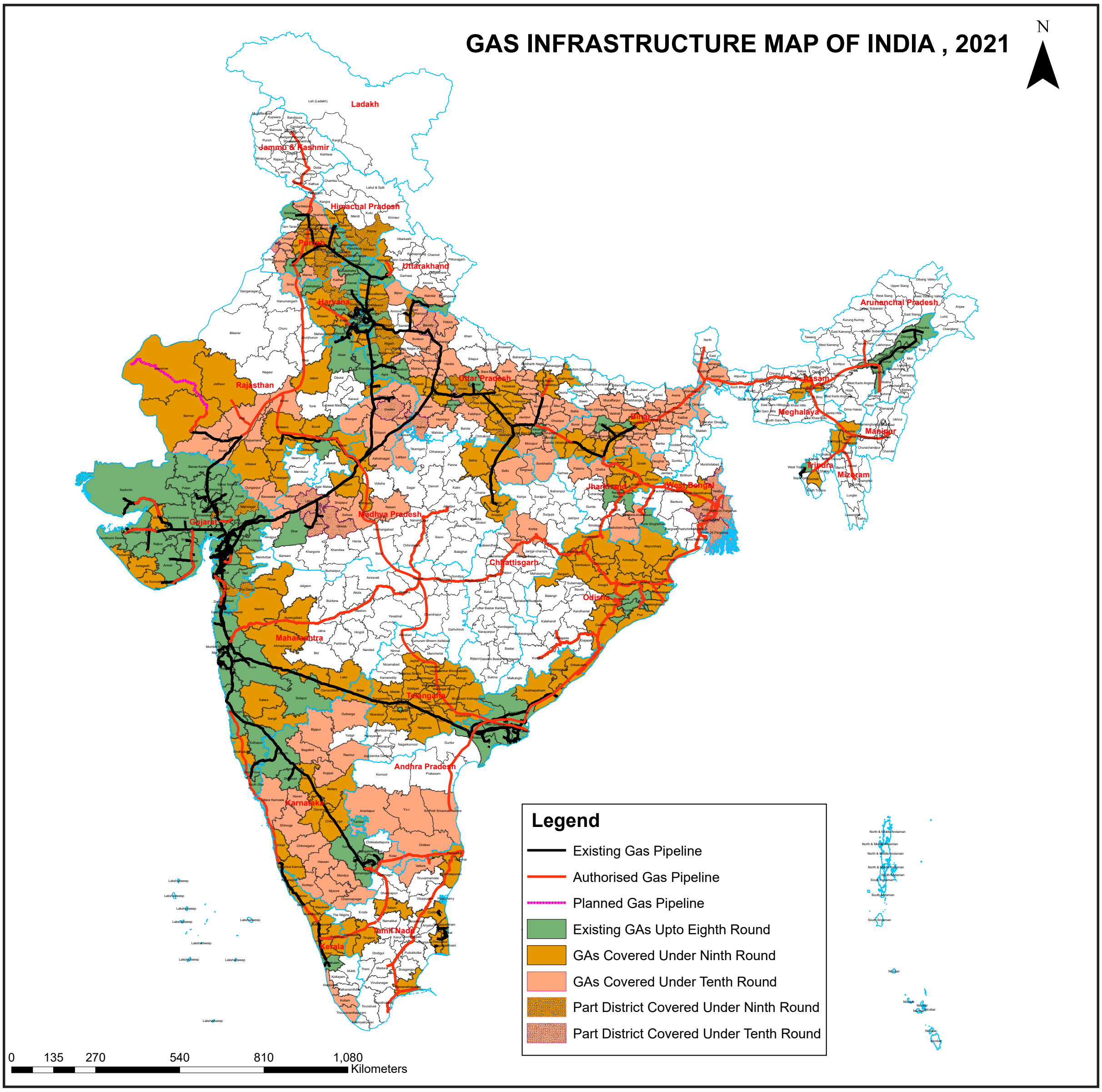
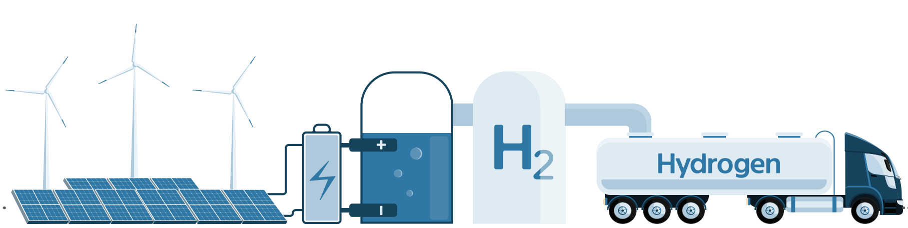


Figure 11: Gas infrastructure map of India (2021)

Source: Ministry of Petroleum and Natural Gas (2021)[32]

32 Details available at <https://mopng.gov.in/en/pdc/investible-projects/oil-amp-gas-infrastructure/natural-gas-pipelines>



Demand for Hydrogen

The annual demand for hydrogen (Figure 12) in India was around 6.9 million tonnes (MT) in 2021, majorly consumed by refineries (53%) and fertiliser industries (44%)[33], and is expected to reach around 28 MT by 2050.[34]

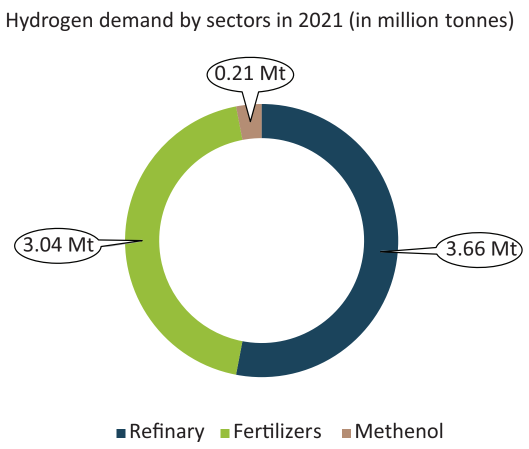


Figure 12: Sector-wise annual demand for hydrogen (2021)

Source: Argus Media (2021)

The demand for hydrogen in India could reach 28 MT by 2050 (Figure 13) and industries mainly refinery, fertilisers, methanol, and new industries such as steel, cement would be the major consumers of hydrogen. The recent green hydrogen policy could be one of the main drivers for adopting green hydrogen in the steel and cement industries.

In order to cater to the surging demands, there would be a substantial requirement for electrolysers for green hydrogen production. Based on an analysis carried out by Larsen & Toubro (L&T), with adequate policy support, around 30 GW (Figure 14) of electrolysers would be needed to meet the green hydrogen demand, and around 80% of all electrolysers would be needed in industries.

In the initial stages, refineries would be the key areas for promoting the adoption of green and blue hydrogen. It is also an opportune moment to mandate the blending of green hydrogen in existing refineries and fertiliser industries by the government. In addition to this, newer areas like green steel and fuel cell transport must be accelerated to understand the initial results.

Hydrogen Projects in Kerala[35]

State government of Kerala has announced its plan to become carbon neutral by 2050. The state government has already prepared plan for decarbonising various sectors through green hydrogen and Electric Vehicle programs. Cochin Shipyard, a public sector ship building company has plans to

33 Details available at <https://www.argusmedia.com/en/news/2240506-india-eyes-hydrogen-as-cleaner-fuel-source>

34 Details available at <https://www.cnbctv18.com/energy/view--the-potential-of-green-hydrogen-and-indias-opportunity-11679032.htm>

35 Details available at https://renewablewatch.in/2022/04/21/views-of-k-r-jyothilal/assessed on June 28, 2022

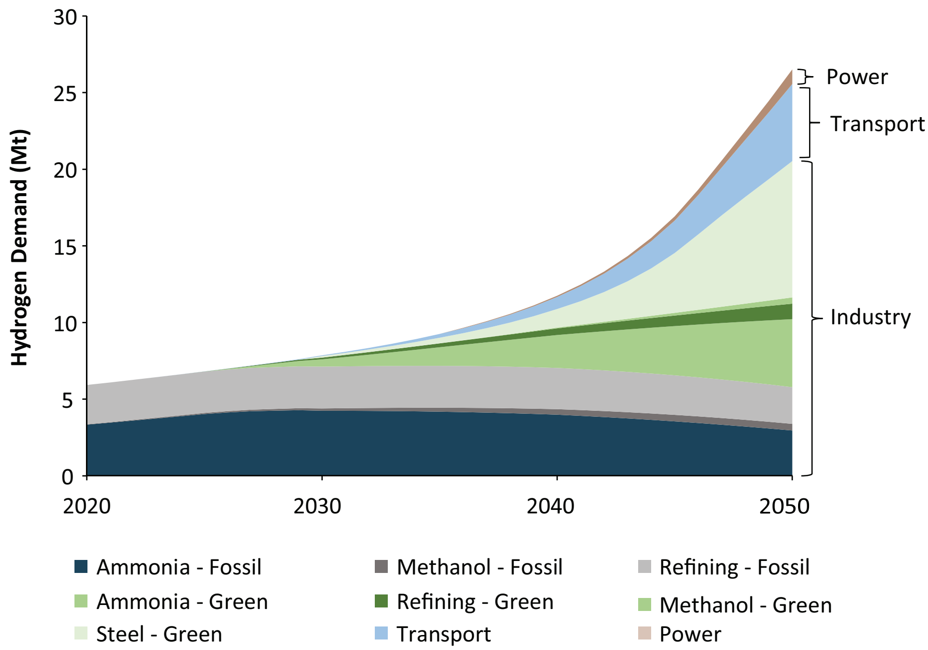


Figure 13: Hydrogen demand projection in the low-carbon scenario, 2020–2050

Source: TERI analysis

Note: Demand projections exclude the potential use of hydrogen in shipping, aviation, and petrochemicals. The term 'power' is used to depict the role of hydrogen in long-term power storage.

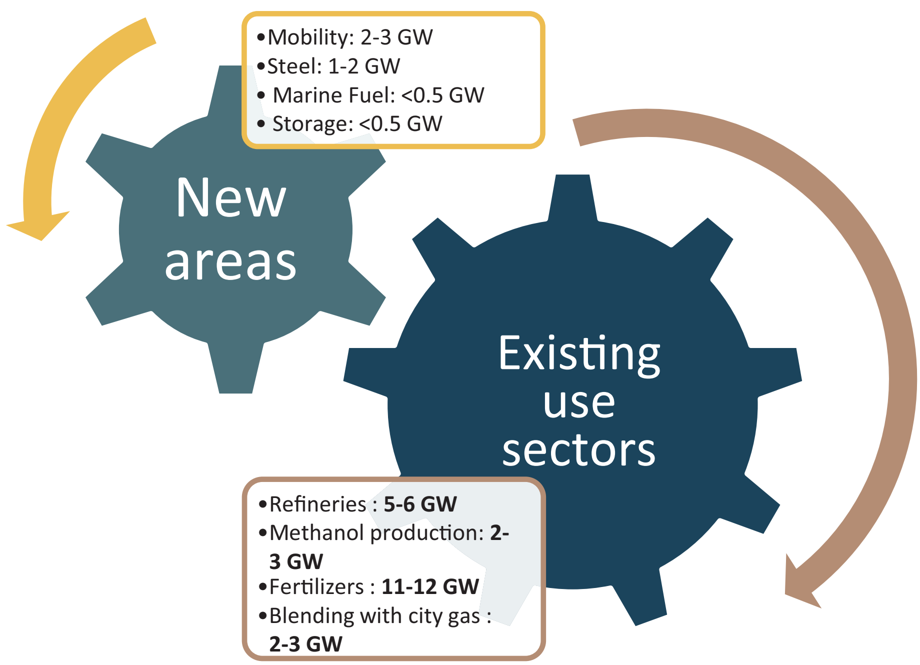
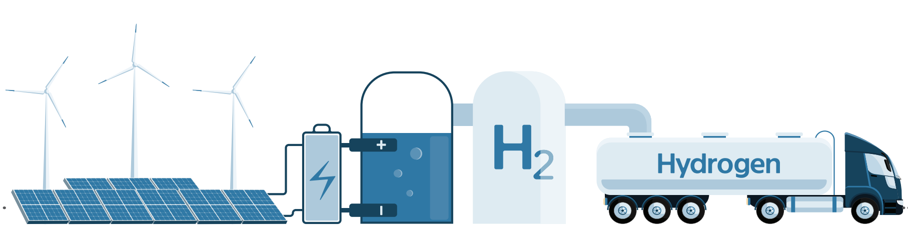


Figure 14: Electrolyser demands in India by 2030

Source: L&T



develop fuel cell powered ships for inland waterways. Various pilot projects including establishment of hydrogen storage facilities at port areas, hydrogen refuelling stations, ammonia production facilities, etc., are planned. Cochin Shipyard Limited is also working on ammonia projects. In fact, Ashok Leyland, Bosch and IIT Madras are working on using methanol as an alternative to diesel, which will be helpful for the broader decarbonisation goals of the state. Kerala is planning hydrogen valleys in select cities, just like the projects developed in the Netherlands. Fuel cell trains across the state are also being planned. Across the country, municipal bodies should contemplate using municipal waste for hydrogen generation to fuel their cities. The state government has made budgetary provision of INR 10 million for viability gap funding to procure ten hydrogen fuel cell powered feeder buses for Kochi Metro and airport services. These are few of the many initiatives announced by the state government.

Demand–Supply Analysis

Although some companies are currently producing hydrogen, meeting the 5 MT per annum green hydrogen targets by 2030 would necessitate careful planning and swift execution. According to the future scenario, there will be a significant need for sustainable hydrogen, and the following observations will be useful for the sector:

» Industries consuming grey hydrogen (refinery and fertilisers) need separate infrastructure for establishing the electrolysers for green hydrogen production. Industries needs to deploy large numbers of electrolysers to fulfil the demands of green hydrogen to replace the grey hydrogen and provision of an uninterrupted green hydrogen supply to these industries would be a crucial aspect.

» Some industries, for instance, steel and cement are new areas for green hydrogen applications. However, not many developments in the areas of hydrogen generation and utilisation are occurring in the country. Therefore need for hydrogen R&D projects with CCUS technology and accessing gaps in technical feasibility for hydrogen applications in the industries needs successful overseas experiences.

» Mobility is one of the areas where hydrogen fuel cell-based applications would be implemented but gaps in developing a concrete strategy for addressing storage, infrastructure and safety issues must not be ignored.

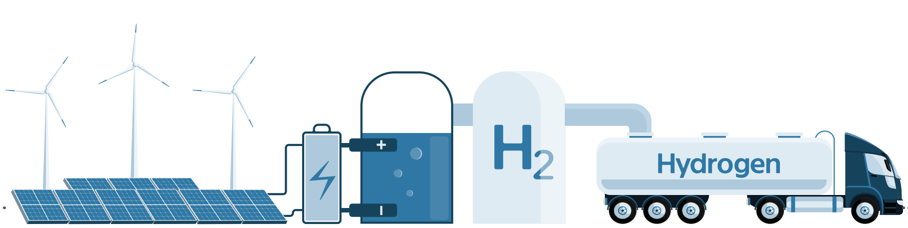
» There will be a gradual shift from grey to blue to green hydrogen in ongoing processes. Technologies such as CCUS would be deployed in the initial phase to use existing infrastructure and processes. The gradual shift will occur over some time to the use of green hydrogen. This is likely to be driven by the policies like green hydrogen obligation. Later on, as the cost of green hydrogen becomes competitive with blue hydrogen, the preference for green hydrogen will increase.

» The first phase of the Green Hydrogen Policy, published by the Government of India, focuses more on the supply side for hydrogen and reducing the cost of the green hydrogen, however, on the demand side, there are several gaps in creating a huge demand in industries.

» Green ammonia transport, hydrogen applications in marines, liquid hydrogen fuel for the aviation sector, and associated infrastructures are yet to be developed. The feasibility of a hydrogen storage systems and hydrogen transportation network near the port areas are a few grey areas that need urgent actions.

» Hydrogen blending with existing natural gas pipelines has high potential in India, however, at present this application is experiencing limited activities. There are gaps in addressing safety standards, regulations mandates for blending, and so on. These need to be addressed on priority basis.

As can be seen from the above, India's hydrogen sector development has just started. In short span of time the Indian industry has announced number of pilot projects and investment plans. Considerable investments are happening in infrastructure development including manufacturing and research & development. The time is ripe for international collaborations and investments to happen.



5. Overview of the Dutch Hydrogen Sector

The Netherlands is one of the pioneering hubs in Europe for a clean hydrogen-based economy.

The Netherlands is Europe's second largest producer of fossil-based hydrogen and it has expertise, technology and infrastructure to be a global player in the foundation of a hydrogen economy. It has hundreds of companies working in all parts of the value chain, from producing crucial components for electrolysers, to manufacturers of special vehicles and buses. Besides this, since the 1960's it has built up one of the world's most sophisticated natural gas infrastructures (pipelines of 136,000 km long), and acquired much expertise in handling, monitoring and storing gas. There is a flourishing scientific ecosystem with hubs like TNO's Faraday laboratory in Petten, which is one of Europe's largest hydrogen research facilities. Due to its large offshore wind potential and synergies between offshore wind and hydrogen production, and favourable geographical conditions with salt caverns for underground storage of hydrogen, the Netherlands has been recognized as a key centre for the development of hydrogen technology and designated as a Hydrogen Valley, and the Port of Rotterdam has the ambition to become an international hub for hydrogen production, import, application and transport to other countries in Northwest Europe.

The Dutch energy supply mix is dominated by natural gas (45%) and oil (37%). The share of renewable energy stands at 10% and the rest is contributed by coal and nuclear power (Figure 15).

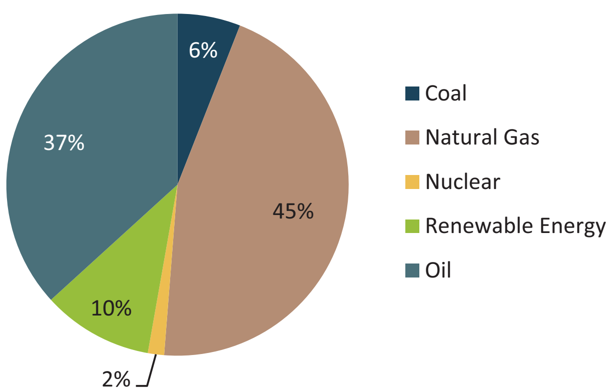


Figure 15: Dutch energy mix

Source: IEA (2022)[36]

Note: Renewable energy includes solar, wind, biofuel and wastes, and hydro.

[36] Details available at <https://www.iea.org/countries/the-netherlands>

Owing to the growing concerns of climate change and the resulting urgency of reducing reliance on oil and natural gas for meeting energy demands, the Dutch Government is targeting the transition to a low-carbon economy through the Dutch Climate Policy.[37]

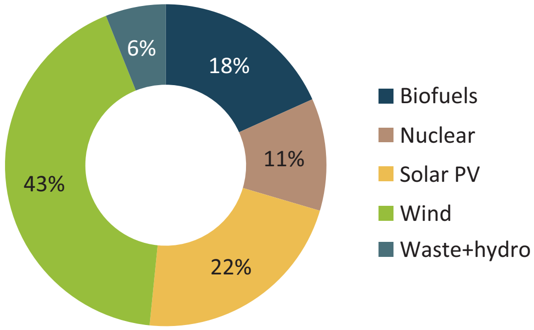


Figure 16: Energy generation in the Netherlands through low-carbon resources (2020)

Source: IEA Analysis (2022)

Among renewable energy sources, the majority of electricity generation in the country comes from wind (43%) and solar PV (22%). The Netherlands aims to reduce its GHG emissions by 100% by 2050 (Figure16).

The Government of the Netherlands is extensively involved in promoting low-carbon technologies, including hydrogen technologies, for sustainable energy requirements through strong policy and regulatory arrangements.

Policies for the Hydrogen Economy

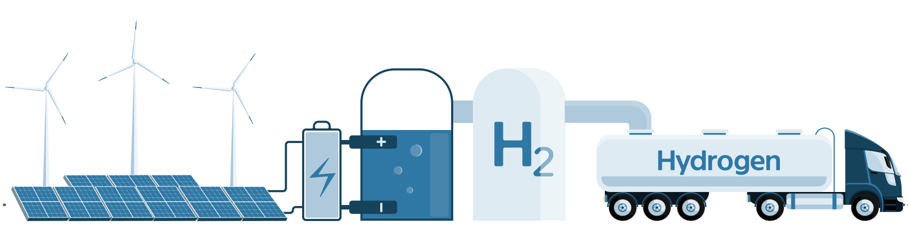
National Climate Agreement (NCA), 2019

The Government of the Netherlands has set an ambitious target to reduce greenhouse gas (GHG) emissions by 49% by 2030 and by 95% by 2050 (with respect to 1990 level) under the NCA, 2019.[38] These goals were laid down in the Climate Act on May 28, 2019. In addition to this, the Netherlands encourages carbon capture and storage (CCS) technologies in industries including power plants and waste incinerators. To increase the share of renewable energy (RE) in the total energy mix, the country has plans to install offshore wind projects in the North Sea.

The agreement includes specific targets in the mobility sector for 15,000 fuel cell cars, 3,000 fuel cell heavy-goods vehicles, and 50 hydrogen refuelling stations by 2025.

[37] Details available at <https://www.government.nl/topics/climate-change/climate-policy#:~:text=To%20combat%20climate%20change%2C%20the,Act%20on%20May%2028%2C%202019>

[38] Details available at >https://www.trade.gov/country-commercial-guides/netherlands-energy#:~:text=2021%2D11%2D09-,Overview,plant%20and%20one%20LNG%20terminal>



National Hydrogen Strategy, 2020

The Netherlands issued its national hydrogen strategy in 2020 to develop a hydrogen-based economy in the country to align with national targets of decarbonisation. The strategy focuses on deploying green hydrogen infrastructure in the country and targets to install 0.5 GW electrolyser capacity by 2025, and 3–4 GW by 2030. The globally declining cost of hydrogen and the Netherlands' extensive gas grid infrastructure could be a suitable opportunity for the country to transport the generated hydrogen. The strategy also links green hydrogen production and offshore wind tenders to accelerate the development of green hydrogen.

The Government of the Netherlands recognises the potential of hydrogen to become a globally traded commodity with large-scale imports and exports. The strategy supports the idea of using large electrolysers in the coastal regions of the Netherlands in addition to setting up smaller-scale production sites. The ambition is to make the Netherlands an energy hub in the future due to its favourable location, its ports, and its extensive gas grid and storage capacity. The strategy mentions pipelines to be the cheapest option for the transport of hydrogen across the country and across Europe. The demand for hydrogen would mostly come from the existing industrial clusters and from refuelling stations for heavy duty road transport, for shipping and also for aviation. Pilot plants are also planned to assess viability for building heating sector. Currently, the Netherlands is second largest manufacturer of hydrogen in Europe.

In the strategy, it is clearly indicated that in the forthcoming first phase of development, it is crucial to reduce the costs of clean hydrogen production through upscaling of production plants, which can start with the industrial clusters in which there is currently already a demand for hydrogen. In later stages of development, transportation and storage aspects can be developed.

The strategy acknowledges the need for a policy framework to accelerate the development of a hydrogen economy, and proposes a policy agenda based on the following four pillars:

- **Legislation and regulation** such as for using the existing gas grid, developing market regulations, providing guarantees and certification, safety, and infrastructure development.
- **Cost reduction and scaling up green hydrogen** by supporting schemes for research, piloting and scale-up; linking hydrogen to off-shore wind energy, and setting blending obligations.
- **Sustainability of final consumption** in ports and industrial clusters, transportation, built environment, electricity, and agriculture.
- **Supporting and flanking policy** through an international strategy, regional policy, and research and innovation could be a vital step.

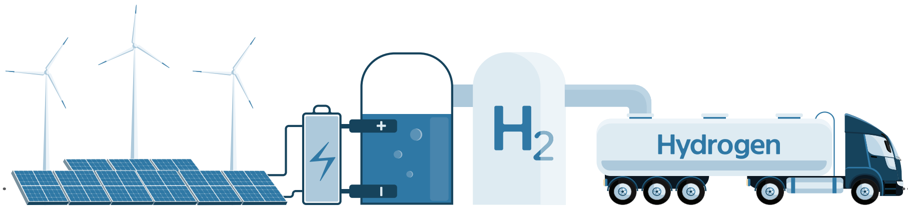
Figure 17: Scope of hydrogen transport in existing gas pipelines

Source: Government of Netherlands

Looking out for each other, looking ahead to the future — 2021–2025 Coalition Agreement

In December 2021 a new government coalition agreement was launched and had a large focus on combating climate change. Its goals include the following:

- To become climate-neutral by 2050. The Netherlands is tightening up its 2030 goal which was set out in the Climate Act to a reduction in carbon emissions of 60% by 2030 and 80% by 2040.
- A €35-billion Climate and Transition Fund is established for the next 10 years, over and above the current Renewable Energy Grant Scheme SDE++. €15 billion out of this fund is allotted for scaling up renewable energy technologies and hydrogen. It may be noted that previous government has already allocated funds for repurposing part of gas grid into hydrogen backbone. This will help to create the required energy infrastructure for electricity, heat, hydrogen and CO_2.
- Developing skilled professionals to meet the carbon-neutral goals by 2050.
- Focus on high-quality research on developing climate-neutral technologies and provisions for promoting circular economy.



- Increasing share of renewable energy in the total energy mix by deploying extra offshore wind farms, more solar panels on roofs, geothermal energy, green gas and aqua thermal energy. In addition to this scaling up the production and imports of hydrogen.
- As per the Paris Agreement, the country would increase the capacity for CCS. A ceiling will remain for CCS and will be adjusted where necessary so that the goals can be achieved.
- An obligation to supply green gas via the national grid will be introduced.

Additionally, the Dutch Government is eager to place hydrogen prominently on the international agenda. Under The North Sea Wind Power Hub project, the Netherlands is working with Germany and Denmark. The Netherlands also takes an active part in wider international initiatives through programmes such as International Partnership for Hydrogen and Fuel Cells in the Economy (IEA), Clean Energy Ministerial, and Mission Innovation. The Dutch focus heavily on close international cooperation in research and innovation, with Dutch initiatives aligned with European partners and EU-wide innovation programmes such as Horizon Europe (100 billion Euro research investment fund).

Nationally, under this government coalition agreement, government has decided to develop a heavy transport subsidy programme for supporting the purchase and operation of hydrogen fuel cell trucks. The Netherlands also has a deep focus on deploying CCUS/CCU projects in the country. As of now, several activities have been planned for blue hydrogen generation. One such key project is called the Porthos—Port of Rotterdam CO_2 Transport Hub and Offshore Storage project and will be executed by Energy Beheer Nederland, Gasunie, and the Port of Rotterdam. It is expected to store an annual amount of 2.5 million tonnes of CO_2 from industry in empty gas fields beneath the North Sea by 2024.

Some of the Dutch CCUS projects:

- **CATO Programme:** Dutch CCS research programme
- **AVR:** Start with the construction of a large-scale CO_2 capture installation
- **HVC:** Pilot plant for capture from bio-energy plant
- **OCAP:** CO_2 is captured at Shell Pernis and at Alco in Rotterdam
- **WarmCO$_2$:** CO_2 and heat from Yara in Terneuzen are utilised by the adjacent glasshouse horticultural area.

6. Learnings from Stakeholder Interactions

As part of the project TERI organised two interactions with Dutch and Indian stakeholders in March 2022. The first roundtable was for business and government stakeholders, and the second was for research and government stakeholders. The major discussion points are captured here.

Indo–Dutch Stakeholder Meet (Business-to-Business)

This meeting was attended by top industry players from India and the Netherlands working in the hydrogen sector. The discussions were held around the key business opportunities and bottlenecks in the Indian hydrogen sector to explore the mutual interests. The input points of the same are as follows:

Price:

» A combination of lower cost of renewable energy from India and effective electrolyser technology from the Netherlands can tackle the issues of the higher cost of green hydrogen. In this way, India could be one of the largest producers of green hydrogen and can be an export hub. The Government of India has announced its intention of developing India as hydrogen-exporting hub in near future. It is expected to leverage the high potential and lower costs of renewable electricity and engineering capabilities of the Indian industry.

» The government should focus on cost reduction of green hydrogen production by providing the investment/subsidy support to industries.

» The low-hanging fruits for Dutch industries in India are developing the low-cost electrolyser manufacturing capability and bringing Dutch experience of blending hydrogen with CNG pipelines.

» India has the advantage of cheap labour, rich experience in the RE sector, skilled knowledge base in RE, and Dutch industries have ample experience in hydrogen implementation in the industrial sector.

» Urgent need for public–private partnership collaborations and removing financial barriers for creating the demands for hydrogen-based needs in India.

New focus sectors:

» Feedstocks for hydrogen generation through biomass gasification routes could be a potential area to be explored in India. Indian and Dutch companies should come together for this.

» Green hydrogen deployments in refineries, petrochemical, and fertiliser industries, where grey hydrogen can be replaced with green hydrogen.

- The interest in Dutch technology transfer in the Indian transport sector may be one of the key areas of the cooperation between the two countries. Dutch industries can help India in developing transport mega-hub corridors.
- New areas of cooperation would be exploring offshore wind for green hydrogen and developing hydrogen components infrastructure in India.

Government necessities:

- Industries have emphasised that support from the Indian Government would be expected for: green hydrogen purchase obligations, carbon pricing for grey hydrogen, reduction of GST on electrolyser manufacturing, and reduction of duties on green hydrogen imports.
- The government should focus on cost reduction of green hydrogen production by providing the investment/subsidy support to industries.

Bottlenecks:

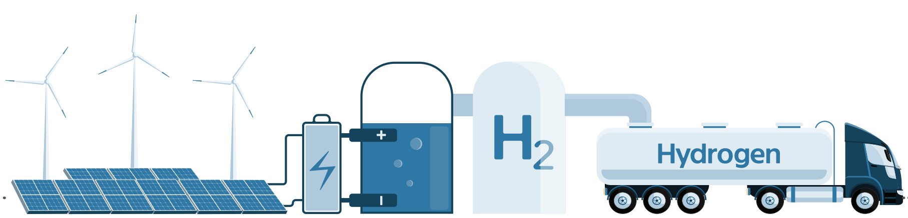
- For Dutch industries bottleneck to entering the Indian market would be localisations of technology in the Indian market, scaling-up hydrogen technology, focusing on indigenous supply chain, ease of adopting the European technology through schemes, and focusing on skill developments.
- Codes and standards for hydrogen fuelling stations and other hydrogen technologies, redesigning the products with existing international standards would also be a challenge for Dutch Industries in India.

An Indian power sector giant has also offered land, water, and other infrastructure to the interested Dutch companies for establishing hydrogen manufacturing facilities in India.

Indo–Dutch Stakeholders' Meet (Research-to-Research)

This meeting was attended by key research and development institutions from India and the Netherlands. The main agenda of the meeting was to understand the potential collaboration opportunities and bottlenecks in the India Hydrogen sector.

India has initiated a range of R&D projects and demonstration/pilot projects across hydrogen ecosystems. It is also part of international R&D collaboration initiatives like Mission Innovation. The Department of Science and Technology (DST) has also signed bilateral R&D collaboration agreement with European and Asian countries in many areas including hydrogen. Although the link between R&D institutions and industries still needs to be strengthened, recent initiatives by DST to provide R&D support to industry have started giving results. Current government has initiated schemes such as Make in India and Atmanirbhar Bharat to promote locally developed technologies. It is also promoting start-up companies to support innovation. The environment in the country is ripe for investments in technologies and innovations. Dutch companies and research institutes can leverage the situation by supporting Indian research and innovation through joint projects. With this background, the participants discussed the opportunities and bottlenecks in developing joint research programmes.



The major takeaways are summarised below and can be clustered as follows:

Expert exchange and talent building

» DST has bilateral agreements with developed countries on sector-specific research and development initiatives. Similar agreement with the Netherlands has been proposed. Going further, a focused approach on expert exchange and capacity- building programmes to enhance the technical skills on Indian scientists and technical professionals is proposed.

» The advice of launching Specific Calls for Mobility of Researchers by DST for developing skilled manpower could be an initial step for the both countries.

» Establishing an Indo–Dutch Centre of Excellence in India and the Netherlands could be proposed to respective ministries. Dutch institutions such as TU Delft and University of Groningen together with IIT's like IIT Delhi can explore possibilities of setting up a Centre of Excellence in Hydrogen Technology in India. The Centre can focus on adopting technologies to convert them in marketable products, developing applications of technologies, setting up benchmarking, certification, and testing facilities for hydrogen technologies, skill-building of technical professionals and so on.

Research focus

» IITs and IISc in India are working on developing hydrogen-powered IC engines and exploring research opportunities in the transport sector. The international collaboration between industries such as automobiles and academic institutions is proposed for developing hydrogen fuel cell-based road, rail, and shipping mobility in India.

» India will need anywhere between 3 GW and 4 GW of electrolysers by 2030. This is huge market opportunity for Dutch companies, in addition, being a welcome opportunity for India and the Netherlands to collaborate to scale-up electrolyser technology.

Public private partnerships

» Industry–academia synergy is important for deployment of home-grown technologies and bringing in more investments. So far, this has been the weakest link in India. On the contrary, the Dutch Government has successfully developed and invested large-scale demonstration projects with multiple partners from industry and research institutes.

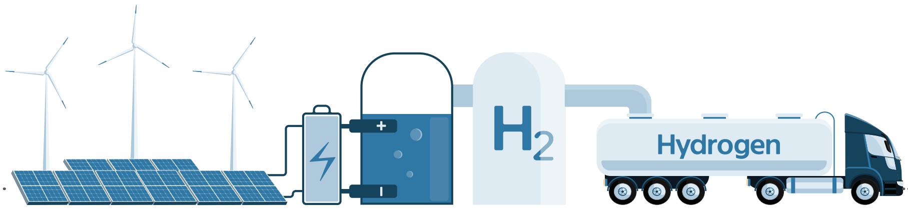
» The Dutch ecosystem strives to create flexible, fast-moving networks of specialist companies and research institutes and creation of the dozens of 'field labs' in which such networks translate fundamental research into innovative solutions and test them in real-life pilot environments. India needs such kind of strategy to take its research to the field. Dutch as a country is focusing on developing Hydrogen Valley in the Netherlands. During the discussions, it was observed that Triple Helix has a strong interest in India for developing hydrogen valleys. A hydrogen valley is basically a geographically concentrated ecosystem for hydrogen generation, storages, and utilisation. It brings in scale of operations, integration of various technologies and concentrated manufacturing facilities which help in reducing costs and developing local skill sets. A similar concept is being proposed by the DST and also by the Government of Kerala. The minister of science and technologies has conceptualised three hydrogen valley projects to be set up in India. Kerala is one of the frontrunners in India for developing hydrogen valleys and has ambitious plans to set up hydrogen infrastructure at ports and use hydrogen in inland shipping.

Participants of the roundtable suggested that Dutch partners in academia and possibly government can support these types of initiatives with technical assistance and through research, trade and technology partnerships.

» A few companies that are R&D-heavy, for example, Shell and Tata Steel have a notable presence in both countries, this can accelerate the hydrogen research activities in India. Similar kinds of collaborations can be explored in near future.

» HyGear, a Dutch firm is already working in India for hydrogen production through biomass routes. The Netherlands is a strongly emerging market in Europe in utilising hydrogen for shipping purposes, hydrogen generation through biomass routes, and fuel cell transport. In this regard, the Netherlands can provide a significant support to India in building infrastructures in the green shipping, hydrogen trucks, and hydrogen generation through biomass gasification route.

» To accelerate the hydrogen infrastructure, there is an immediate need for technology transfer from countries with advanced skills in hydrogen. Also, this is the time to build a consortium approach to develop the ecosystem and mitigate the financial constraints.



7. Collaboration Opportunities between India and the Netherlands

Introduction[39]

India and the Netherlands have a long and strong history of bilateral relations. This year they celebrate together 75 years of diplomatic ties, that started in the year of India's independence in 1947. The Netherlands was the third-largest investor in India, after Mauritius and Singapore for FY 2019/20 with FDI inflows of US$6.5 billion. From the period between April 2000 and December 2020, the Dutch investments in India comprised US$36.28 billion, standing at the fourth position. In FY 2019/20, the Netherlands was the fourth-largest destination for overseas direct investment (ODI) from India with investments estimated at US$1.23 billion.

The Netherlands was India's fifth-largest trading partner in Europe, after Germany, Switzerland, the United Kingdom, and Belgium in FY 2019/20 with a total two-way trade of US$11.75 billion with export from India, amounting to US$ 8.36 billion and imports from the Netherlands at US$3.39 billion. There are over 200 Dutch IT companies present in India, and over 200 Indian companies present in the Netherlands, including all the major IT companies such as TCS, HCL, Wipro, Infosys, Tech Mahindra, Sun Pharmaceuticals, and Tata Steel. This healthy bilateral relationship can be leveraged to tap mutually beneficial opportunities in the hydrogen sector.

Opportunities for Indo–Dutch Hydrogen Collaborations

The Indian hydrogen sector has US$160 billion investment potential by 2030. These investments will come across the value chain and for multiple opportunities in research and development, technology transfers, supply of equipment and technologies, consulting, industry, projects, and so on. A multipronged approach, starting with government to government engagements and extending it to research and academia and finally to industry to industry collaborations is suggested. Dutch companies can explore setting of manufacturing facilities in India as the costs of labour and infrastructure are lower. India and the European Union are set to hold an initial round of negotiations on a Free Trade Agreement in June with the aim of concluding an FTA by late 2023 or early 2024. This will open new opportunities for the hydrogen sector as well. Some identified opportunities are explained in the ensuing section.

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39 Details available at <https://mea.gov.in/Portal/ForeignRelation/Bilateral_Brief_April_2021.pdf>

Collaboration Platforms for Joint Research Work

To make these discussions and partnerships forward, a joint-level research and development programme in the hydrogen sector, joint feasibility studies in the mobility, ports and shipping sector, and taking forward the hydrogen valley initiatives in Indian cities through mutual corporations are recommended. In addition to this, there is also a need of sharing information related to technology transfer, policy dialogues, and brainstorming sessions to formulate safety standards for hydrogen storage and transportation. In this regard, city to city-level cooperation initiative would be a good starting point. For example, northern Netherlands has HEAVENN h2 valley project which can be an interesting partner.

Potential for Electrolyser Industry

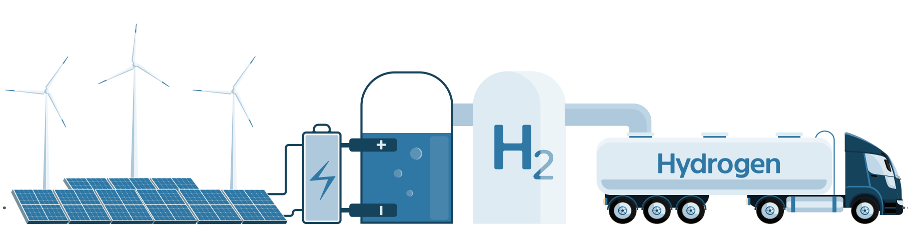
Recent announcements by the Government of India indicate the country's intent to focus on green hydrogen in the future. The Netherlands's goal to expand the global adoption of electrolysers aligns well with India's ambition to become a global hub for the production of green hydrogen. However, domestic electrolyser capacity in India is limited, and a significant scale-up of domestic R&D is required. Several Indian industry players have announced commitments to set-up production capacity and are exploring various routes for low-carbon hydrogen production. Partnerships with leading electrolyser-manufacturing companies in the Netherlands would facilitate knowledge exchange and could increase the flow of information between early-stage R&D and commercial-scale manufacturing. India's requirement for electrolysers is expected to be in the range of 3–4 GW by 2030 which is similar to the target set by the Netherlands.

Blue Hydrogen

To reduce CO_2 emissions focus should also be on CCUS technologies or blue hydrogen production. India has negligible experience in the production of blue hydrogen through carbon capture. The Netherlands is already deploying CCUS technology for producing blue hydrogen. For example, the Porthos project facilitated the need for carbon capture in port areas. India also has ports which can be part of such initiatives. The scope for blue hydrogen in India is uncertain as the country still needs an analysis of storage sites and examination of end-uses of the captured carbon. Dutch industries consortium is already working on the world's largest CCS project worth 2 billion euros in subsidies at the Port of Rotterdam. A project of Tata Steel, in its unit established in the Netherlands, is committed to reduce 30% of CO_2 from the steelmaking site of Ijmuiden. The E-Thor project investigates the possibilities of processing CO/CO_2, and flue gases into methanol through a5 MW electrolyser in Botlek industrial areas. These are a few areas of collaborations in future.

Areas of collaborations would include the following:

- Site identification and site assessments for CO_2 storage. Partnerships in this area could be in the form of joint feasibility studies to assess the potential of CCUS/CCS technologies in India.
- CCUS technology assessments and technology transfer to Indian companies.



» CCUs project initiation. These can be joint venture projects with Central Public Sector Units (CPSUs).
» Joint research activities for CCUS technology development and CO_2 conversion technologies.

Green Hydrogen Exports

Green hydrogen is expected to become cost-competitive with grey hydrogen by 2030. Going forward, India has plans to become a green hydrogen exporter. In a recent study, the Hydrogen Council classified India as a potential net exporter of green hydrogen by 2030 due to cheap renewable tariffs.[40] This would open up opportunities for Dutch expertise in hydrogen handling, storage, and shipping. Indian ports need to be equipped with infrastructure to handle hydrogen. This will be a good opportunity for experts and technologies from the Netherlands. At the same time, the Netherlands and its Rotterdam port, which has ambitions to be the Gateway to Europe, could be a preferable entry port for exported from India hydrogen.

Hydrogen Blending and Pipeline Infrastructure

India has limited experience in utilising natural gas pipelines for green hydrogen blending and only a pilot project of producing 10 kg/day of green hydrogen for blending with natural gas has started recently. However, there is a need of scaling up the technology for industrial applications in India. On the other hand, the Netherlands has been executing several such projects not only in their country but also at the international level. India is in the initial phase of exploring offshore wind potential of 71 GW. A joint Indo Dutch venture to directly use the offshore wind power for hydrogen generation using sea water. Owing to cheap RE power, India could become a green ammonia export hub. Therefore, there are ample opportunities for Dutch industries to collaborate with Indian industries and set up manufacturing units in India.

Transport Sector

The Netherlands is currently running multiple research and demonstration projects in their country, ranging from heavy-duty vehicles to hydrogen-based marine applications. The H2RenT project started in 2020 aims to develop 6 hydrogen-powered trucks. In another case, the RH2RINE project intends to deploy 10 hydrogen-powered ships and 3 refuelling stations by 2030. SkyNRG aims to produce sustainable hydrogen aviation fuels.

Potential for similar opportunities in India provides collaboration opportunities for Dutch companies. Major opportunities exist in the areas of technology transfer, know how exchange, consultancy, and investments in Indian joint ventures. Indian organisations like Cochin Shipyard are interested in working on hydrogen powered ships for cargo and transport. Collaboration opportunities can be explored with companies like Cochin Shipyard.

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40 Details available at <https://www.downtoearth.org.in/blog/pollution/green-hydrogen-can-drive-india-s-transition-to-clean-energy-combat-climate-change-77685>

Potential Challenges for Dutch Organisations

While India has progressed in the Ease of Doing Business Index in recent times, there still exists a few challenges for international investors and industries to start business in India. India does not have specific regulations for hydrogen technologies and there are some essential regulations that might create challenges for Dutch companies to enter the Indian hydrogen market. The following gaps in standards and regulations need to be filled for establishment of a hydrogen-based economy in India:

» India is a member of the International Organisation for Standardisation (ISO) in the ISO Technical Committee 197 (Hydrogen Technologies) and the International Electro-technical Committee IEC TC 105 (Fuel Cells), and needs to incorporate the globally harmonised hydrogen standards for the Indian context through the Bureau of Indian Standards (BIS).

» A uniform set of technical standards and safety certifications for industrial clusters and commercial-scale use-cases for high-pressure and liquefied hydrogen storage and transportation are not in place and are important for building an international value chain.

» Amendments are to be introduced to the Gas Cylinder Rules, 2004 to incorporate standards and regulations on hydrogen storage cylinders. Petroleum and Explosives Safety Organisation (PESO) would need to issue regulations on hydrogen storage equipment and refuelling systems.

» There is no currently standard to regulate the specifications of controlling material quality, procedures, and ensuring safety while blending hydrogen with existing natural gas pipelines.

Tariff Barriers

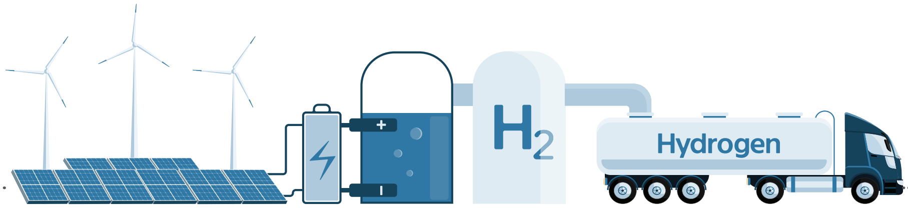
» India has eased tariff barriers and is following WTO guidelines. However, some tariff barriers are expected in the sector.

» Urgent need for public-private partnership collaborations and removing financial barriers for creating the demands for hydrogen-based applications in India.

As mentioned earlier, about 200 Dutch industries are currently operating in India and have vast experience with Indian regulatory and legal ecosystem.

Way Forward

This document gives an overview of the opportunities for hydrogen industry and research collaborations between India and the Netherlands. There are a few initiatives which are already happening, but now is the time to consolidate the efforts and chalk out a common action plan with definite targets, defining roles of various stakeholders. Some quick action projects are discussed next.



Recommended Collaborations/Projects

The following concepts are proposed for kick-starting Indo–Dutch collaboration on clean hydrogen:

1. Bilateral research collaboration agreement for funding joint research on hydrogen with industry participation.
2. Talent and expert exchange programs
3. Hydrogen infrastructure design consultancy.
4. Establishment of Centre of Excellence for carrying out pilot projects, training, and capacity building, testing and technology benchmarking infrastructures.
5. Planning for hydrogen valleys in three regions.
6. Development of standards and safety regulations.

Hydrogen Generation and Storage

1. Joint venture project for offshore wind hydrogen production facility.
2. CCUS and CCS studies for storage sites and CO_2 utilisation technologies.
3. Joint venture projects for electrolyser-manufacturing facilities with Indian industries.
4. Consulting opportunities for infrastructure development, especially hydrogen handling and storage facilities at both ports and generation plants.
5. Joint research projects with Indian research institutes.
6. Consulting opportunities in hydrogen pipeline infrastructure design, development, and installation.

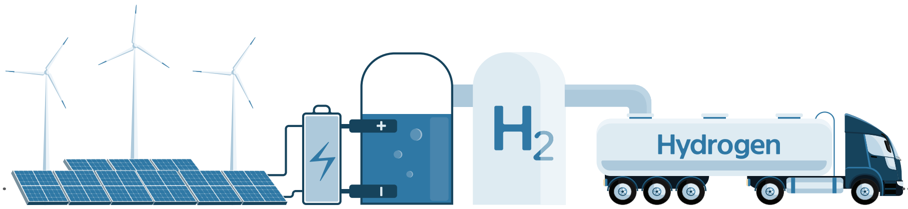
Hydrogen Utilisation

1. Project development/consulting in setting up hydrogen plants/facilities at refineries, fertiliser plants, steel plants, cement plants, and so on.
2. Joint venture opportunities with Indian shipbuilding companies for hydrogen.
3. Joint projects with major public sector organisations for demonstration projects such as hydrogen fuel cell-powered buses, trucks, and fork lifts.
4. Fuel cell-manufacturing facilities in India.
5. Indian investments in facilities in the Netherlands.
6. Joint projects with the state governments to plan and create integrated facilities based on hydrogen valley concept.

To kick start activities related to utilisation of hydrogen, we propose the following recommendations:

» The Ministry of New and Renewable Energy, Government of India, the nodal ministry for renewable energy and hydrogen development, and the Embassy of the Netherlands in Delhi can form a joint action group with members from other ministries and organisations including representatives from industry and think tanks. The group can then focus on developing road map for joint collaborations.

- A separate call for research and development cooperation with DST can be designed. The call could be industry-driven, focusing on transfer of technology.
- "Seeing is believing." A joint visit of Indian industry, research, and academia can be organised to the Netherlands to visit various projects and research facilities. This visit would be useful for mutually benefitting collaboration.
- Government-to-government collaborations with the Indian state governments/state government-owned public sector units for infrastructure planning and development.



Annexure

A1. Indian Industry Profiles

Reliance Industries Limited

Founded in 1960, Reliance Industries Limited (RIL), is an Indian multi-national conglomerate, headquartered in Mumbai**.** RIL is India's largest company as per revenue measured with the total market capitalisation of US$243 billion. The company operates its business majorly in energy, petrochemicals, natural gas, retail, telecommunications, mass media, and textiles. The Jamnagar refinery in Gujarat is the world's largest refinery with capacity of 1240,000 barrels per day.[41] RIL is also investing heavily in renewable energy sector and expected to invest US$80 billion by 2030. The company has a plan to develop 100 GW RE projects and bringing down the cost of green hydrogen to $1 per kg by 2030.[42] RIL is targeted to become a carbon-neutral company by 2035. The company is aimed to become world's largest blue hydrogen producer by re-purposing the Jamnagar refinery.

Adani Group

Headquartered in Ahmedabad, Adani Group is an Indian multi-national conglomerate founded by Gautam Adani in 1988. Recently, Adani Group became the third Indian conglomerate to cross US$100 billion in market capitalisation.[43] The group has diverse businesses including port management, energy, airport operations, electricity generation and distribution, mining, food processing, infrastructure, and many more. Group's RE company—Adani Green Energy Limited (AGEL)—is one of the leading RE company of India. Presently, the AGEL has a project portfolio of ~5.41 GW and around 14.87 GW capacities are under construction phase. The AGEL has planned to develop their RE portfolio to 25 GW by 2025.[44] The company is operating one of India's largest solar projects—the Kamuthi Solar Power project of 648 MW capacity in Tamil Nadu state. AGEL won SECI's solar bid of 8GW capacity, which is world's largest bid worth of US$6 billion.[45] Additionally, the AGEL acquired Soft Bank Energy

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41 Details available at <https://www.ril.com/OurBusinesses/PetroleumRefiningAndMarketing.aspx>

42 Details available at <https://economictimes.indiatimes.com/industry/renewables/reliance-to-invest-80-billion-in-green-energy-projects-in-gujarat/articleshow/88877199.cms>

43 Details available at <https://www.business-standard.com/article/companies/adani-group-becomes-3rd-indian-conglomerate-to-cross-100-billion-in-m-cap-121040600984_1.html>

44 Details available at <https://www.adanigreenenergy.com/>, last accessed on 13 April 2022>

45 Details available at <https://www.business-standard.com/article/markets/adani-green-hits-new-high-stock-zooms-127-in-three-months-120060900281_1.html>

India in 2021 for US$3.5 billion.[46] Adani Group is extensively involved in leveraging green hydrogen opportunities in India for which agreement framework with Canadian firm—Ballard—was being signed to manufacture the electrolysers in India.

NTPC Limited

Established in 1975, NTPC is India's largest power-generating company, owned by the Government of India. In the Platts Top 250 Global Energy Company rankings, NTPC is ranked second amongst independent power producers (IPPs). The total installed power capacity of NTPC stand at around 68.96 GW[47] including coal, hydro, and RE. Besides power generation, the Business Company of NTPC also engages in consultancy, power trading, training of power professionals, rural electrification, ash utilisation, and coal mining as well. NTPC is also leading several leading energy transition activities through its subsidiary—NTPC Renewable Energy Limited (NTPCREL) which is well-known for its engagements in developing large-scale solar, wind and hybrid projects in various parts of the country. The company has planned to install 60 GW of renewable energy by 2032. NTPC is also working on utilising green hydrogen for transportation by mixing the fuel with natural gas for city gas distribution (CGD) network. It has planned to run hydrogen fuel cell-based buses in Leh and Delhi, and the world's largest hydrogen-based micro grid in Andhra Pradesh. As of date, the commissioned capacity of NTPC is 1.66 GW with 1.95 GW under implementation.

Indian Oil Corporation Limited

Indian Oil Corporation Limited (IOCL) is a Ministry of Petroleum and Natural Gas, Government of India entity, working in oil and gas sector and has been headquartered in New Delhi. In 2021, IOCL was ranked 212th on the Fortune Global 500 list of the world's biggest corporations and reported a net profit of $6.1 billion for the financial year 2020/21. IOCL business covers exploration and productions of oil and gas, refining, pipeline transportation, marketing of petroleum products, natural gas and petrochemicals productions, and so on. The company also operates overseas in Sri Lanka, Mauritius, Europe and Middle East through its subsidiaries. Towards India's commitment of decarbonised economy, IOCL has planned several clean sources of energy including hydrogen. IOCL's R&D Wing in collaboration with Society of Indian Automobile Manufacturers (SIAM) and other vehicle manufacturers had explored the feasibility of blending of hydrogen with CNG for sustainable transport. Along with it, IOCL is working extensively to replace the conventional hydrogen generation resources with green hydrogen plants. It has announced to installed green hydrogen plant in its Mathura and Panipat refineries. IOCL has aimed to produce 70,000 tonnes of green hydrogen annually by 2030, which accounts 10% of its overall consumption.[48] Recently, IOCL has formed joint venture with L&T and ReNew Power to develop green hydrogen projects in India.

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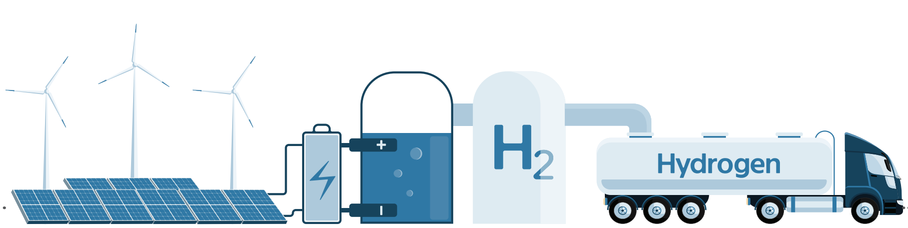
[46] Details available at <https://www.adanigreenenergy.com/newsroom/media-releases/AGEL-completed-the-acquisition-of-SB-Energy-Holdings-Ltd>

[47] Details available at <https://www.ntpc.co.in/en/about-us/ntpc-overview#:~:text=The%20total%20installed%20capacity%20of,and%205%20renewable%20energy%20projects>

[48] Details available at <https://www.deccanherald.com/business/business-news/new-policy-to-cut-green-hydrogen-cost-by-40-50-iocl-1083338.html>



GAIL (India) Limited

GAIL (India) Limited was incorporated in August 1984 as a Central Public Sector Undertaking (PSU) under the Ministry of Petroleum and Natural Gas (MoPNG). It is the largest natural gas company of India and works in across value chain of natural gas including trading, liquefied petroleum gas (LNG) production and transmission, city gas distribution (CGD), petrochemicals, electricity generation, renewable energy projects, and many more. GAIL has biggest natural gas network of 13,340 km spread across the length and breadth of country. GAIL's market share in gas transmission and gas trading are 70% and 50% respectively.[49] The company has a huge portfolio in CDG and LNG markets in India, also expanding its business through its subsidiaries and joint ventures. It has added renewable energy projects including solar, wind, and biofuels in direction to move towards energy transitions goals. It is also working significantly to implement blending of hydrogen in its gas grids. Recently, it has commenced India's first hydrogen blending project in Indore, Madhya Pradesh. GAIL's JV Avantika Gas Limited will supply blended CNG to automobiles and in households of Indore city.

Bharat Heavy Electrical Limited

Established in 1956, Bharat Heavy Electrical Limited (BHEL), is a Ministry of Heavy Industries, Government of India entity, working in engineering and manufacturing sector. It is India's largest power generation equipment manufacturer. BHEL's operation includes design, engineering, manufacturing, construction, testing, commissioning, and servicing of a wide range of products, systems and services for the core sectors of the economy, including but not limited to power, transmission, industry, transportation, renewable energy, oil and gas, and defence. To improve product quality and innovation, BHEL invests hugely on research and development (R&D) and amongst largest in the corporate sector in India. To support efficient technologies, BHEL collaborates with NTPC to install India's highest efficiency thermal power plant based on Advanced Ultra Supercritical Technology, pilot plant for conversion of high ash coal to methanol and high efficiency PERC cells amongst others. BHEL is also adopting renewable technology like solar energy on its establishments to meet energy demands. During 2019/20 company has installed a total of 28 MWp of solar projects, which generated 32.43 million units of electricity, resulting in saving 31,130 MT of CO_2.[50]

Larsen & Toubro

Larsen & Toubro (L&T) is an Indian multi-national conglomerate operating in 50 countries. L&T mainly deals in engineering, construction, manufacturing, technology, and financial services. L&T was founded in 1938 by two Danish engineers—Henning Holck-Larsen and Søren Kristian Toubro. L&T solar, a subsidiary of L&T, is developing solar projects in India and developed solar projects in various part of the country. Recently, L&T has collaborated with IOCL and ReNew Power for green hydrogen projects.

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49 Details available at <https://gailonline.com/ABGailstory.html>

50 Details available at <https://www.bhel.com/sites/default/files/Sustainability_Report_2019-20_web.pdf>

A2. Key Institutions in India for Research and Development of Hydrogen Ecosystem

Research Projects in Electrolyser

There have been several Research and Development projects in hydrogen technology arena. The projects supported by the Department of Science and Technology (DST), Government of India, in hydrogen production cover range of issues which include:

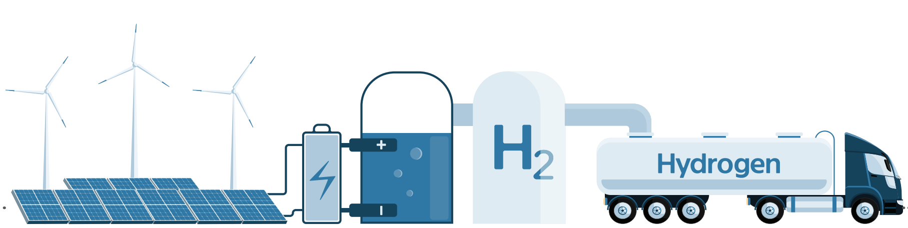
1. More efficient reforming processes and development of newer membranes.
2. Improving the efficiency of water-splitting reaction.
3. Development of cost-efficient and earth-abundant catalyst for photo–electrochemical water splitting.
4. Newer materials, catalysts, electrodes to accelerate the reaction.
5. Sorption enhanced reforming for improved H_2 production from biogas.

Details on some of the projects undertaken by various academic and research institutes are outlined below.[51]

1. **Bhabha Atomic Research Centre (BARC) Mumbai** is examining several hydrogen production technologies: a) using only electricity, that is, alkaline water electrolysis (AWE) and proton exchange membrane-based water electrolysis (PEM), b) using only heat source, that is, thermochemical splitting of water like iodine–sulphur (I–S) process and copper–chlorine (Cu–Cl) process, and c) using both electricity and heat sources such as high-temperature steam electrolysis (HTSE) and hybrid sulphur (Hy-S) cycle.

   In AWE, BARC technology is available for commercialisation for 10 Nm^3/h. In HTSE using solid oxide cells, suitable microstructure and processing conditions have been developed for several mixed ion electron conductors electrode materials and its suitability has been studied. The three reactions under the iodine-sulphur process have been tested at BARC. The institute has also developed suitable iron-based catalysts to minimise the use of platinum-based catalysts. Extensive research is being carried out for other hydrogen-production technologies such as Hy–S process, Cu–Cl process, and PEM-based electrolysis. BARC is also developing a high-temperature reactor capable of supplying process heat at a temperature of around 1000°C, where nuclear energy could play a significant role.
2. **Council of Scientific and Industrial Research–Central Electro Chemical Research Institute (CSIR-CECRI), Karaikudi** is exploring the design of electrodes and electrolytes for hydrogen generation using seawater. Reduced titania was used as a catalyst. Based on the materials developed, electrolyser technology was developed and transferred to the industry.

[51] Details available <https://dst.gov.in/sites/default/files/Country%20status%20report%20final%20Hydrogen.pdf>



3. **Institute of Chemical Technology, Mumbai**, is carrying out H_2 production via sorption-enhanced reforming process. Hybrid bi-functional materials, which combine the benefits of both the reforming catalyst and CO_2 absorbent, are being explored. Feedstocks include bio-ethanol, bio-butanol, bio-oil, and bio-gas.
4. The chemistry research group at the University of Lucknow is examining the use of transition metal-mixed oxides for AWE. Low-temperature synthesis routes have also been explored to synthesise Spinel (ferrites and cobaltites) and Perovskite oxides. Improved electro-catalytic properties have been observed for these materials.
5. Multiple institutes are collaborating for the generation of solar hydrogen. This has been initiated and supported by the Technology Systems Development Programme of the DST. The project is being undertaken by a consortium comprising IIT Kanpur, IIT Madras, Dayalbagh Educational Institute Agra, IIT Jodhpur, CECRI, Karaikudi and BARC Mumbai. The project aims to develop scalable designs of solar hydrogen generation systems using multiple technologies. The central emphasis of the project has been to design, synthesise, and characterise the best possible solar–chemical–materials combination suitable for large-scale applications. Materials close to international standards for material design are being developed. Apart from the photocatalytic and photo-electro catalytic route, an electrolyser integrated to photovoltaic modules will also be fabricated. Some institutions are also working on hydrogen generation from methanol.
6. **ONGC Energy Centre (OEC)** is investigating thermo-chemical water splitting for large-scale hydrogen generation. The group has developed a new patented Cu–Cl cycle and has demonstrated a closed-loop I–S cycle. The centre is at an advanced stage of developing an open-loop I–S process. Other research activities include examining process improvements, developing materials used in the construction of reactors and electrodes, membranes of electro-chemical processes and gas separation, catalysts, and so on.
7. **Thermax Limited** is exploring hydrogen generation via the catalytic route (on-board generation of hydrogen from liquid organic compounds).

Institutions in India are engaged in exploring the methods or technologies to improve the cost and efficiency of the electrolysers. The details on R&D projects in electrolyser technologies are given in Table 8.

Table 8: Details of electrolyser R&D projects in Indian institutions

Institution	Project(s)
IIT Delhi	» Conducting studies on catalytic decomposition of sulphuric acid in the I–S process, Bunsen reactor for production of sulphuric acid production and HI using electrochemical cell, and so on.
IISc, Bangalore	» Using biomass gasification for fuel cell applications. » Multi-fuel gasification system which uses woody biomass or biomass briquettes. » Developing semiconductor nano-composites for photo-catalytic water splitting under solar light irradiation.
IIT Madras	» Electrocatalysis and photocatalysis for hydrogen production, generation of solar hydrogen.
IIT Guwahati	» Exploring production of bioethanol and biohydrogen from lignocellulosic biomass in a fluidised-bed reactor.
IIT Kharagpur	» Mission mode project will explore hydrogen production using biological routes.
IIT Kanpur	» Developing photo-electro-chemical water splitting and fuel cells.
IIT Hyderabad	» Exploring the use of non-thermal plasma-assisted direct decomposition of H_2S into H_2 and S. » Using low-temperature plasma catalysis to transform greenhouse gases, for example, methane and CO_2 into syngas/H_2.
IIT Indore	» Hydrogen generation through catalytic route.
CSIR–NEERI	» Development of hydrogen supply system through liquid organic hydrides.
IIT (Banaras Hindu University)	» Photocatalysis for water splitting, conversion of methanol to hydrocarbons. » Catalytic cracking of methane.
UPES, New Delhi	» Establishment and demonstration of H_2 production and utilisation facility through photovoltaic–electrolyser system at NISE, Gwalpahari » Survey on inventory and quality of by-product H_2 potential in selected major sector in India.
IICT, Hyderabad	» Methanol reformer to produce 10 kL/h paired with a-10 kW fuel cell and 50 kL/h paired with a-50 kW fuel cell. » Catalysts for reformation of glycerol. » H_2 generation through biomass derived from glycerol
C-MET, Pune	» Exploring photocatalytic decomposition of toxic hydrogen sulphide » Developing a prototype photoreactor for hydrogen production from hydrogen sulphide under natural sunlight. » Photocatalysts development
NIT, Calicut	» Investigation on bio-hydrogen production using the thermochemical method.
NIT Rourkela	» Hydrogen production from biomass and waste using fludised bed gasifier.

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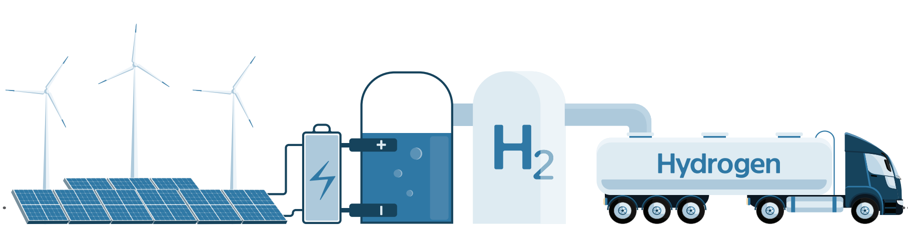


Table 8: Contd...

Institution	Project(s)
CSIR-IMMT, Bhubaneswar	» Developing transition metal tantalates and oxynitrides for water splitting. » Functional hybrid nano structures for photo–electrochemical water splitting.
ICT, Hyderabad	» Generation of H_2 from biomass derived glycerol.
ICT, Mumbai	» Analysis for Cu–Cl thermo–chemical production process. » ICT–OEC process for Cu–Cl thermochemical hydrogen production, reaction of metals with HI.
CECRI, Karaikudi	» Oxidation of CuCl and recovery of Cu, CuCl, HCl system for preparing $CuCl_2$ and H_2 electrodes and electrolytes for water electrolysis.
ARCI–CFCT, Chennai	» Novel electrocatalysts, depolarisers for water electrolysis, sea water electrolysis.
The Energy and Resources Institute	» Technology packages for woody and briquetted biomass, bioreactor facility for bio-H_2 production.
Naval Material Research Laboratory, Mumbai	» Bio-hydrogen with chemical fuel cells for electricity generation, hydrogen generation using ATR.
NIT Raipur	» Electrolytic cell design for bio-H_2 production from leafy biomass by electro-hydrogenesis.
NIT Tiruchirappalli	» Combined pyrolysis and steam gasification to establish multi-fuel Quraishy production.
CSIR–IIP, Dehradun	» Open loop thermochemical S–I cycle of H_2S split for carbon-free H_2 production in petroleum refinery.
OEC, Mumbai	» Thermochemical H_2 production, and I–S and CuCl cycle for H_2 production.
CIMFR, Dhanbad	» H_2 production using renewable and fossil fuel-based liquid and gaseous hydrocarbons by non-thermal plasma reforming.
Sardar Patel Renewable Energy Research Institute, Gujarat	» Dual fuel and thermal application, forced, and natural drafts biomass gasification process.
IACS, Kolkata	» Hydrogen Evolution Reaction (HER) by the FE–FE, hydrogenase enzymes, and graphene oxide modified aza terminated ITO supported graphene as electrode material, catalyst development. » Bio-inspired catalysts for reversible conversion.
ONGC	» Thermochemical hydrogen generation.
University of Rajasthan	» CNT-doped polymeric membranes for hydrogen purification.
JNTU Hyderabad	» Hydrogen production through bio routes, PEM electrolysis, and catalysts for hydrogen from glycerol. » Studies on the novel ways of enhancing CO_2 utilisation in catalytic oxidative dehydrogenation reactions.

Contd...

Table 8: Contd...

Institution	Project(s)
SPIC Science Foundation Chennai	» PEM methanol electrolyser for production of 1 NM^3/ h of hydrogen.
Shiksha 'O' Anusandhan University, Bhubaneswar	» Porous grapheme-modified metal oxide photo anode for electro-chemical water splitting.
Thapar University, Patiala	» Reforming of biogas for utilisation in CI engine under dual fuel mode.
DEI, Agra	» Synthesis and characterisation of nanostructured metal oxides and quantum dots for solar hydrogen production, photo–electrochemical generation.
IIT (BHU) Varanasi	» Hydrogen production with gasification and solar energy in the Centre of Excellence in Energy and Resources Development, Mechanical Engineering Department.

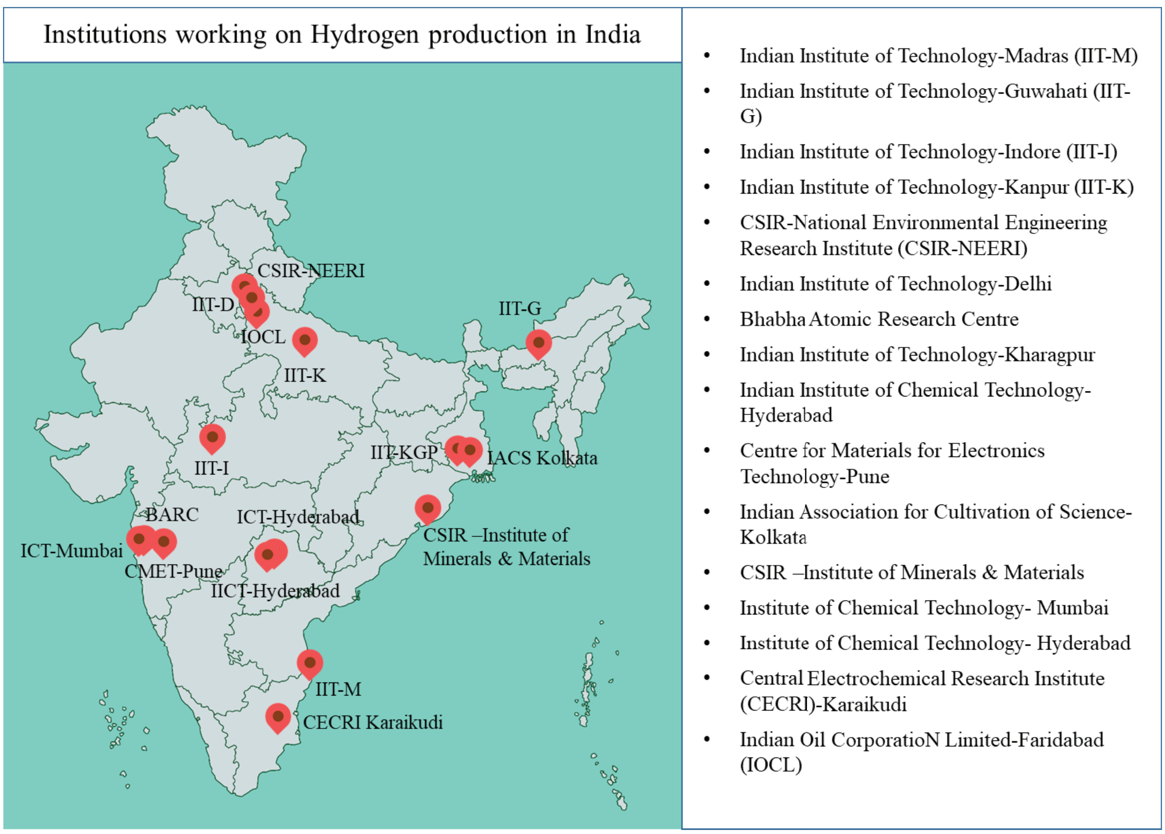
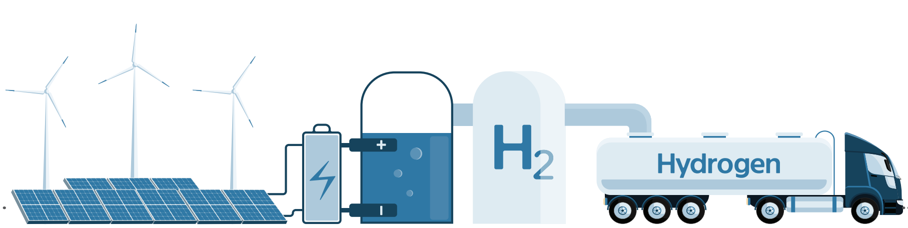


Figure 18: Institutions working in research and development of hydrogen production

Source: India Country Status Report on Hydrogen and Fuel Cells, Department of Science and Technology (2020)



A3. Key projects in the Indian Clean Hydrogen Sector

Name of industry	Initiatives taken by the industries
Reliance Industries Limited	» Targeted to become a net-zero company by 2035, $75 billion investment in the clean energy sector including hydrogen. » Achieving green hydrogen production cost of $1/kg by 2030.[52] » Targeting to become the largest producer of blue hydrogen by re-purposing its Jamnagar refinery that currently converts petroleum coke into synthesis gas to produce[53] blue hydrogen for $1.2–$1.5/kg. » RIL and Stiesdal: a Danish electrolyser manufacturer signed agreements to start local manufacturing in India.[54]
Adani Group	» Signed an agreement with Ballard company, Canada to manufacture hydrogen fuel cells in India.[55] » A new company Adani New Industries Limited (ANIL) formed to undertake green hydrogen projects.[56] » Investment of $70 billion in the renewable energy sector. » A vision of becoming the largest producer of green hydrogen.[57]
NTPC	» India's first Green Hydrogen Microgrid Project in NTPC Simhadri, Andhra Pradesh.[58] » An initiative of blending green hydrogen in the Gujarat Gas Limited's (GGL) PNG network at NTPC Kawas, Gujarat.[59] » Green hydrogen mobility project focusing on buses / public transport in Leh and Delhi.

52 Details available at <https://economictimes.indiatimes.com/industry/renewables/ambanis-reliance-seeks-to-be-worlds-top-blue-hydrogen-maker/articleshow/89522436.cms>

53 Details available at <https://www.business-standard.com/article/companies/reliance-industries-seeks-to-be-world-s-top-blue-hydrogen-maker-122021200514_1.html>

54 Details available at <https://www.livemint.com/industry/manufacturing/ril-and-denmark-s-stiesdal-to-manufacture-hydrogen-electrolyzers-in-india-11634070307183.html>

55 Details available at <https://www.moneycontrol.com/news/business/economy/adani-group-in-pact-with-ballard-for-hydrogen-fuel-cells-in-india-8144311.html>

56 Details available at <https://economictimes.indiatimes.com/industry/renewables/anil-to-be-adani-groups-vehicle-for-new-energy-business/articleshow/88788754.cms>

57 Details available at <https://www.adani.com/blogs/green-hydrogen-holds-strong-promise-for-india-energy-self-reliance>

58 Details available at <https://www.ntpc.co.in/en/media/press-releases/details/ntpc-awards-india%E2%80%99s-first-green-hydrogen-microgrid-project>

59 Details available at <https://www.thehindubusinessline.com/companies/ntpc-inks-pact-with-gujarat-gas-to-blend-green-hydrogen/article65294198.ece>

Name of industry	Initiatives taken by the industries
IOCL	» Joint venture with ReNew Power and Larsen & Toubro for developing green hydrogen infrastructure. » Announcement of India's first Green Hydrogen plant at Mathura refinery.[60]
GAIL	» Commenced India's first-of-its-kind project of blending hydrogen into the natural gas at Indore, Madhya Pradesh.[61] » Announced to build India's largest green hydrogen plant.[62]
BHEL	» Exploring collaborations for electrolysers and fuel manufacturing. Regarding this, BHEL issued a global Expression of Interest in 2021.[63] » BHEL has developed India's first phosphoric acid-based fuel cell.[64]
Larsen & Toubro	» Partnership with Norway-based HydrogenPro for technology transfer in India.[65] » Partnership agreement with ReNew Power for tapping the green hydrogen possibilities in India.[66] » Formed JV with ReNew Power and IOCL for developing green hydrogen-based technology.
Cochin Shipyard Limited	» Hydrogen shipbuilding
Ports in India	» Development of hydrogen facilities at ports.
FC TecNrgy	» The first company to create a Direct Methanol Fuel Cell market in India. » Partnership with SFC Energy AG of Germany for developing hydrogen fuel cell to address energy requirements of up to 25 kW.

[60] Details available at <https://iocl.com/NewsDetails/59274>

[61] Details available at <https://pib.gov.in/PressReleasePage.aspx?PRID=1794428>

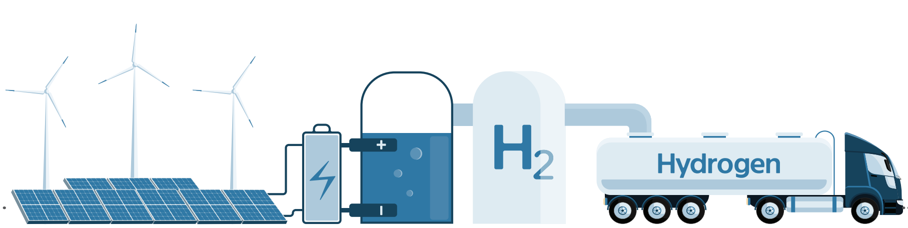
[62] Details available at <https://www.livemint.com/companies/news/indias-largest-green-hydrogen-plant-to-be-built-by-gail-11634815896991.html>

[63] Details available at <https://www.bhel.com/sites/default/files/EoI-%20Hydrogen%20Economy_10-11-2021.pdf>

[64] Details available at <https://www.downtoearth.org.in/news/powered-by-hydrogen-16101>

[65] Details available at <https://www.larsentoubro.com/pressreleases/2022-01-27-lt-signs-mou-with-hydrogenpro-for-manufacturing-hydrogen-electrolysers-in-india/>

[66] Details available at <https://www.larsentoubro.com/pressreleases/2021-12-02-lt-and-renew-announce-partnership-to-focus-on-the-green-hydrogen-business-in-india/>



Name of industry	Initiatives taken by the industries
India Hydrogen Alliance (IHA)	» Formation of six working groups for developing hydrogen economy in India.
JSW Future Energy	» Signed agreement with Australia's Fortescue Future Industries (FII) for green steel projects.[67]
TATA Group	» Tata Motors received 15 hydrogen fuel cell buses ordered from IOCL.[68] » Tata steel's plant in the Netherlands aimed to reduce CO_2 emissions by five million tonnes a year by 2030 by implementing clean hydrogen-based interventions.[69]
ACME Group	» Green hydrogen and ammonia production plant in Bikaner powered by 5 MW of solar PV.[70] » Developing a green hydrogen, ammonia facility in Oman SEZ. » The company aims to achieve 10 million tonnes per annum capacity for green hydrogen and green ammonia by 2030.[71]

67 Details available at <https://www.business-standard.com/article/companies/jsw-energy-australia-s-fortescue-future-join-hands-for-green-hydrogen-121072901103_1.html>

68 Details available at <https://www.tatamotors.com/press/tata-motors-bags-order-of-15-hydrogen-based-fuel-cell-buses-from-indian-oil-corporation-ltd/>

69 Details available at <https://www.tatasteeleurope.com/corporate/news/tata-steel-opts-for-hydrogen-route-at-its-ijmuiden-steelworks#:~:text=Tata%20Steel%2C%20the%20leading%20international,by%20adopting%20a%20hydroge-n%20route>

70 Details available at <https://www.ammoniaenergy.org/articles/tour-acme-groups-green-hydrogen-ammonia-plant-in-india/>

71 Details available at <https://www.acme.in/green_hydrogen>

B1. Dutch Industry Profiles

There is a strong collaboration between government and industries in the Netherlands. Significant investments and research and development activities are in various stages of development in the country. Industries are experimenting and setting up green hydrogen projects, hydrogen-based fuel cells in the mobility sector, and carbon capture (CCU/CCUS) opportunities in the industries to produce blue hydrogen. The key industries involved in the hydrogen sector are mentioned in Table 9.

Table 9: Matrix of key industries in the Netherlands

S. No.	Company name	H_2 production	Storage/ flow solutions	Mobility	Maritime	Engineering/ infrastructure/ environment	Electricity
1	ABB	✓	✓	✓	✓	✓	✓
2	ABC-Techniek B.V.				✓	✓	
3	AquaBattery B.V.	✓	✓		✓	✓	
4	Bosch Rexroth B.V.	✓	✓	✓	✓	✓	
5	Bredenoord					✓	✓
6	BrigH2	✓		✓		✓	
7	Bürkert Fluid Control Systems	✓	✓	✓	✓	✓	
8	Stichting Cenex Nederland (Cenex NL)			✓			
9	Desu Systems B.V.	✓	✓	✓	✓	✓	
10	Dutch Marine Energy Centre (DMEC)	✓			✓		✓
11	Eekels Technology B.V.	✓	✓		✓	✓	✓
12	Elestor B.V.	✓	✓			✓	✓
13	Eltacon Engineering B.V.	✓	✓			✓	✓
14	ENGIE Services Nederland N.V.	✓	✓			✓	✓
15	ERIKS bv	✓	✓	✓	✓	✓	✓
16	Fluor	✓	✓			✓	
17	Frames Renewables	✓	✓		✓	✓	
18	H2 Circular Fuel B.V.	✓	✓	✓	✓	✓	
19	HOWDEN	✓	✓	✓	✓	✓	

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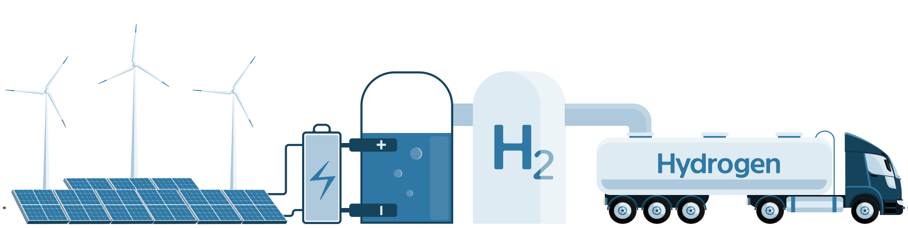


Table 9: Contd...

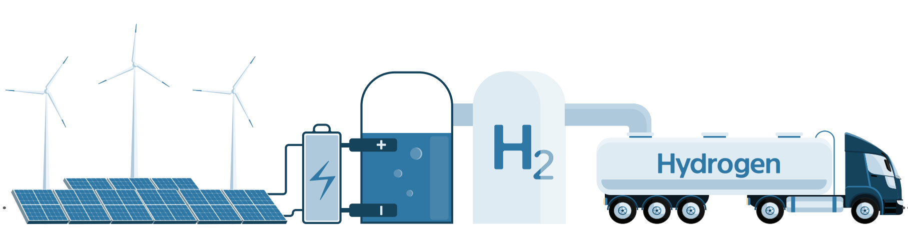
S. No.	Company name	H_2 production	Storage/ flow solutions	Mobility	Maritime	Engineering/ infrastructure/ environment	Electricity
20	Hy-Cell Co. Ltd			✓	✓		✓
21	HyET Hydrogen B.V.		✓	✓	✓	✓	✓
22	HyGear	✓	✓	✓			
23	HyMove B.V.		✓	✓			
23	Hystream B.V.	✓	✓	✓	✓	✓	✓
24	Kiwa	✓	✓	✓	✓	✓	✓
25	Koninklijke Van Twist						✓
26	MAGNETO special anodes B.V.	✓	✓	✓	✓	✓	
27	MTSA Technopower B.V.	✓	✓	✓	✓	✓	
28	New Cosmos - BIE	✓	✓	✓	✓	✓	✓
29	New Energy Coalition	✓	✓	✓	✓	✓	✓
30	Port of Amsterdam	✓	✓	✓	✓	✓	✓
31	Port of Rotterdam	✓	✓	✓	✓	✓	✓
32	Pure Water Group	✓					✓
33	REDstack B.V.	✓	✓				✓
34	SHV Energy N.V.		✓	✓			✓
35	Siemens Energy B.V.	✓	✓	✓	✓	✓	✓
36	R. Stahl Electromach			✓	✓	✓	
37	Stork	✓	✓	✓	✓	✓	
38	Summit Engineering B.V.	✓	✓	✓	✓	✓	✓
39	SuWoTec B.V.	✓	✓	✓	✓	✓	
40	Tieluk B.V.	✓				✓	
41	TNO	✓	✓	✓	✓	✓	✓

Contd...

Table 9: Contd....

S. No.	Company name	H_2 production	Storage/ flow solutions	Mobility	Maritime	Engineering/ infrastructure/ environment	Electricity
42	TSG Netherlands B.V.	✓	✓	✓		✓	
43	VDL Energy Systems B.V.	✓	✓	✓	✓	✓	✓
44	Vecom Group B.V.	✓	✓	✓	✓	✓	✓
45	Visser & Smit Hanab	✓	✓			✓	
46	VONK	✓					✓
47	Royal Vopak		✓	✓	✓	✓	
48	Witteveen+Bos	✓	✓	✓	✓	✓	
49	zepp.solutions	✓		✓	✓		✓
50	Zeton B.V.	✓					

Source: Excelling in Hydrogen – Dutch technology for a climate-neutral world (report)



B2. Dutch Research and Development (R&D) Institutions

Table 10: R&D institutions in the Netherlands

S. No	Name of institute / university	Nature and R&D activities
1	HAN University of Applied Sciences	» Testing, validation of small and medium-scale hydrogen applications, and conducting feasibility studies
2	TNO, The Hague	» Materials for PEM and SOE electrolysers, hydrogen for industrial applications, feasibility studies, and fuel cells. Key hydrogen projects are Hydrohub, NorthH_2, Gigawatt, and others with public universities.[72]
3	Hanze University of Applied Sciences, Groningen	» It is a megawatt testing centre located at the University's Energy Transition Centre. Institute for Sustainable Process Technology (ISPT) Hanze University, TNO carries out research in low-temperature water electrolysis and green hydrogen at a large scale.[73]
4	Univesity of Groningen, Groningen	» Center for Economics Research researches hydrogen economics feasibility, policy, and hydrogen markets.[74] » Academic lead 'HEAVENN' project to transform Northern Netherlands into a hub of green hydrogen energy.[75] » Partner in WAviatER project: hydrogen production technology for the aviation sector and energy applications.[76]
5	TU Delft, Delft	» New materials research for hydrogen storage research, developed versatile hydrogen sensor, fuel cell research. » TU Delft students designed a solar boat running on a hydrogen fuel cell under the HYDRO MOTION project. » Underground storage project under ADMIRE Hydrogen Lab.[77]

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[72] Details available at <https://www.fme.nl/system/files/publicaties/2021-04/NL%20Dutch%20solutions%20for%20a%20hydrogen%20economy%20V-April%20A4-digiexport.pdf>

[73] Details available at <https://www.hanze.nl/eng/research/strategic-themes/energy/hydrohub-tki?r=https://www.hanze.nl/eng/research/overviews/researchprojects>

[74] Details available at <https://www.rug.nl/ceer/research/research-on-economics-of-hydrogen-at-ceer?lang=en>

[75] Details available at <https://www.rug.nl/feb/news/2019/university-of-groningen-transforming-northern-netherlands-into-green-energy-hub?lang=en>

[76] Details available at <https://www.rug.nl/news/2022/03/hydrogen-will-fly-in-the-northern-netherlands?lang=en>

[77] Details available at <https://www.tudelft.nl/en/2022/internationale-vrouwendag/underground-storage-of-hydrogen-catalyst-of-sustainable-energy-transition>

Table 10: Contd...

S. No	Name of institute / university	Nature and R&D activities
6	Eindhoven University of Technology (TU/e), Eindhoven	» TU/e researchers developed a new catalyst that can reduce the size of the electrolyser and can store 20 times more energy.[78]
7	Fujifilm, Tilburg	» The development of ion-exchange membranes and gas separation membrane technology takes place at the R&D labs, Tilburg, the Netherlands
8	AquaBattery B.V.	» Working in green energy storage research including hydrogen storage
9	Berenschot, Utrecht	» Preparing blueprint for a Hydrogen Exchange in the Netherlands. » Scenario-building research for grey and green hydrogen.
10	Leiden University, Leiden	» Metal hydride hydrogen storage system research » Training programme and transfer of knowledge activities in the hydrogen sector.[79]
11	BrigH2	» Developing a-50 MW gasification unit to produce 6300 MTPA renewable hydrogen, pure bioCO_2 and » Biochar. » Hydrogen fuel cell research for the mobility sector.
12	Stichting Cenex Nederland (Cenex NL), Amsterdam	» H2ME (2016–22): EU's largest FCEVs and refuelling infrastructure demo project » ZEFER (2017–22): Commercial and operational viability of high-usage vehicles. » HyTrec2 (2014–20): Hydrogen vans, trucks and refuse collection vehicles in North Sea Region.
13	Elestor B.V., Arnhem	» Research and development of low-cost hydrogen storage system. » Elestor storage systems produce hydrogen during charge (consumes during discharge) the technology offers a unique capability to integrate the worlds of 'electricity storage' and 'hydrogen production.

Contd...

78 Details available at <https://www.tue.nl/en/news/news-overview/storing-energy-in-hydrogen-20-times-more-effective-using-platinum-nickel-catalyst/>

79 Details available at <https://www.universiteitleiden.nl/en/research/research-projects/science/mcrtn-hydrogen>

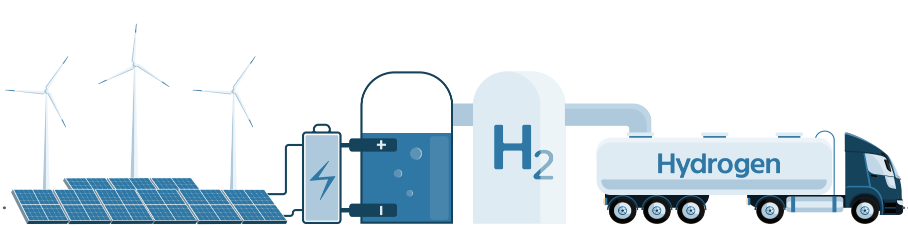
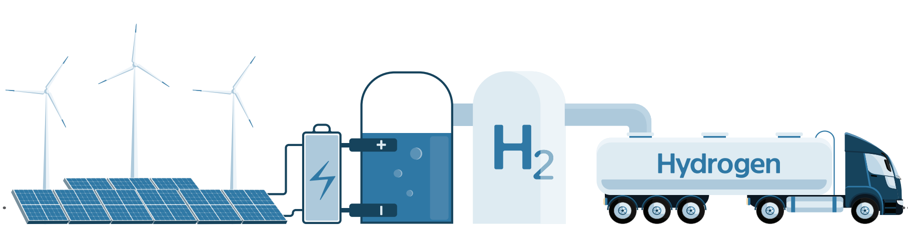


Table 10: Contd...

S. No	Name of institute / university	Nature and R&D activities
14	HyET Hydrogen, Arnhem	» Developed the first commercially viable electrochemical hydrogen compressor (EHC) in 2017 » HyET Hydrogen developed a technology that can extract and purify hydrogen from » mixed gas streams.
15	HyGear, Arnhem	» Develops technologies to generate and recycle hydrogen at the end user's site. » Partner in the HyGrid project and conducting R&D in metal hydride storage for stationary hydrogen supply and fuel cell systems.
16	Hysolar	» Installing 2 MW electrolysers for green hydrogen productions. The facility aims to generate 250 tonnes of hydrogen/ year and plans to run 750 cars and 25 buses on daily basis.

B3. Key Projects in the Dutch Hydrogen Sector

Project name	Details	Year and company
DJewels -20 MW electrolysers in Delfizli	Design an electrolyser that can generate 3,000 tonnes of green hydrogen per year	2020–Present / Nouryon and Gasunie
Hydrogen Delta	Designing a Gigawatt Electrolysis Plant for Zeeland (research project)	2019/ Institute for Sustainable Process Technology (ISPT), Nouryon
H2.50	Building 250 MW (45,000 tonnes of green hydrogen annually)	2019–22 / Nouryon, Port of Rotterdam, and British Petroleum
Porthos	CCUS Infrastructure for Blue Hydrogen in Port of Rotterdam	2020–23/ Gasunie
Westereems	100 MW Hydrogen Plant for Westereems Wind Farm	2019/ innogy
Hemweg hub Amsterdam	Building a-100 MW hydrogen power plant on the Hemweg site as part of a fossil free hub for providing green electricity, heating and fuels for Amsterdam Metropool Region.	2019/VATTENFALL
H-vision	The production of blue hydrogen based on natural gas and through the reuse of refinery gases. Carbon capture and storage below the North Sea.	2020–26/ Air Liquide, BP, Deltalinqs , Gasunie, Havenbedrijf Rotterdam, Power Plant Rotterdam, Shell, Uniper en Vopak
GreenH2UB	Creating a green hydrogen ecosystem in Noord Brabant.	2019–30/BOM and Force Renewable
HEAVENN	H_2 energy applications in Valley Environments for Northern NL	2020–25/ New Energy Coalition
Hydrogen Delta	Gigawatt-scale green hydrogen factory in the Delta Region	2020–30/Various partners
GZI NEXT	Possibilities of using the existing infrastructure for the generation of green gas through fermentation or gasification and for the generation of hydrogen.	2018–Present
Bio Energy Netherlands	Wood Gasification with Production of hydrogen and CO_2	2019–21 / HYGEAR
Hydrogen Gas Turbine Retrofit	Hydrogen gas turbine operating on hydrogen fuel	2019–202 l/Ansaldo Energia



Project name	Details	Year and company
Hydrogen Mill	Development of 4.8 MW Lagerweij windmill and a-2 MW electrolyser to demonstrate the production of hydrogen by windmills.	2020/Hygro
PosHYdon	Hydrogen production from the North Sea water on an offshore platform	2019–21/Neptuneenergy and TNO
H2ermes	Building a-100 MW Hydrogen Plant in Amsterdam for Tata Steel	2019/TATA Steel & Nouryon
NortH2	The Production of green hydrogen from a wind farm in the North Sea	2020–40/Gasunie
H2GO	A-2.5 MW electrolyser will be producing green hydrogen at Goeree Overflakkee Island	2017–30/TU Delft and +30 parties
HyNetherlands	Building a-100 MW electrolyser in the Eemshaven	2021–22/Gasunie

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