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A Rare Earths Strategy for India

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TAKSHASHILA DISCUSSION DOCUMENT 2020-16

V1.0, 24 December 2020

Executive Summary

Post-pandemic geopolitical and economic trends offer a precious opportunity for India to emerge as a rare earths supplier for the world. This discussion document lays out a prioritisation framework and a strategy for India to do that. We recommend that the Government of India should:

- Create a new Department for Rare Earths (DRE), which would play the role of a regulator and enabler for businesses in this space.
- Allow private sector companies to participate in upstream and downstream processing of rare earth elements.
- Offer Viability Gap Funding to businesses in upstream processing to help them set up operations.
- Provide enabling infrastructure close to ports, implement Ease of Doing Business Measures, and create a whitelist of international suppliers for businesses in downstream processing.
- Build a rare earths reserve along with partners such as the Quad as a geostrategic move to ensure India can compete in the manufacturing of high-tech products in the coming decades.

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Introduction

Rare earth elements (REE) allow the manufacture of some of the most economically and strategically valuable products of the 21st century, from processors to advanced alloys to electric vehicles to consumer electronics and industrial machinery. We estimate (generously) that India trades in nearly $200bn worth of intermediary and finished goods derived from rare earths every year,[1] not counting the economic value generated by the use of these products. Yet, despite having the fifth largest deposits of REEs in the world, India imports much of these goods from China.

Indeed, China currently controls nearly 90% of the world's REE mining and refinement as well as supply chains dependent on them. China has a well-established record of using trade as a coercive tool in international diplomacy. In a 2019 study, we identified “export restrictions, tightening customs hurdles, and triggering nationalistic boycotts” as examples of such behaviour.[2] In 2009, in the midst of a territorial dispute with Japan, China (which then controlled 97% of the market) imposed export quotas on rare earths, though it denied that these were related.[3] The end result was panic as policymakers and industries began to realise the risks of overdependence on China, as a result of which “most of the prices of RE metals and oxides experienced a thousand-percent increase”[4] by 2011.

The shock to global supply chains in the early months of the COVID-19 pandemic brought these concerns to the fore once again, as China was forced to shut down many major manufacturing hubs to slow the spread of COVID-19. The risks – whether intentional or unintentional – posed by a single country acting as the world's miner and manufacturer have never been clearer. In a May 2020 study, *India in the Post COVID-19 World Order*, we came to the conclusion that “the globalisation project will change as a result of economic nationalism... hitherto highly-optimised global supply chains will change to include multiple sourcing and the

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removal of supply chain bottlenecks”. As US-China geopolitical rivalry begins to impact more sectors of the global economy, further supply-side shocks to the system cannot be ruled out. Indeed, a broad consensus on reducing dependence on China, particularly in rare earths, is already beginning to emerge in the US, which has REE reserves of considerable size. Former Secretary of Defense James Mattis outlined a six-point plan: “promoting domestic production; diversifying mineral imports away from China; cooperating with allies to insulate each other from Chinese control; developing multiple alternative supply chains; stockpiling rare earths to create shock absorbers in case of a crisis; and reducing demand by investing in alternatives.”[5] Similar moves are also discernible in other countries with large REE deposits, especially Australia. These are discussed in detail in a later section of this document.

With the Indian economy already sluggish due to deep structural issues, growing unemployment, and the impact of the COVID-19 pandemic, a strategy is needed to blunt the effectiveness of coercive Chinese economic policies. Though India does not consume many REEs either in their raw form or as concentrates, it does consume many materials and products developed from them (see Figure 1). India needs to develop a rare earths strategy due to the increasing risk of China restricting the export of these products to India, or restricting the export of raw REEs and their concentrates to countries from whom India imports finished products. Given the growing global consensus in favour of clean energy (which will require batteries with REEs as critical components) and more diversified supply chains for critical minerals, there is no better time for India to utilise its large deposits of rare earth elements.

This document aims to provide a general framework for policymakers to better understand and respond to the challenges and opportunities presented by rare earths. We begin by providing a brief overview of the sources and uses of rare earths, and then then examine their processing and the potential side effects thereof. This is followed by a framework for prioritising India’s rare earth needs. We then discuss issues with India’s current strategy and suggest different approaches with which they can be addressed. These are finally then used to develop a portfolio of actions for India.

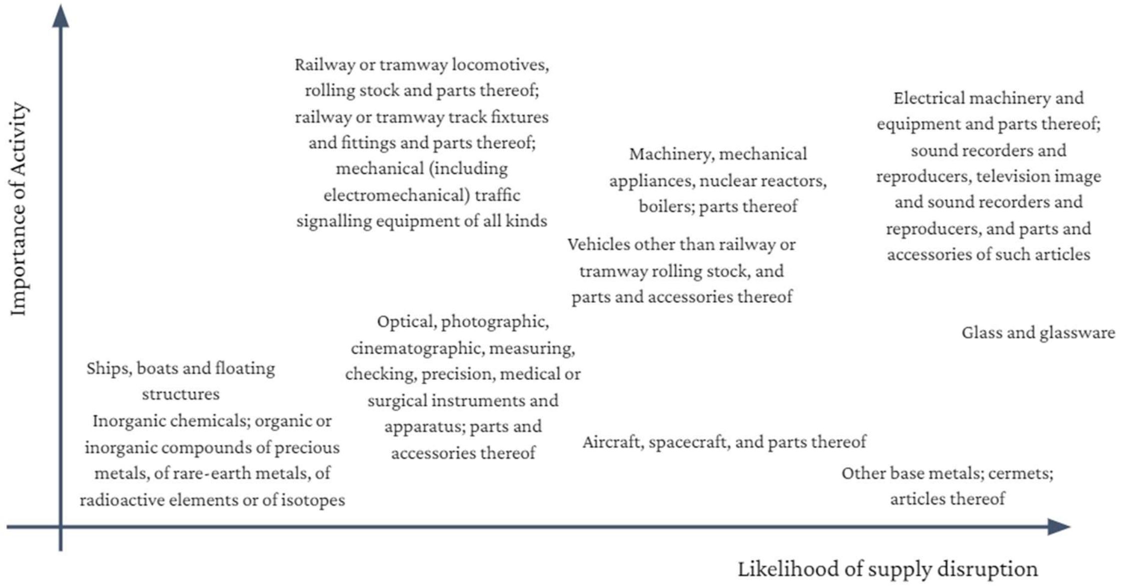

Figure 1. Risk of supply disruptions to Indian imports that use rare earths. This figure categorises rare earth applications by importance of activity and the likelihood of supply disruption. The importance of an activity is determined by its share in India's Gross Domestic Product (GDP) of the country. The higher the (import + export)/ GDP ratio of the activity, the more important it is. The likelihood of supply disruption depends upon the concentration of exporters, India's changing relations with the exporting countries, and availability of appropriate substitutes. The data for this analysis was obtained from the WTO.

Rare Earths: Where and Why

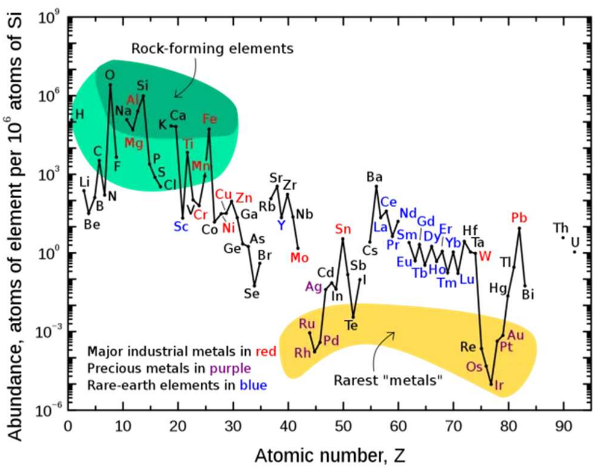

Figure 2. Abundance of various elements. Rare earths are in blue. Source: US Geological Survey/Wikimedia Commons.

The term "rare" in "rare earths" refers not to their scarcotu, but to their earliest industrial application – glass colouring. "Rare" in this 19th-century sense meant "extraordinary", "astonishing". "Earths" comes from an equally antiquated usage, meant to refer not to varieties of difficult-to-find muds but rather the metal oxides from which "rare" elements could be extracted.

As Figure 2 indicates, REEs (in blue) are generally orders of magnitude more abundant than gold or platinum. Their electronic configuration, providing for loose electrons as well as similar physical and chemical properties, drive many applications of rare earths today. About 60% of global rare earth consumption today is for three types of uses: as catalysts, in alloys, and in magnets. Lanthanum is used primarily in battery alloys and catalysts; cerium in catalysts, glass, ceramics, polishing, and phosphors (for lighting, TV screens, lasers etc). Praseodymium, neodymium, samarium, and dysprosium are used to make high-quality permanent magnets. Europium, gadolinium, and terbium are used for phosphors; holmium, erbium, thulium, ytterbium and lutetium have fewer economic applications in comparison to the others. Finally, scandium and yttrium are used in metallurgy.

In general, it can be said that the light rare earth elements (LREEs, in light grey below) – lanthanum to samarium – have properties that are most useful in magnets, glass, polishing, catalysts, ceramics, and alloys. The heavy rare earth elements (HREEs, in dark grey below) – europium to lutetium, plus scandium and yttrium – have properties that are useful in phosphors, ceramics, metallurgy, and glass.

	La	Ce	Pr	Nd	Sm	Eu	Gd	Yb	Dy	Ho	Er	Tm	Yb	Lu	Sc	Y
Battery Alloys	Green															
Catalysts	Green	Green														
Ceramics		Green	Yellow	Yellow	Yellow				Yellow		Yellow		Yellow		Yellow	Green
Glass	Yellow	Green	Yellow	Yellow	Yellow		Yellow				Yellow		Yellow	Yellow		Yellow
Polishing		Green														
Magnets			Green	Green	Green			Yellow	Green							
Metallurgy	Yellow	Yellow		Yellow											Green	Green
Phosphors	Yellow	Green			Yellow	Green	Green	Green	Yellow		Yellow				Yellow	Green
Others	Yellow	Yellow	Yellow	Green	Yellow	Yellow	Yellow	Green	Yellow	Yellow	Green	Yellow	Yellow	Yellow	Yellow	Green

Table 1. Functional usage of rare earth elements, based on Zepf 2013[6]. Green indicates extensive use, yellow indicates a moderate use, and white indicates little to no use.

Over the next decade, the global demand for rare earths is expected to grow rapidly. Clean energy and electric vehicles will be major drivers of this demand. In comparison to other elements, neodymium and praseodymium, which are used in batteries and magnets, will grow their market share.[7]

STRATEGIC APPLICATIONS

The unique electrochemical properties of rare earths make them very useful in high-tech sectors such as electronics, and they are ubiquitous in printed circuit boards and components such as capacitors and resistors. As mentioned above, many REEs have applications in permanent magnets and phosphors, and thus have great value in defence systems. Some key applications include:

REEs are crucial to many strategic applications including missile navigation and sensor systems.

- *Guidance, Propulsion and Control Systems:* Neodymium-iron-boron (NdFeB) magnets are among “the smallest, lightest, and most powerful magnets currently known to science”.[8] Other magnets derived from rare earths, such as samarium-cobalt magnets, are less powerful, but retain their magnetic properties at high temperatures. Due to their wide ranging and versatile applications, they are perhaps the single most vital REE derived component for the defence industry. The applications of permanent magnets range from even the crudest of electrical motors to fin actuators for guided missiles, munitions, unmanned aerial vehicles etc. This encompasses all conceivable propulsion systems in use today across sea, land and air platforms. Emerging technologies and platforms like railguns and Electromagnetic Aircraft Launching Systems (EMALS) also use high quality NdFeB magnets.[9,10]
- *Optics:* Europium, ytterbium, and terbium are used as glass doping agents for lasers, night vision, displays, laser targeting systems etc.
- *Early Warning Systems:* Lanthanum can be used to detect gamma radiation levels and is thus important in early warning systems for nuclear threats.
- *Sensors and Electronic Warfare:* Europium, ytterbium, neodymium, lanthanum and lutetium are used in the production of sonar transducers, radar, and other systems on the electromagnetic spectrum.[11]

SOURCES OF RARE EARTHS

While REEs are hardly rare, they are not often found in economically viable deposits. They form a variety of compounds – silicates, carbonates, oxides, phosphates, borates, halides, and sulphates – all of which in turn have their own distinct geochemical properties and can be found in various proportions in different kinds of rock.

Major producers of rare earths include China, Australia, and the US.

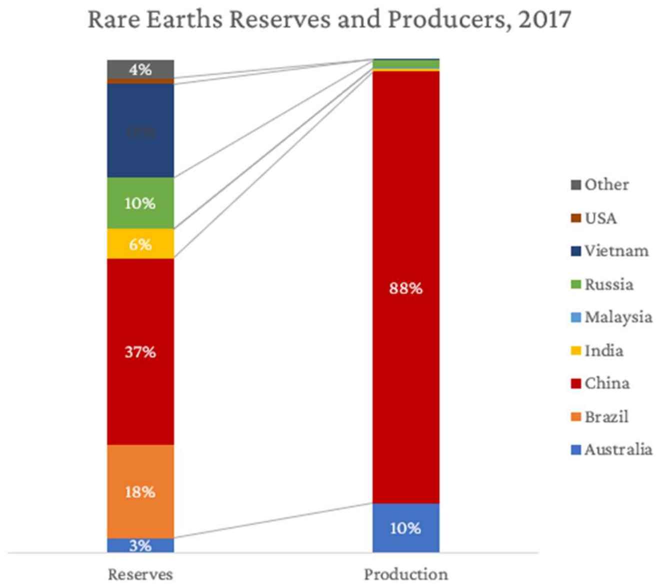

Figure 3. Percentage of global reserves versus production by country, based on data from the US Geological Survey.

Lighter rare earth elements are far more abundant than heavier rare earth elements.

Major deposits of REEs are found across the world, with the largest in China, Brazil, Vietnam, and Russia. However, not all of these deposits are equally economically viable and well-developed; the world's major suppliers are the US, China, Australia, and Myanmar, as seen in the visual above. Most of these deposits are rich in LREEs.

The world's largest source today is Bayan Obo ore. Found in Inner Mongolia, this is a highly lucrative deposit rich in LREEs that has powered China's rare earth dominance over the last decade. Combined with the capacity to refine the ores and concentrates once mined, taking advantage of lax labour and environmental laws to offer competitive prices, it has enabled China to push all other major players out of the market. Cheap, high-quality rare earth alloys were also crucial to China's growth as one of the world's biggest consumer electronics manufacturers.

The next major source of REEs is monazite, a mineral often found in beach sand, and which has historically been processed for rare earths in India and Australia.[12] However, much of Australia's rare earth production today comes from the Mount Weld carbonatite deposits, mined by the Lynas Corporation, which recently secured a $250 million investment from Japan.[13] Both of these minerals are rich in LREEs.

The US has announced partnerships with Australia for the extraction of REEs.

Another crucial deposit is in Mountain Pass, California. The US has recently expanded the capacity of mines at Mountain Pass. Though there may be serious cost obstacles in the long run,[14] the US and Australia have already signalled a clear intent to move away from their dependence on China with a series of joint projects.[15] The US Department of Defence has signed a contract with the Lynas Corporation to process rare earths in a Texas facility,[16] and Lynas has announced a $500 million expansion of its production capacity for neodymium and praseodymium.[17] A deposit at Round Top in Texas may also yield HREEs.[18]

Other potential REE suppliers include Russia, Vietnam, Myanmar, and Brazil.

Other major potential suppliers include Russia, Vietnam, Myanmar, and Brazil. In all cases, rich deposits of high-grade ore have been discovered, but availability of ore is not a guarantee of dominance in the rare earth market. Russia, for example, still exports rare earth concentrates to China and imports alloys and finished goods.[19] Ambitious plans to ramp up production and invest in extraction and refining capabilities have been announced. Russia's deposits are particularly promising because of the presence of scandium and yttrium as well as LREEs.[20]

Vietnam has rich rare earth deposits on its China frontier, with LREEs and some HREEs (europium and gadolinium),[21] but these are yet to be developed. Brazil, similarly, could be a potential source of LREEs.[22] Myanmar is already a major exporter of rare earth oxides, particularly dysprosium; China is its main trading partner.

India also has rich deposits of rare earths, which remain largely untapped. India's reserves of rare earths, nearly 6.9 million tonnes,[23] are the fifth largest in the world, nearly twice as much as Australia.

India has among the world's largest REE reserves, but they remain underutilised.

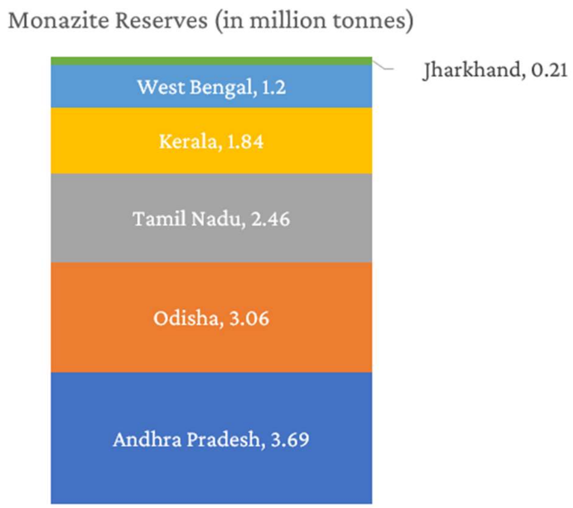

Figure 4. Reserves of monazite sand by state in India. Data from the Indian Bureau of Mines.

The largest feasible deposits for LREEs in India are to be found in beach sands (monazite). Monazite deposits are located primarily in the coastal states of West Bengal, Kerala, Tamil Nadu, Odisha, and Andhra Pradesh. Some of these are already being exploited in limited capacities. Much smaller deposits are found in inland stream sediments and hydrothermal vents, which contain minerals rich in LREEs as well as xenotime, which contains HREEs. The most viable of these are in Jharkhand and Chhattisgarh. Gujarat and Maharashtra also have minor deposits of REEs.

India remains a provider of low-cost ore, concentrates, and oxides to the rest of the world.

As will be discussed later, efforts at utilising these reserves have been few and far between, and mostly dominated by a few government agencies. Most rare earths in India are imported in finished form, and India remains a low-cost ore, concentrate, and oxide provider to the rest of the world.

POTENTIAL FUTURE SOURCES

Due to ecological concerns surrounding REE mining from traditional beach sand deposits and inland sources, it is imperative to explore other alternative sources of REEs that have less of a negative ecological footprint. If not replacements, then these can at least serve as supplemental sources for the ever-increasing demand for REEs. Some of these sources are more feasible today (Urban Mining and Deep-Sea Mining, discussed in Appendix A) and some are still on the experimental side (Agro Mining and Bio Mining, discussed in Appendix B).

Recycling and deep-sea mining may prove to be sustainable sources of rare earths in future, but require further technological innovation.

Urban Mining is the recycling/extracting of useful material from e-waste piles in urban scrapyards, garbage dumps and landfills etc. Currently, it has low rates of efficiency, due to the difficulty of purifying recyclate material to extract REEs. Deep Sea Mining involves the extraction of polymetallic nodules from the sea bed, and is potentially more sustainable and non-intrusive than other means of extracting REEs. However, the deep diving platforms required to make it a reality are still in experimental stages.

Extraction and Processing

Rare earth compounds found in ore are converted into economically viable forms through a series of electrochemical processes. After mining, the raw ore is put through a chemical or physical "sieve" to remove other compounds, resulting in a rare earth concentrate. **These processes are referred to as "upstream processes" in this document.** In general, upstream processes do not require a great deal of technological sophistication to perform and are conducted in a number of countries which have rare earth deposits. Their end result, rare earth concentrates, are relatively easy and cheap to obtain in global markets.

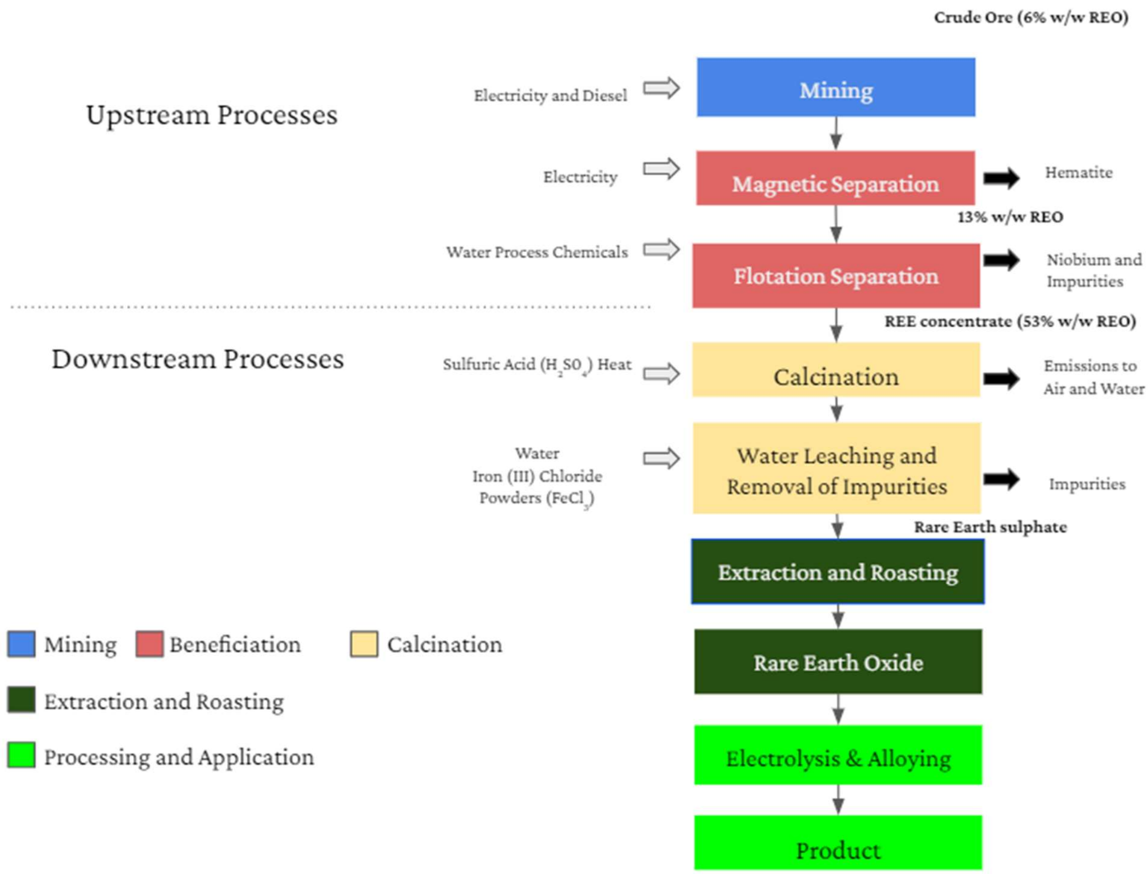

Figure 5. Process diagram for the extraction of REEs, modified from Zaimes et al 2015.

Downstream processes are more energy and capital intensive but result in the most valuable products. Rare earth concentrates are treated with chemicals and heat to produce rare oxides; these then undergo further extraction and alloying to produce metals that can be used in applications discussed above, resulting in a tremendous value addition. These processes are only performed in a few countries that have the capital, the technological wherewithal, the industrial base, and the environmental regulations that make them viable.

RISKS AND CONCERNS

The process of obtaining rare earth metals in a pure form from ore have both high up-front costs and high running costs. Of particular concern are the environmental side effects. Rare earths are also extremely energy intensive to extract from their ores: production of heavy rare earth oxides "consumes almost 20 times more primary energy as compared to steel (per unit mass)".[24] Even mining is fraught with hazards. The Bayan Obo fields of Inner Mongolia, in particular, are recorded to have depleted and eroded soils, destroying their agricultural potential.[25]

The processing of rare earths is complex, expensive, and produces large quantities of toxic waste. These have proven to be major challenges in India before.

Toxic and radioactive waste can be released during the mining and extraction process. Indeed, rare earth facilities in India have previously run into controversy due to the erosion of beaches[26], groundwater pollution[27], and the unsafe discharge of dangerous by-products.[28] Extensive processing of waste material and strict enforcement of environmental regulations would be needed to reduce the environmental footprint of these activities. It should be noted that these can make the final end product more expensive - as noted above, the lack of environmental standards in China was a big reason for its low-price rare earths. Today, a massive lake full of radioactive sludge, 11 square kilometres in area according to some estimates, exists near the Bayan Obo fields.[29]

A Framework for Assessing India's Needs

Based on the discussion above, we present a framework for understanding the uses and availability of rare earths.

- Light grey elements are LREEs, dark grey elements are HREEs.
- "Strategic Potential" refers to how useful an element is in crucial defence applications such as sensor systems, missile guidance systems, and so on, which India may wish to develop wholly indigenous supply chains for.
- "Commercial Potential" refers to an element's usefulness in industrial processes, finished and intermediate consumer goods, and so on - in general, applications

which may involve more transnational supply chains, both existing in India and with the potential to exist in India.

- "Availability in India" is a rough estimate of how much of the element may be made available for use by Indian industries.
- Short term is 0-5 years, and medium term is 5-10.

				Availability in India		
Atomic No.	**Element**	**Strategic Potential**	**Commercial Potential**	**Short Term**	**Medium Term**	**Where are they found?**
57	Lanthanum	Medium	High	Medium	High	Monazite Beach Sand
58	Cerium	Low	High	Medium	High	Monazite Beach Sand
59	Praseodymium	Low	High	Low	Medium	Deposits needing open pit mines
60	Neodymium	Very high	High	Medium	High	Monazite Beach Sand
61	Samarium	High	High	Low	Medium	Deposits needing open pit mines
63	Europium	Low	Medium	Low	Medium	Deposits needing open pit mines
64	Gadolinium	Low	Medium	Low	Medium	Monazite Beach sand, hydrothermal veins
65	Terbium	Medium	Low	Low	Low	NA
66	Dysprosium	Medium	Medium	Low	Medium	Hydrothermal veins
67	Holmium	Low	Low	Low	Low	NA
68	Erbium	Low	Low	Low	Low	Hydrothermal veins
69	Thulium	Low	Low	Low	Low	NA
70	Ytterbium	High	Low	Low	Low	NA
71	Lutetium	Medium	Low	Low	Low	NA
21	Scandium	Low	Low	Low	Low	NA
39	Yttrium	Low	High	Low	Medium	Deposits needing open pit mines

Table 2. A framework for assessing India's rare earth needs.

A few key trends are visible in the above framework.

First, LREEs in general have high commercial potential and are available in relative abundance in India, due to their occurrence in monazite. A sustainable supply of LREEs can be developed by reforming India's rare earth policy to take better advantage of its reserves, thus increasing their availability in the medium term. This will be discussed in a later section.

Second, HREEs are far less easily available even with better exploitation of reserves. Extracting them will be capital intensive and come with major environmental consequences, whereas commercial potential in India is relatively low, because it will be difficult for India to develop a comparative advantage in industrial processes that consume them. As such, India may wish to secure them as needed through trading with its strategic partners.

Neodymium, europium, dysprosium, terbium, and yttrium have been identified as Critical Materials for the US[30] due to their applications in clean energy[31] and supply risk. India faces less risk to LREE supply, as noted above, but may wish to plan ahead to secure HREEs, if it wishes to take advantage of global trends toward clean energy and electric vehicles. One way to do this is to invest proactively in potential suppliers and friendly countries such as Vietnam and Russia or enter into strategic partnerships with Australia and the US. This will be discussed in detail in the next section.

India's Rare Earths Strategy

CURRENT APPROACH

In India, efforts at utilising rare earths have been few and far between, and mostly dominated by a few government agencies. Most rare earths in India are imported in finished form, and India remains a low-value material provider to countries which specialise in downstream processing.

The extraction of REEs in India is effectively the monopoly of IREL – a government agency which is focused on another group of elements entirely.

Exploration in India has been conducted by the Bureau of Mines and the Department of Atomic Energy. Mining and processing has been performed by some minor private players in the past, but is today concentrated in the hands of IREL (India) Limited (formerly Indian Rare Earths Limited), a Public Sector Undertaking under the Department of Atomic Energy. Established in 1950, IREL mines titanium, zirconium and thorium and beach sand minerals such as monazite, ilmenite, sillimanite, garnet, zircon, and rutile. It has four mineral sand separation plants in Manavalakurichi (Tamil Nadu), Aluva and Chavara (Kerala), and OSCOM-Chatrapur (Orissa). Kerala Mines and Minerals Limited (KMML), a Kerala government undertaking, mines zirconium (which is used as a neutron absorber in nuclear plants).

IREL's primary purpose appears to be the production of raw materials such as thorium and uranium for India's nuclear energy programme: indeed, its website describes its vision as "to be a significant contributor of strategic materials to [the] Department of Atomic Energy."[32] This evidently shows that its primary remit is meant to be actinide series elements such as thorium, which have some radioactive properties, not the lanthanide series which include rare earths. Indeed, under the most recent amendment to the Atomic Mineral Concession Rules (2016), all Beach Sand Mineral deposits containing more than 0.75% thorium are reserved for Government-owned corporations. Since these sands often contain rare earths in addition to thorium, the extraction of

REEs in India is thus effectively the monopoly of a government agency which is focused on another group of elements entirely.

IREL's capacity to produce rare earths is growing, but slowly. As of 2018, it had an installed capacity of around 11,314 tonnes for various rare earth compounds, but produced only 2265 in 2016-17.[33] The only major buyer of IREL's rare earth compounds was Toyotsu Rare Earth India Pvt. Limited, a Japanese company which further refined and exported them.[34] It should be emphasised that these numbers are only a small fraction of global production of REEs and are low in the value chain.

IREL's capacity is growing, but slowly. It might not be able to compete with much larger international REE conglomerates.

IREL noted in its 2018-19 report that its newest rare earth extraction plant was nearing capacity, and that it was in the process of adding more capacity.[35] The company has also announced that it will be manufacturing permanent magnets "of strategic importance to the nation" at Vizag,[36] and is working on setting up a "Rare Earths Theme Park" in Bhopal to scale up laboratory-level technologies and "facilitate setting up value chain in the Rare Earth sector."[37] These projects will likely take years to begin operations, but seem to indicate some sort of strategy to create a wholly indigenous supply chain for rare earths. But sticking to this alone would be to put all of India's hopes in a single public sector corporation, leading to a high risk of losing the opportunity that exists in the rare earths space right now. This might ultimately relegate India to at best a small role in the profitable value chains derived from these elements.

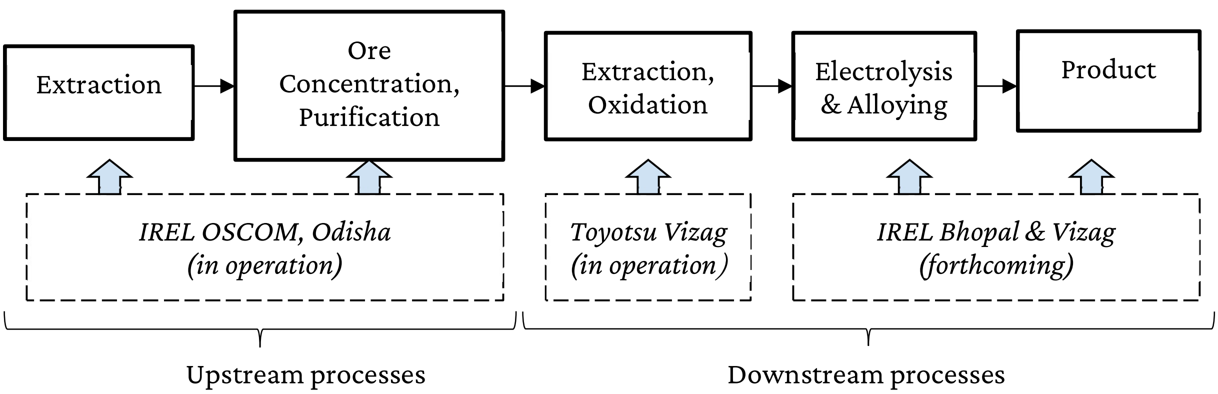

Figure 6. The REE production process and value chain in India, based on Mancheri 2015.[38]

Reform and Modernisation of the Rare Earth Sector in India

THE CASE FOR REFORM

According to data from the US Geological Survey and Indian Bureau of Mines, India's reserves of rare earths are the fifth largest in the world – nearly twice as much as Australia. Despite this, India's production is a miniscule fraction of global production, and it plays almost no role in the global market for REEs.

India produces low quantities of REEs compared to the size of its reserves, and is low in the value chain.

The reasons for this are primarily to do with the bottleneck created by government monopoly in general and IREL in particular. Schedule 2 of the Export Policy under the ITC (HS) appears to have a fairly progressive stance, stating that "Rare Earth compounds are freely exportable, but rare earth phosphates, which contain uranium and thorium are prescribed substances."[39] However, as noted above, the Atomic Minerals Concession Rules (2016) have granted IREL an effective monopoly on rare earths, leading the Indian Bureau of Mines to confidently claim that "Export of Beach Sand Minerals… shall be canalized through Indian Rare Earths Limited (IREL)."[40] IREL, due partially to its own constraints and to complicated approval and funding procedures, has not used this monopoly as effectively as might be wished.

Once again, it must be emphasized that what little rare earth compounds that India does produce are very low in the value chain. The most profitable activities related to rare earths, as the below visual indicates, happen in countries which have downstream industries which use them to manufacture profitable finished goods, such as consumer electronics.

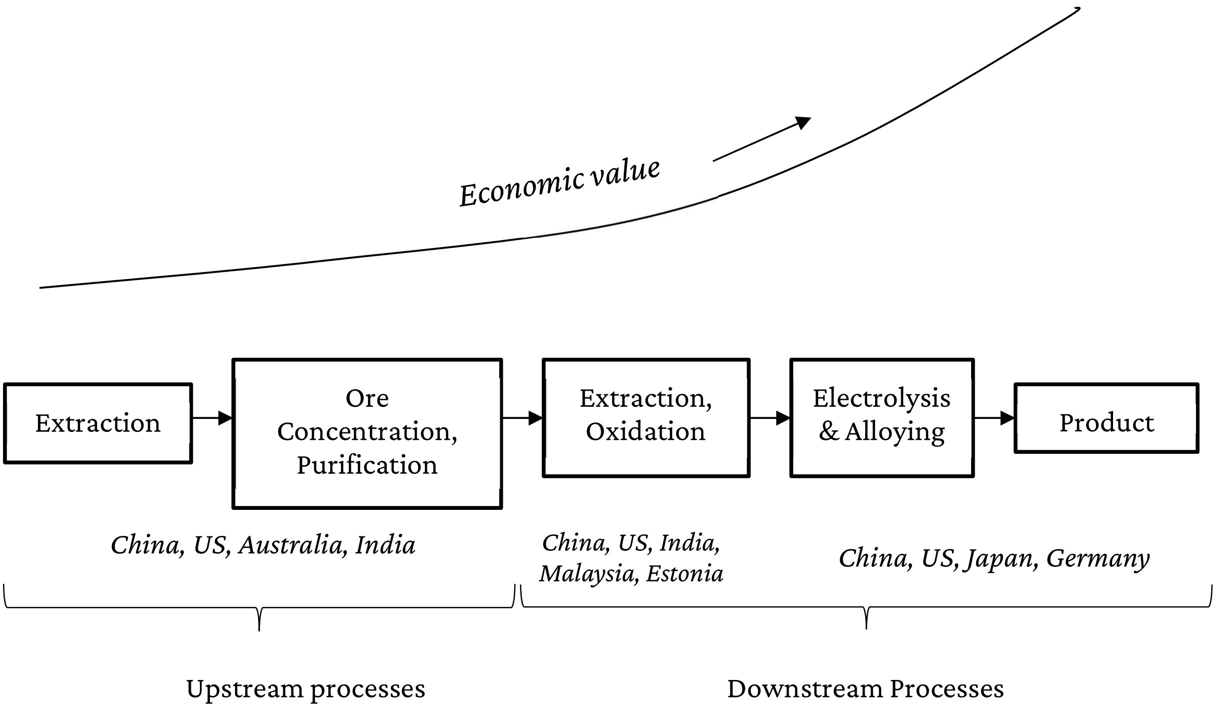

Figure 7. The REE production process and value chain, modified from Mancheri 2015.

India needs to drastically change its rare earth strategy to take advantage of new trends in global markets and move higher up in the value chain. There has arguably never been a better time to do so. China's global image has changed over the last decade into that of a pugilistic and revisionist power, and a gradual consensus against its belligerent diplomatic and military tactics appears to be emerging. The costs that companies pay to do business there – political, reputational, and economical – will only increase as US-China competition grows.

There exists an unprecedented opportunity for India to emerge as a global REE supplier.

As a result of these factors, it is likely that companies will increasingly seek to diversify their suppliers and aim to build in redundancy into their supply chains. The global consensus today is also shifting towards cleaner energy sources and modes of transportation, both of which require batteries and magnets that will be derived from rare earths and other minerals such as arsenic and gallium.[41] China dominates global markets in these elements today, and there is an emerging consensus, especially in the US, that this poses a serious risk to manufacturing supply chains in the future.[42]

Though there may be serious cost obstacles in the long run,[43] the US and Australia have already signalled a clear intent to move away from their dependence on China with a series of joint projects.[44] Australia has also indicated an interest in working with India on rare earths as well as other areas.[45]

For India to allow IREL's monopoly to continue is to play the global rare earths game with one hand tied behind its back.

For India, whose economy has been severely impacted by the COVID-19 pandemic, this is a precious opportunity. India has large reserves of rare earths – 6,900,000 tonnes – which are not yet being exploited to their potential. It also has the human capital necessary to extract them. What it lacks is capital, infrastructure, and a stable policy environment. Resolving these issues could have an enormous payoff over the next 25 years.

Given all this, for India to allow IREL's monopoly over beach sand minerals to persist is to play the global rare earths game with one hand tied behind its back. Introducing more players into the value chain at various levels will lead to better utilization of its rare earth deposits, prompting innovation and leading to better availability and prices of end products, as companies compete to make their processes as efficient and profitable as possible.

A combination of government financing and regulatory reform will be needed to develop a flourishing REE industry.

In addition, some parts of the value chain for REEs with significant strategic applications require government financing. In particular, upstream processes (extraction and concentration) require an enormous amount of capital investment, and private sector investment alone may not suffice to solve for India's strategic requirements.

Downstream processes, in comparison, can be unreservedly thrown open for private sector participation. Provided that companies strictly comply with environmental and industry guidelines, they should be allowed to do business in this sector. A *laissez-faire* approach can help attract investment and purchasers as more efficient processes are put in place. The processing of rare earth oxides, alloying and extraction, and the production of intermediate and finished goods can all benefit as a result.

All this said, competition is not a magic wand to fix the rare earths sector. A recent study by an Australian think tank highlights a "chicken and egg" problem: "potential financiers would want to see binding take-off contracts before committing, but potential customers will not commit until they are sure the project can deliver the volume and quality or purity of the material they require."[46] Advance Market Commitments (AMCs) by the Indian government for REEs with strategic applications can help resolve this starting problem.

India must attract foreign investment and encourage competition and innovation in order to unlock the economic potential of its REE reserves.

Ramping up the production of rare earths now through deregulation (to attract foreign investment) and an increased role for the private sector (to stimulate competition and innovation) would allow India to play a larger role in global rare earth markets. More importantly, the availability of large quantities of high-quality rare earths could make it easier for highly profitable downstream industries – such as chip fabrication and consumer electronics manufacturing – to grow in India, moving it further up the value chain. The Beach Minerals Producers Association estimates that "the rare earth mineral downstream industry can net a capital employment of about Rs 121,000 crore, including Rs 50,000 crore worth of foreign exchange".[47] Finally, a successful shift in India's rare earths strategy would grant India more strategic autonomy by reducing its dependence on China, and making it a trusted supplier and valuable partner to countries such as the US and Australia.

In summary, India needs to act now to create new industries based on the extraction, refinement, and manufacture of products derived from rare earths.

REORGANISATION

Given the complexities and opportunities offered by India's rare earth reserves, the best move forward might be to create a new Department for Rare Earths (DRE) under the Ministry of Petroleum & Natural Gas, with members seconded from the Ministry of Coal for their expertise on exploration and mining. Much of the value in rare earth reserves, as discussed above, lies in their processing, thus making the Ministry of Petroleum &

A new Department of Rare Earths should be given charge of developing India's REE reserves.

Natural Gas a natural fit given its existing expertise in exploration, exploitation, refining, and regulation.

The DRE would oversee the formulation of policy and focus on attracting investment and promoting R&D. It should also create an autonomous regulator, the Rare Earths Regulatory Authority of India (RRAI), which would resolve disputes between companies in this space. Supervision of IREL should be shifted from the Department of Atomic Energy (DEA) to the DRE, and its primary remit needs to change from atomic minerals to rare earths. The DEA could be involved in the DRE's activities as far as radioactive materials and by-products are concerned, but no further.

THREE APPROACHES TO INDIA'S RARE EARTHS SECTOR

The DRE's goal must be the exploration and exploitation of India's rare earth reserves in a way that best serves the national interest. There are three possible approaches to doing so, outlined below. It should be noted that none of these is the "best" or sole approach that should be taken. Rather, the DRE should be able to shift the weight and orientation of its policies and resources to whichever resource best suits India's needs.

The "Mineral First" Approach

This approach prioritises securing access to minerals with the highest strategic value. As discussed above, these would primarily be LREEs (lanthanum, cerium, praseodymium, neodymium, samarium), which are often found in beach sand minerals. Facilities for extraction and some upstream processes (refer to Figure 6) would need to be set up near mineral deposits, likely with some sort of government intervention, but with more room for private players in processing and refining. Actinide elements in general can be decontrolled, but particular care would need to

The government could finance mineral extraction to ensure access to strategic REEs.

be taken for radioactive minerals: the DRE should come out with a process for their extraction and storage.

It should be noted once again that these operations might not prove to be profitable, given the plethora of suppliers for rare earth minerals and concentrates in global markets. However, given India's large deposits of LREEs, it can help the government secure access to critical strategic materials such as neodymium, samarium, and lanthanum, which can be used in India's sensor and ballistics research programmes. Should the DRE be unable to exploit them given its own reserves, it should consider granting approvals to private companies to do so, with some sort of viability gap funding.

In the future, a "minerals first" approach would also involve exploration and mining of the deep sea bed. At this point, officials from the Department of Earth Sciences, which is the nodal agency for exploration of the sea bed, should be seconded to the DRE as advisors, and the DRE should adopt a similar approach as outlined above to begin extraction of polymetallic nodules.

The "Demand/Application First" Approach

Setting up infrastructure near port facilities and adopting a progressive regulatory stance can encourage a downstream processing industry.

This approach focuses on delivering to the commercial potential of rare earths by catering to global demand. The orientation is towards making it easier for businesses to process and refine rare earth concentrates and oxides in India, turning India into a rare earth metal producer for the world – just as we produce aluminium and steel. This approach is likely to be the most financially viable, and have the largest multiplier effect in terms of creating jobs; however, securing supplies of rare earths might still prove to be a challenge given volatility in global markets and the limited development of India's own resources.

Rare earth processing facilities should be located close to ports, perhaps within SEZs. Businesses can be attracted to these locations and be allowed to function unimpeded provided they meet environmental and processing guidelines established by the

DRE. One precaution that may be considered is to make it mandatory for these businesses to build up a stockpile of raw material for at least three months, purchasing from an official whitelist of preferred foreign suppliers, including partners such as Australia and the US. The objective is to make it as easy as possible for them to import raw materials from the rest of the world and process them to satisfy local and global demand without the risk of serious supply side disruptions.

A flourishing downstream rare earths industry will also make Indian manufacturing of goods such as consumer electronics and electric vehicles more resilient. This process could be aided by nurturing deeper ties between the private sector and research institutions to develop alternatives to HREEs, as well as recyclable designs of consumer electronics items that are tailored for the changing global economy and suited for urban mining operations in India in the years to come. As technology advances, the DRE should be prepared to regulate urban mining operations (as above, with a focus on environment and safety) as well.

Geostrategy First Approach

A key geostrategic move for India is to position itself as a major supplier of processed rare earths as an alternative to China. India must build up capacity to extract and refine rare earths and secure investment and purchase agreements from its strategic partners. Without a clear intent and policy in this space, India risks being relegated to low-value activities, once again missing out on crucial opportunities and jeopardizing its attempts to shift to more lucrative high-end manufacturing and clean energy.

A coordinated effort with India's global partners can help secure access to strategic minerals and hedge against China.

This approach involves working with India's global partners, making rare earths instrumental to our overall strategic posture. It would involve developing India's reserves and refinement facilities primarily in order to build a resilient supply of rare earths along with partners such as the Quad. For example, India could send LREE concentrates and receive processed lanthanum, neodymium etc. equivalent in value in exchange, perhaps from a decentralised Quad reserve based in multiple countries. This would demand far more involvement from the DRE as well as the Ministries of Commerce, External Affairs, and possibly Defense. The backing of the Prime Minister's Office to could help signal that this is a priority to the Quad and other potential partners. All this may be needed in case of a global supply crisis akin to that seen in 2009-2011.

Summary of Approaches

As mentioned above, policymakers can shift between the above approaches in response to the challenges and opportunities that India faces. These are summarised below.

Approach	**Facilitating Conditions**	**Key Actions**
Mineral First	• Establishment of DRE • Viability Gap Funding for businesses in upstream processing	• Set up extraction and processing facilities close to India's REE deposits
Demand First	• Establishment of DRE • Ease of Doing Business measures for businesses in downstream processing	• Set up SEZs close to ports • Establish whitelist of preferred suppliers • Nurture deeper ties between research institutes
Geostrategy First	• Establishment of DRE • Increasing competition in high-tech sectors leading to REE supply shortages	• Work with partners such as the Quad to ensure that REEs are available for manufacturing and strategic use

Table 3. Summary of potential approaches to an Indian REE strategy.

Conclusion

India has a rare opportunity today to leverage its natural reserves of rare earth elements to build a prosperous economy. Global geoeconomic and geopolitical trends offer a chance that India could seize. To ensure that its resources are put to good use and offer a secure foundation for developing a competitive and high-value rare earths sector, India should implement the following policy recommendations:

1. Create a new Department for Rare Earths (DRE) under the Ministry of Petroleum & Natural Gas, with members seconded from the Ministry of Coal for their expertise on exploration and mining. The DRE would oversee the formulation of policy and focus on attracting investment and promoting R&D. It should also create an autonomous regulator, the Rare Earths Regulatory Authority of India (RRAI), to resolve disputes between companies in this space. It would also take over supervision of IREL and change the company's primary remit to rare earths instead of atomic minerals.
2. The government should end IREL's monopoly on beach sand minerals and allow private sector companies to get involved in upstream and downstream processing of rare earth elements, while implementing safeguards for the processing of radioactive by-products.
3. Should India choose to prioritise the securing of REEs of strategic value, Viability Gap Funding for businesses in upstream processing would help them set up operations.
4. Should India choose to cater to global demand and maximise the commercial potential of its REE reserves, it should provide enabling infrastructure close to ports and enact Ease of Doing Business Measures for businesses in downstream processing. Risks to supply can be managed through establishing a whitelist of preferred international suppliers.
5. Finally, as a geostrategic move, India could look to build a resilient supply of rare earths along with partners such as the Quad, to ensure that it can become a major manufacturer of high-value and high-tech goods such as electric vehicles in coming decades. This could involve direct involvement from the proposed Department of Rare Earths in the exploration and exploitation of India's reserves.

The authors would like to thank Pranay Kotasthane for his valuable inputs on the recommendations in general, and on the proposed Department of Rare Earths in particular.

Appendix A
URBAN MINING

Urban mining is the recycling/extracting of useful material from e-waste piles in urban scrapyards, garbage dumps, landfills etc. The actual percentage of recycled REEs globally has been less than 1% (as reported in 2018)[48]. The desirability of urban mining as a source of REEs, however, depends on the balance of production in more traditional mining methods around the world.[49]

For example, with traditional mining methods, when seeking to extract neodymium from REE ore, more abundant elements like lanthanum and cerium are also produced because of their natural occurrence.[50] This can throw off the economic calculations by which a country's ratio of total ore extraction to neodymium production might become economically viable. In this case, targeted recycling of neodymium from reprocessed permanent magnets found in E-waste can reduce the total amount of ore to be mined from traditional sources, and thus lower the wastage and overhead costs associated with traditional mining practices.

The main technical difficulty in urban mining has been in "purifying" the recyclate material from which REEs have to be extracted in the desired form. Different recyclates have different degrees of efficiency of recovery. The most efficient process which is viable on an industrial scale is the recovery of REEs from lamp phosphors (up to 80%), with the recycling efficiency of permanent magnets (55%) and NiMH batteries (50%)[51] following thereafter.

With the newfound strategic value of diversifying sources and restructuring supply chains, there is renewed interest in this sector. That said, urban mining has not proved economically viable historically due to factors like the fluctuating demand and price of REEs, the historical neglect of ecological factors (leading to regulatory and legal consequences with financial implications), as well as the low efficiency of the recycling processes – a problem more dire in case of some sources and the elements derived from them than others.

One major way of making urban mining less expensive would be to pre-process and repurpose e-waste rich in REE and REE-derived intermediate products, either stripping it for parts or quickly turning it into recyclate material that can be further purified into specific and distinct rare earth oxides and metals.[52] Currently, most such waste ends up in furnaces, turning into a sludge of different materials, from which REEs are harder and costlier to extract.[53]

This repurposing and pre-processing can range from simple disassembly and repurposing of E-waste components – for instance, end of life motors yielding neodymium magnets (that can be reused to build new products) – to leaching yttrium and other heavy REEs from old cathode ray tubes and lights. The latter can be reprocessed and used for manufacturing new lamp phosphors and metal alloys, which would at least in part meet the demand for those intermediate or downstream products derived from REEs.

E-waste will be available in ever-increasing quantities in future decades as consumer electronics, hybrid vehicles etc being produced today reach the end of their lifespans. In order to take advantage of this, India could encourage the development of its own manufacturing capabilities, move towards recyclable designs of consumer electronics, and lay down guidelines for recycling and pre-processing.

DEEP SEA MINING

In its more sustainable and non-intrusive form, deep sea mining is the process of scooping up polymetallic nodules from the ocean bed with the help of a deep diving autonomous or semi-autonomous/remote piloted platform that is supported by a logistics support/operations base ship on the surface.[54]

Deep sea mining efforts around the world are still at a nascent stage, with the International Sea Bed Authority (ISA) administering licenses to mining corporations and their sponsor nations that apply for exploring and exploiting deep sea mineral deposits, including REEs, outside their Exclusive Economic Zones (EEZs) with a sustainable plan for a limited time span.[55]

As an early signatory and strong supporter of UNCLOS (which also laid the foundation for ISA and its regime of authorisation and regulation for deep sea mining), India can be said to be ahead of the curve, having been granted the status of pioneer investor in 1987 by the UN.

For this early confidence and cooperation in the international effort to prospect and exploit polymetallic nodules, India was bestowed an area in the Central Indian Ocean Basin to the tune of fifty thousand sq kilometres.

Following this, in 2002, India signed a fifteen-year term contract with the ISA which stated that India will only retain around half of the originally assigned area i.e. 75,000 sq km exclusive to it for its deep sea mining activities. This original contract with a fifteen-year term was extended for 5 more years during the 23rd session of the ISA in 2017.[56] India's area of interest for these nodule extraction operations appears to be at a depth of 5500 metres.

Deep sea mining will require deep diving remotely piloted systems, but these are still in the development and testing stages.[57] Most of the ventures approved by ISA are yet to start operations.[58] Should it become technologically feasible, however, deep sea mining holds enormous potential as a source of REEs with far fewer ecological concerns attached to the mining process.

Appendix B
INNOVATIONS AND EXPERIMENTS WITH "GREEN CHEMISTRY"

1. Bio Mining: One of the forms of Bio Mining can be extracting REEs from Phosphate Rock Waste (also called Phosphogypsum) with the help of organic acids derived from bacterial cultures.[59]
2. Agro Mining: A REE "Hyperaccumulator" plant has been discovered, generally called the False Staghorn Fern and better known to the scientific community as *Dicranopteris linearis*. The plant can collect 0.2 to 0.3% of REEs in terms of dry matter weight on its leaves.[60]

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