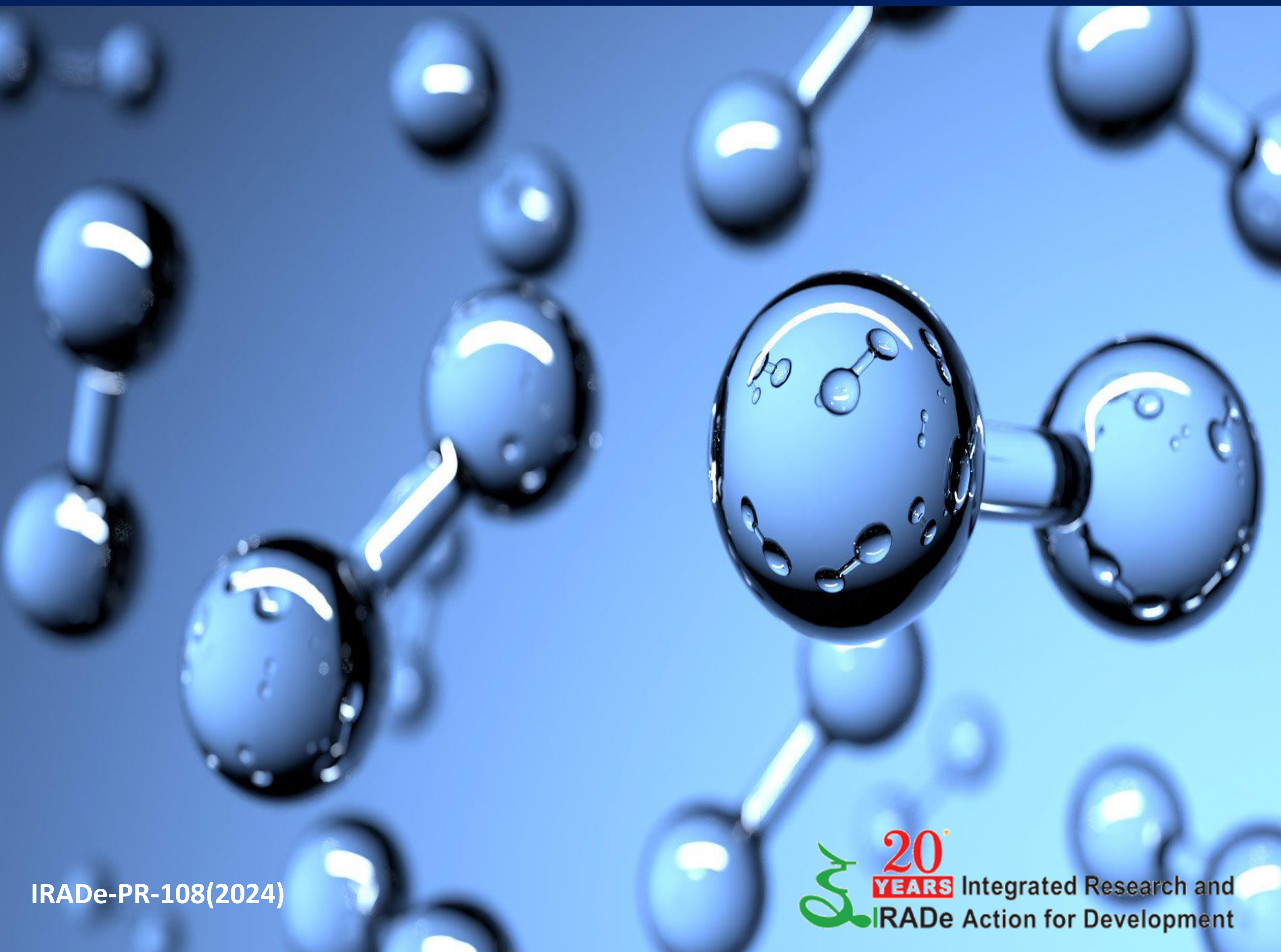
Pathways for the Green Hydrogen Development in India



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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. The National Green Hydrogen Mission (NGHM) aims to make India the Global Hub for the production, usage, and export of Green Hydrogen/derivatives and enable it to take technology and market leadership in the Green Hydrogen fuel chain (GOI, 2023). The NGHM 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 an export market.

As water electrolysis using renewable electricity is expected to be the key hydrogen production method, the Indian power system, which was producing electricity to meet (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 periods also offers a storage option to improve power system reliability. Indeed, 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 to determine the optimal configurations of both the power system and the hydrogen fuel chain.

Key objective of this project:

- contribute in strengthening the Indian policy and decision-making process by providing the relevant quantified (wherever possible) technical and economic information regarding the development of the hydrogen fuel chain (water electrolysis) and inter-connected Indian power system over the time horizon 2030-70.

A least-cost integrated modelling framework of the Indian power system and hydrogen fuel chain based on International Atomic Energy Agency's MESSAGE software, is used for simulating scenarios with exogenous demand for electricity (industry, households, etc.) and green hydrogen. Two green hydrogen production 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 networks 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, drawing green electricity.

Additionally, there is one NoH2BAU scenario when the power system only meets conventional electricity demand, and no hydrogen production occurs.

Technical and economic outputs are as follows:

- for Hydrogen fuel chain: requirement of electrolyser capacity and electricity, investment on electrolyser and green power infrastructure connected with the electrolysers;
- for power system: capacity (generation and storage) by technology, electricity generation, optimal allocation of green power sources between conventional electricity demand and green hydrogen, investment etc.
- green hydrogen potentials of the India power system up to 2070
- economics of green hydrogen as storage to meet flexibility of the power system.

Additionally, comparing the results of the green scenarios with those of the NoH2BAU scenario, impacts on the power system (additional capacity, investment, generation, technology mix, resource allocations) due to the introduction of hydrogen production are quantified. Furthermore, the issues on hydrogen storage and transportation, electrolyser manufacturing and critical minerals are addressed and some policies and measures are suggested.

The outputs would be useful for policymakers, power system and hydrogen fuel chain planners, investors, and industries with interests in electrolyser manufacturing, development, installation, and power sector development, among others.

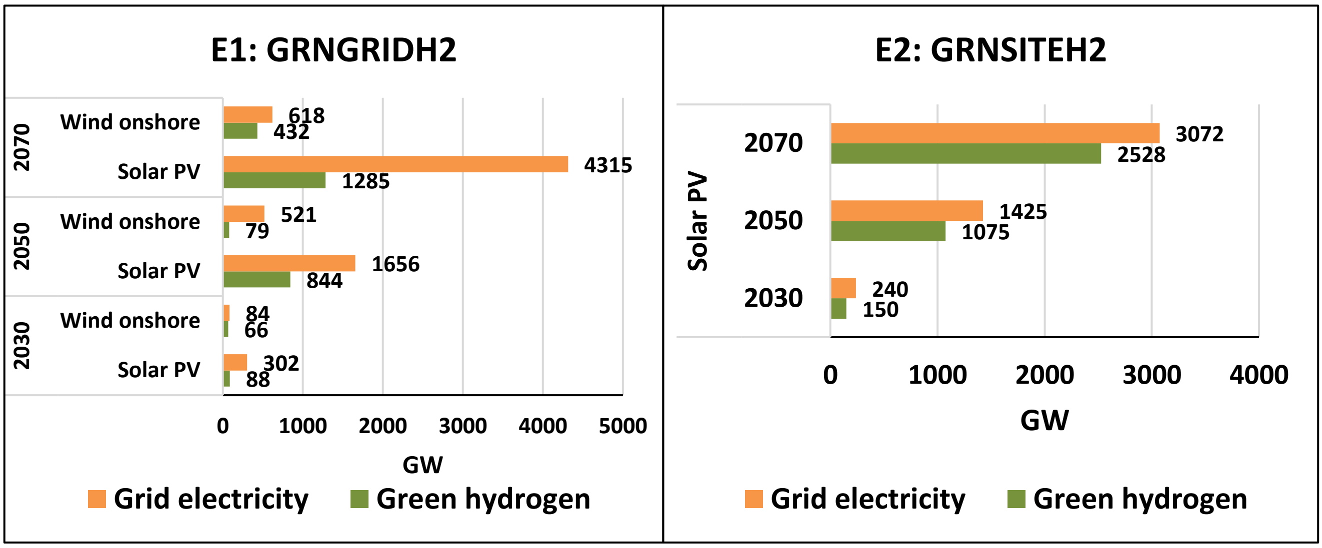
Key findings:

Table E.1 resents the **electrolyser capacity, green electricity, green power infrastructure and investment on electrolyser and green power infrastructure in two scenarios to meet green hydrogen production/demand targets**. Meeting NGHM target of 5 Mt in 2030 needs electrolyser capacity of **60-100 GW** depending on scenarios and green electricity of **257 TWh**.

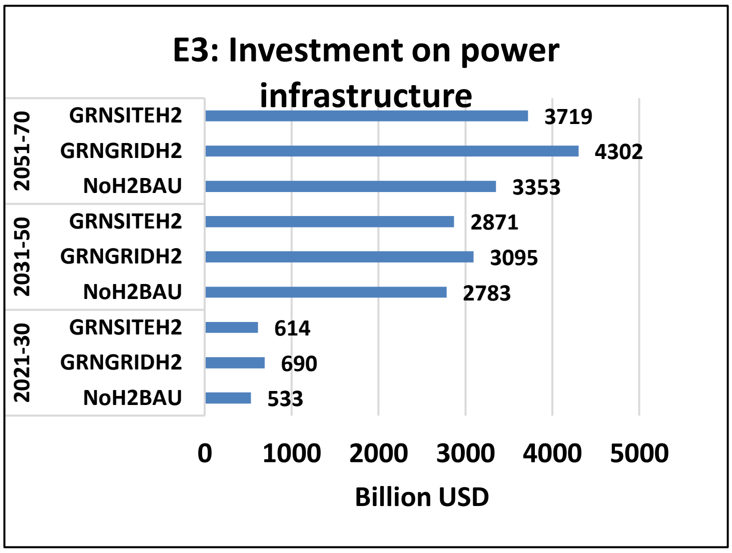
Table E1

	Unit	2030	2050	2070
Hydrogen demand/ production target	Million tonne	NGHM target 5 Mt	28.7	50
Electrolyser capacity	GW	60-100	462-603	572-1092
Green electricity	TWh	257	738	2300
Green power and storage	GW	150-155	Power 923-1075 GW; Storage 29 -114 GW	Power 1716 -2528 GW; Storage 55-414 GW
Investment:				
-Electrolysers	Billion USD	41-70	110-139	110-210
-Green power infrastructure	Billion USD	63-122	447-313	772-611

When compared with the NoH2BAU scenario which produces only electricity to meet conventional demand, **9-10% more electricity needs** to be generated in 2030 to meet the 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 restrictions on new coal capacity, limited domestic gas, and high prices of imported gas. Along with renewables, India needs to accelerate its nuclear power development, which has been slow in the past.



Figures E.1 and E.2 present the **optimal allocations of green resources** between green hydrogen production and grid to meet conventional electricity demand in two green scenarios. In the GRNGRIDH2 scenario, out of the total potential (as assumed in Table 3.3) of **390 GW of solar PV and 150 GW of wind onshore in 2030, 88 GW of solar PV and 66 GW** of onshore wind would be optimally allocated to green hydrogen production. The remaining **302 GW of solar PV and 84 GW of wind onshore** would be allocated to the grid to meet conventional electricity demand. In the 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.**



Comparing **investments** in power infrastructure (generation+storage+transmission and distribution) for supplying electricity to meet conventional electricity demand and and hydrogen production, **the GRNGRIDH2 scenario requires 690 billion USD during 2021-30, which is 29% (160 billion USD) higher than the NoH2BAU scenario (Figure E.3). Respective number is 15% for the GRNSITEH2 scenario.**

Comparing **total cumulative supply (2021-70) costs** (investment in electrolyser + power infrastructure, fixed and variable operating and maintenance costs, fuel costs), meeting green hydrogen demand entails substantial additional costs compared to the NoBAUH2 scenario where only electricity demand is met. GRNGRIDH2 scenario costs **an extra 32%, whereas, it would be 21%** more in GRNSITEH2 scenario.

Green hydrogen potentials

Green hydrogen potentials for five cases of hydrogen price development (between 5 USD/kgH2 to 1 /kgH2), declining at 0.5 USD/kWH every five year are assessed in both green scenarios over the time horizon 2030-70.

Table E1

Year	Price (US$/Kg)	GRNGRIDH2 H2 Potential	GRNSITEH2 (Million tonne)
2030	5	4.2	4.8
	3	0	0
2050	3	7.3	11.7
	1.5	0.7	4.5

- Production potentials depend on cost of H2 production and availability (imposed upper limits) of green resources. Green hydrogen production cost is higher in the GRNGRIDH2 scenario than the GRNSITEH2 scenario.
- **Hydrogen production cost of meeting NGHM target in 2030 ranges between 4-5(+) USD/kgH2 and costs decline over time** (Table E2).
- In GRNGRIDH2 scenario, at USD 3/kgH2 in 2050, the potential is 7.3 Mt, which declines to 0.7 Mt at cost of USD 1.5/kgH2.
- In the 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, a large amount of potential (36-60 Mt) exists even at a price of USD 1.5/kgH2.
- A higher price in the initial years favours hydrogen infrastructure creation which helps to reduce cost in the long run. 1 USD/kg H2 is possible in the future but not in the near term.

Hydrogen as Storage for Power System Reliability

Use of green hydrogen as storage to provide flexibility to the power system requires substantial reductions in the production and storage costs of hydrogen, as well as improvements in the cost and efficiency of turbines, fuel cells, etc.

Transportation and Storage of Hydrogen

The development of a successful hydrogen fuel chain depends not only on building production infrastructure but also transportation, storage, and utilisation. Globally, both the 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. Modes of storage include storage tanks, natural underground storage in salt caverns and salt domes. Choice depends on factors such as distance, volume, infrastructure availability, and specific application requirements. Some cost features:

- The levelised cost of storage (LCOS)(Bloomberg) of small volumes in gaseous state for daily consumption is 0.19 USD/kg, with a possible future reduction to US$ 0.17/kg.
- For long-distance transportation, pipelines are the cheapest option to transport gaseous hydrogen for distances 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 the future. The total cost of local distribution by truck would be USD 2.9/kgH2.

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

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

Electrolyser Manufacturing

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

To limit dependency on imports and ensure supply chain resilience, it is critical to develop a robust domestic electrolyser manufacturing ecosystem in India. India aspires to be a leader in the technology and manufacturing of electrolysers. The growing global interest in hydrogen also presents a promising export opportunity. The national strategies (NGHM) largely seek to tackle the common underlying challenges of developing technologies, skill development, and designing enabling policies and regulations with a 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 mark the first step toward promoting domestic production of electrolysers. Recently pilot bids for manufacturing of 1.5 GW of electrolysers along with the production of 0.5 Mt of green hydrogen under this scheme have been invited which drew significant interests. Further support considered includes promoting multilateral engagement and collaboration with various international hydrogen initiatives and the development of hydrogen hubs/clusters.

With supportive government policies, moderate manufacturing capability, and good infrastructure including port facilities, India possesses a strong potential to lead the global electrolyser manufacturing industry. The PLI programme showcases the government's dedication.

However, India imports the entire requirement of critical minerals, nickel, platinum group of elements, etc., which are needed for electrolysers. The Indian government has taken several measures to reduce import dependence and improve supply security as described in the next section. Indian manufacturers need to secure raw materials, make careful choices of technology, and invest in scaling up production. Traditionally, India has been technology importers; R&D and 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

Critical minerals are characterised with supply vulnerability due the lack of availability, or concentration of extraction, or processing of these minerals in a few geographical locations. Alkaline electrolysers require about 1000 tonnes of nickel per GW and also need zirconium, aluminium, and steel. PEM electrolysers require precious minerals, platinum, and iridium which makes them 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 the NGHM target of producing 5 Mt of hydrogen in 2030, India needs 29.6 Kt-49.8 Kt of nickel in 2026-30 for ALK electrolysers and respectively 8.9-15 tonne of platinum and 20.8-34.9 tonne of iridium for PEM type of electrolysers. This study projects the use of only PEM electrolyser beyond 2030, therefore, there would be growing need for platinum and iridium if India aims to meet electrolyser needs through domestic manufacturing. In the next 10-year 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 the nickel resources. Around 60% of the extraction takes place in Indonesia, whereas China dominates processing with a 60% share followed by about 30% in Indonesia. 90% of the reserves of the platinum group of elements lie in South Africa.

India currently imports its entire requirement of nickel and platinum group of minerals. Securing reliable supply chains of these minerals is key if India aims at a sustainable domestic electrolyser manufacturing industry to supply domestic needs and export markets. Both domestic and international obstacles are recognised by the Indian government, and necessary steps are being taken:

- The Ministry of Mines, has introduced a series of policy initiatives, reforms, and amendments in Acts & Rules during the year 2023.
- The first part of critical minerals auction of 20 blocks worth an estimated 450 billion rupees ($5.40 billion) has been launched. Additionally, the government has identified 100 blocks of the 24 critical minerals for next year's (2024) auction.

International cooperation with relevant countries to ensure a secure supply chain has been initiated:

- Collaboration on critical minerals has been a key topic in the recently concluded G20 Presidency.
- *Khanij Bidesh India Limited* (KABIL), established in 2019 to secure critical mineral assets at an international scale, is engaged in evaluating and exploring business opportunities with countries like Australia, Chile, and others.
- India is participating in a number of partnerships/initiatives such as the US-led multilateral Minerals Security Partnerships.

The current focus is primarily on lithium and cobalt, and to some extent, nickel. If India decides for PEM type electrolyser manufacturing, the focus should also include Platinum group minerals. India also needs to accelerate domestic R&D and international partnerships on electrolyser technologies with less dependence on critical minerals.

Some suggestions on policies and measures

India has launched National Green Hydrogen Mission with ambition of building a domestic green hydrogen industry to contribute in energy security, decarbonisation and possibly export earnings also. India also aspires to take technology and market leadership in the Green Hydrogen fuel chain.

Building an industry that is also new and unknown needs a comprehensive approach covering all segments of the fuel chain and strong government's interventions and hand-holding at least at the infant stage. India government has shown strong commitments and involvements. Several policies and measures at segments like production, installation, electrolyser manufacturing are announced and being implemented. The central policies have been complemented by state level policies. However, still lots more to be addressed, policies and measures need to be designed and implemented, some of them are suggested here based on the findings of the current study.

- Although, general understanding is India has plenty of renewable resources, however, why setting big targets for hydrogen production and exports, it needs to be noted that India also needs to meet its steeply rising electricity demand for other uses, like industries, homes, transportation etc. Green resources used for hydrogen production should not deprive electricity needed for other uses. Integrated planning of electricity and green hydrogen is necessary so that green hydrogen targets and policies ensures sufficient availability of electricity to meet growing electricity demand for other uses.
- Our study shows that onsite production is more economic that would also reduce losses (electricity) and need for transmission and distribution infrastructure. Large user should be encouraged if necessary with incentives, to develop on-site integrated production facilities which will also reduce need for hydrogen transportation and storage infrastructure as well as conversion and reconversion infrastructures and losses, and would have significant impact on landed costs of green hydrogen and overall investments.
- Current study shows India has significant domestic demand potentials for electrolysers, therefore, it makes sense to build a domestic electrolyser manufacturing industry with export possibility as added advantage. Electrolyser technologies are still at development stage with China, European countries, USA etc taking as lead. India needs extensive international collaboration to ensure access to technologies and strong domestic R&D capacity to develop, adapt and improve technologies.
- India lacks critical minerals needed for the production of electrolysers. India imports 100% of its critical minerals requirement. These minerals are limited to a few countries. Government is concerned of critical minerals issues, however current focus is primarily battery related minerals such as lithium, cobalt, and to some extent nickel. If India wants to get into electrolyser manufacturing, equally serious efforts are needed for the relevant critical minerals such as nickel, platinum etc, Also, efforts for developing technology with less dependent on critical minerals are needed.
- Development Green hydrogen supply chain involves a set of advanced technologies, some of which are under development, therefore requires workforce with sophisticated scientific, technical and engineering skills. India needs to further enhance/expand its educational program and training to supply required skills and capabilities.