Integrated Research and Action for Development
IRADe 20 YEARS

Stakeholders' consultation meeting on

"Roadmap for Green Hydrogen development in India"

Date & Day : February 29, 2024 (Thursday), Time: 2:30 PM-5:00PM IST

Draft Agenda (Hybrid mode)

Conference Hall, C-80, Shivalik Colony,
Malviya Nagar, New Delhi 110017.

Duration	Session Details
2:30 PM – 3:00 PM	**Registration and Tea**
3:00 PM – 3:05 PM	• Welcome and Opening Remarks by **Dr. Jyoti K Parikh**, ED, IRADe
3:05 PM – 3:15 PM	• Opening Address, **Shri Ajay Yadav**, Joint Secretary, Ministry of New and Renewable Energy, New Delhi
3:15 PM – 3:25 PM	• Keynote address by **Shri Rajnath Ram, Adviser (Energy), Niti Aayog**
3:25 PM – 4:40 PM	Technical Session: Chaired and Moderated by **Prof Kirit Parikh,** Chairman, IRADe
3:25 PM – 3:35 PM	**Chairman's Opening Remark**
3:35 PM – 3:55 PM	Presentation by **Dr Anjana Das**, Senior Adviser, IRADe on **"Roadmap for Green Hydrogen Development in India"**
3:55 PM – 4:40 PM	**Discussion session and feedback from the stakeholders**
	Session Chair: Dr Kirit Parikh, Chairman, IRADe ▪ Mr Manoj Upadhyay, Deputy Adviser, Niti Aayog ▪ Representative from MNRE* ▪ Representative from CEA* ▪ Representative from Ministry of Mines* ▪ Mr L.N Lalwani, Executive Director, TORRENT Power ▪ Prof. Pratibha Sharma, Head, Centre for Hydrogen Storage, IIT(B) ▪ Mr Anurag Pandey, Business Head, Hydrogen Value Chain, Reliance Industries Limited ▪ Prof. K. A. Subramanian, Department of Energy Science and Engineering, IIT(D) ▪ Prof. Anil Verma, Department of Chemical Engineering, IIT(D) ▪ Mr Rajan Varshney, Deputy General Manager, NTPC
4:40 PM – 4:50 PM	Q & A Session and Feedback
4:50 PM – 5:00 PM	Closing Session and Vote of Thanks: **Dr. Jyoti Parikh**, Executive Director, IRADe
5:00 PM -5:30 PM	High tea and networking

- To be confirmed

Roadmap for Green Hydrogen Development in India

20 YEARS
IRADe Integrated Research and Action for Development

IRADe-PR-108(2024)

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Executive Summary

Indian policymakers recognise the critical role of green hydrogen in improving energy security and achieving Net Zero by 2070. Vast renewable energy resources may offer potential surplus hydrogen for export. National Green Hydrogen Mission (NGHM) aims to make India the Global Hub for the production, usage and export of Green Hydrogen/derivatives and enable to take technology and market leadership in the Green Hydrogen fuel chain (GOI, 2023). The Mission targets to build capabilities to produce at least 5 million tonnes (Mt) of Green Hydrogen per annum by 2030, with the potential of reaching 10 Mt if there is export market.

As water electrolysis using renewable electricity is expected to be the key hydrogen production method, Indian power system which was producing electricity to meet the conventional demand for industry, households etc., now needs to accommodate green electricity needed for hydrogen production. Green hydrogen production will compete for limited green power generation resources (solar, wind etc) with electricity produced to meet conventional demand. Green hydrogen produced using surplus electricity during low demand period also offers a storage option to improve power system reliability. Indeed, the hydrogen energy planning cannot be assessed as an isolated issue, but it must be carried out by analysing the role of hydrogen production in the whole electricity system for determining the optimal configurations of both the power system and the hydrogen fuel chain.

Key objective of this project:

- to bring out technical and economic information regarding development of the hydrogen fuel chain (water electrolysis) and inter-connected Indian power system over the time horizon 2030-70, which would be relevant and strengthen the Indian policy and decision-making process on the development of the green hydrogen industry.

An integrated modelling framework of the Indian power system and hydrogen fuel chain is developed using International Atomic Energy Agency’s MESSAGE software based on dynamic and linear cost optimisation approach and is used for simulating scenarios. Two hydrogen scenarios are designed based on green electricity supply modes to the electrolysers,

1) GRNGRIDH2 scenario: a hybrid system of solar PV, wind onshore power plants and battery storage connected with separate transmission and distribution network delivering green electricity to the electrolysers.
2) GRNSITEH2 scenario: electrolysers are coupled with solar PV plants and battery storage located at the same site at the demand point and drawing green electricity

There is one NoH2BAU scenario when power system is only meeting conventional electricity demand and no hydrogen production.

Technical and economic outputs are:

- for Hydrogen fuel chain: requirement of electrolyser capacity, technology and usage in scenarios, electricity requirement in hydrogen production, optimal electricity generation and storage capacity connected with the electrolysers supplying green electricity, investment on electrolyser and green power infrastructure;
- for power system: optimum power generation and storage capacity by technology, electricity generation and technology mix, transmission and distribution infrastructure, optimal allocation of power generation sources between conventional electricity demand and green hydrogen production, investment on power infrastructure (electricity for conventional demand + hydrogen production), and emissions.
- green hydrogen potentials of the India power system up to 2070 at 5 different cases of declining hydrogen prices.
- economics of green hydrogen as storage to meet flexibility of the power system.

Additionally, comparing results of the green scenarios with the same of the NoH2BAU scenario, impacts on power system due to the introduction of hydrogen production, in terms of additional capacity, investment and electricity generation, impacts on technology mix and resource allocations are quantified.

Further, hydrogen transportation and storage issues are covered. Issues on critical minerals needed for electrolysers and developing a domestic electrolysers manufacturing industry are addressed.

Outputs would be useful for policy makers, power system and hydrogen fuel chain planners, investors, industries with interests on electrolyser manufacturing, development, installation and power sector development etc.

Key findings:

- To meet NGHM target of 5 Mt of green hydrogen by 2030, 60 GW of electrolyser capacity is needed in GRNGRIDH2 scenario, which is increased to 100 GW in GRNSITEH2 scenario. By 2050, to meet a hydrogen demand target of 28.7 Mt (as reported in NITI/RMI report), there would be 6-8 times (462 GW-603 GW) increase in electrolyser capacity requirement indicates the market and investment potentials for electrolysers installation and manufacturing industries exist in the country.
- hydrogen production will create substantial amount of new electricity demand. 5 Mt of green hydrogen target needs about 257 TWh of green electricity in 2030 which needs about 150-155 GW of renewable capacity (being part of the optimized integrated system, it will feed grid also). Green electricity requirement would go up to 738 TWh, 1320 TWh and 2300 TWH in 2040, 2050 and 2070.
- In 2050, green grid needs 844 GW of solar PV, 79 GW of wind and 29 GW of battery storage. Notably, apart from supplying electrolyser, green grid also supplies 139 TWh to the main grid. To produce green hydrogen on site, it needs 1075 GW of solar PV and 114

GW of battery storage in 2050. Apart from supplying 1320 TWh of green electricity to the electrolysers, these plants also supply 33 TWh to the grid.

- Concerning investment on electrolyser, meeting 2030 NGHM target, 41 billion USD of investment is required between today and 2030, USD 7 billion per year. Investment on electrolyser in the same period would be 70% higher at 70 billion USD in GRNSITEH2 scenario, USD 10 billion per year. In the subsequent decades, investment requirement would be in the range of USD 39-71 billion in GRNGRIDH2 scenario. However, in the GRNSITEH2 scenario, investment required to be 10-80% higher compared to the same in GRNGRIDH2 scenario.
- Regarding investment on green power infrastructure, during 2025-30, 63 billion USD would be needed to build solar PV capacity at the same site of the electrolyser to supply required green electricity (GRNSITEH2 scenario). This will go up to 122 billion USD in Green Grid scenario (GRNGRIDH2) to build solar and wind power plants and also transmission and distribution infrastructures to deliver green electricity to the electrolysers. In later three decades up to 2060, investments of respectively, 216 Billion USD, 230 billion USD and 398 billion USD will be needed. Respective numbers are 156 billion USD, 156 billion USD and 271 billion USD in GRNSITEH2 scenario.
- When compared with NoH2BAU scenario, 9-10% more electricity needs to be generated in 2030 to meet NGHM target. As green hydrogen demand grows, additional electricity generation is even higher by percentage in following years. Large hydro, Nuclear and renewables supply the additional electricity requirement due to the restriction on new coal capacity, limited domestic gas and high price of imported gas. Along with renewables, India needs to accelerate it nuclear power development also which has been slow in the past.
- Regarding optimal allocation of green resources between electricity demand and hydrogen production, in GRNGRIDH2 scenario, out of total potential (as assumed in Table 3.3) of 390 GW of solar PV and 150 GW of wind onshore, 88 GW of solar PV and 66 GW of wind onshore would be optimally allocated to green hydrogen production in 2030. Remaining 302 GW of solar PV and 84 GW of wind onshore would be allocated to the grid to meet conventional electricity demand. In 2050 and 2070, respective optimal allocations of solar PV to the green grid are 844 GW and 1285 GW; remaining 1656 GW and 4315 GW would go to the main grid as total potentials are respectively 2500 GW and 5600 GW. Respective allocations of wind onshore to the green grid are 79 GW and 432 GW. Grid allocations are respectively 521 GW and 618 GW.
- In GRNSITEH2 scenario, which uses only solar PV for green hydrogen production, optimal allocations of 390 GW solar PV in 2030 between hydrogen production and grid are respectively 150 GW and 240 GW. In remaining years, out of respective total upper limits of 2500 GW in 2050, 1425 GW and 1075 GW will be optimally allocated between main grid and green hydrogen production at site. In 2070, respective allocations are 3072 GW and 2528 GW. In all years, entire potentials of both solar and wind onshore are used.

- Comparing investment on power infrastructure supplying electricity to meet conventional electricity demand and hydrogen production, GRNGRIDH2 scenario needs investment of 690 billion USD during 2021-30, which is 29% (160 billion USD) more when compared with NoH2BAU scenario. GRNSITEH2 scenario needs 15% higher investment on power infrastructure compared to the NoBAUH2 scenario to meet same target of 5 Mt hydrogen in 2030.
- Comparing total supply costs (investment (electrolyser + power infrastructure), fixed and variable operating and maintenance costs, fuel costs), meeting green hydrogen demand has substantial additional costs compared to the NoBAUH2 scenario when only electricity demand is met. Meeting green hydrogen through green grid infrastructure (GRNGRIDH2 scenario) costs 32% extra costs, whereas, it would be 21% more when green hydrogen is produced at site with electrolyser and solar PV plants are co-located at the demand point.

Green hydrogen potentials

- Green hydrogen potentials for five different cases of hydrogen price development (between 5 USD/kgH2 to 1 USD/kgH2), declining 0.5 USD/kWH every five year are assessed in both green scenarios over the time horizon 2030-70. Production potentials depend on cost of H2 production and availability of green resources (imposed upper limits in Table 4). GRNGRIDH2 scenario is more expensive than GRNSITEH2 scenario in terms of green hydrogen production cost. Hydrogen cost of meeting NGHM target range between 4-5(+) USD/kgH2. Costs decline over time and in 2050, at USD 3/kgH2, production is 7.3 Mt which declines to 0.7 Mt at cost of USD 1.5/kgH2.
- In GRDSITEH2 scenario, in 2050, at 3 USD/kgH2, about 11.7 Mt production potential exists, which goes down to 2.4 Mt at USD 1.5/KgH2. Beyond 2060, large amount of potentials (36-60 Mt) exist even at price of USD 1.5/kgH2, but it requires deployment of large amount of Solar PV capacity and battery storage. Higher price at the initial years favours hydrogen infrastructure creation which helps to reduce cost in the long run. 1 USD/kg H2 is possible in future but not in near term. As grid and hydrogen production infrastructure are optimised together, large amount of solar is diverted for hydrogen production, whereas other options including coal+ CCS, more nuclear (at the later years) are employed to produce grid electricity meeting conventional electricity demand.

Hydrogen as storage for power system reliability

Use of green hydrogen as storage to provide flexibility of the power system as replacement of the pump hydro and battery storage need substantial reduction in production and storage cost of hydrogen and cost and efficiency of turbine/fuel cells etc.

Transportation and Storage of hydrogen

Development of a successful hydrogen fuel chain depends on not only building production infrastructure but also transportation, storage, and utilization. Globally, both technology and economics of storage and transportation are improving. Transportation infrastructure includes pipelines, compressed gas cylinders, blending with natural gas in existing pipeline, liquid hydrogen, and hydrogen carriers. Mode of storage include storage tanks, Natural underground storage in salt caverns and salt domes. The choice of mode depends upon factors such as distance, volume, infrastructure availability, and specific application requirements. Some cost features:

- Levelised cost of storage (LCOS)(Bloomberg) of small volumes in gaseous state for daily consumption is 0.19 USD/kg, with possible future reduction to US$ 0.17/kg.
- For long distance transportation, pipeline is the cheapest option to transport hydrogen as gas for distance less than about 1 500 km and would cost around USD 1/kgH2.
- Compressed gas tube trailers and liquid hydrogen tanks are expected to be the main distribution modes in future. The total cost of local distribution by truck would therefore be USD 2.9/kgH2.

At the initial stage of hydrogen market development in India, the National Green Hydrogen Mission (2023) stresses on green Hydrogen production centred on clusters of industrial demand to avoid storage and transportation challenges. At least two such Green Hydrogen hubs are planned and more across multiple states are proposed. Linking large-scale projects and hubs, with connective infrastructure such as pipelines should be next step. Cheap storage options at various scales should be assessed.

Ammonia offers one option for transportation and storage of hydrogen and India has good experience on handling and storage of ammonia although minimal transportation experience. Repurposing of existing natural gas pipelines and blending could be also options need to be examined at this stage of market development. Government in partnership with the private sectors and other countries should play role in development of transportation and storage infrastructures.

Electrolyser manufacturing

To meet NGHM target of 5 Mt of green hydrogen by 2030, electrolyser capacity need is projected as 60-100 GW. This is expected to go up by 6-8 times (462 GW-603 GW) in 2050.

To limit dependency on imports and ensure supply chain resilience in the sector, it is critical to develop a robust domestic electrolyser manufacturing ecosystem in India. India aspires to be a leader in technology and manufacturing of electrolysers. The growing global interest on hydrogen presents also a promising export opportunity for electrolyzer manufacturers. The national strategies (NGHM) largely seek to tackle the common underlying challenges of developing technologies, skill development, and designing enabling policies and regulations with clear focus on government funding and support for R&D.

Production-Linked Incentive (*PLI*) schemes with budgetary outlay of Rs 4440 crore for electrolyser manufacturing under the Strategic Interventions for Green Hydrogen Transition (SIGHT) initiative marks the first step toward promoting domestic production of electrolyser.

Depending upon the markets and technology development, specific incentive schemes and programmes will continue to evolve as the Mission progresses.

In July, India invited pilot bids of manufacturing of 1.5 GW of electrolysers along with production of 0.5 Mt of green hydrogen. Twenty companies including Reliance Industries, Adani Group, Jindal India, Larsen & Toubro, and Bharat Heavy Electricals have submitted bids for incentives to manufacture electrolysers. Ohmium, a US based company into polymer electrolyte membrane (PEM) electrolyzers making, is sponsoring research into new material to support the next generation electrolyzer technology at the research laboratories in India. Further support considered includes promoting multilateral engagement and collaboration with various international hydrogen initiatives, development of hydrogen hubs/clusters.

With supportive government, moderate manufacturing capability, good infrastructure including port facilities, India possesses a strong potential to lead the global electrolyzer manufacturing industry and drive green hydrogen production. PLI program showcases the government's dedication.

However, it faces multiple challenges. India imports entire requirement of critical minerals including nickel, platinum group of elements etc. which would be needed for electrolysers. South Africa is the source of over 70% of platinum and over 85% of iridium required globally, two key minerals needed in PEM electrolyser making. India government has taken several measures to reduce the import dependence as described in the previous sections. Indian manufacturers need to secure raw materials, making careful choice of technology, and invest in scaling up production. Traditionally, India has been technology importers; R&D, international partnerships on electrolyser technology segment are essential components. Furthermore, strategic partnerships, robust and continuous policy support, and purchase obligations, are essential. By taking these steps, India can expedite its transition to a green hydrogen-powered future and stand at the forefront of this transformative industry.

Critical Minerals

These minerals are essential for economic development and national security, the lack of availability of these minerals or even concentration of existence, extraction, or processing of these minerals in few geographical locations may lead to supply chain vulnerability and disruption (MOM, 2023). Alkaline electrolysers need about 1000 tonnes of nickel per GW and need zirconium, aluminium, and steel. PEM electrolysers need precious minerals, platinum and iridium which makes it very expensive. Based on scenario results on electrolyser capacity by technology, nickel, platinum, and iridium requirements are estimated if India wants to build domestic electrolyser manufacturing facilities. To meet NGHM target on hydrogen production in 2030, India needs 29.6 Kt-49.8 Kt of nickel in 2026-30 for ALK electrolysers. In the same period, India also needs respectively 8.9-15 tonne of platinum and 20.8-34.9 tonne of iridium for PEM type of electrolysers. Study projects use of PEM electrolyser thereafter, therefore, growing need for platinum and iridium if India aims to meet electrolyser needs through domestic manufacturing. In next 10 years period of 2031-40, India needs respectively between 58.4.2-65.5 tonnes of platinum and 136.3-152.9.7 tonnes of iridium.

Indonesia and Australia together account for 42% share of nickel resource, at 21 million metric tons each. Around 60% of the extraction takes place in Indonesia, whereas China dominates processing with 60% of share followed by about 30% in Indonesia. 90% of the reserves of the platinum group of elements lies in South Africa.

India currently imports its entire requirement of nickel and platinum group of minerals such as platinum, iridium etc. Securing reliable supply chains of these minerals is key if India aspires to establish a sustainable domestic electrolyser manufacturing industry supplying domestic needs and export markets. There are both domestic and international obstacles and Indian government recognises that and steps are taken:

- Ministry of Mines is responsible for survey, exploration, and mining of all minerals (other than natural gases, petroleum, and atomic minerals), has introduced a series of policy initiatives, reforms and amendments in Acts & Rules during the year 2023.
- Royalty rates for certain minerals are specified
- first part of its critical minerals auction of 20 blocks worth an estimated 450 billion rupees ($5.40 billion) has been launched and has also identified 100-odd blocks of the 24 critical minerals for next year's (2024) auction.

India recognises the importance of international cooperation with relevant countries to ensure a secured supply chain and has taken various steps.

- Collaboration on critical minerals has been a key consideration in the recently concluded G20 Presidency.
- *Khanij Bidesh India Limited* (KABIL) is established in 2019 to secure critical mineral assets at the international scale. Since then, KABIL is engaged to evaluate and explore business opportunities with countries like Australia, Chile and so on.
- India is participating in a number of partnerships/initiatives such as US-led multilateral Minerals Security Partnership, Comprehensive Economic Cooperation Agreement (CECA) with Australia.

Current focus is more on lithium and cobalt and to some extent nickel. If India decides for PEM type of electrolyser manufacturing, then focus should also include Platinum group of minerals. India also needs to accelerate domestic R&D and international partnership on electrolyser technologies with less dependent on critical minerals.

Furthermore, to keep up with shifting domestic and international conditions, a separate department on Critical Minerals under Ministry of Mines should be involved in reviewing the critical mineral issues and in the assessment of critical minerals for India must be updated every three years.