<u>CHINA'S MONOPOLISATION OF RARE EARTH ELEMENTS (REE) AND ITS IMPACT ON INDIGENISATION EFFORTS OF INDIAN DEFENCE INDUSTRY</u>

A Dissertation submitted to the Punjab University, Chandigarh for the award of the degree of Master of Philosophy in Social Sciences, in partial fulfilment of the requirement for the Advanced Professional Programme in Public Administration

by

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Certificate

I have the pleasure to certify that **Brigadier Puneet Ahuja, SM, VSM** has pursued his research work and prepared the present dissertation titled '**China's Monopolisation of Rare Earth Elements (REE) and its Impact on Indigenisation Efforts of Indian Defence Industry**' under my guidance and supervision. The dissertation is the result of his own research and to the best of my knowledge, no part of it has earlier comprised any other monograph, dissertation, or book. This is being submitted to the Punjab University, Chandigarh, for the purpose of Master of Philosophy in Social Sciences in partial fulfilment of the requirement for the Advanced Professional Programme in Public Administration (APPPA) of the Indian Institute of Public Administration (IIPA), New Delhi.

I recommend that the dissertation of **Brigadier Puneet Ahuja, SM, VSM** is worthy of the award of M.Phil. degree of Punjab University, Chandigarh.

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New Delhi **Brigadier Puneet Ahuja**

March 2022 **Roll No – 4702**

Declaration

I, the undersigned, hereby declare that the dissertation titled '**China's Monopolisation of Rare Earth Elements (REE) and its Impact on Indigenisation Efforts of Indian Defence Industry**' is my own work and that all the sources I have accessed or quoted have been indicated or acknowledged by means of completed references and bibliography. The dissertation has not been submitted for any other degree of this university or elsewhere.

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ABSTRACT

Rare Earth Elements have gained centre stage in the recent past with the world expressing concern over Chinas monopolisation of the global supply chains. Events in the past in the Senkaku / Diayutai standoff between Japan and China in 2010 and the more recent friction between the US and China in 2019 – 20 over economic sanctions, are witness to the fact that China does not shy away from using their monopoly over these strategic minerals. Understanding the REEs and their peculiar role in the technological revolution underway and their possible applications in growth story, the status of India's REE pursuit, their role in the defence industry and finally the impact on India's effort to gain self reliance in the defence sector all make a study on REEs imperative.

REEs are a set of seventeen elements which include fifteen lanthanides on the periodic table in addition to scandium and yttrium that show similar physical and chemical properties to the lanthanides. These minerals have unique magnetic, luminescent, and electrochemical properties and thus are used in many modern technologies, including consumer electronics, computers and networks, communications, health care, national defence, etc. In fact most electronics now days including displays of TVs, mobile phones etc have REEs. Even futuristic technologies need these REEs

They are called 'rare earth' because earlier it is difficult to extract them from their oxides forms. They occur in many minerals but typically in low concentrations so as to be refined in an economical manner. China has over time acquired global domination of rare earths. China thus has a near monopoly on the supply chains and thereby, has the tool which it can use for

coercion. US and several other countries have started addressing the issue and undertaken measures to secure their supply chains with respect to REEs. The models offer good insight into options available to India to ensure strategic independence in the availability of this critical mineral.

India has the world's fifth-largest reserves of rare earth elements, and yet it imports most of its rare earth needs in finished form from China. Exploration in India has been conducted by the Bureau of Mines and the Department of Atomic Energy. India has granted government corporations such as IREL a monopoly over the primary mineral that contains REEs: monazite beach sand, found in many coastal states. IREL produces rare earth oxides (low-cost, low-reward upstream processes), selling these to foreign firms that extract the metals and manufacture end products (high-cost, high-reward downstream processes) elsewhere. There are few steps being taken to address the issue and a Rare Earth Permanent Magnet (REPM) plant is being set up in Vizag, a Rare Earth and Titanium Theme Park has been set up in Bhopal, there has been an augmentation in the capacity of Rare Earth producing units, mining of beach sands has been further regulated, DMRL has developed the technology for making three different classes of rare earth magnets, a licensing agreement for Transfer of Technology (ToT) has been signed between DRDO and IREL. In addition, to enhance the scope of discovery of REE ore 58,626 square kilometres area has been delineated to be potential for REE occurrences in the country. Yet, this appears too little and too slow and various lacunae continue to exist, including the lack of a nodal agency to pursue the strategic needs to deal with REEs, need for change in policy structures, lack of privatisation, low incentives to pursue downstream processes, absence of an REE ecosystem and lastly no strategic reserves.

The Government has set out on a path to achieve aatmanirbharta in the defence sector, and has announced several policy measures. Notable among them which are related to the REE segment are the positive indigenisation list of 209 items, indigenisation list on parts and assemblies of equipment / weapons**,** large infusion of capital, permitting defence exports and lastly permission to increase in FDI in defence sector. Interestingly, of the 209 items forming part of the positive indigenisation list, up to 84 systems are likely to use REEs or part of the rare earth value chain in the manufacturing process in a significant manner. Pursuit of self reliance in the Defence Industry is not likely to significantly affect the import basket of REEs by Indian vendors in the short term. In the next five years, in order to achieve the laid down import embargo targets, Indian vendors are likely to perform the role of system aggregators and integrators while importing key components which are not produced within the country. In the long term however, the success of the Atma Nirbhar Bharat program will depend upon the generation of component manufacture in India and the setting up of downstream industries in the rare earth value chain. This would lead to creation of value chains for items other than defence also and would ultimately lead to strategic autonomy and lesser reliance on the global supply chains.

The need to reduce vulnerabilities in the defence manufacturing sector was felt in other nations also and studies carried out in the US and UK in 2013 and 2016 respectively. In the absence of any open source data on the type and quantity of REEs essential for Indian Defence Manufacturing, inferences have been drawn from these studies. The study indicates that availability of seven REEs will be central to aatmanirbharta programme in defence sector; namely dysprosium, erbium, europium, gadolinium, neodymium, praseodymium, and yttrium. Of these, except for Yytrium, there is a fair amount of adequacy of ore in the country. And hence, to secure the value chain for defence manufacture, India needs to pursue the downstream industry for the Light REEs and look at import for Heavy REE (Yytrium).

The need of the hour to pursue self reliance in the defence sector is to address the vulnerabilities and set up an entire eco system in India. Several recommendations have been made for this, and these hold good equally for the 'Make in India' Program in other sectors also. To begin, there is a need to diversify the Supply Sources and reduce over reliance on China; as regards mining and exploration of REEs, the recommendations made in the 'Strategic Plan For Enhancing REE Exploration In India' made jointly by the Geological Survey of India and the and there is a need for high investments in sophisticated survey and spatial data management technologies to produce more detailed data and information of areas and depths so far unexplored. There is a need to pursue identification of HREE deposit**s**. In aspects of policy, a nodal agency needs to be set up possibly by creating a new department for rare earths (DRE), which would play the role of a regulator and enabler for businesses in this space. It is recommended that measures be taken for indigenisation of the value chain which can be done by inviting private players, private investments and also incentives to industry. Efforts need to be directed towards Research and Development in this emerging technological sphere and encouraging participation of academia and scientific community with a view to finding innovative means of subsidising more critical elements, seeking measures for affordable recycling of REEs and finding better and more environment friendly means to process REEs. Help can be sought from friendly nations for technology and investments to set up downstream industries. Lastly, to address India’s critical needs for the next five years, there is a need to build a strategic reserve of the REEs to cater for any disruptions in the future.

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Chapter 1 : Introduction

"The Middle East has oil; we have rare earths ... it is of extremely important strategic significance; we must be sure to handle the rare earth issue properly and make the fullest use of our country's advantage in rare earth resources[1]."

Deng Xiaoping

Introduction

Raw material availability is under growing strain as a result of rapid global industrialisation and population development. Rare Earth Metals, a collection of elements, have become a highly sought-after resource for high-tech and low-carbon businesses. Global demand is currently expanding, raising concerns about future availability. Rare earths have a wide range of applications in electrical and electronic components, lasers, glass, magnetic materials, and industrial processes, but their names and properties are unfamiliar to most people because they do not occur as base metals or in lump or visible quantities like iron or aluminium. So what are Rare Earths and what are the issues which have propelled them into prominence in the last decade or so, this study seeks to carry out a comprehensive study of these and their impact on India's *aatmanorbharta* programme.

Rare Earths are a group of 17 elements starting with lanthanum in the periodic table of elements and include scandium and yttrium. They are moderately abundant in earth's crust but not concentrated enough to make them economically exploitable. The REEs find key applications in defence, electronics, energy systems etc; as an example, magnets made from REEs are many times more powerful than conventional ones. Along with energy

[1] Dian L. Chu (November 11, 2010). "Seventeen Metals: 'The Middle East has oil, China has rare earth'", Business Insider. Available at https://www.businessinsider.com/seventeen-metals-the-middle-east-has-oil-china-has-rare-earth-2011-1?IR=T

critical elements (ECE), such as, lithium which has become ubiquitous battery material, REEs have emerged as strategic elements essential for sustainable energy systems.

REE are gradually becoming central to all technological applications. They are used as catalysts in alloys and are used to make several electronic items used in daily life and are assisting miniaturization and high technology items. Their unique properties of REE make them very useful in high-tech sectors such as electronics, and are used in printed circuit boards and components such as capacitors and resistors. REEs also have great value in defence systems. The space industry, electronics, information technology and communications, the energy sector, electric batteries, the nuclear industry among others are all significantly dependent on various REEs. Specific areas of Defence Industry which use REEs are night vision devices, laser range finders, guidance systems, advanced communication systems, fluorescent devices like lamps and monitors, amplifiers in fibre optic communications, permanent magnets which are stable at high temperatures, precision guided ammunition and stealth technology.

The centrality of REEs in a large number of emerging and existing technologies is a well established fact and they are being increasingly used the world over and will continuously be used in emerging technologies. The global supply chain for extraction, processing and distribution of REEs is currently dominated by China and as an emerging power, China does not shy away from using its stranglehold on these Rare Earths as an instrument of state policy. There is an increasing concern in the world that China could use this domination to enhance its global influence and also use it as a tool of coercion in the times to come. In the past also, China has shown its ability to use this as a tool to exert pressure as was witnessed with Japan during a standoff between China and Japan over the Senkaku Islands (Diaoyutai Islands in Chinese) in 2010 where China placed an embargo of rare earths on Japan. By throttling rare earth supplies, countries' industrial and military capacities can be crippled while stunting future technological growth. With rare earths being an inexorable requirement for modern life itself, China has leverage their control to bully its way in international relations.

India holds large deposits of the Light REE ores and yet imports almost its entire requirement of REE and its alloys. As India pursues modernization and works to increase its manufacturing base with the Aatmanirbhar programme and ramps up production, these Rare Earths will be extensively used and hence required. There is thus a need for India to secure the supply chain of REEs. This requirement gets more pronounced in the defence manufacture sector where we are pursuing a path of strategic autonomy by attempting to achieve maximum self- reliance in the defence manufacturing. The recent face off with China in 2020 highlights this vulnerability even further.

Statement of the Problem

China has established a firm hold and dominance of the Global Supply Chain of REEs. It provides more than 85 per cent of the world's REEs and is home to about two-thirds of the global supply of these scarce metals and minerals that are essential for the manufacture of electric car batteries, satellites, weapons, wind turbines and solar panels. The world powers including the US and Europe are worried that any disruption to their supply chains for such products would hurt key industries and can be used as a tool to create criticalities in the world manufacturing sector.

Similarly, as India’s neighbour and competitor, China can disrupt the supply chain and availability of REEs for Indian industry in general and the Indian Defence Industry in specific. As India is striving to achieve self reliance in the defence sector, what would be the adverse impact of Chinese control over REE on Indian Defence Industry with specific reference to the ‘*Atmanirbhar Bharat*’ program of the Government of India?

Objectives

The objectives of the Study are as under :-

1. To study the level and implications of China’s ability to control the Global Supply Chain of REEs.

2. To study the implication of disruption in Global Supply Chains of REEs on the Indian Defence Industry.

3. To suggest options available to India to sustain its requirements of REEs in the long term to pursue self reliance for the defence manufacturing sector.

Research Design

The study has endeavoured to provide an insight into China’s stranglehold on the REE supply chain and its implications on the Indian Defence Industry. This involved an in - depth study of books and articles written on the subject and an analysis of the same. Papers and articles on the issue which have been published in various renowned journals and news papers were also analysed for better understanding of the subject. A Congressional Study on a similar challenge facing the US Defence Sector and a report to the UK Parliament on the subject were also analysed for deeper insight. In addition to the above, websites of Defence Public Sector Undertakings dealing with manufacture of weapon systems were analysed for a measure of REE utilization and possible requirement. Interviews were conducted from officers in Department of Defence Production and leaders of industry attempting to venture into REE extraction and processing. Therefore, the Research Design is Quantitative (Descriptive and Causal) in nature.

Brief Reasons for Study

Over the years, China has established a monopoly on the refining of REEs and it currently controls nearly 85% - 90% of the world's REE mining and refinement with their supply chains dependent on them. China is assessed to have developed the capacity to disrupt the manufacture of military systems of all countries of the world.

In the past, China has used trade as a tool for coercion in international diplomacy. Though India does not consume many REEs either in their raw form or as concentrates, these REEs are increasingly being used in all high technology items and are appreciated to be central to several futuristic technologies. Resultantly, their increasing use is appreciated in India, as it pursues a policy of *Aatmanirbharta*, especially in the field of defence manufacture.

India is pursuing a program to achieve self-reliance in the manufacturing sector, with specific reference to the Defence Industry. Non availability of REEs or alternatively, the disruption of supply chains of REEs will have the potential of impeding India's defence production, hi-tech manufacturing industry and the renewable energy industry. While India has adequate reserves of REEs, there is a criticality of their extraction and processing and consequent inadequacy in domestic production. It is this felt that India will not be able to guarantee its critical requirements.

China is India's largest trading partner and one of the major suppliers of REE to India. However, the recent past has witnessed a setback in the bilateral relations with the border clashes in 2020 and loss of lives on both sides. The ongoing border dispute with China has also had a negative impact on bilateral trade. It is thus imperative for India to develop a strategy for REEs due to the increasing risk of China restricting the export of these products to India in the future, or restricting the export of raw REEs and their concentrates to countries from whom India imports finished products.

Research Questions

1. What are the characteristics of the REEs and what is their requirement in defence production?

2. How are REEs being used in the Indian Defence Industry and where are they being sourced from?

3. What is the appreciated use and dependence of REEs in the indigenous defence industry (both government and private)? The analysis of future defence industry would be carried out in view of the 'Atmanirbhar Bharat' program of defence industry.

4. What would be the impact of a partial and complete disruption in the supplies of REEs on the defence sector in the current and future perspective?

5. What are the options available to India to ensure assured availability of REEs for the Indian Defence Industry?

Limitations of the Study

1. REEs have multiple uses in future technologies and in military hardware. This study will endeavour to focus on and draw conclusion on the defence industry only, although the recommendations and future course have a bearing on the overall policy with respect to self reliance in terms of supply chain management of REEs in India.

2. Information and data on the quantum of REEs currently used in each item of defence manufacture is not available in the open domain and remains classified.

3. With the positive indigenisation list (also called the negative import list) in defence procurements being promulgated, the setting up of defence manufacturing plants in India is difficult to ascertain in the short term. The requirement of REEs in the defence manufacturing plants is thus correspondingly difficult to quantify and forecast.

Research Methodology

The methods applied in this research were a combination of exploratory and analytical. The research is based mostly on secondary sources and primary sources were limited.

Primary sources included interactions with officers from Department of Defence Production (DDP), DRDO and Headquarters Integrated Defence Staff (HQ IDS). Open ended questionnaire and opinions from strategic thinkers, institutions and think-tanks were also explored. The secondary sources were the study of unclassified documents and official figures on REE from DPSU websites, Government of India Websites including Niti Aayog etc. In addition, books, articles and documents published on the subject were a major source of the research. The literature reviews that explore concepts and theories was also utilised. Over and above, relevant data from open sources helped supplement the topical analysis to arrive at conclusive deductions.

Chapterisation

The thesis has been covered in the following chapters:-

Chapter 1 :. Introduction. The chapter gives a brief insight into Chinas monopolisation of REEs and its using such tools to further its strategic aims. It covers the Statement of the Problem, Research Objectives, Research Design, Rationale or Justification for the study and the Research Questions

Chapter 2 : Literature Review. The chapter elaborates on the survey of literature and details of research methodology.

Chapter 3 : Understanding Rare Earth Elements. The chapter dwells upon REEs – what they are, their characteristics, relevance, the challenges in their extraction and production. It also examines the military applications of REEs.

Chapter 4 : Importance of REEs and their Associated Geopolitics. The Chapter studies China's ascent to global monopoly in REE extraction and production, the availability of REEs globally, the global supply chains, manufacturing bases and Chinas monoplosiation of REE supply chain and its using REEs to further strategic interests and finally it studies the US and other countries efforts to reduce dependence on China.

Chapter 5 : REEs in the Indian Context. The chapter traces the growth of rare earth industry in India, look into the availability of REE resources in India, the current Indian initiatives on REE enhancement and finally the challenges facing the sector.

Chapter 6 : REEs and *Aatmanirbharta* in Defence Manufacturing. The chapter broadly studies the REEs and defence indigenisation plans under four broad heads namely, government policy for pursuing self reliance in defence sector, REE use in defence manufacture in India, examination of government initiatives on self reliance in defence sector: the REE context and finally forecasting type of REES required in India's self reliance in defence sector and their availability

Chapter 7 : Securing the Rare Earth Supply Chain – Findings and Recommendations

Chapter 2 : Literature Review.

There is a lot of literature available on the science behind REEs and few studies undertaken by various countries to avaoid Chinese monoploisation of REEs against a possible tool for coercion. More recently, the alarm bells in India on our dependence on China have led to few journals deliberating on the subject. Literature review of major books/ significant articles are as under:-

(a) **Lele, Ajey (2019). "India's Need for Strategic Minerals". Vivekananda International Foundation Vol.II.** The study dwells upon the concept of strategic metals and their importance, policy structures for the mining/ mineral sector in India to include 'Mines and Minerals (Development and Regulation) Amendment Act, 2015' and 'Atomic Minerals Concession Rules, 2016' and ultimately arrives at the challenges for India's mining/mineral sector. The author identifies through the study that 12 critical minerals (including beryllium, germanium, rare earths (heavy and light), rhenium, tantalum, etc.) have an important role in the Make in India programme. The findings indicate that despite abundance of minerals in India, the import of REE is more cost effective than creating an industry structure for its extraction within the country. The study concludes that the entire domain of undertaking assessments, factoring strategic needs, managing domestic production and deciding on export/import policies would be a complex and multidisciplinary task. Hence, it has been recommended that it is important to evolve a separate structure within the government apparatus (along with the members from industry) for undertaking this task. The study is however silent on the exact usage of REE in manufacturing sector including in the defence industry. It also does not suggest any strategy to create self sufficiency in supply chain of REEs.

(b) **Mazumdar, Rahul & Khurana, Mayank (2020). "India Securing Rare Earth Elements". Working Paper No 97, EXIM Bank Report.** The study highlights the status and availability of REEs globally, and in India and also the initiatives taken by other countries globally to secure REE. The study findings point out that China still holds majority share of global REE and the resultant attempt by USA to address this 'strategic vulnerability'. It points out that several countries have made commitments to research and design as also funds for alternative sources of REE supply chain and India is also pursuing a policy of self reliance in manufacture. The study examines models being pursued by other global powers to secure REE and concludes by suggesting possible strategies which India can adopt to secure its access of REEs. The study is however silent on the REEs being used in the Indian Defence Industry and where are they being sourced from. It also does not study the appreciated use and dependence of REEs in the indigenous defence industry.

(c) **Kanisetti Anirudh, Pareek Aditya, and Ramachandran Narayan (2020). "A Rare Earths Strategy for India". Takshashila Discussion Document 2020-16 V1.0.** This excellent study highlights the sources of rare earths and their strategic applications, extraction and processing of REEs and the associated risks and concerns. The study highlights the potential future sources and appreciates India's current Rare Earths strategy. The authors finally recommend a route for reform and modernisation of the rare earth sector in India and suggest creation a new Department for Rare Earths (DRE) with the role of acting as a regulator and enabler for businesses in this space, allowing private sector companies to participate in processing of rare earth elements, funding to businesses in processing REEs to help them set up operations, establishing of enabling infrastructure close to ports and finally, building 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. The study is however silent on the requirement or use of rare earths in the defence sector and their future potential.

(d) **Singh, Yamuna (2020). "Rare Earth Element Resources: Indian Context", Society of Earth Scientists Series, Hyderabad, India: Springer.** Dr Yamuna Singh in his book, has meticulously compiled the REE mineral deposits in India, systematically classifying them in terms of the geological setting and presenting them in order of their current commercial importance and industrial potential. He has outlined several aspects of the Rare Earth Mineral industry in the international field that need consideration in planning our future developments. The scientific study is however silent on the usages of REEs and their strategic applications as also their use in the defence manufacturing sector.

(e) **Van Veen, Kelsi and Melton Alex (2020). "Rare Earth Elements Supply Chains, Part 1: An Update on Global Production and Trade". United States International Trade Commission EBOT: Executive Briefing on Trade, Dec 2020.** The authors, in their report, study global REE production and supply chain for the USA and point at the Chinese dominance of global REE production. They arrive at the conclusion that China still holds majority share of global REE and 75 percent of US imports come from China. They opine that the continued reliance on China for REEs has motivated the US to seek alternative reserve sources and develop new processing capacity however highlight that most REE applications require at least 99.9 percent purity and very few countries can fully transform the raw material into its final usable form. The study does not dwell upon the strategic use of REEs. The study is also silent on the global supply chains of REE including India and does not suggest routes or sources of REEs.

(f) **Kumar, Atul (2020). "How Rare Earths dictate strategic interests of India in Defence, Nuclear, Space sectors". Defence Capital Journal, 12 Sep 2020.** The article dwells upon the global distribution of REE's, India's REE demand and supply and finally REE extracting and processing facilities / ventures in India. The author highlights that India currently has abysmal production capacity of 1800 metric tons per year - only 1 per cent of global output. He contends that the investments, market and India's huge reserves of raw materials make Research & Development in this segment a highly valuable venture that will boost the development of a large number of strategic hi-tech products and industries. The study is however silent on India's total imports of REE and their forecasted growth as also the sector wise utility of REE and their use in defence industry

(g) Lucas Jacques, Lucas Pierre, Le Mercier Thierry, Rollat Alain & Davenport William , Rare Earths, Sep 2014, , Rare Earths, Elsevier,. The authors dwell upon the technology and environmental applications of REE stressing upon their importance and uses as technology develops. It provides a scientific understanding, properties and uses of REEs. It also points at options to efficiently recycle REEs and their possible use in new technological applications and devices. In all, it provides an integrated picture of production and use (present and future) of rare earths and the science behind this picture. The book is however silent on supply chains or REE and focuses on technology associated with REEs.

(g) **Congressional Research Service, & Grasso, V. B. (2013, December).** ***Rare Earth Elements in National Defense: Background, Oversight Issues, and Options for Congress*****. Congressional Research Service**. The study was ordered soon after the Senkaku / Diayutai Island dispute between Japan and China and use of REEs by the Chinese as a tool for coercion. It is an elaborate study which included a background on Rare Earth Elements, how and where they are produced, how they are used in the defence sector, supply chain issues along with a historical perspective on the potential impact of Chinese policies on rare earth materials. The study dwells upon US dependence on foreign sources for REEs and finally options for Congress, An excellent study while it is nearly 10 years old, it is fairly contemporary for India and offers valuable options and insights.

(h) **Powell-Turner, J., & Antill, P. D. (2017). Critical Raw Materials and UK Defence Acquisition.** ***Emerging Strategies in Defense Acquisitions and Military Procurement.*** Following close to the US Congressional Study, this is a study commissioned in the UK to assess the impact of critical raw material (REEs) in the defence industry. The study links the use of hazardous substances in the production of defence equipment and the impact of EU legislations on environment on the defence manufacturing. It dwells on how the UK Ministry of Defence (MOD) has begun to deal with the legislations, availability of critical materials (REEs) including the use of alternative products. Chapter 8 titled '*Critical Raw Materials and UK Defence Acquisition: The Case of Rare Earth Elements'* examines the factors which could affect future critical raw material availability for UK defence, focusing on the availability of rare earth elements (REE). It dwells upon regulatory policy and its enforcement, export policies, promoting greater efficiency in resource use, efforts to mitigate resource depletion and more efficient resource extraction while reducing its associated environmental impact. Thereafter, it deliberates on global supply chains, the impact on material insecurity and how this may aggravate the issue of their use in UK defence acquisition. It highlights the vulnerabilities of supply chain disruptions and the availability of REE on the United Kingdom's defence sector. It offers good clues on the types of REEs essential to UK in defence manufacturing but remains silent on the quantities required.

(j) **Geological Survey of India (GSI), Atomic Minerals Directorate for Exploration and Research (AMD). (2020, November).** ***Strategic Plan for Enhancing REE Exploration in India*****.** The study, possibly the first of its kind in India examines REE mineralization and the strategy to explore them in India. The study offers a view on the geological, geochemical and, geophysical characteristics of REEs. This baseline geo-science data will be of immense use for REE and Rare Metals (RM) mineral prognostication. It also offers good and relevant recommendations for the future which will provide a good path for the country. The document is however silent on the breakdown of REE usage, specifically in the defence sector.

(k) **Bhattacharya, D. (2022, January 9).** ***A rare earths roadmap for India: Seeking atma nirbharta in Indian technology*****. Firstpost.** The article published in en online daily, offers good insight to the needs of this strategic material. It traces China's growth with near control in the global supply chain of REEs and thereafter gives out the reasons and benefits which China seeks to accrue by maintaining the pole position. It also gives good insight into the strategies being adopted by China towards this effort. Finally, it gives some recommendations for India to pursue to break shackles of Chinese monopoly. The article is contemporary and merits close attention, however is silent on the current usage, likely future usage and sector – wise consumption of REEs.

(k) **IREL (India) Limited. (2021, October).** ***Compendium on Rare Earths and Heavy Minerals*****. IREL (India) Ltd.** The compendium by IREL charts out the growth of the company and traces the origins of REEs in India. In simple pectorals, it gives usage of REEs in various applications and in defence technology. The report however falls short of giving out the quantities of REEs required in the defence sector and also the details of their application and usage. It also does not cover the strategy being pursued by the country to meet emerging challenges nor does it recommend a roadmap for the future.

Chapter 3 : Understanding Rare Earth Elements

General

Rare Earths are a group of 17 elements starting with lanthanum in the periodic table of elements and include scandium and yttrium (Figure 3 – 1 below refers). Their names and Atomic Numbers are given in Table 3 - 1. They are moderately abundant in earth's crust but not concentrated enough to make them economically exploitable. The REEs find key applications in defence, electronics, energy systems etc. For instance, magnets made from rare earths are many times more powerful than conventional ones. Along with energy critical elements (ECE), such as, lithium which has become ubiquitous battery material, REEs have emerged as strategic elements essential for sustainable energy systems.

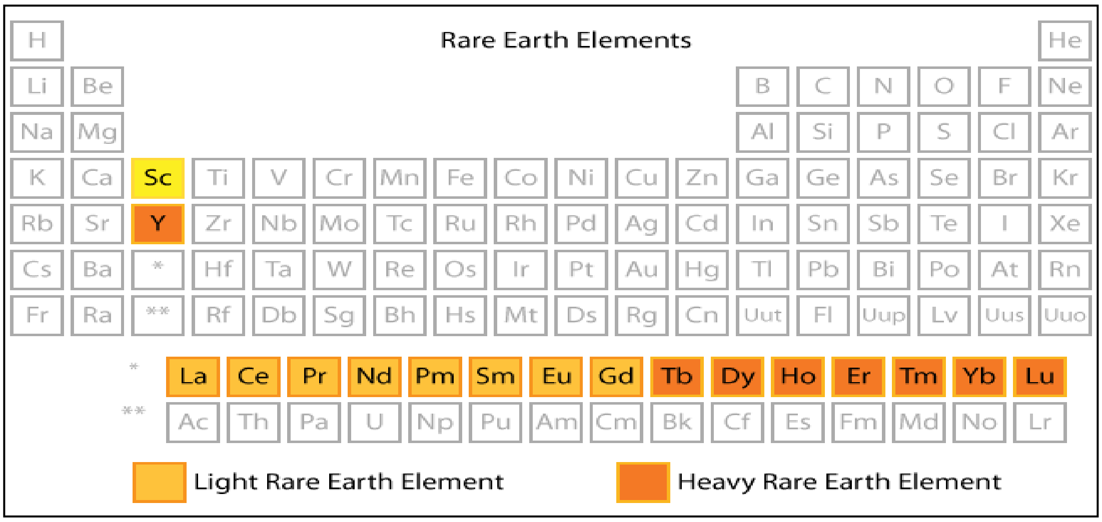

Figure 3-1. Rare Earth Elements in the Periodic Table[2]

REEs are characterised by high density, high melting point, high conductivity and high thermal conductance. A number of rare-earth minerals contain thorium and uranium in variable amounts, but they do not constitute essential components in the composition of the

[2] Singh, Y. (2020). *Rare Earth Element Resources: Indian Context (Society of Earth Scientists Series)* (1st ed. 2020 ed.). Springer.

minerals. This has added to the complexity in their extraction, processing and ultimate privatisation.

Table 3-1. Names and Atomic Numbers of REEs[3]

Symbol	Element Name	Atomic Number		Remarks
Sc	Scandium	21		
Y	Yttrium	39		
La	Lanthanum	57	Consist of 98 percent of REEs	
Ce	Cerium	58		
Pr	Praseodymium	59		
Nd	Neodymium	60		
Pm	Promethium	61		Radioactive and does not occur naturally
Sm	Samarium	62		
Eu	Europium	63		
Gd	Gadolinium	64		
Tb	Terbium	65		
Dy	Dysprosium	66		
Ho	Holmium	67		
Er	Erbium	68		
Tm	Thulium	69		

[3] Singh, Y. (2020). *Rare Earth Element Resources: Indian Context (Society of Earth Scientists Series)* (1st ed. 2020 ed.). Springer.

Yb	Ytterbium	70		
Lu	Lutetium	71		

<u>Light Rare Earth Elements (LREE) and Heavy Rare Earth Elements (HREE)</u>

The rare earth metals are grouped into the Light Rare Earth Elements (LREE) and the Heavy Rare Earth Elements (HREE). Although these elements tend to occur together, the lanthanide elements are divided into two groups. The light elements are those with atomic numbers 57 to 63 (La, Ce, Pr, Nd, Pm, Sm and Eu) and the heavy elements are those with atomic numbers 64 to 71 (Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu). The LREE are Lanthanum through Gadolinium. The HREE are Yttrium and then Terbium through Lutetium. The classification is determined by the electron configuration of the atoms of the element. The LREE do not have any paired electrons, while the HREE do have paired electrons. The element yttrium is considered an HREE because it has similar chemical properties to the other heavy rare earth metals and a comparable ionic radius. Scandium forms a trivalent ion, like the other rare earth elements, but it does not meet the electron configuration criterion for an LREE and does not share enough chemical properties with the HREE to be considered one of them.

<u>Sources and Availability of Rare Earths</u>

The principal sources of REE are Bastnasite (a fluorocarbonate which occurs in carbonatites and related igneous rocks), Xenotime (Yttrium Phosphate) commonly found in mineral sand deposits, Loparite which occurs in alkaline igneous rocks and Monazite (a phosphate). The rare earths occur in many other minerals and are recoverable as byproducts from phosphate rock and from spent uranium leaching[4]. In India, Monazite is the principal source of rare earths and Thorium.

Lanthanum to Samarium account for 98 percent of the rare earths while the balance elements account for 2 percent. The high atomic number rare earths are rarer and more expensive. The most challenging requirement in the production of REEs is the separation of the pure metals from the minerals and from each other for scientific analysis and for use in manufacturing. The rare earth industry involves the upstream chain of exploration, extraction and production of metal oxides, metals, alloys and the downstream chain of manufacture of products like permanent magnets, catalytic convertors, rechargeable batteries etc. For effective value addition, a nation there is a need to have presence in both the upstream and downstream chains. This may be entirely domestic or may be secured through collaborations, partnerships, trade agreements and transnational supply chains.

Mining and Purification Process

REEs occur in nature predominantly as metal oxides, carbonates, silicates, phosphates and sulphates. The most commonly found rare earth minerals are Bastnasite (carbonate ore), Monazite (phosphate ore) and rare earth adsorption clays. The percentage by mass of rare earths in Bastnasite and Monazite are comparatively high (5-15 mass percent), while that in the adsorption clays is low (0.2-0.3 mass percent). The deposits of bastnasite and monazite are spread across the world with India having sizeable monazite reserves. Rare earth clays are primarily found in China. The extraction process of rare earths from clays is relatively easier using a process of ion exchange; however large amounts of minerals have to be mined and treated to extract the metals.[5] The extraction process of

[4] Lucas Jacques, Lucas Pierre, Le Mercier Thierry, Rollat Alain & Davenport William , Rare Earths, Sep 2014, , Rare Earths, Elsevier, ISBN: 9780444627353

[5] Lucas Jacques, Lucas Pierre, Le Mercier Thierry, Rollat Alain & Davenport William , Rare Earths, Sep 2014, , Rare Earths, Elsevier, ISBN: 9780444627353

Bastnasite and monazite is a complex and resource intensive process. The mining processes involve concentration followed by purification. Figure 3- 2 below gives out the process.

- The open pit method of mining is primarily used to extract the ores which are available as close to the surface igneous deposits. Largest deposits of these ores are found in the Bayan Obo mines in Mongolia, China.

- Before the rare earth metals are extracted and purified, the ores are concentrated as an intermediate process through a process of froth floatation.(The Froth Floatation process is used to separate the rare earth minerals from the waste rocks and aggregates. It uses a large water filled tank where the mixed ore is agitated using air bubbles. The concentrated rare earth ore floats on the surface and is separated.)

- Monazite is found mainly in the form of high density beach sand deposits. The initial process of mining consists of dredging followed by concentration using gravity, magnetic, electrostatic and density separators.

- The rare earth rich clays are relatively newly discovered forms of minerals. They are soft and found close to the surface of the earth. The process of concentration involves leaching using ammonium sulfate solution and through precipitation.

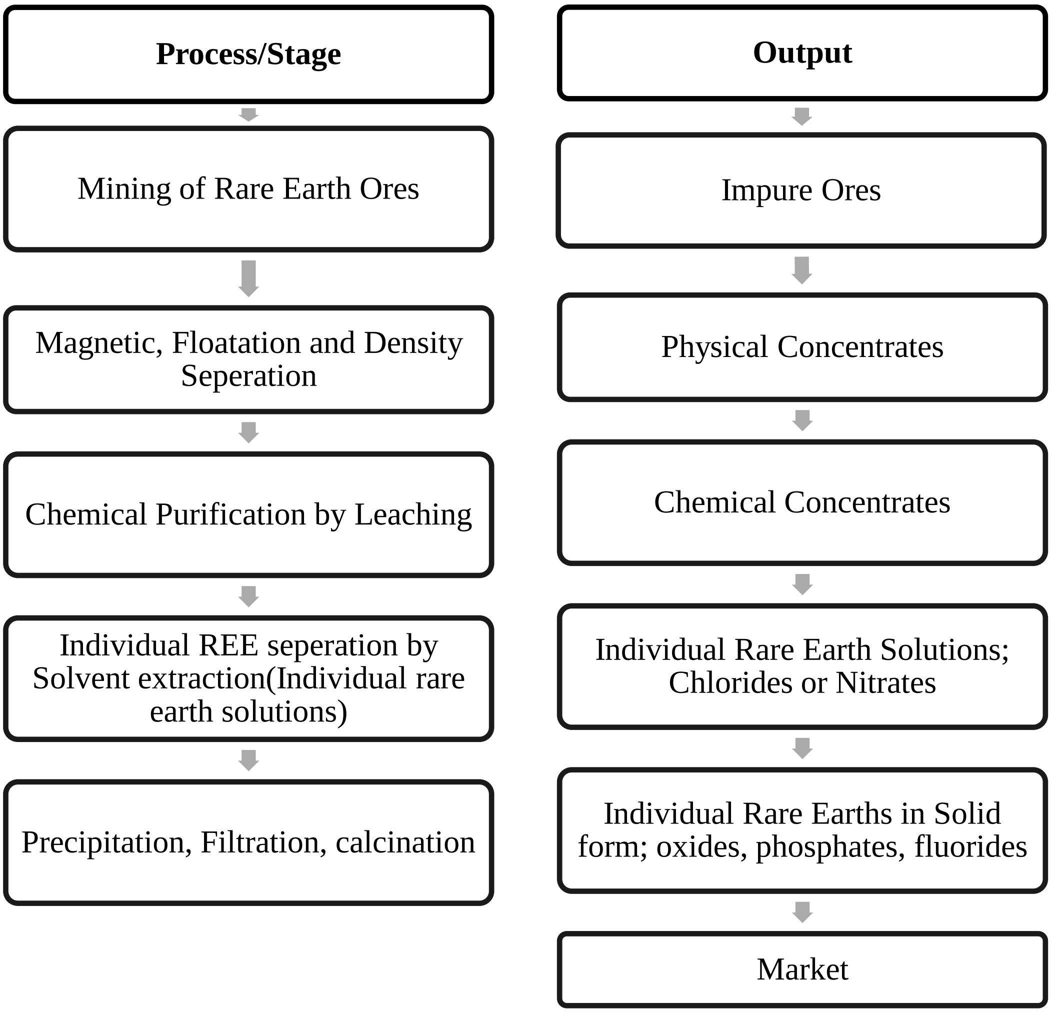

Figure 3-2. Flowchart for Rare Earth Production Process[6]

The purification of the concentrates is carried out in purification plants. The method of purification employed depends on the type of the mineral and the content of rare earth in the mineral (quantity and type of metal). Certain rare earth ores like monazite have traces of radioactive elements like Thorium, hence the purification process involves the steps towards removal of radio activity. India finds itself uniquely placed in this context since it has the third largest reserves of Thorium in the world in form of its monazite ores (estimated to be between 3 to 8.5 lakh tonnes) (More details of this aspect will be deliberated upon in Chapter 5). Extraction of REEs from concentrates is done using a process of leaching.

[6] Lucas Jacques, Lucas Pierre, Le Mercier Thierry, Rollat Alain & Davenport William , Rare Earths, Sep 2014, , Rare Earths, Elsevier, ISBN: 9780444627353

Caustic soda is used for high concentration and sulfuric acid is used for low concentration minerals. In case of adsorption clays ammonium sulfate is used for leaching. This stage of the purification process results in pollutant residues and by products and has been one of the primary reasons for the developed countries from pursuing the industry and outsourcing the same to China which willingly accepted it along with associated risks and environmental damages. The chemical concentrates are put through further precipitation and calcination in order to extract pure rare earth oxides, fluorides and phosphates in solid form. These are ready to be used in industrial applications and also for further reduction to metals. Pure metals are used in magnets, batteries and other specialist manufacturing as part of the downstream manufacturing.

Extraction and Separation of Pure Metals

Reduction of pure rare earth metals is a specialist and high technology process. It uses a high temperature and high vacuum process of converting of metal oxides to metal vapour and further depositing of the vapour as solid metal on a cool surface. This method of vapour deposition can be used for metals having high vapour pressure like Samarium and Ytterbium. The other method of extracting pure metals from fluorides uses calcium reduction. The metals extracted using vapour and calcium reduction is adequately pure for majority of industrial uses. They can be further purified by vacuum casting or vacuum vapourisation. Vacuum casting is more popular. It involves melting the metal to a specific temperature and casting it under vacuum. Impurities vapourize under high temperature while dissolved gases escape; hence the cast metal is in pure form. The process of purification of metals is expensive and also leads to losses. Figure XX below gives out the extraction process for REE while categorizing it into Upstream and Downstream processes[7].

[7] https://takshashila.org.in/wp-content/uploads/2020/12/A-Rare-Earths-Strategy-for-India_TDD_AK_AP_NR_v1.0.pdf

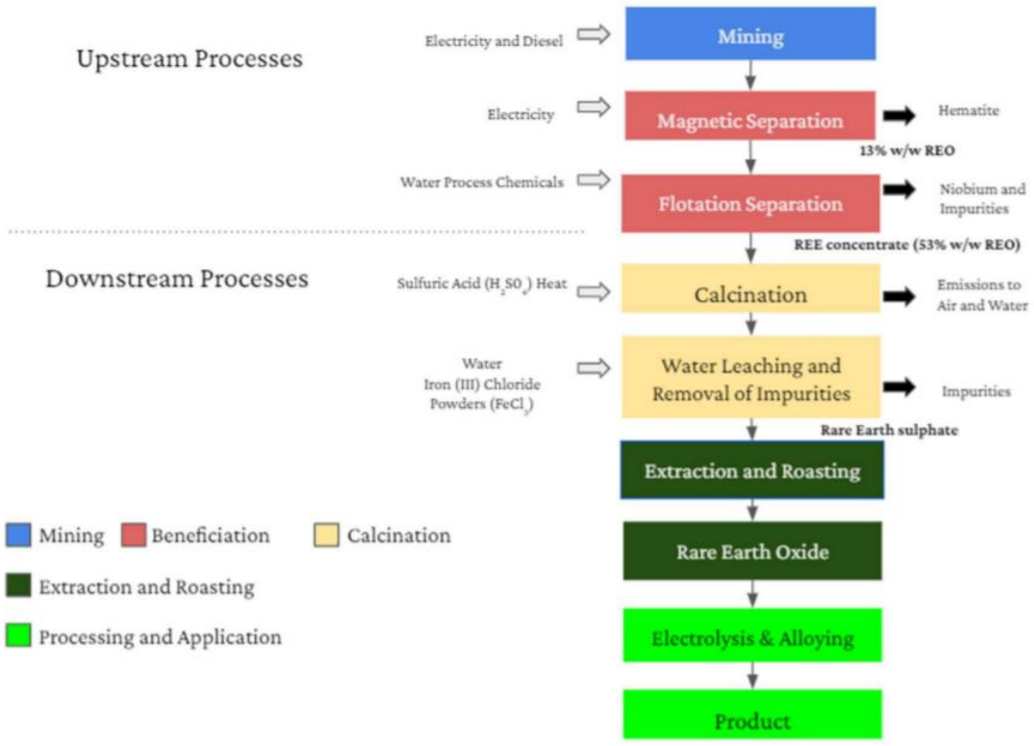

Figure 3 - 3 : Extraction and Processing of REEs

Removal of Radioactive Impurities, Rare Earth ores contain radioactive minerals in very small proportions. Hence the purification and extraction processes involve a stage of separation of radioactive components. Typically, the radioactive isotopes found in rare earth ores are Thorium 232, Uranium 238 and Uranium 235. Thoruim and Uranium traces are removed by exclusive chemical processing or solvent extraction. In addition to this, the Thorex process (The Thorex process is a specialist process which was used in France to extract radioactive elements) can also be used to remove radioactive elements from monazite concentrates. The separation of rare earth metals from each other and from impurities seen in conjunction to the separation of radioactive traces makes the production energy intensive and expensive. This stage makes the rare earth extraction process distinct from other mining processes. The process is also time consuming as the purification cycles have to be repeated multiple times to achieve desired levels of purity.

Characteristics and Uses of Rare Earth Elements

As highlighted above, REEs comprise a group of 17 elements; Fifteen Lanthanides along with Scandium and Yttrium. Each of these elements has very specific properties, and substituting one rare earth with another is often not possible. REEs are characterised by high density, high melting point, high conductivity and high thermal conductance. A number of rare-earth minerals contain Thorium and Uranium in variable amounts, but they do not constitute essential components in the composition of the minerals.

The unique properties of rare earth elements can be traced to the atomic characteristics. The elements Lanthanum to Lutetium have increasing atomic numbers 57 to 71. The common characteristics are found in the 4f orbitals which are gradually filled from one to fourteen, after Lanthanum. The orientation or atomic particles, spin, quantum characteristics and the way these atoms interact with other atoms gives unique properties of magnetism, optics, abrasion and luminescence. The properties are stable and the rare earth elements behave in distinct manner while interacting with other elements. These unique properties make them indispensable for many modern applications including military equipment, industrial processes and systems.

Rare Earths have multiple applications and it is the vitamin of modern technology. They are used in small quantities in variety of products in the field of e-mobility, green energy, catalysts, consumer electronics, defence, aerospace, etc. For enhancing performance, technological superiority, incorporation of innovations to meet new challenges, miniaturization, all electronic items commonly used like mobile phone, computers and smart TVs contain Rare Earths. Petrol and diesel used in two-wheelers, cars, boats, buses and trains are separated in refineries with the help of Rare Earth catalysts. The rare earth metals are used in a variety of materials and products, including superconductors, extremely powerful magnets, phosphors and pigments, catalysts, lasers and masers and steel and other alloys; their application across sectors same is elucidated below in Figure 3 – 4 and Figure 3 – 5.

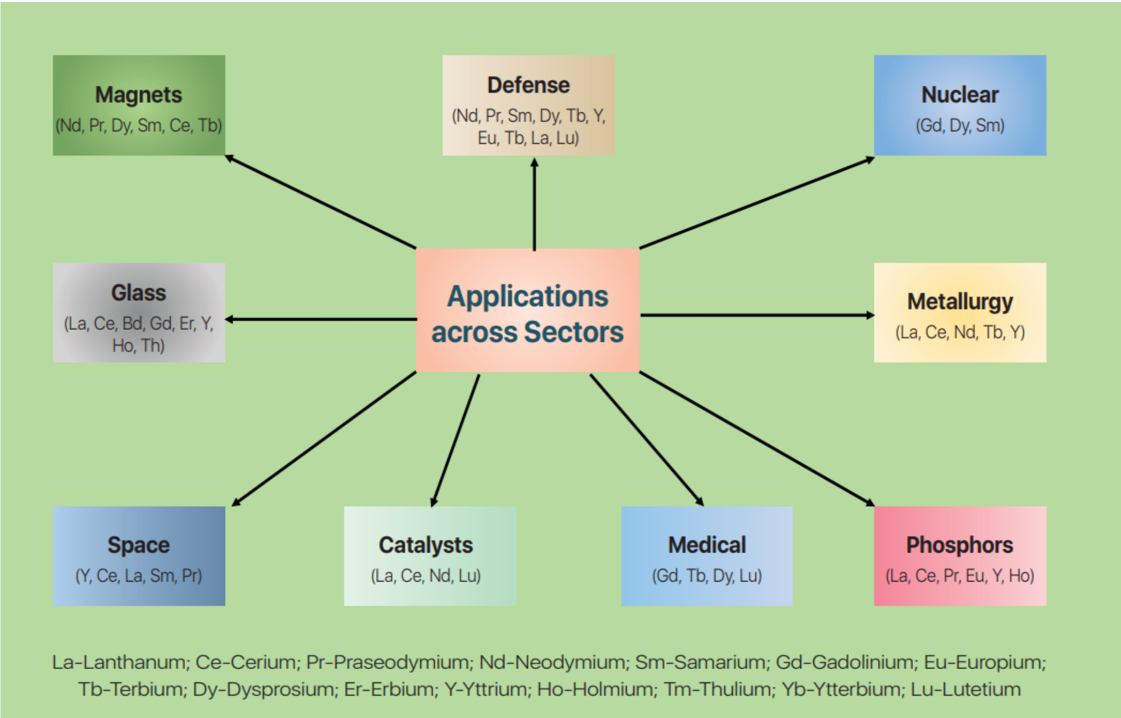

Figure 3-4. Applications of Rare Earth Elements[8]

Rare Earths & Heavy Minerals are used as performance ingredients in consumer electronics, automotive, renewable wind and solar energy, ceramic, refractories, welding electrode, foundries, glass industry, telecommunication, aerospace, paint and pigments, gas mantle, petroleum, pharmaceuticals, satellite, aerospace, defence applications etc. Use of each REE in various applications as also the utilisation of REEs, the world over, are is given at **Appendices A and B** respectively. Few common applications based on properties are enumerated as under.

- The rare earth elements are used to speed up chemical reactions and processes. Lanthanum chlorides and nitrates are used in petroleum industry in the

[8] Compendium on Rare Earths and Heavy Minerals, Oct, 2021, IREL (India) Limited, available at https://www.irel.co.in/documents/20126/457486/Compendium+on+Rare+Earths+and+Heavy+Minerals+Book.pdf

process of distillation of petrol and diesel. Cerium oxide is used in conjunction with platinum, palladium and rhodium as a vehicular pollution reducer in catalytic convertors. Other applications as catalysts in the process of production of hydrogen gas, synthetic gases, synthetic rubber, plastics and ethanol. A significant application of rare earth elements is in the diesel engine pollution removal systems which reduce solid particulates (soot). Such systems use the properties of catalysis in filters and find wide usage in diesel engines and generators including military equipment.

- Modern rechargeable batteries are predominantly Nickel Metal Hydride (Ni-MH) type, which uses electrodes of nickel doped with rare earth metals. Rare earths used in the alloy with nickel improves the storage capacity and enhances the rapidity of hydrogen absorption and de-sorption, which forms the basis of such batteries. The rechargeable batteries are increasingly being used in hybrid vehicles. The use of rare earths in batteries is expected to rise exponentially along with the growth of the hybrid vehicles industry. Other used of Ni-MH batteries are in cells and small batteries used to power electronic devices. Ni-MH batteries are used extensively in the defence industry to power night vision equipment, communication equipment, cameras and positioning equipment amongst others.

- Addition of rare earth traces can significantly improve the properties of known metal alloys. Cast iron is a commonly used alloy of iron, carbon and silicon used in heavy industry and is conducive to machining. However, cast iron is also brittle in nature and susceptible to flaking. This can be improved by adding magnesium and rare earths to the alloy. Critical components in military hardware like helicopters, aircrafts, ships, vehicles and other moving equipment use rare earth doped alloys. The alloys also exhibit superior resistance against corrosion, metallic creep and flammability.

- Polishing powders like cerium oxide are extensively used in industry for fine polishing of glass. It is used in beveling flat glass, ophthalmic and precision lenses, liquid crystal displays, electronic devices and in glass-based storage disks. Polishing powders are used to remove surface defects and achieve superior planarization. A critical sector which requires fine polishing is the electronic semiconductor industry which has strategic and military applications. The powders are used in fine planarization of metal films and dielectric materials which are used in the integrated circuits. Glass-based magnetic storage disks offer performance advantages over traditional metal magnetic platter disks. The glass layers in the storage disks are polished using cerium oxide before application of the magnetic layer.

- Use in magnets is a critical domain where rare earths have revolutionized the ubiquitous electro-mechanical industry. Rare earth ferromagnets have wide spread applications and have dominated the industry requirement of strong, light weight and permanent magnets. Neodymium and Samarium are commonly used to obtain magnetic alloys with iron or cobalt or both. Rare earth alloys also display a unique property which is a basic drawback in traditional ferromagnets. Traditional ferromagnets demonstrate degrading magnetic property with increase in temperature. At a critical temperature which is termed as the Curie Temperature, ferromagnetism is completely lost. Rare earth alloy magnets have distinctly higher Curie Temperatures. Neodymium alloy magnets are stronger as compared to Samarium alloys, however Samarium alloys have higher Curie Temperature of 750°C. Rare earth magnets are used in power generation, electric motors, medical instruments, loudspeakers, computers, new energies and in defence systems.[9] Manufacturing of rare earth magnets is the most significant downstream process and

[9] Jacques Lucas, Pierre Lucas, Thierry Le Mercier, Alain Rollat, William Davenport, Rare Earths,(Wattham USA, Elsevier, 2015), 213,230

has a direct implication on the strategic capability of a nation. The manufacture of rare earth magnets is a complex and technology intensive process which involves induction melting of components, milling into fine powder, magnetic alignment and sintering (Sintering is a process of densification at high temperatures upto 1000°C) into solid magnets. The final step involves magnetization using high currents of 30 kilo amperes. The key properties of rare earth magnets which lends itself to extensive use are mentioned in succeeding paragraphs.

- A high-quality Neodymium magnet can lift several thousand times its own weight. The principle of high attractive force finds use in decontamination of metallic particles in coal, chemical, agriculture and plastic industry.

- Strong magnetic fields created by rare earth magnets is used to convert mechanical energy to electric energy in alternators, power generation systems and in wind turbines.

- The rare earth magnets find predominant use in electric motors which convert electric energy to mechanical energy. The source of the electric energy is mainly from rechargeable batteries which in turn use rare earths. Hence electric vehicles have high dependence on such magnets. Rare earth magnets are also used in niche applications like computer hard disks, 3D printers and drones.

- Rare earth magnets are used in devices like audio speakers which convert electrical energy to mechanical energy and further to sound energy.

- The use of permanent and strong rare earth magnets is increasingly finding use in medical imaging processes such as MRI (Magnetic Resonance

Imaging). Magnets are also used in directing strong beams on tumours and affected body parts.

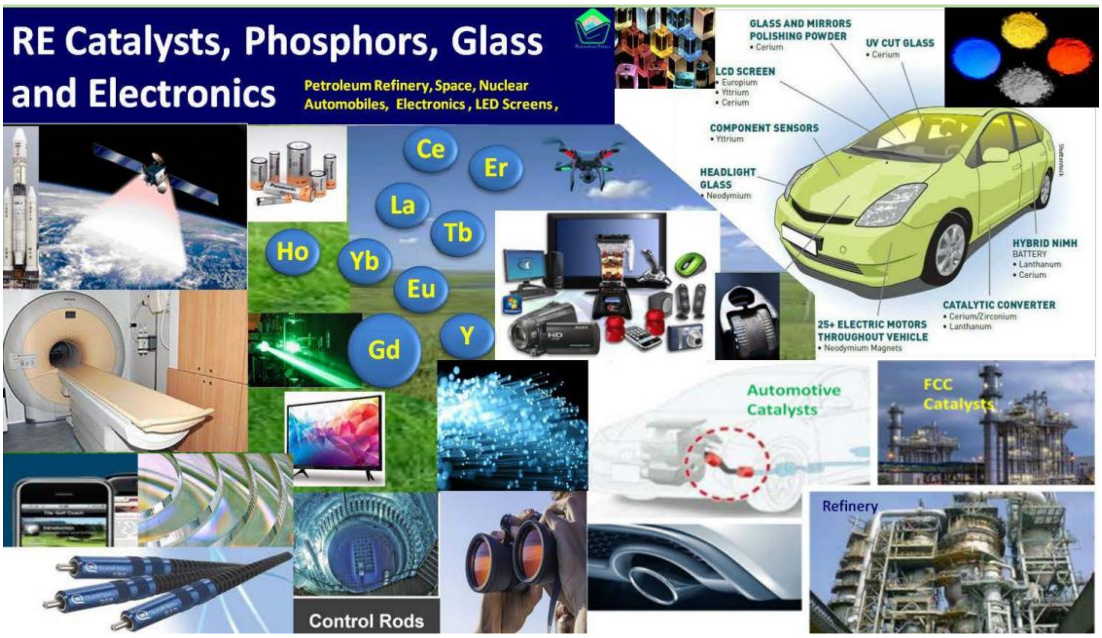

Figure 3-5. Application of Rare Earth Elements[10]

Military Applications of Rare Earth Elements

The applications in the defence segment are a direct fallout of the unique properties of the rare earth elements and their alloys. The efficiency and performance parameters of defence hardware has been enhanced through widespread use of these metals in the defence industry. Advanced and futuristic military systems including high impact weapon systems, heavy vehicles, night vision devices, electro-optical sensors, precision-guided munitions, communication systems, navigation equipment and radar batteries. The rare earth doped alloys are strong, light and have minimum flaking at high temperature and friction. The use of such alloys is increasing in military aircraft, armoured vehicles, jet engines and projectiles. Large platforms like the fifth generation fighter aircraft, nuclear powered submarines, warships, guided cruise missiles, long-range ballistic weapons and onboard

[10] Compendium on Rare Earths and Heavy Minerals, Oct, 2021, IREL (India) Limited, available at https://www.irel.co.in/documents/20126/457486/Compendium+on+Rare+Earths+and+Heavy+Minerals+Book.pdf

systems like sensitive EO-IR sensors use REEs in varied quantities. For example, a new age stealth fighter jet could utilise over 400 kg to 450 kg of REEs while a nuclear submarine could employ as much as around five tons of REEs[11]. There are no known substitutes for REEs as per current scientific knowledge. Figure 3 – 6 below depicts some of the military systems where REE are used.

Figure 3-6. Use of REE in the Defence Sector[12]

According to Dr Mayank Dwivedi, (Scientist G at DRDO), REEs are central to most of the defence application directly or indirectly[13]. From basic uses like OFCs, magnets, used in every weapon system and electro optic device, touch screens and monitors, all use REEs. They have become an indispensible part of defence manufacturing and future advancements in defence technology are reliant on new alloys of REEs. Some of the more commonly used applications of REEs include:-

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[11] Kumar Atul, How Rare Earths Dictate Strategic Interests of India in Defence, Nuclear Sectors, Defence Capital, 12 Sep 2020, available at https://defence.capital/2020/09/12/how-rare-earths-dictate-strategic-interests-of-india-in-defence-nuclear-space-sectors/ ,accessed on 15 Sep 2021

[12] Compendium on Rare Earths and Heavy Minerals, Oct, 2021, IREL (India) Limited, available at https://www.irel.co.in/documents/20126/457486/Compendium+on+Rare+Earths+and+Heavy+Minerals+Book.pdf

[13] Interview of Dr Mayank Dwivedi by the author in DRDO on 10 Feb 22

- Fin actuators in missile guidance and control systems.
- Superalloys and coatings that are used to protect engine parts in gas turbine and jet engines or as a defensive measure against certain types of radiation.
- Disk drive motors installed in computer equipment inside armoured vehicles, aircraft, missile systems and C3I (Command, Control, Communications and Intelligence) systems.
- Rechargable batteries and fuel cells. Examples include nickel metal hydride (NiMH) batteries that power many mobile products (a mixed REE alloy is used as an anode in the battery) and solid oxide fuel cells (SOFC), which is a clean, low-pollution technology that electrochemically produces electricity highly efficiently.
- Lasers for rangefinders, mine detection, friend-or-foe interrogators, underwater mines and mine countermeasures.
- Phosphors that are used in TVs and computer displays (for example, aircraft avionic systems).
- Satellite communications, radar systems and sonar systems.
- Multi-spectral targeting systems.
- Optical equipment and speakers.
- For use in functional ceramics such as semiconductor sensors, microwave dielectric and piezoelectric ceramics.

NdFeB (Neodymium Iron Boron) magnets are considered as the world's strongest permanent magnets and are essential to many military weapons systems. SmCo (Samarium Cobalt) magnets retain their magnetic strength at elevated temperatures and is ideal for military technologies such as precision guided missiles, smart bombs, and aircraft. The superior strength of NdFeB allows for the use of smaller and lighter magnets in defence weapon systems which includes fin actuators in missile guidance and control systems, disk drive motors installed in aircraft, tanks, missile systems, and command and control centers, lasers for mine detection, interrogators, underwater mines and countermeasures, satellite communications, radar, and sonar on submarines and surface ships and Optical equipment and speakers. Other areas of applications are beam control (travelling wave tubes, magnetrons), inertial navigation (gyroscopes, accelerometer, instrumentation), electro-mechanical devices (actuators, RF switches) and permanent magnet alternators, brushless motors, high speed rotors, etc.[14]

[14] Hedrick, J, 2010, *Rare-earth industry overview and defense applications*. Presentation at the CECD (University of Maryland), 1 March 2010, available at http://www.cecd.umd.edu/publications/Argonne%20Lab/Report%20Rare%20Earth%20Ind%20Overview%20March%2010.pdf

Chapter 4 : China's Monopolisation of REEs and Associated Geopolitics

General

Rare Earth Elements come primarily from Australia, USA, Brazil, China, India, Malaysia, Russia, and Thailand, with China being the dominant world producer and largest commercial exporter. Till about the 1950s, Monazite was the primary ore which was mined for extraction of REEs. The deposits were mined predominantly in Unites States, India and Brazil. The Mountain Pass Mine in California became the iconic global producer and supplier of REEs, primarily the light rare earth metals, with smaller production of heavy metals and till the late 1980s and early 1990s, USA was the global leader in rare earth production.

China soon joined the list of REE producers as it entered the REE production scenario in the 1970s. Bastnaesite was the primary ore from which REEs were mined, however it produced pollutant fluorides which led to concerns about health and biological defects in humans. The largest deposits of Bastnaesite were discovered in the Bayan Obo Mines in Nei Mongol (Inner Mongolia). The mining and production received systematic incentive and support from the government. China has several rare earth enterprises producing REE and metals and it has undertaken a major state-led consolidation of REE suppliers. China also diversified its sources with the discovery of extensive deposits of rich adsorption clays. The adsorption clays deposits are spread across multiple mines in China. The percentage of heavy REEs is also higher in the adsorption clays leading to greater economic value. The process of purification is relatively less resource intensive and results in lower contamination and pollution. Processing and manufacturing of the global supply of rare earths began to shift to China, as did downstream value-added forms such as metals, alloys, and magnets and gradually China edged out the other competitors. The major reason for this shift was due to lower labour costs and lower environmental standards[15]. Currently China has attained undisputed leadership position based on production from these clays and from the Mongolian mines although, its stranglehold is gradually decreasing.

China's dominance of the rare earths industry is the result of a reckless and destructive ecological campaign to cut down costs, and a long-term strategic plan involving more than 20 years of precise planning by the Chinese state. It is fully aware of just how strategically important their position is. It has never shied away from using strong arm tactics to progress its strategic interests and agendas and to make others tow the line. The Chinese REE sector has succeeded in lowering global prices through financial and environmental subsidies, forcing the closure of various mines throughout the world, including the Mountain Pass mine in the United States. According to reports in the media, China's ministry of industry and information technology is fine-tuning a rare earth weaponization strategy.

An incident of 2010 highlights Chinas use of REEs as a tool to pursue its agendas. It was during the Diayutai /Senkaku showdown with Japan that China (which then controlled 97 per cent of the market), imposed export quotas on rare earths and stopped all supplies to Japan. As a result, the prices of RE metals and oxides increased by 700 to 1,000 percent. This dealt a devastating blow to Japanese firms who relied on the alloys in their production. Within two months, the Japanese electronics industry had been brought to its knees, necessitating the sending of a Japanese delegation to Beijing. More recently, amid the trade war between the United States and China, hints of REE non-availability sparked alarm bells in the United States, prompting the country to take multiple actions to ensure strategic autonomy in the availability of these vital metals. While the United States has had no

[15] Powell-Turner, Julieanna & Antill, Peter. (2016). Critical Raw Materials and UK Defence Acquisition: The Case of the Rare Earth Elements. 10.4018/978-1-5225-0599-0.ch008.

significant capacity to refine, fabricate, or alloy REEs for many years, this reliance on imports is progressively changing, and global powers are taking steps to minimise their strategic reliance on China for REE supply and availability. Mining operations have been restored at Molycorp's Mountain Pass complex in the United States, which has also witnessed multi-million dollar investments in value-adding operations like separation and alloying. Understanding the actions adopted by the major world powers will give us in India valuable insight into how to deal with the issue, which continues to be a source of concern as China continues to dominate production and reduce exports.

China's Ascent to Global Monopoly in REE Extraction and Production

Pre-1965. Before 1965 there was relatively little demand for rare earth elements. At that time, most of the world's supply was being produced from placer deposits in India and Brazil. In the 1950s, South Africa became the leading producer from rare earth bearing monazite deposits. At that time, the Mountain Pass Mine in California was producing minor amounts of rare earth oxides from a Precambrian carbonatite.

Initial Demands. The demand for rare earth elements saw its first explosion in the mid-1960s, as the first color television sets were entering the market. Europium was the essential material for producing the color images. The Mountain Pass Mine began producing europium from bastnasite, which contained about 0.1% europium. This effort made the Mountain Pass Mine the largest rare earth producer in the world and placed the United States as the leading producer.

China's Initial Forays. China began producing notable amounts of rare earth oxides in the early 1980s and became the world's leading producer in the early 1990s. Through the 1990s and early 2000s, China steadily strengthened its hold on the world's rare earth oxide market. They were selling rare earths at such low prices that the Mountain Pass Mine and many others throughout the world were unable to compete and stopped operation.

Increased Demands. The world demand enhanced manifold as rare earth metals were designed into a wide variety of defence, aviation, industrial, and consumer electronics products. China capitalized on its dominant position and began restricting exports and allowing rare earth oxide prices to rise to historic levels.

China's Reaching Apex Levels. The Chinese dominance is appreciated to have peaked in 2010 when they controlled about 95% of the world's rare earth production, and prices for many rare earth oxides had increased from five to ten times in a matter of a few years. The global production of REE from 1985 till 2020 is given at Table 4 – 1. The year 2010 was an awakening for rare earth consumers and miners throughout the world and a broad consensus on reducing REE dependence on China began emerging in the US and the West. The efforts of US and the Western Powers in their diversification of REM oxides since 2010 is best exemplified in Figure 4 – 1 below

Table 4 -1: Global Production of REE from 1985 till 2020[16]

Year	U.S. Production (metric tons)	China's Production (metric tons)	Rest Of World Production (metric tons)	U.S. % Share	China's % Share
1985	13,428	8,500	17,757	34%	21%
1990	22,713	16,480	20,917	38%	27%
1995	22,200	48,000	9,700	28%	60%
2000	5,000	73,000	5,500	6%	87%
2005	0	119,000	3,000	0%	98%
2010	0	120,000	11,000	0%	92%
2015	5,900	105,000	19,100	5%	81%

16 Bhutada Govind, Rare Earth Metals Production is No Longer Monopolized by China, ELEMENTS NEWSLETTER, Published March 30, 2021, Accessed at https://elements.visualcapitalist.com/rare-earth-metals-production-not-monopolized-china/

Year	U.S. Production (metric tons)	China's Production (metric tons)	Rest Of World Production (metric tons)	U.S. % Share	China's % Share
2020	38,000	140,000	62,000	16%	58%

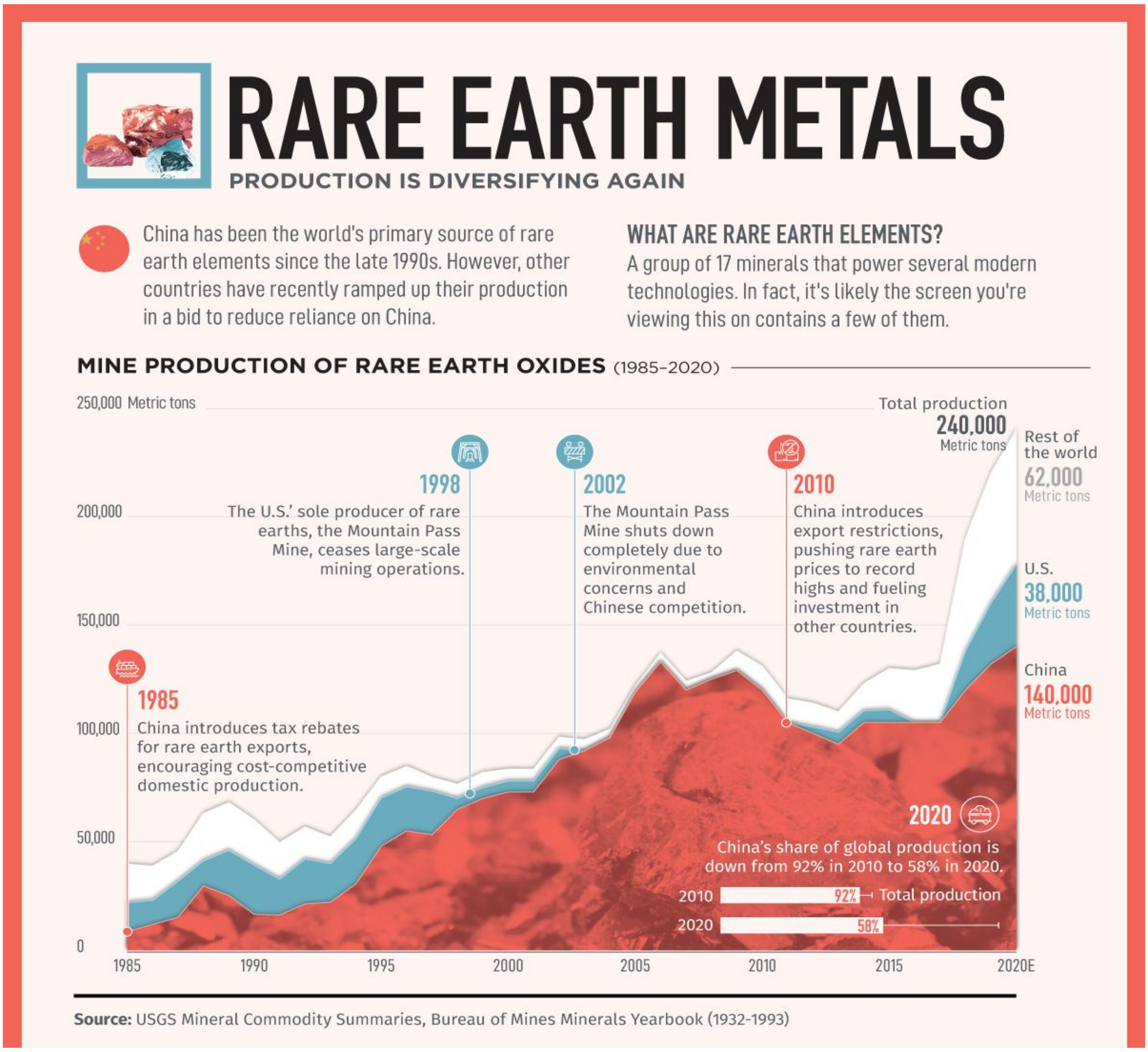

Figure 4–1 : Global REM Oxide Production from 1985 to 2020[17]

[17] Bhutada Govind, Rare Earth Metals Production is No Longer Monopolized by China, ELEMENTS NEWSLETTER, Published March 30, 2021, Available at https://elements.visualcapitalist.com/rare-earth-metals-production-not-monopolized-china/

Global Availability and Production of REEs

The entire world reserves of rare earth oxides (REO) equivalent content are projected to be 120 million tonnes, with China accounting for 44 million tonnes (37%) and Brazil, Vietnam, and Russia each accounting for 18%. (10 percent), details[18] of which are given in Table 4 – 2 and Figure 4 – 2 below

Table 4–2 : World Reserves of REE (By Principal Countries)

Country	**Reserves** (In '000 tonnes of REO equivalent content)
World: Total (rounded off)	120000
Australia	3300
Brazil	22000
Myanmar	NA
Canada	830
China	44000
Greenland	1500
India	6900
Russia	12000
South Africa	790
Tanzania	890
USA	1400
Vietnam	22000
Other countries	310

[18] Rare Earths September, 2020, Indian Minerals Yearbook 2019 (Part- III : Mineral Reviews), Government of India Ministry of Mines Indian Bureau of Mines, available at https://ibm.gov.in/writereaddata/files/10012020172151RareEarth_2019_AR.pdf

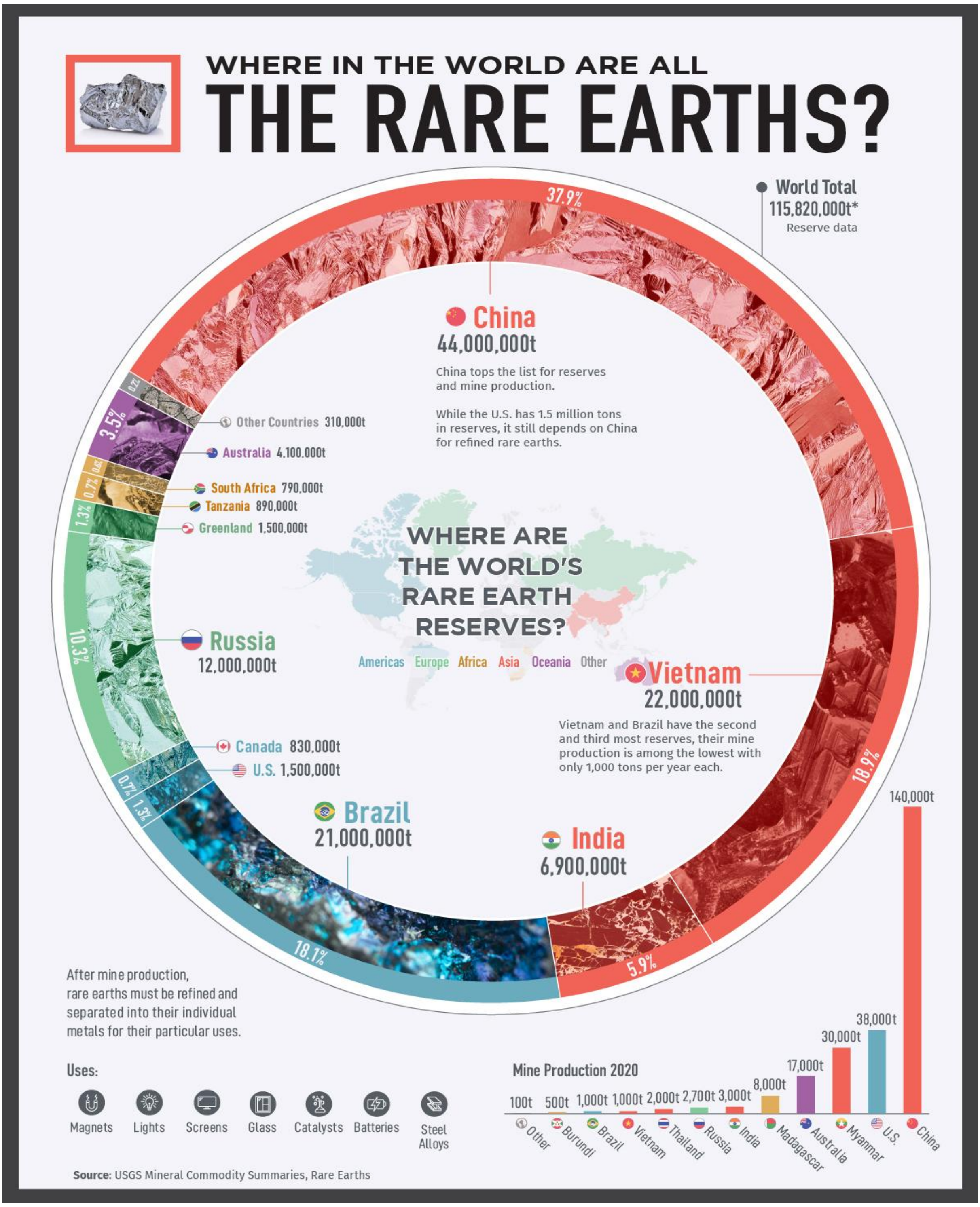

Figure 4–2 : Graphic Representation of World REE Reserves[19]

[19] LePan Nicholas, Rare Earth Elements: Where in the World Are They?,, ELEMENTS NEWSLETTER, Published Nov 22, 2021, Available at https://elements.visualcapitalist.com/rare-earth-elements-where-in-the-world-are-they/

China holds the leading position among producers of rare earth oxides with 140 thousand tonnes. The other major producers are Myanmar, Australia, USA, Russia and Malaysia (Table 4-3).

Table 4–3 : World Production of Rare Earths Oxides[20] (By Principal Countries)

(In tonnes)(Year ending 30th June following that stated)

Country	2016	2017	2018
China(b)	140000*	140000*	140000*
Myanmar	4500*	20000*	23000*
Australia(d)	8799	12631	16003
USA	0	0	9000*
Russia	3063	2500	2596
India(a)	2265	2000e	2000e
Malaysia	1221	196	1012
Vietnam	220*	200*	400*

* Estimated

Many places in Europe, the United States, Japan, and China process concentrates/partially processed intermediate goods. Baotou, Inner Mongolia, and Jiangxi and Sichuan provinces in China are the main manufacturing centres for rare earths. Bastnaesite is collected as a by-product of iron ore mining in Baotou, whereas it is found as a principal mineral in Sichuan and Gansu. Ion adsorption clays are the source of the majority of world yttrium production in Jiangxi, Guangdong, Hunan, and Jiangsu provinces. The Russian Rare Earths Industry relies on loparite, a titanium-tantalum niobate mined in the Murmansk region's Lovozero massif. Rare earth minerals have been recovered as by-

[20] Rare Earths September, 2020, Indian Minerals Yearbook 2019 (Part- III : Mineral Reviews), Government of India Ministry of Mines Indian Bureau of Mines, available at https://ibm.gov.in/writereaddata/files/10012020172151RareEarth_2019_AR.pdf

products from titanium-bearing heavy sands, particularly in Australia and from tin dredging in Malaysia[21].

Chinas Monopolisation fo REE Supply Chain

China's current leadership position is not unique, but rather the result of a lengthy and persistent strategic effort. The "863 Program," which was established in 1986 to develop innovative technologies, featured a focus on "New Materials," which was later expanded over time. The Chinese government has consolidated its current supremacy in the area by taking a long-term approach and providing consistent assistance. China marketed rare earth minerals as a strategic commodity in the 1980s and utilised a variety of economic tactics to grow the business over the decades. Market manipulation, intellectual property theft, capital limitations, export restrictions, and subsidies are all common Chinese methods. Two further dunious approaches are being used to strengthen Chinese capabilities: utter disregard for environmental concerns and strategic purchase of foreign enterprises for their technical know-how after bankrupting them through price collapses. Moving up the value chain and collecting strategic know-how by any means necessary is a thinly veiled Chinese goal that is not unique to the rare earth market.

The storey of Magnaquench, a US company that was procured by a Chinese State-Owned consortium led by Deng Xiaoping's family member in 1997, exemplifies China's path to monopoly in REEs. Magnaquench was a Neodymium magnet industry leader with applications in data storage, automotive, and critical armament. Despite a ten-year 'Mitigating Agreement' prohibiting Magnaquench's new Chinese owners from moving production and jobs to China, the company's Neodymium-Iron-Boron magnet production line was literally duplicated in China and after the Chinese were convinced that the plant worked, the company's US production in Indiana was shut down. Magnaquench was the

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only source of Neodymium-Iron-Boron magnets in the United States, which have critical applications in armament and defence.

In 2010, China began to maintain a critical supply chain link within the country. It started to give stimulus to encourage the export of high-value downstream (finished) products and discourage the export of raw materials, in addition to consolidating the number of domestic and joint venture enterprises and imposing production and export limitations. The way the export quotas were released reflected this shift in emphasis toward completed product exports. As a result, the world, particularly Western nations, have become increasingly reliant on China to supply raw materials and/or value-added components to meet their high technological demands, both commercial and defence related.

Chinese firms have been buying rare earth minerals in other countries to ensure their domination. China Non-Ferrous Metal Mining Business purchased a majority stake in Lynas Corporation, an Australian company with one of the greatest rare earth element outputs outside of China, in 2009. In Zambia, they also bought the Baluba Mine. Recently, the Chinese have made significant investments in mining in Afghanistan and are prospecting for rare earth elements in Africa and Latin America.

China's equivalent of DARPA, the State Administration for Science, Technology, and Industry for National Defense (SASTIND), is reported to be monitoring foreign technologies, particularly those imported into China through joint ventures. China is pursuing a variety of approaches of translating, analysing, and integrating foreign technological data for industrial and military objectives.

Such is the strategic importance which China attaches to rare earths that their President Xi Jinping has made it a habit to flex muscle by visiting to Rare Earths Hub, mining sites and plants frequently. The results are clearly evident. Figure 4 – 3 below gives out the global REM production and reserves in 2018.

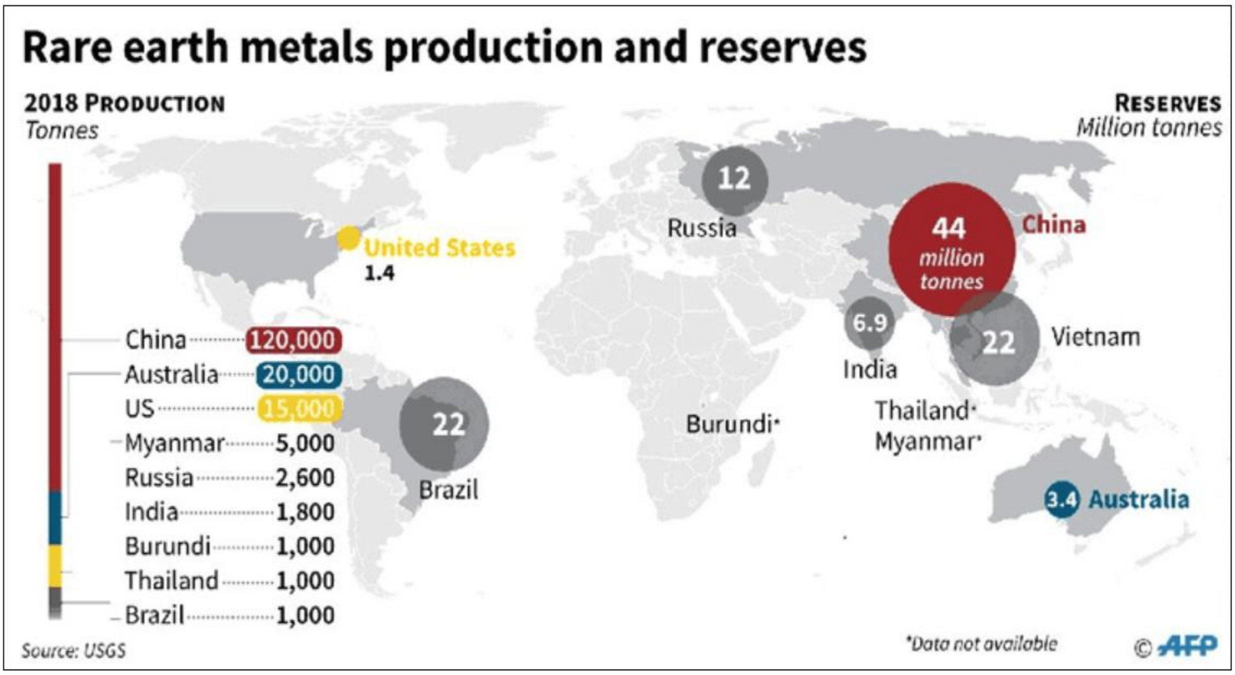

Figure 4–3. Global REM Production and Reserves in 2018[22]

China has planned and strategised to reach and stay on top of the global supply chain of REEs and it is built around multiple factors as under:-

- China recognised the strategic potential of these items early on and had the insight not to evaluate these products just on the basis of their monetary value or trade volumes.

- Planned and progressive exploitation of of rare earth minerals which available in abundance in China and the control over the resource by state owned mining companies.

- A deliberately lax regulatory framework with the government ensuring that environmental and health concerns remain in the background.

[22]Supply Chain Graphic of the Week: What is the Big Deal with Rare Earth Metals?, Supply Chain Digest, 30 May 2019. Available at https://www.scdigest.com/ontarget/19-05-30-1.php?cid=15521

- A concerted effort to incentivize research and development and the setting up of research establishments with a focus on technological breakthroughs in mining, extraction and purification of rare earths.

- Government assistance in setting up of industries on downstream processes and channelizing the products to domestic manufacturers thereby ensuring sustained domestic demand.

- Ensuring the closure of competitors' world over, by manipulating costs and making it economically unviable for others to continue operations. This would often be linked with plans to take over of the production units and shifting of the manufacturing to China.

- At the same time, China aggressively pursues procurement of REEs from foreign shores. It is already importing rare earths from Africa, Australia, India, Malaysia, Vietnam and Myanmar.

Using REEs to Further Strategic Goals – China's Interests

China does to hesitate to use strategic leverages to pursue its geopolitical aims. It has maintained a long-term vision and worked deliberately to assist the REE supply chain with a vice-like hold on extraction and processing, resulting in others' dependency. This reliance has been exploited at times, such as when China utilised their rare earth monopoly as a means of intimidating Japan over a territorial dispute. Trade conflicts between the United States and China are a current example of geopolitical sway, with China using its control over Rare Earths to browbeat the US. That dominance has abruptly highlighted Rare Earths supply chain issues, as China threatened to step up its reaction.[23]

China could use its monopoly on REE supply chains on any other country in pursuit of its strategic goals, which could have serious ramifications in the countries' manufacturing capabilities as also its electronics and strategic capacities. And hence it is this pursuit of strategic goals that Chinas continues to focus on the REE supply chains. Some of the associated advantages which China seeks to accrue are as under:-

- **Economic Gains Through Vertical Integration.** China wants to keep control of raw resources and downstream sectors in order to protect its economic interests. From mining to end-product production, China has created a formidable, integrated ecosystem in rare earths that operates as a competitive obstacle for other competitors. Sunrise technologies are rare earth-intensive, and controlling their supply chains can help China ensure its future as the world's advanced systems manufacturing hub, akin to China's existing hegemony over solar panel manufacture. China's unrivalled rare earth mining and processing capabilities benefit China's domestic industry and military while putting the rest of the globe vulnerable to Chinese diktats.

- **Civil-Military Fusion**: China has in the last century, has a stated strategy of maintaining little distinction between the civil and military. It pursues an unbridled ambition of developing a strong military in its ambition to become a global power with a strong defence force which are technologically advanced. This requires removing distinctions between civil and military industries. Translating this to the

[23] Kumar, A. (2020). How Rare Earths dictate strategic interests of India in Defence, Nuclear, Space sectors. *Defence.Capital Journal*, *September 2020*. https://defence.capital/2020/09/12/how-rare-earths-dictate-strategic-interests-of-india-in-defence-nuclear-space-sectors/

field of REEs, clearly, vertically integrated industries within a context of weak intellectual property rights and the lack of rule of law provide an attractive means of accreting strategic technologies.

- **Attempt to Limit Technological Growth of Competitors** : Because of access to and control over the entire environment, China's concentration of rare earth minerals value chains, from resource to finished product, provides a relative edge in research. China maintains a scientific edge by impeding the creation of such ecosystems in other countries. For China's worldwide ambitions, new-age technologies, particularly those relating to green energy and communications, are critical. In China's geopolitical calculus, controlling key technologies is a top priority.

- **Pursuing Domestic Manufacturing with *Make in China***. China has maintained to focus on 'New Materials,' which include permanent magnets, as one of the ten industries that would receive targeted State assistance under the Made in China 2025 project. As a result, China continues to prioritise the entire rare earth industrial ecosystem. China has a diverse industrial portfolio ranging from mining to innovative uses, all of which is backed up by a strong research system aimed toward both military and industry advancements. Rare earths will thus play an important role in China's envisioned economic future, which will be greener, smarter, and centred on high-value-added products aimed at local consumption rather than exports.

- **Destroying Competition by Market Manipulations**. China is well-known for dumping a wide range of items on the global market in order to eliminate competition. Off-the-books reserves, preserving overcapacity, export quotas, and state subsidies are all used in tandem to achieve this. India has had to implement anti-dumping taxes on a number of occasions to protect its sectors against waves of Chinese dumping, ranging from steel to chemicals. The rationale for such activities is self-evident. By periodically flooding markets with artificially low-cost products, market prices are depressed, and enterprises based in other nations become unprofitable, forcing them out of business. It is impossible to reopen or re-enter markets in industries with high capital expenditures, extended gestation periods, or highly specialised knowledge. Thus, China reaps supernormal profits in the years after dumping as it can charge inflated premiums in markets devoid of competition. The aspect is exemplified in Figure 4 – 4 below, giving out the average prices of REE per metric ton for the period from 2000 to 2018[24].

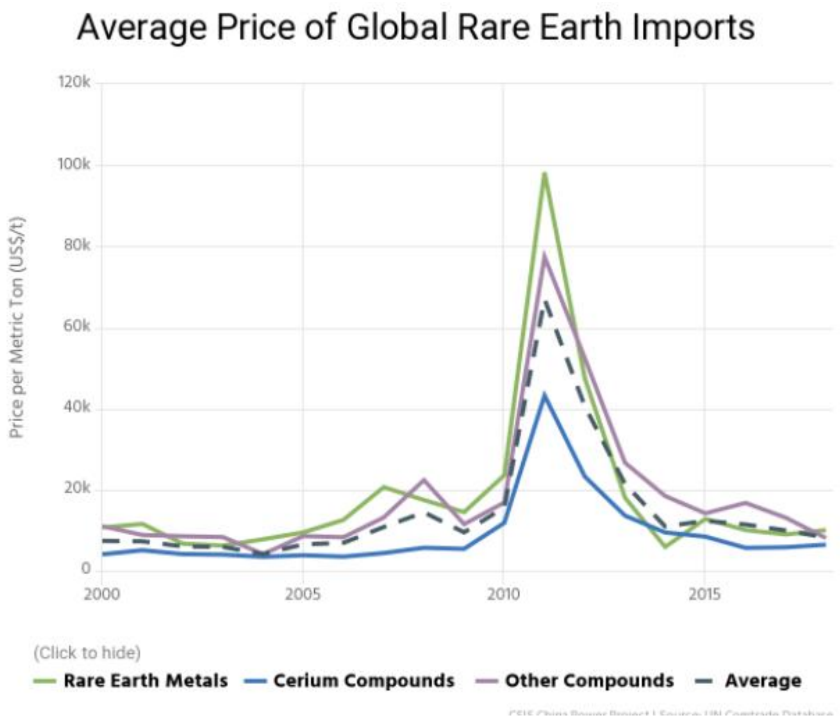

Figure 4 – 4: Average Prices of REE per metric ton for the period from 2000 to 2018

[24] Bhattacharya Deekhit, **A rare earths roadmap for India: Seeking atma nirbharta in Indian technology, published in The Firstpost , 09** January 2022, available on https://www.firstpost.com/india/a-rare-earths-roadmap-for-india-seeking-atma-nirbharta-in-indian-technology-10270901.html

- **Developing the Local Economy:** During periods of severe export limitations, such as those experienced in 2010-11, the entire world was forced to scramble for Rare Earths supply. The intentional placement of export limitations on China's rare earth shipments resulted in a 700 percent increase in global prices, hurting downstream sectors worldwide that rely on rare earths. The supply glut enabled Chinese-based companies to create crucial components like magnets at lower prices than ever before, resulting in a windfall for them. Indeed, such export limitations resulted in a favourable raw material surplus for businesses, allowing them to scale up efficiently. As a result, China has a monopoly on the world market for important rare earths items. The Chinese have three vertically integrated monopolies: mining, processing, and production, which operate as a strategic choke point for the rest of the globe while also acting as an implicit subsidy for its strategic industries. The World Trade Organization (WTO) deliberated on the case for four long years to rule against China for their export quota action, long after the crisis had passed.

- **"Unrestricted Warfare"**. In 2010, China and Japan witnessed rising diplomatic tensions due to a frictions in their territorial dispute on the Senkaku/ Diayutai islands. The dispute came to the fore when a Chinese fishing boat, often appreciated to be that of the Chinese Maritime Militia, collided with Japanese patrol boats, and was captured. China retaliated by imposing an unofficial embargo on REE exports to Japan. Later, China used the same tool for economic coercion against the US when it began to investigate Chinese firms' trade practices for illegalities. This appears part of the appreciated strategy of "unrestricted warfare"- where pressure is built on one sphere of interstate relations so as to gain concessions in another

- **Dual Use Technology**. Acquisition, absorption, and refinement of dual-use technology are critical for China (i.e. having both industrial and military uses). China has also been vigorous in its efforts in the realm of rare earths. The usage of REEs in the defence industry is well established, and by controlling the supply of important metals and alloys, China may inflict massive blows on vital defence applications while profitably using them to boost its defence manufacturing and exports.

US and Other Nations Efforts to Reduce Dependence on China

According to the study, China still controls the lion's share of the worldwide REE supply chain, accounting for more than 85% of global rare earth exports and producing roughly 70% to 75% of global REE production. The United States gets 80 percent of its rare earths from China. For the supply of these vitally crucial commodities, the European Union and Japan are completely reliant on Beijing's abundance. With about 60% of China's total REMs exports, the EU was the top purchaser of Chinese Rare Earths products in 2018. China is also the world's largest consumer of REMs. China also is the dominant REMs consumer. Japan and the US are the second and third largest consumer of Rare Earth Materials.

The fact that rare earths have a dominant supplier in China is clearly a source of concern. Countries' economic and military capabilities can be damaged while future technological advancement is stifled if rare earth sources are restricted. The world has taken a number of initiatives to address this monopoly and diversify their needs, as well as their suppliers. Some of the measures undertaken by the US and West, which also **offer clues for us in India**, are enumerated below:-

- **Government Evaluation of the Criticality**[25]. In June, the Biden administration released its 100-day assessment, "Building Resilient Supply Chains, Revitalizing American Manufacturing, and Fostering Broad-Based Growth," which included a section on strategic and crucial commodities and minerals, as well as its views on rare earths. Similarly, the UK government has commissioned a research of the use and availability of rare Earths in the defence sector. As part of their ambitious climate and technology policies, the US government and Department of Energy have prioritised rare earths as a domestic supply chain priority. In February 2021, Mr. Biden signed an executive order targeted at examining gaps in the domestic supply chains for rare earths. Similarly, the Department of Energy announced a $30 million project to explore and secure the domestic supply chain for rare earths and other key minerals in the United States.

- **Rebuilding Domestic Capabilities**. Several states in the United States, notably Wyoming, Texas, and California, are pursuing rare earth extraction projects. Several firms are working to re-establish the domestic rare earths supply chain from mine to magnet, focusing on neodymium-praseodymium in the hopes of becoming low-cost magnet producers.

- **Government Funding and Support.**

  - ❖ Few US companies, such as MP Materials and Round Top Mine, USA, have won a slew of funds and contracts from the Departments of Defence and Energy in recent years to investigate and strengthen domestic capabilities. MP Materials was awarded a $10 million Defence Department grant to assist in the construction of a

[25] Magnuson Stew , U.S. Startups Seek to Claw Back China's Share of 'Technology Minerals' Market, 07 Sep 2021, National Defence Journal, Available at https://www.nationaldefensemagazine.org/articles/2021/9/7/us-startups-seek-to-claw-back-chinas-share-of-technology-minerals-market

$200 million light rare earth refinery facility. The business anticipates the building to be operational in 2022, after breaking ground in 2021. Lynas Corporation, one of the largest rare earth processors outside of China, is another important participant in the field. The Pentagon recently awarded $30.4 million to the Australian mining business, which has a separation facility in Malaysia, to establish a Texas light rare earths processing facility and a heavy REE separation facility.[26]

- **Mitigating Environment Challenges.** While efforts are being made to expand domestic supply chains, rare earth extraction is problematic due to a mix of environmental, technical, and political factors. Many regions, including the EU, have these resources in plenty but lack the expertise to use them. The US, EU, Japan, and Australia are promoting mutually beneficial technology exchange to improve mining, processing, and disposal without disrupting ecosystems or releasing harmful byproducts into the sky. The Department of Energy's Ames Laboratory in Iowa is one of many national institutions working on programmes to replace rare earths or find new, more environmentally friendly ways to recover them.

- **Research and Development**

  ❖ There are proposals for building up a system for recycling old batteries or disc drives, while others are working on extracting rare earths from coal. The recycling of important raw materials used in the electric vehicle industry is garnering more attention and will help recycle REEs.

  ❖ Efforts are being made by scientists to recover byproducts such as copper and nickel. Another Idaho lab is investigating how potato wastewater may be used as a low-cost food supply for a bacterium that helps recycle rare earths..

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- **New Explorations.** Several countries are attempting to capitalise on the abundance of rare earths found in the United States and Europe, as well as to end China's monopoly on rare earths refining and reclaim some market share. USA Rare Earth has also purchased a mothballed magnet production facility from Hitachi Metals America Ltd. in North Carolina, which it is reconditioning with the intention of generating 2,400 tonnes of magnets per year. Furthermore, ore concentrations are being mapped and mining is being encouraged in a number of locations around the world.

Mining firms in the Western world, such as those in the United States, Australia, Canada, and other countries, have begun to reevaluate old rare earth opportunities and look for new ones. Manufacturers were also compelled to perform three things as a result of the high prices namely looking for ways to reduce the amount of rare earth elements used in each of their goods; looking for alternative materials to replace rare earth elements; and finally designing alternative products that do not require rare earth elements.

As a result of this work, the amount of rare earth materials utilised in various types of magnets has decreased, and the use of rare earth lighting goods has shifted to light-emitting diode technology. The average consumption of rare earths per unit of manufactured product in the United States has declined, but demand for additional products containing rare earth elements has enhanced.

Chapter 5 : REEs – The Indian Context

General

India is endowed with rich REE reserves, with almost seven million tonnes of REE reserve, it is appreciated to hold more than five per cent of global REE reserves which is the fifth largest in the world. India started efforts to develop domestic REE production capacity in 1950s, when it established the Indian Rare Earth Ltd (IREL) for mining and processing of REE. Nonetheless, in spite of rich reserves and an early start, India has not been able to develop the REE industry and its share in global REE market has remained negligible. Consequently, for years, REE production in India remained stagnant at around 2,000 tonnes before increasing to 4,215 tonnes in 2018-19[27].

Despite having the world's fifth largest REE reserves, India imports the majority of the REMs it requires from China due to its poor manufacturing capabilities. Despite having more ore than the United States, India only extracted three thousand tonnes of REEs in 2020, compared to 38,000 tonnes in the United States. Furthermore, because India's REE supply chain is limited or rather confined to upstream processing, whatever little REE we produce falls very low in the value chain (extraction and purification). The more profitable activities related to rare earths are related to downstream industries that use them to manufacture profitable finished goods, such as consumer electronics. This becomes significant with the increasing risk of China restricting the exports of these products to India.

India is a minor player in global supply chains, seen mostly as a supplier of low-cost minerals. Despite its early start in REE exploration and pursuit, only minimal progress has been made in a few upstream processes, while downstream processes remain unaddressed.

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[27] Baskar B, A 'Rare' Opportunity for India, The Hindu, BusinessLine, Jan 16, 2022, Available at https://www.thehindubusinessline.com/opinion/a-rare-opportunity-for-india/article64863510.ece

India's rare earth business is inextricably related to the country's atomic energy programme. IREL(India) Limited, formerly Indian Rare Earths Limited, the Department of Atomic Energy, and, in some situations, the Defence Research and Development Organization, are in charge of the domestic industry.

Post the directive of the Prime Minister to pursue Make - in - India in 2014, all ministries prepared an actionable plan for its implementation with the primary objective of making India a global manufacturing hub, by encouraging both domestic as well as foreign OEMs to manufacture their products within the country. It is a huge national project aimed at encouraging investment, encouraging innovation, and constructing world-class manufacturing infrastructure. The plan placed a strong premium on the development and growth of the domestic aerospace and defence industry. REEs and REE-related final products, not unexpectedly, play a critical part in this national effort because they are essential to all present and future manufacturing operations. This is evident from Figure 5- 1 below which gives their use in almost all arenas of manufacturing which Indian Industry hopes to pursue.

Figure 5 – 1 : Application of REE –Manufacturing and *Aatmanirbharta* Context[28]

[28] Rare Earth Minerals - The India Scenario, DECCAN CHRONICLE, Jul 21, 2016, available at https://www.deccanchronicle.com/science/science/210716/rare-earth-minerals-the-india-scenario.html

Given the use of REEs in every sphere of manufacturing, their use and hence availability, will play a central role to the mission of transforming India into a manufacturing hub. Besides, as India's manufacturing industry (hi-tech devices, heavy machinery and medical equipment) is burgeoning, demand for these strategic infrequent metals will energize significantly in the foreseeable future. Similarly, in the sphere of defence manufacturing, the use of REEs has been well established and as India embarks on it ambitious Aatmanirbhar Bharat Programme, the need of these rare earths will only increase.

Tracing the Growth of Rare Earth Industry in India

The rare earth sector in India has had a unique start and has altered objectives in response to changing circumstances. In India, the Department of Atomic Energy has been in charge of producing REEs and commercially viable derivatives. The rare earth sector was viewed as a sideline that grew out of India's nuclear power programme. Rare earth compounds were produced as a byproduct of the program's primary goal of producing fuel-grade Uranium and Thorium. India has a declared three stage nuclear power program which was formulated by Homi Bhabha in 1950. It aimed to meet the country's long-term power needs by utilising Uranium and Thorium resources found in the sands of coastal peninsular India's beaches. Because of its large reserves, thorium is a particularly appealing prospect for India. India now has the world's largest thorium reserves. The Atomic Minerals Directorate for Exploration and Research of the Department of Atomic Energy has conducted a systematic search for nuclear fuel sources around the country. Due to low global Uranium costs, the viability of Uranium as a nuclear fuel is currently more appealing. The 2008 Indo-US Nuclear deal has also ensured the continued availability of Uranium as a fuel for the Indian power plants and thrown up more options for the evolving nuclear power program. With the relative lower demand for Thorium, the related rare earth industry in India has been perpetually under the shadow of the atomic industry and failed to take off as an independent product line. REE demand in India has been muted, and it has been confined to the low-cost and low-end of the product spectrum. Ilmenite, rutile, zircon, monazite, sillimanite, and garnet are the most common minerals found in beach sand deposits in India. Rare earth traces can be found in monazite, zircon, and garnet, but monazite is the predominant source. Other beach sand minerals have a wide range of uses, including atomic energy. The Indian rare earth industry eventually changed its focus to other minerals that could be mined from beach sands and sold around the world.

Indian Rare Earths Limited (IREL). In the 1920s, the first plants to separate Thorium Oxide from monazite were built in Manavalakurichi, Tamil Nadu, and Chavara, Kerala. India was a pioneer in the export of ilmenite (used in paints) and monazite from the 1920s to roughly 1947. The newly independent Indian government recognised the importance of the mineral and imposed a ban on monazite exports in 1947. Indian Rare Earths Ltd was founded in August 1950 as a Private Limited Company under the Indian Companies Act of 1913. The corporation was given the job of establishing thorium and uranium processing units for monazite extraction. Mixed rare earth chloride was produced in the process. The first plant under the newly formed company was setup in Alwaye in Kerala. The technology was provided by Rhodia, France, which was a technology leader in the sector. In Trombay, Maharashtra, a factory was built to convert thorium concentrate into thorium nitrate and thorium oxide. The Indian Rare Earths Ltd was a government-owned company that operated under the Department of Atomic Energy before being nationalised in 1963. It also took over the management of all of the country's relevant processing plants. To meet domestic demand and export to the worldwide market, IREL gradually increased production of the heavy minerals ilmenite, rutile, zircon, monazite, and rare earth chlorides. In addition, IREL began to add value to its products by separating mixed earth chlorides into distinct rare earth salts. The IREL established the Rare Earths Division (RED) in Udyogamandal, Kerala, to drive this product line.

IREL – Changed Trajectory. Since the 1970s, the rare earth industry has benefited from the discovery of a variety of novel applications. Leading rare earth manufacturers such as Rhodia in France and Molycorp in the United States, as well as a number of Chinese firms, reaped the benefits of the rising demand. By the 1990s, Chinese corporations had established a global monopoly through a strategy of pricing manipulation and shutting out competition, as described in the preceding chapters. Because of the low costs of Chinese products, the Rare Earths of IREL product line became unprofitable, and the business gradually diversified its portfolio with government assistance. The primary purpose of IREL was to produce atomic fuel and REEs, however it started to produce (for export), the easier to extract beach sand minerals like Ilmenite and Zircon. It added Samarium oxide used in the production of Samarium-Cobalt permanent magnets and Cerium Oxide used in the polishing industry. The technology for extraction of Samarium oxide was indigenously developed by Bhabha Atomic Research Centre (BARC). Recognizing the emerging potential of Neodymium in the manufacture of Neodymium-Iron-Boron permanent magnets, the RED added a plant for the manufacture of Praseodymium-Yttrium-Neodymium-Cerium (PRYNCE) in 1998.

Foreign Collaboration. After the global rare earth crisis in 2011-12, India took a big stride ahead when IREL formed a joint venture with Toyota Tsusho in Andhra Pradesh to produce REEs including neodymium, lanthanum, and cerium. However, due to administrative and implementation issues, the collaboration with Japan on REEs has not achieved the intended outcomes. Toyotsu Rare Earths India, a Toyota Tsusho company, buys some rare earths from IREL and exports refined metals to Japan, the United States, and Europe. Current rare earth product line of IREL includes Cerium Carbonate (used in metallurgy, glass, ceramics and phosphors), Lanthanum Carbonate (used as a fuel cracking catalyst, glass, , alloys, batteries) and Neodymium-Praseodymium Oxalate (used for production of rare earth magnets).

REE Resources in India

In India, REE prospects and occurrences are distributed in the states of North Eeastern Region, Bihar, Jharkhand, Rajasthan, Odisha, Andhra Pradesh, Tamil Nadu, Chhattisgarh, Uttar Pradesh, Kerala, Karnataka, Himachal Pradesh, Maharashtra, Madhya Pradesh, Haryana, Gujarat, and Jammu & Kashmir in the order of extent of geologically potential areas. Figure 5 -2 below gives out these areas on a map. Based on the study and distribution of several prospects and nearly 145 occurrences of REE & RM, its genetic association, geologic set-up, a total of 58,626 sqkm area has been delineated to be potential for REE occurrences in the country. However, with progressive exploration and advances in geoscience, it is expected to extend the search space for exploration of REE-RM in India

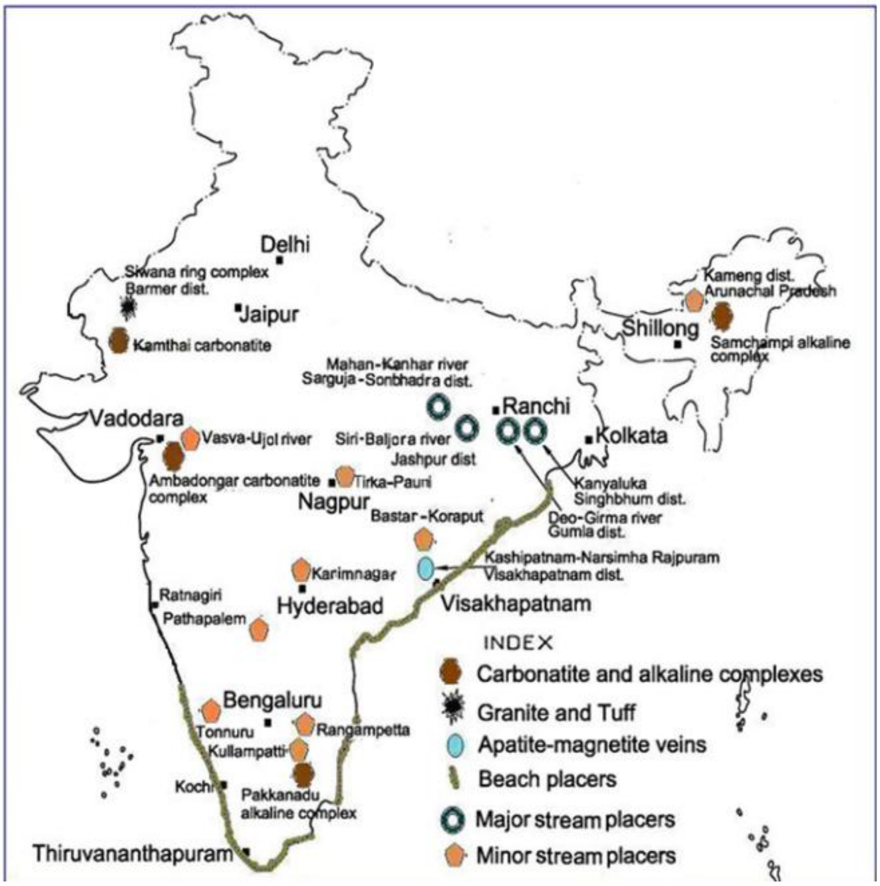

Figure 5 – 2 : Geographical Locations of Selected REE Deposits/Occurrences of India[29]

[29] Singh, Y. (2020). *Rare Earth Element Resources: Indian Context (Society of Earth Scientists Series)* (1st ed. 2020 ed.). Springer.

The primary resource of rare earths in India are the widely available beach sands. Rare earth resources have also been identified in inland stream sands, carbonite rocks, hydro thermal veins, natural sources and industrial sources.

- **Beach Sands**. Monazite bearing beach sands were first discovered in India in 1909 by Schomberg, a German Scientist.[30] From 1950, the Atomic Minerals Directorate for Exploration and Research of the Department of Atomic Energy, Government of India has carried out extensive exploratory activities across the country. Almost 2100 km out of the 6000 km coastline of India has been identified with relevant rare earth deposits. Apart from monazite, rare earth minerals such as garnet and zircon and sillimanite have been discovered.

Table 5 – 1 : Monazite Resources in India[31]

State	Resources (in Million Tons)
Andhra Pradesh	3.72
Gujrat	0.003
Jharkhand	0.22
Kerala	1.90
Maharashtra	0.002
Odisha	2.41
Tamil Nadu	2.46
West Bengal	1.22
Total All India	11.935

(Source : Indian Bureau of Mines 2018)

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31 Rare Earths September, 2020, Indian Minerals Yearbook 2019 (Part- III : Mineral Reviews), Government of India Ministry of Mines Indian Bureau of Mines, available at https://ibm.gov.in/writereaddata/files/10012020172151RareEarth_2019_AR.pdf

- **Inland Stream Deposits**. Along various inland streams in India, rare earth mineral deposits such as xenotime and monazite can be found. In comparison to the more abundant beach sands, inland stream placers have a higher concentration of heavy rare earth elements. Deposits have been reported in Jharkhand, West Bengal, Chhattisgarh, Uttar Pradesh, Odisha, Maharashtra, Gujrat, Telangana, Karnataka, Tamil Nadu, Arunachal Pradesh, and Meghalaya. IREL established a recovery factory in Kunkuri, Chhattisgarh, in the 1980s. Inland Stream placers are significant due to the higher concentrations of the Heavy REEs.

- **Carbonatites**. Igneous rocks are carbonatites. A few carbonatite complexes in India show promise for REE recovery. The Amba Dongar and Panwad-Kawant complexes in Chota Udaipur, Rajasthan, the Kamthai complex in Barmer, Rajasthan, the Samchampi and Barpung complexes in Assam, the Samalpatti and Pakkabadu-Mulakkadu complex in Tamil Nadu, and the Beldih-Kutni complex in West Bengal are among the notable complexes. Light rare earth elements are found in higher concentrations in Indian carbonatites. There are a number of other carbonatite complexes that have yet to be investigated for rare earth content, and the area has enormous promise.

- **Peralkaline-Alkaline Felsic Rocks**. Felsic Rocks are igneous rocks which typically are rich in feldspar and free quartz. Granite is a common Felsic Rock. The exploration of Felsic rocks for possible rare earth concentrations has been under progress in India and certain positive results have been found. Some of the deposits exist in Siwana-Nakora in Barmer Rajastan, Dhorio-Jamnagar-Junagarh-Mehsana in Gujrat, Nanded-Yeotmal in Maharashtra, Prakasham in Andhra Pradesh, Dongargarh in Chattisgarh and Pala Lahara and Kumarkunti in Odisha.

- **Hydrothermal Veins.** Veins arise when a preexisting crack or fissure inside a host rock is filled with fresh mineral material. Because they are formed by hot weather, these deposits are usually hydrothermal. Rare earth element-bearing hydrothermal deposits can be found in eastern India in the Shingbhum-South Purulia West Bengal area. REE deposits can also be found in portions of Western India, notably Rajasthan. South India's deposits are found in the Gogi and Bhima basins of Karnataka, as well as the Vishakhapatnam area of Andhra Pradesh. REE deposits are discovered in close proximity to uranium and sulphide ore resources.

- **Pegmatites.** Pegmatites are igneous rocks that are formed during the final stages of magma crystallization. The contain large crystal formations. In India Pegmatite rich regions of Chhattisgarh, Odisha, Bihar Andhra Pradesh and Karnataka are known for mica mining. The recovery of REE is feasible as a byproduct of the mica mining industry. However, with the fall in demand of sheet mica across the world, the industry has seen a downturn.

- **Other Natural Sources**. In India, preliminary research has been carried out on the possible sources of REEs in a variety of natural sources. Quartz minerals, iron oxide hydrothermal complexes, phosphatic sediments, bauxite, laterite, sea bottom, and ion adsorption clays are only a few examples. These potential sources must be investigated further in order to be exploited.

Secondary Sources. The rise of rare earth elements as a critical resource, combined with rising demand to fulfil the needs of the electronics, electric vehicle, and green energy industries, has prompted research into the possibility of recovering these elements from industrial process outputs. Fly ash, bauxite residue, mining tailings, metallurgical slags, and waste water are examples of these leftovers. In addition, when REE-bearing items, such as permanent magnets and phosphor lamps, approach the end of their useful lives, direct recycling and REE-bearing products, such as permanent magnets and phosphor lamps, are being examined. Countries that do not have a natural resource base can benefit from such sources. In India, exploration of secondary sources is at a nascent stage, however the potential is evident. India is known to have a large re-cycling industry, albeit which is under the cloud of environmental and human exploitation.

Current Indian Initiatives on REE

India was one of the most important destinations for rare earths in the 1950s. India has roughly 6.9 million metric tonnes of rare earths, with substantial footprints of rare elements like Lanthanum, Cerium, Praseodymium, Neodymium, Samarium, Gadolinium, Yttrium, and Dysprosium. Despite having huge reserves, India's rare earth sector has been underutilised due to a variety of factors, including a lack of government emphasis and mining experience and industry.

Indian Rare Earths Limited (IREL) and Uranium Extraction Division of Bhabha Atomic Research Centre, holds control over the country's rare earth and responsible for mining and valorization of these Rare Earth metals. Realising the strategic importance of Rare Earths, several steps have been taken to limit our vulnerability and secure our future interests. Some of these are listed below.

- Given the inter ministerial scope of REE in India, Niti Aayog has brought the sector under its review ambit. The minerals vertical is responsible for building a strategic and long-term policy for the mines and minerals sector. This division also provides a platform for the resolution of inter-sectoral and inter-departmental issues and impediments in the growth of the minerals sector. An expert committee was constituted by NITI Aayog to build a roadmap towards developing self-reliance in Rare Earths by addressing the restrictive trade practices and harnessing the availability of domestic and global resources[32]. The committee submitted its report, and its recommendations are being taken up through sub-committees details of which are as under:-

[32] Annual Report 2020-21. Niti Aayog, Government of India. Report available at https://www.niti.gov.in/sites/default/files/2021-02/Annual-Report2020-2021-English_0.pdf

❖ Committee for Overseas Acquisition of Rare Earths and Agency to Promote RE.

❖ Committee for Augmenting and Updating RE Resources.

❖ Committee for Establishing Technologies for RE Extraction from Fly Ash and Red Mud.

❖ Committee for Strengthening Recycling of e-Waste.

❖ Committee for Establishing the Prospects of RE Conversion to Magnets.

- A **Rare Earth Permanent Magnet (REPM) plant** is being setup by IREL at Visakhapatnam for production of samarium-cobalt magnets for use by DAE, Defence and Space sectors. The plant is to be constructed in the premises of the Bhabha Atomic Research Centre Vizag campus. The plant will implement indigenous technology developed by BARC and DRDO (Defence Material Research Laboratory Hyderabad). Apart from the strategic use, the domestic demand for the upscale rare earth products is expected to multiply due to the aggressive electric vehicles policy and policy on green energy as promulgated by the government.
- IREL is also in the process of setting up a **Rare Earth and Titanium Theme Park** at Bhopal for demonstrating the technologies being developed by BARC in the rare earth value chain. Pilot-scale plants would be established in the theme park to attract entrepreneurs to adopt and put the technology to commercial scale, leading to a viable value chain.
- IREL is also **augmenting the capacity** of its Rare Earth producing units at Odisha and Kerala.[33] In response to Parliamentary questions, the government has indicated that monazite extracted rare earth products are being treated as strategic products and monazite has been shifted to threshold value 'zero' in schedule 'A' of

[33] Indian Minerals Yearbook 2019 (Part- III : Minerals Reviews) 58th Edition Rare Earths (Advance Release) Government of India, Ministry of Mines, Indian Bureau of Mines

the Atomic Minerals Concession Rules (ACMR) 2016[34]. Mining of beach sands has been further regulated under the IREL/Department of Atomic Energy. Mine leases given to private players earlier have also been cancelled.

- Defence Metallurgical Research Laboratory (DMRL) has **developed the technology for making three different classes of rare earth magnets**[35]; SmCo5, Sm2Co17 and Nd-Fe-B (Samarium-Cobalt and Neodymium-Iron-Boron). Different shapes and sizes of rare earth magnets for defence and aerospace applications have been made, assembled in the devices and tested. This has been the result of extensive Research and Development efforts. BARC is also in an advanced stage of developing a cost-effective technology to build Sm-Co (Samarium–Cobalt) magnets. As of 2018, IREL has a project underway to set up a 3,000-kg Sm-Co magnets manufacturing facility.

- In an effort towards ‘Make in India’ and thereby totally indigenise the production from mineral to magnet, a **licensing agreement for Transfer of Technology (ToT)** has been signed between DRDO and IREL. IREL plans to reduce the rare earth salts it sources from the beach sand by acquiring the technology established by BARC and use this indigenous raw material to produce magnets in large scale by adopting the technologies developed by DMRL. The technology involves compaction of powder in high magnetic field followed by sintering/annealing under vacuum and inert atmosphere. Several system laboratories of DRDO (DRDL, RCI, SSPL, MTRDC, NPOL, NSTL, CVRDE), ISRO (VSSC and LPSC) and DAE (BARC and IGCAR) have used magnets developed at DMRL for strategic applications. The technology offers great promise considering the abundant reserves of rare earth minerals in India. A **joint venture** of Vikram

[34] Government of India Department of Atomic Enargy Lok Sabha unstarred question No 2879 to be answered on 10 Jul 2019 Illegal mining of Sand Minerals 2879 Shri NK Premachandran
[35] https://www.drdo.gov.in/rare-earth-permanent-magnets

Sarabhai Space Centre (VSSC) and Defence Metallurgical Research Laboratory (DMRL) was also formed to **develop permanent magnets** for use on Indian rockets and satellites.

- With respect to **Policy**, an amendment to Atomic Mineral Concession Rules (AMCR) 2016 now stipulates reserving all Beach Sand Mines (BSM) deposits containing more than 0.75 per cent monazite in the Total Heavy Minerals (THM) for Government-owned corporations. As per the Foreign Trade Policy, 2015-2020 and the effective policy on export and import, the import of ores and concentrates of rare-earth metals and of rare-earth oxides including rutile sand are permitted 'freely'. Export of Beach Sand Minerals is to be canalised through IREL only[36].
- The major agencies involved in **exploration activities** in the country related to REMs are the Atomic Minerals Division (AMD) of the Department of Atomic Energy (DAE) and the Geological Survey of India (GSI). Based on the study and distribution of several prospects and nearly 145 occurrences of REE & RM, its genetic association, geologic set-up, a total of 58,626 sq. km area has been delineated to be potential for REE occurrences in the country[37]. In general, GSI carried out about 14 mineral exploration projects annually from 2012 to 2017. More thrust was given for REE search in the country from the year 2017. More than 20 exploration projects were mounted to enhance the chance of discovery of REE zones in the country from the year 2017 to 2020[38]. (figure 5 -3 below illustrates the same)

[36] Rare Earths September, 2020, Indian Minerals Yearbook 2019 (Part- III : Mineral Reviews), Government of India Ministry of Mines Indian Bureau of Mines, available at https://ibm.gov.in/writereaddata/files/10012020172151RareEarth_2019_AR.pdf

[37] STRATEGIC PLAN FOR ENHANCING REE EXPLORATION IN INDIA, November 2020, November 2020, Geological Survey of India, Ministry of Mines, Govt of India, Available at https://www.amd.gov.in/WriteReadData/userfiles/file/GSI_AMD_Vision_Document_REE.pdf

[38] - do -

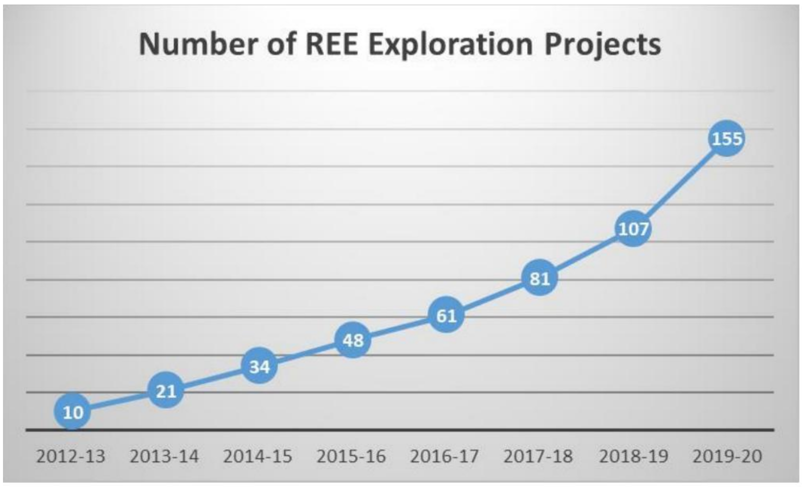


Figure 5 – 3 : Cumulative Graph of Number of Mineral Exploration Projects by GSI since 2012

- To enhance its reach, India is tying up **exploration and extraction** of REE on **foreign soil**. Three Indian state-owned organisations — National Aluminum Company Limited (NALCO), Hindustan Copper Limited (HCL) and Minerals Exploration Corporation Limited (MECL) — have established a **joint venture** named **Khanij Bidesh India Limited** to explore, acquire and refine strategic rare earth metals primarily in **Latin American** countries.[39]

Challenges

Few inferences on what ails our exploiting our potential arise from the aforementioned examination of historical linkages, expansion, and current features of the REE business in India. With the Indian Rare Earths Limited (IREL), which has been in operation since 1949 and has decades of industry expertise, India was clearly one of the pioneers in the rare earth sector. Despite this, we import about 95% of our requirements from China and are reliant on the rest of the globe to supply our needs, which is critical for the government's Make in India plan to succeed. These problems and weaknesses in REE development and manufacturing self-sufficiency are obvious, and in order to remedy our

[39] Kumar, A. (2020). How Rare Earths dictate strategic interests of India in Defence, Nuclear, Space sectors. *Defence.Capital Journal*, *September 2020*. https://defence.capital/2020/09/12/how-rare-earths-dictate-strategic-interests-of-india-in-defence-nuclear-space-sectors/

manufacturing self-sufficiency, we must first analyse the flaws in our current system. Salient aspects of the same, as analysed, are enumerated below. A study of these is imperative to ascertain the measures we as a nation need to undertake for the optimum utilisation of our potential in REEs.

- **Policy Structure**. A number of aspects of India's current underperformance are a direct result of policy difficulties. In rare earths mining, IREL, the PSU, has a monopoly. In light of India's nuclear energy programme, which espouses the long-term goal of using Thorium as a nuclear fuel, rare earth mining falls within the purview of the Department of Atomic Energy (DAE). Thorium is currently mined from beach sands, which also include other rare earth minerals. As a result, the Atomic Energy Act of 1962 has classified these mineral-rich beach sands as "prescribed substances." The Atomic Mineral Concession Rules, 2016, which follow the 2015 amendments to the Mines and Minerals (Development and Regulation) Act, have strengthened these restrictions. When taken together, these two acts show that most rare materials, such as Beryllium, Lithium, Titanium, and Niobium, have been placed under the DAE's jurisdiction, which enhances government monopolies and exacerbates pre-existing bottlenecks.
- Lack of **Privatisation**. The restricted scope of future privatisation and operationalisation of market forces in pursuit of this strategically essential commodity flows directly from the ibit. Despite rumours that the government is considering partial privatisation, it is believed that the situation will not improve considerably given the current policy limits. In actuality, because to a lack of motivation to create intricate and costly processing facilities, IREL exports low-value rare earth ores, often to Chinese processors. One-off projects, such as the forthcoming Samarium-Cobalt Permanent Magnet factory in Visakhapatnam, may

not be a viable replacement for a lab-to-product ecosystem, which must be focused on strategic needs and commercialization.

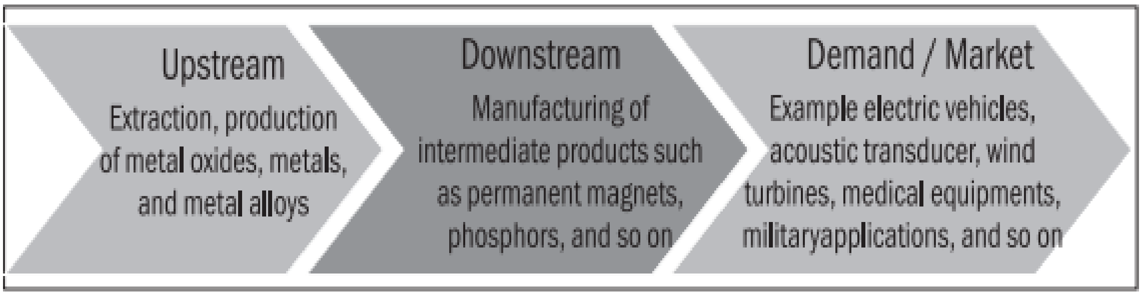
- **Inadequate Exploitation of Indigenous Expertise**. The existing policy structure lumps all rare earths into a single domain, namely atomic energy. As a result, the rare earths ecosystem becomes isolated from other R&D ecosystems such as electronics or metallurgy, compromising strategic research and undermining the interdisciplinary and integrative nature of modern, solution-oriented research. In the same way, other agencies such as the Geological Survey of India (GSI), Mineral Exploration Corporation Limited (MECL), and Atomic Minerals Directorate for Exploration and Research (AMD) operate in overlapping areas but have different visions and declared methodologies.

- **Lack of Incentives**. Despite its monopoly, IREL's principal source of revenue is not rare earths; instead, it makes the majority of its money from activities involving other minerals found in beach sands, such as Ilmenite, Sillimanite, and Zircon. In light of the valued requirements of domestic industry, this leaves IREL with low to no incentives to explore Rare Earths. IREL has also confined itself to the extraction of Rear Earths, with no plans to refine the metals. As a result, India continues to be a low-cost exporter of rare earth oxides rather than higher-value-added products, putting India's strategic needs at the mercy of countries like China, which process and sell completed products with significant profit margins. Value addition is the crux of not just strategic self-reliance but to move up Global Value Chains, whereby India can supply intermediate and finished products instead of exporting cheap raw material.

- **Working in Silos**. The many components of India's rare earth ecosystems appear to be disconnected. The DAE and the Bhabha Atomic Research Centre (BARC) dominate rare earths research. The DMRL is used by the DRDO to do research, although there is little or no engagement with the scientific community through academic institutes such as IITs. There appears to be no coordination amongst research stakeholders and private industry R&D is almost non-existent.

- **Absence of REE Ecosystem**. India clearly lacks an ecosystem where meaningful research may take place, and ultimately be translated into goods, due to its exporting of ores and insufficient R&D or processing of REE. While the policies implemented are to blame, the truth remains that there is no institutionally coordinated focus on rare earths, and just a few isolated efforts functioning in isolation. Between miners and processors on one end and end-users on the other, a similar break-in relationship occurs. The availability and demand of rare earth materials, as well as their associated costs, necessitate rigorous study and information flow. Mining and manufacturing ecosystems must have a constant discussion about the quality and amount of needs in order to develop a cohesive strategy. This interchange of expectations is a prerequisite for coordinated research and production efforts, which are required by any emerging industrial ecosystem. While the Niti Aayog and the Department of Atomic Energy (DAE) monitor Rare Earths in India at the highest levels, there appears to be no broad strategic direction in place where a coordinated, unified effort can be made in conjunction with end-user requirements.

- **The Value Chain Paradox**. India is typically thought of as a low-value mineral supplier. What India now lacks is the capacity and expertise to carry out valorization activities in order to integrate into the global value chain for strategic products, which provides a strategic edge in addition to economic benefits. India sells REE oxides at a low cost and imports refined value added REE products at a higher cost due to a lack of knowledge in the downstream sector. A good example is the supply of low-cost raw REE chlorides to the Japanese company TERI, which in turn supplies refined strategic minerals to Europe, the United States, and Korea, resulting in economic and strategic benefits. Though India has made significant headway, a downstream project of putting up a 3000 Kg REPM plant in Vishakapatnam has arisen from a collaboration between Bhabha Atomic Research Centre (BARC) and IREL for the production of high-value Samarium Cobalt (Sm-Co) magnets. This is an excellent example of economic and strategic exploitation of indigenous resources through collaboration between a scientific institute (BARC) and a commercial enterprise (IREL). The tenets of achieving valorization through closing the supply and demand value chain are met by this paradigm.See Figure 5 – 4 below.



<u>Figure 5 – 4 : Supply & Demand Chain of REE</u>

- **Regulations and Licenses.** REE mining continues to be governed by a complex and rigorous regulatory environment, with clearances being costly and time-consuming. The 2016 Atomic Minerals Concessions Rules effectively nationalised beach sands by lowering threshold values for a variety of minerals. Private enterprises were forced out of the scene, while IREL's grasp on Beach Sands and Mozanites was strengthened. Exploration and mining of REEs have also been hampered by long periods of bureaucratic delay, such as environmental concerns and approvals.
- **No Strategic Reserves.** Despite being designated as a strategic material, India lacks stated domestic stocks for the majority of crucial commodities, leaving it

vulnerable to external supplies, particularly from China. Such reserves are necessary to protect against price variations as well as protect against external pressures.

- **Lack of Strategic Vision**. The example of collaborative linkages between BARC and IREL for production of Samarium-Cobalt (Sm-Co) magnets is not visible across the spectrum of policy /decision making and is not the result of a long term strategic vision or policy direction. There are several documents which provide statistical details and broad policy statements related to mines and minerals. Official publications of Ministries/ Organizations/ Corporations associated with mines, minerals and rare earths viz National Mineral Policy of India-2019 by Ministry of Mines[40], Strategy Plan for Ministry of Mines[41], 69th Annual Report 2018-19 by IREL (India) Ltd[42], Indian Minerals Year Book-2019 Volume III by Indian Bureau of Mines (IBM) [43] have been referred. In addition, NITI Aayog vision statement 'Strategy for New India @ 75' of November 2018, as well as annual reports was also examined to ascertain the National vision/ approach towards crucial minerals. It is observed that there is no stated policy which provides a policy/ strategic vision on this vital issue. A single comprehensive policy covering this vital aspect of India's stated *Atmanirbhar* vision is conspicuous by its absence.

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[40] National Mineral Policy of India-2019. Available at https://mines.gov.in/writereaddata/Content/NMP12032019.pdf

[41] Strategy Plan for Ministry of Mines. Available at https://mines.gov.in/writereaddata/UploadFile/Strategic%20Plan%20Document.pdf

[42] Annual Report 2018-19 by IREL(India) Ltd, Available at http://www.irel.co.in/documents/20126/114997/IREL+AR+18-19+Webfile.pdf/d61cbaae-fddb-f274-a2af-c3596ebc3f96?t=1592994698374

[43] Indian Minerals Year Book-2019, Indian Bureau of Mines. Available: https://ibm.gov.in/index.php?c=pages&m=index&id=1473

Chapter 6 : REEs and *Aatmanirbharta* in Defence Manufacturing

General

India has been the world's second largest importer of major arms during 2014-18, as per the Stockholm International Peace Research Institute (SIPRI). According to estimates, with the current trends, the Indian Armed Forces are projected to spend around $130 billion in capital procurement in the next five years. The Government of India nevertheless, has set course on a path of self reliance or *aatmanirbharta* for defence manufacture.

While the exact figures with respect to usage of REEs in the Defence Sector are not available, it is widely known that despite their being central to all defence equipment, the requirement of REEs for the domestic defence industry has been low as most of the items have been of import nature. Presently Indian imports of rare earths is driven by the nascent electric vehicles (EV) industry and several other uses like mobile phones and other electronics are imported as parts and assembled in India. The total consumption of REEs during the year 2015 -16 was 31.9 Tons and it increased nearly six times to 1867.9 tons in the year 2016 – 17 (Table 6 -1 and 6 -2 below refers). As we further pursue indigenisation in the manufacturing sector, this demand and consumption is going to grow manifold.

Table 6 – 1 : Consumption of Rare Earths, 2013-14 to 2015-16 (By Industries) [44]

(In tonnes)

Industry	2013-14	2014-15	2015-16
All Industries	**31.18**	**30.49**	**31.9**
Paints Driers/Pigments	-	-	-
Cinema Arc Carbon	-	-	-
TV Colour picture tube	0.93	1.59	0.9
Glass/Optical polishing	0.09	0.09	0.09
Glassware decolouring	3.9	2.25	3.9
R&D and others	26.26	26.56	27.01

[44] Indian Minerals Yearbook 2017 (Part- III : Mineral Reviews) 56th Edition, Government of India, Ministry of Mines, March 2018, Available at https://ibm.gov.in/writereaddata/files/03202018145809Rare%20Earths_AR_2017.pdf

Table 6 – 2 : Consumption of Rare Earths, 2016-17 (By Industries) [45]

(In tonnes)

Industry	2016-17	2017-18	2018-19
All Industries	**1867.90**	-	-
Rare Earth Compounds Producers	1862.0	-	-
Paints Driers/Pigments	-	-	-
Cinema Arc Carbon	-	-	-
TV Colour picture tube	1.0	-	-
Glass/Optical polishing	1.0	-	-
Glassware decolouring	0.4	-	-
R&D and others	3.0	-	-

At the same time imports of Rare Earth Metals in 2018-19 increased to 643.41 tonnes as compared to 492.41 tonnes in 2017-18. Of these, China (97%), USA (2%) were the main suppliers to India[46]. This clearly indicates India's dependence on China for its REE needs. While the current Indian demand (2017 figures as above) for REEs is driven by the Green Energy appliances like Electric Cars and Scooters, electronics, hybrids, glass and medical industry; there is likely to be an enhanced demand in the defence industry which seeks to manufacture most of the requirements of arms and military hardware in house. The predominant demand would be for the Samarium Cobalt (SmCo), Neodymium Iron Boron (NdFeB) magnets and rare earth alloys.

REEs and Defence Indigenisation Plans. It has been clearly established that India has increased the use of REEs in pursuit of manufacturing across a wide spectrum of activities, It is quite evident that sectors such as defence production, green technology, automotives etc have huge prospects for growth in India which quintessentially require REEs as indispensable input materials. China remains India's biggest source of REEs and nearly 98% of the downstream products are imported from China. While the breakdown of

[45] Indian Minerals Yearbook 2019 (Part- III : Mineral Reviews) 58th Edition, Government of India, Ministry of Mines, September 2020, Available at https://ibm.gov.in/writereaddata/files/10012020172151RareEarth_2019_AR.pdf

[46] Indian Minerals Yearbook 2019 (Part- III : Mineral Reviews) 58th Edition, Government of India, Ministry of Mines, September 2020, Available at https://ibm.gov.in/writereaddata/files/10012020172151RareEarth_2019_AR.pdf

their usage across the defence sector is not available, it can well be concluded that the stated national design of achieving self-reliance can be achieved in true earnestness only if the complete value chain is indigenized/ secured. Focusing specifically on the defence sector, it is pertinent to analyse as to where we stand in terms of REEs and our current and projected defence manufacturing needs? These can be examined under four aspects namely:-

- What are the stated government policy decisions towards achieving self reliance in the defence sector with the specific point of view of REEs
- Current usage of REEs in defence manufacture,
- Examination of Government initiatives on Self Reliance in Defence Sector from REE application
- The type of REEs which are required in India's planned trajectory of self reliance in defence manufacturing and their availability.

These aspects will be examined in the succeeding paras.

Government Policy for Pursuing Self Reliance in Defence Sector

Indigenisation in defence is critical to national security. It ensures uninterrupted availability of the weapon system and its spares at the time of crisis with little or no leverages available to external powers. In the past, emergency procurements had to be resorted to during the Kargil war and more recently during the recent standoff with China. Such procurements can be both financially prohibitively expensive and also may be at a cost of strategic autonomy wherein the government is forced to agree to certain 'conditions' which the seller country may apply, to permit the sales.

Indigenisation of the Defence Industry. The Indigenisation of Indian Defence Sector can be understood as the capability to develop and produce defence equipment within the country for the purpose of achieving self-reliance and reducing the burden of imports. It aims to design, develop and lead the production of state of the art sensors, weapon systems, platforms and allied equipment for our Defence Forces. Towards this, several steps have been undertaken. Some of the steps which are directly related to the topic of the research are appended below.

- **Positive Indigenisation List**. Possibly the most important directive towards the effort has been the diktat to put a ban on foreign procurements. The Ministry of Defence has promulgated two lists of weapon systems and components which have been identified for import embargo in a tight time bound schedule. The first import embargo list of 101 items was issued on 09 August 2020[47] and a supplementary list of 108 items was issued on 31 May 2021[48]. The list comprises complex weapon systems, sensors, simulators, ammunition, integrated platforms like helicopters, next generation corvettes, air borne early warning and control (AEW&C) systems, high performance engines, radars, missile weapon systems and many more such items to fulfil the requirements of Indian Armed Forces.

- **Indigenisation List on Assemblies / Sub Assemblies and Components.** As a follow up to the two lists above, on 27 Dec 2021, The Department of Defence Production in Ministry of Defence, gave out a fresh list of 351 sub-systems and components whose imports won't be allowed under a staggered timeline beginning December 2022. Details of these components, sub-systems, assemblies and sub-assemblies have been notified on the Government's Srijan portal[49]. These are currently imported by the Defence Public Sector Undertakings (DPSUs). It was the third list released by the Ministry in just 16 months and comes as part of the

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[47] Press Information Bureau, Ministry of Defence, 09 AUG 2020, Import embargo on 101 items beyond given timelines to boost indigenisation of defence production, Available at https://www.pib.gov.in/PressReleasePage.aspx?PRID=1644570

[48] Press Information Bureau, Ministry of Defence, 31 MAY 2021 MoD notifies 'Second Positive Indigenisation List' of 108 items to promote self-reliance & defence exports, Available at https://pib.gov.in/PressReleasePage.aspx?PRID=1723148

[49] List is available at https://srijandefence.gov.in/DPSU%20Indigenization%20List.pdf

government's overall aim to make India a manufacturing hub of military platforms and equipment.

- **Defence Exports**. The defence ministry has set a goal of a $25 billion turnover in defence manufacturing in the next five years that include an export target of $5 billion in military hardware.

- **Foreign Direct Investments (FDI)**. As part of efforts to reduce dependency on import of military equipment and promote the Make in India campaign, the Government has approved the increase in the FDI limit in Defence production to 74 per cent through the automatic route and 100 per cent through the Government approval route under certain conditions.

- **Budgetary Allocations**. Separate allocations have been made in the Defence budget for buying indigenously-made military hardware. The Defence Acquisition Procedure is also being increasingly modified to favour Make in India.

REE Use in Defence Manufacture in India

Uses of REEs in defence manufacturing sector has been deliberated upon in Chapter 3 ibid. They are now being used directly or indirectly in all forms of defence manufacture and are being used for miniaturisation, precision, equipment strength and also for all forms of displays.

In India, the maximum progress has been made in the form of magnets. Rare earths have simply changed the widespread electro-mechanical industry by being used in magnets. Rare earth ferromagnets offer a wide range of uses and have dominated the industry's demand for permanent magnets that are strong, light, and durable. These are currently the most widely used of all defence equipment Magnetic alloys including iron, cobalt, or both are routinely made with neodymium and samarium. Figure 6 – 1 below gives an array of equipment which uses REE magnets and it clearly covers the entire spectrum of defence equipment.

Figure 6 – 1 : Array of Equipment Using REE Magnets[50]

As evident, one of the more important uses of REEs in the defence sector is the manufacture of permanent magnets of which there are two types – samarium cobalt (SmCo) and Neodymium Iron Boron (NdFeB). Neodymium magnets are gradually replacing Samarium Cobalt magnets in most applications especially where high temperatures are not involved, as they have two to three times the magnetic energy of the samarium cobalt magnets and are primarily made of iron, which is substantially cheaper than cobalt. These properties translate into a similar or improved performance while having a smaller physical footprint and are thus highly suitable for applications involving miniaturisation.

Dr Mayank Dwivedi of DRDO in his interview stated that there has been substantial progress in India's research in the field of magnets for defence application. While the exact contours of the progress made and specifics of ongoing research cannot be shared being confidential, it can be stated that the country has progressed substantially in the field[51]. While answering Unstarred Question No 2762 in the Lok Sabha on 11 Mar 2020, Dr

[50] Compendium+on+Rare+Earths+and+Heavy+Minerals+Book.pdf
IREL Handbook
[51] Interview of Dr Mayank Dwivedi by the author in DRDO on 10 Feb 22

Jitendra Singh, minister of State for Personnel, Public Grievances & Pensions and PMO stated that India is setting up a Rare Earth Permanent Magnet (REPM) plant for production of Samarium Cobalt magnets for use by DAE, Defence and space sectors. The plant based on technology developed by BARC and Defence Metallurgical Research Laboratory (DMRL) is being set up in BARC campus, Vizag[52]. (The entire reply is at **Annexure 1)**

DMRL has established process technologies for making three different classes of rare earth magnets namely SmCo5, Sm2Co17 and Nd-Fe-B wherein different shapes and sizes of rare earth magnets for defence and aerospace applications have been made, assembled in the devices and tested. In an effort to 'Make in India' and thereby totally indigenise the production from mineral to magnet, a licensing agreement for ToT has been signed between DRDO and IREL[53]. IREL plans to reduce the rare earth salts it sources from the beach sand by acquiring the technology established by BARC and use this indigenous raw material to produce magnets in large scale by adopting the technologies developed by DMRL.

Examination of Government Initiatives on Self Reliance in Defence Sector: The REE Context

The policy measures announced by the government in its pursuit of self reliance in the defence sector have been given above. An analysis of the ibid policy measures are elucidated below.

- There are 209 items in the positive indigenisation list. These items comprise complex weapon systems, sensors, simulators, ammunition, integrated platforms like helicopters, next generation corvettes, air borne early warning and control

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[52] Department of Atomic Energy, Government of India, Lok Sabha, Unstarrred Question No 2762 on 11 March 2020. Available at https://dae.gov.in/writereaddata/lsusq2762.PDF

[53] Defence Research and Development Organisation (DRDO), Rare Earth Permanent Magnets, https://www.drdo.gov.in/rare-earth-permanent-magnets

(AEW&C) systems, high performance engines, radars, missile weapon system which cater to the requirements of Indian Armed Forces. A close scrutiny of the list indicates that almost all the systems require REEs in some form or the other. However, out of the 209 items identified, up to 84 systems are likely to use REEs or part of the rare earth value chain in the manufacturing process. The list of these items is given at **Appendix C.**

- Simultaneous to the promulgation of the import embargo list, the Department of Defence Production (DDP) has also generated import substitution lists through the respective Defence Public Sector Undertakings (DPSUs). An extract of the import substitution list with a possible ramification on the use of rare earths is at **Appendix D** attached. The lists are continuously under revision. The list comprises items relatively easy for domestic production and offers opportunities for Make in India in Defence albeit is silent on REE related items which could be used in aggregation/ assembly.
- The Defence Sector aims to achieve a 5 billion USD export target and become a net exporter of defence equipment by 2025. The policy also targets Rs 1.75 lakh crore in annual turnover. In order to promote Atma Nirbhar Bharat, a separate budget of Rs 52000 Crore has been set aside for domestic vendors. In addition, there is an increase in FDI limit to 74 percent, promotion of defence corridors in Tamil Nadu and Uttar Pradesh, the Strategic Partnership Model, the liberalised Industrial licensing scheme, the creation of the single window Defence Investor Cell at the Ministry and the Corporatisation of Ordnance Factories Board. These initiatives are good opportunities to create an ecosystem for the processing and production of REM related products. The infusion of funds and incentives through FDI will offer a good route for creation of infrastructure for dual use technology items especially in products related to REEs.

- The 209 items earmarked for import embargo the timelines to achieve domestic production are extremely ambitious (considering past procurement and indigenisation trends), ranging from one to five years. It is evident from the laid down time lines that the program is initially aimed at system and product aggregation instead of ground up domestic production which incorporates production of components and materials. Already, provisions have been created to review exemptions to the list. In the event the domestic industry is not able to supply equipment in the stipulated time-frame, quantity, or where there are inadequacies in the equipment affecting safety of troops, or in case of any other technical issues, such as no valid response to a Request For Proposal (RFP), etc. specific cases for import could be taken up to meet immediate requirement, based on the recommendations of Defence Indigenisation Committee (DIC)[54].

- *Hence the Atma Nirbhar Bharat in Defence Industry is not likely to significantly affect the import basket of REEs by Indian vendors in the short term. In the next five years, in order to achieve the laid down import embargo targets, Indian vendors are likely to perform the role of system aggregators and integrators while importing key components which are not produced within the country. Hence the requirement of REEs is likely to be met through the imported sources for the next five years to a decade. In the long term however, the success of the Atma Nirbhar Bharat program will actually depend upon and hopefully lead to the generation of component manufacture in India and the setting up of downstream industries in the rare earth value chain. This would lead to creation of value chains for items other*

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[54] **Peri Dinakar , MoD makes exemption for import of items notified in 'Positive Indigenisation Lists', The Hindu, 02 December 2021, available at https://www.thehindu.com/news/national/mod-makes-exemption-for-import-of-items-notified-in-positive-indigenisation-lists/article37813923.ece**

than defence also and would ultimately lead to strategic autonomy and lesser reliance on the global supply chains.

<u>Forecasting Type of REEs Required in India's Self Reliance in Defence Sector and their Availability</u>

There is no public statement on the type and quantity of REEs essential for Indian Defence Manufacturing. While several strategic commentators have classified REEs as strategic to India's security requirements, there is little or no articulation on the type and quantity of REEs required. Furthermore, while the consumption of REEs in India has been given out in Table 6 – 2 above, the type and quantity of REEs used by the Indian Defence Industry, both private and public sector, is not available in the open domain.

When faced with the challenge of Chinese monopolisation of REEs, there were concerns expressed in the US over US acquisition of rare earth materials given that China had cut its rare earth exports and appeared to be restricting the world's access to rare earths. With a nearsubstantial US dependence on China for rare earth elements, the US Congress directed a study on the rare earth supply chain issues and develop a plan to address their vulnerabilities. The study report of 2013 titled '***Rare Earth Elements in National Defense: Background, Oversight Issues, and Options for Congress'***[55], offers good insight into the various types of REEs used in the defence manufacturing sector. The report highlights the type of REEs critical to defence manufacturing and the pictures (Figure 6 – 2 to 6 – 5), highlighting the same are given below.

[55] Valerie Bailey Grasso, Rare Earth Elements in National Defense: Background, Oversight Issues, and Options for Congress, Congressional Research Service, December 23, 2013 Available at https://sgp.fas.org/crs/natsec/R41744.pdf

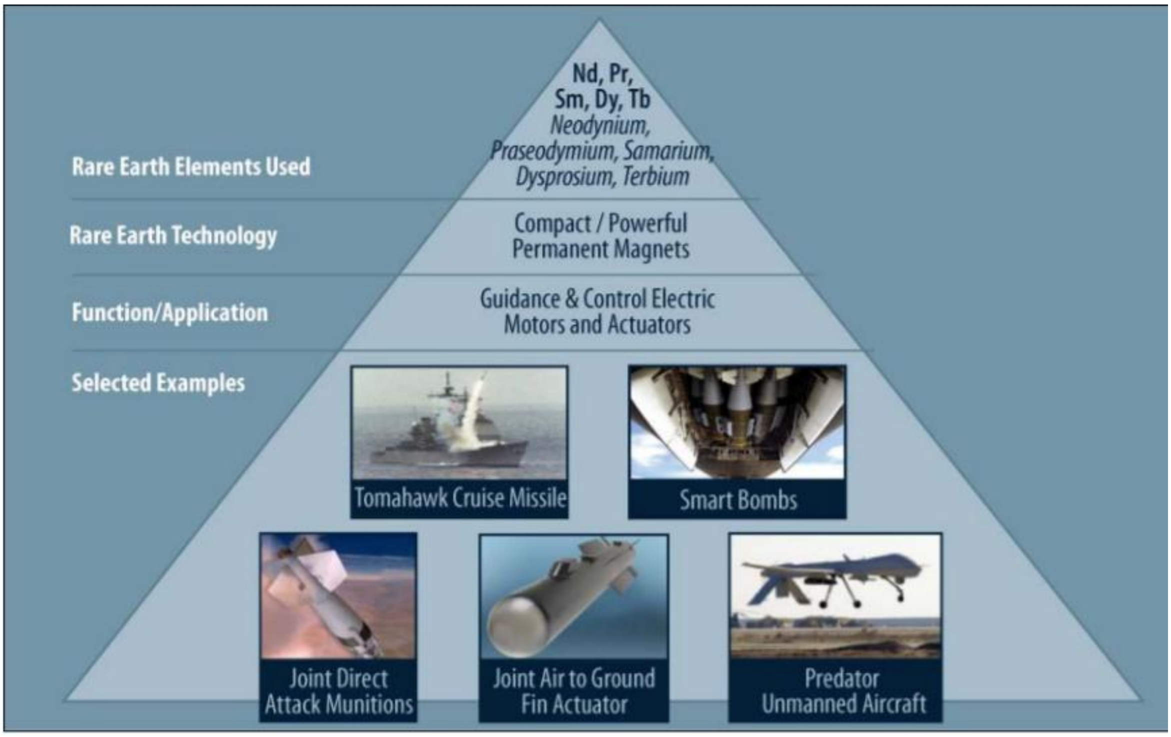

Figure 6 – 2: Rare Earth Elements in Guidance and Control Systems[56]

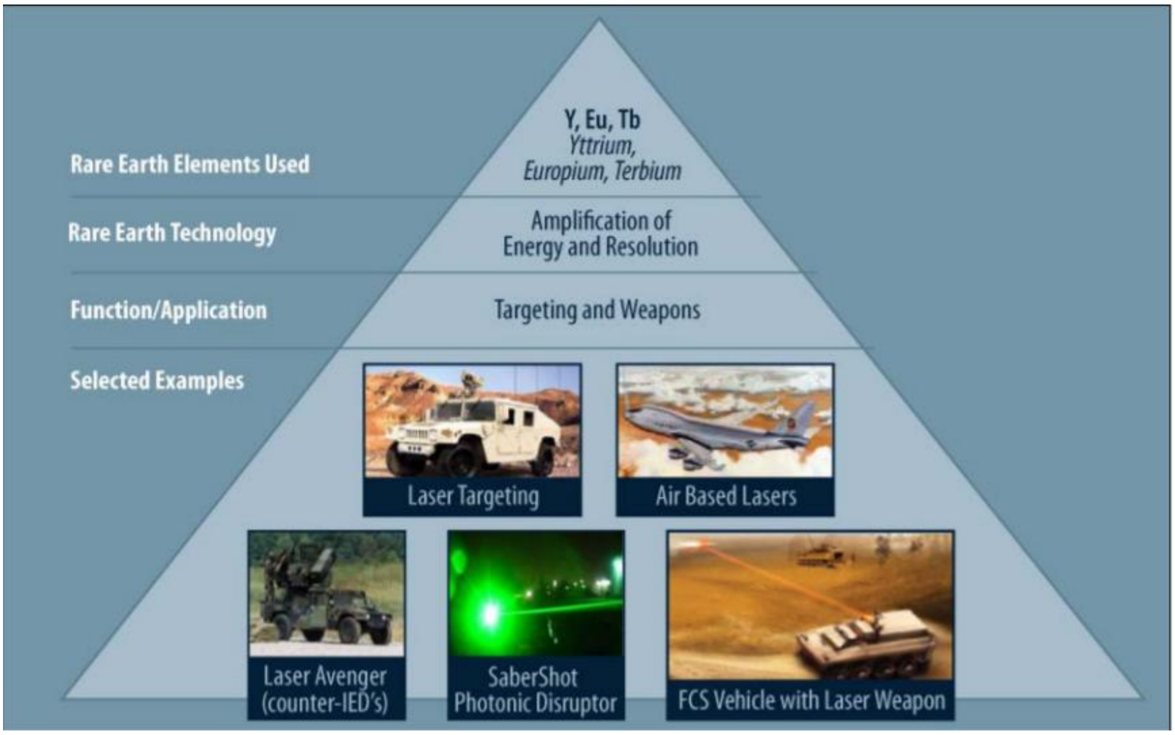

Figure 6 – 3: Rare Earth Elements in Targeting and Weapon Systems[57]

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[56] Valerie Bailey Grasso, Rare Earth Elements in National Defense: Background, Oversight Issues, and Options for Congress, Congressional Research Service, December 23, 2013 Available at https://sgp.fas.org/crs/natsec/R41744.pdf

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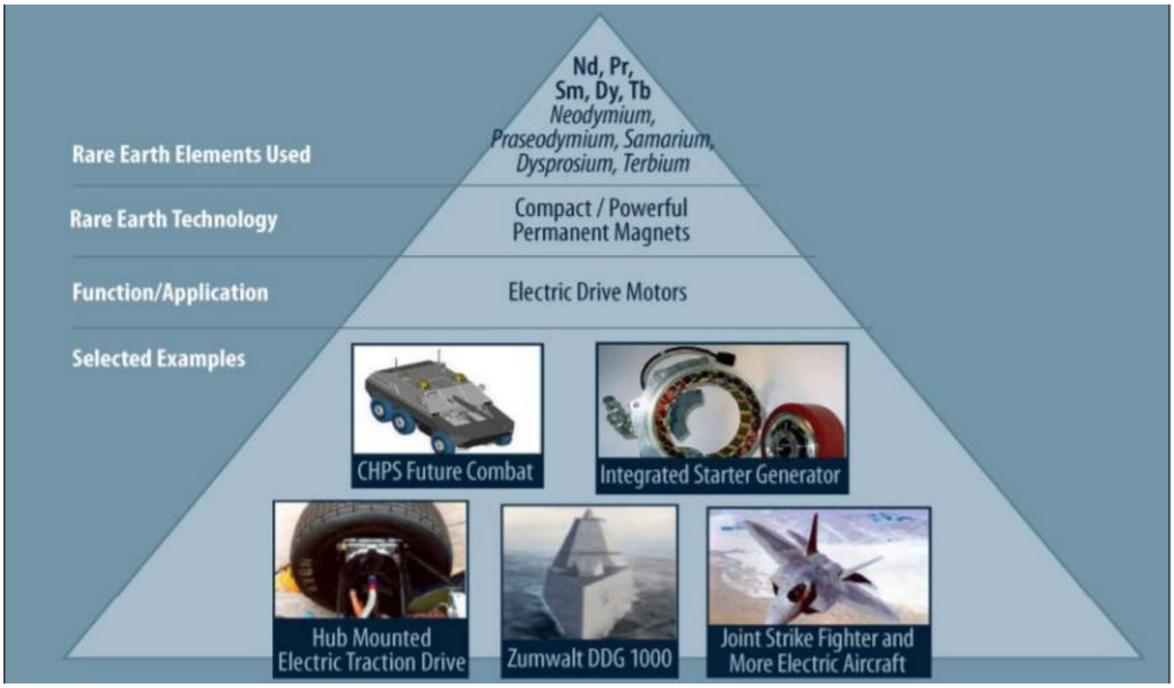

Figure 6 – 4: Rare Earth Elements in Electric Motors[58]

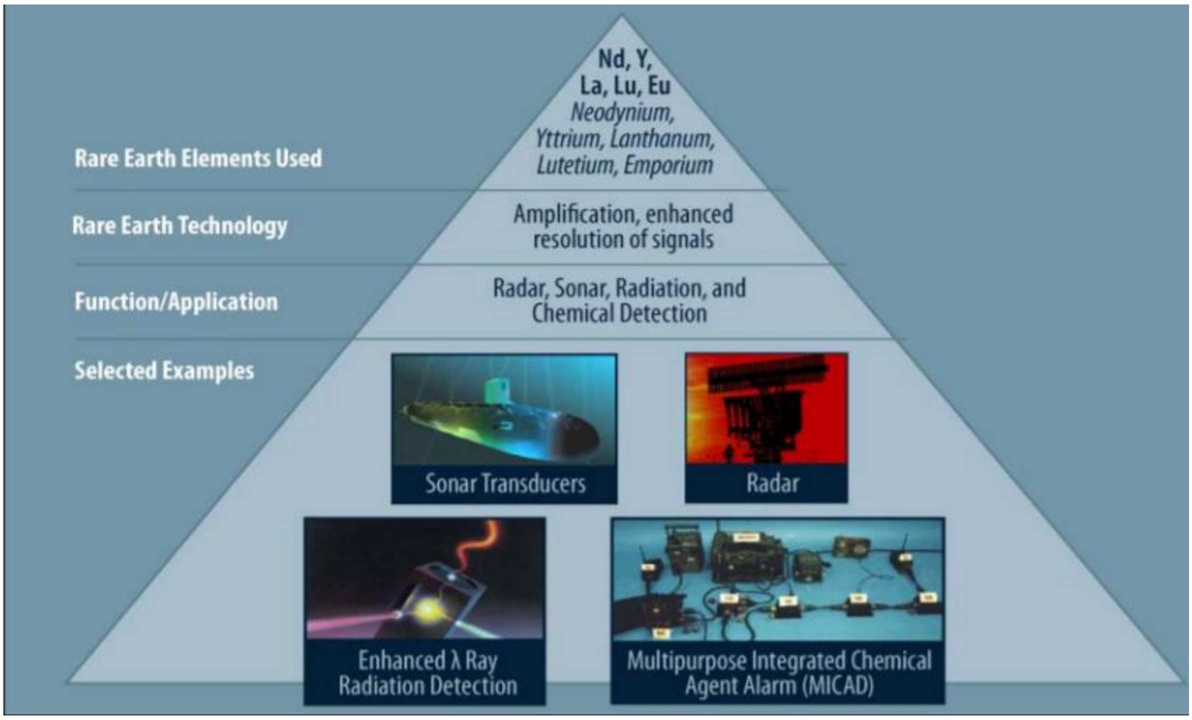

Figure 6 – 5: Rare Earth Elements and Communication[59]

A similar study was undertaken in the UK and the report '***Critical Raw Materials and UK Defence Acquisition: The Case of the Rare Earth Elements***', submitted in 2016[60]

[58] -do-
[59] - do -

highlighted that Overall, the uses of REE in UK defence are in the manufacture of Fin Actuators in missile guidance and control systems, super alloys and coatings that are used to protect engine parts in gas turbine and jet engines or as a defensive measure against certain types of radiation, disk drive motors installed in computer equipment inside armoured vehicles, aircraft, missile systems and C3I (Command, Control, Communications and Intelligence) systems, rechargable batteries and fuel cells, lasers for rangefinders, mine detection, friend-or-foe interrogators, underwater mines and mine countermeasure, phosphors that are used in TVs and computer displays (for example, aircraft avionic systems), satellite communications, radar systems and sonar systems, multi-spectral targeting systems etc. These sectors use mainly oxides of cerium (45%), lanthanum (39%) and yttrium (8%), while the remainder is made up of dysprosium, gadolinium, neodymium and praseodymium. Developing market sectors include ceramics, magnets, battery alloys and high technology related to the defence and aerospace industry. These sectors tend to use the oxides of neodymium (41%), lanthanum (16%), cerium (15%), praseodymium (14%), yttrium (10%), dysprosium (2.5%), gadolinium (1%) and samarium (1%).

Examining the Type and Quantity of REEs Required for Defence Sector. These reports of the US and UK. offers good clues on REEs which will be critical to India's *aatmanirbharta* programme in defence sector.

- To summarize, the REEs most needed in the defence industry have been illustrated above and include dysprosium, erbium, europium, gadolinium, neodymium, praseodymium, and yttrium.
- India has an established relative abundance of Light Rare Earths: elements from Lanthanum to Samarium. Currently, Monazite is the one of the major sources

[60] Powell-Turner, Julieanna & Antill, Peter. (2016). Critical Raw Materials and UK Defence Acquisition: The Case of the Rare Earth Elements. 10.4018/978-1-5225-0599-0.ch008.

of light REMs that constitute around 60 per cent of Monazite composition. It also comprises oxides of Thorium, Uranium, Silicon, Aluminum, Titanium and Zirconium.

- India has the fifth largest deposits of REE in the world with known reserves of 6,900 mt. The deposits mainly comprise of Monazite mineral which falls in the category of LREE which constitutes elements such as Lanthanum(La), Praseodymium(Pr), Neodymium(Nd), Samarium(Sm), and some deposits of Bastnaesite mineral (LREE) comprising of Cerium(Ce), La, Nd, Sm and Europium(Eu).

- In addition, Monazite is the only deposit that contains Thorium as a constituent. India holds over 10 million tonnes of deposits of Monazite. For now, Japan imports Monazite from India for Dysprosium, which is used in NdFeB (Neodymium) magnets for superior qualities.

- ***Hence, except for Yytrium, there is a fair amount of adequacy of ore in terms of REEs***.

- *India has proven its expertise in the extraction and processing of rare earths from mineral ores. However, due to limited expertise in the downstream sector, India exports its upstream products (that is, rare-earth oxides) and imports rare earth containing intermediate products required for various applications*.

- *India does not possess the technology or rather the plants to separate materials like Dysprosium and Thorium from Monazite and supplying highly pure Dysprosium to international market, while Thorium could be used for India's future nuclear energy mission for reducing carbon footprints.*

- *Besides Monazite, India is also working to establish the production of Zirconium and Titanium-based alloy, as India owns large reserves of Titanium and Zirconium in the form of beach sand minerals (Table 6- 3). Zicornium sponge is* *used for building of nuclear grade Zicornium alloy that is employed for making nuclear fuel assemblies, while high grade Titanium alloy is a critical ingredient which would need to be used in various vital military systems including missiles, aircrafts, warships and submarines for high strength and exceptionally light weight.*

Table 6 - 3 : Titanium Ore Reserves in India in 2015

Table NO. 5.65 : Reserves/Resources of Titanium as on 1.4.2015
(By Grades / States)

(In tonnes)

	Reserves				Remaining Resources								Total Resources
	Proved	Probable		Total	Feasibility	Pre-feasibility		Measured	Indicated	Inferred	Reconnaissance	Total	
	STD111	STD121	STD122	(A)	STD211	STD221	STD222	STD331	STD332	STD333	STD334	(B)	(A+B)
All India : Total	**13552280**	**0**	**868436**	**14420716**	**19311670**	**31365**	**117416**	**2198668**	**52373956**	**325171754**	**0**	**399204829**	**413625545**
By Grades													
Ilmenite	12980540	0	832970	13813510	17294168	0	0	1242214	41973121	280193087	0	340702590	354516100
Rutile	558825	0	35466	594291	1099060	0	0	4460	3425835	9007516	0	13536871	14131162
Leucoxene	0	0	0	0	624903	0	0	1994	0	341949	0	968846	968846
Anatase	0	0	0	0	0	0	0	0	3345000	0	0	3345000	3345000
Titaniferous Magnetite	0	0	0	0	293539	0	117416	950000	3630000	35629202	0	40620157	40620157
Not Known	12915	0	0	12915	0	31365	0	0	0	0	0	31365	44280
By States													
Andhra Pradesh	0	0	0	0	0	31365	0	0	0	76702509	0	76733874	76733874
Jharkahand	0	0	0	0	0	0	0	0	3630000	755000	0	4385000	4385000
Karnataka	0	0	0	0	0	0	0	0	0	13862094	0	13862094	13862094
Kerala	0	0	0	0	18995076	0	0	0	22668876	87048716	0	128712668	128712668
Maharashtra	0	0	0	0	293539	0	117416	1172214	846000	1997108	0	4426277	4426277
Meghalaya	0	0	0	0	0	0	0	0	3345000	0	0	3345000	3345000
Odisha	12851284	0	868436	13719720	0	0	0	950000	2196933	48612331	0	51759264	65478984
Tamil Nadu	700996	0	0	700996	23055	0	0	76454	19687147	93914996	0	113701652	114402648
West Bengal	0	0	0	0	0	0	0	0	0	2279000	0	2279000	2279000

figures rounded off

(Source. India Bureau of Mines[61])

Exact Demand for REEs. The next obvious question which arises in the study is to determine the quantities of REEs required in defence manufacture. Since it has been established that India possesses the requisite raw materials of REEs (less Yytrium).

- As regards the exact amount of REEs being utilised by the DPSUs and other defence industry, the nodal officer in HQ IDS said that the details have been collated but cannot be shared being classified in nature. He said that the assessed future requirements had also been arrived at but were not based on the *aatmanirbharta*

[61] India Bureau of Mines National Mineral Inventory: An overview as on 01.04.2015. **Chapter 5. Reserves / Resources as on 01.04.2015 - Mineral**
Available at https://ibm.gov.in/writereaddata/files/08072017115147Titanium.pdf

programme and recent policy decisions announced by the government with respect to the positive indigenisation lists.[62]

- The amount of REE used in the acquisition of assessed Indian defence capability is appreciated to be relatively small given our great reliance on imports but will increase progressively. It will however mirror that of the wider economy. REE's are used due to the benefits they confer on electronic and electrical systems, which include enhanced speed, performance efficiency, agility and thermal stability.
- Hence, the demand for REE is known as a 'derived' demand. As such, it differs from the demand for consumer goods, as it's not really the minerals themselves that are being demanded, but the goods which have them as part of their manufacturing process. This demand therefore, is strongly contingent upon the demand for the final products that have REE in their components, such as flat screen TVs, cars, smart phones etc and in the defence sector, items like monitors for displays, magnets in various parts and motors, strengthened metal structures etc.

[62] Interview of HQ IDS nodal officer by the author in HQ IDS on 05 Feb 22

Chapter 7 : Securing the Rare Earth Supply Chain – Findings and Recommendations

General

The importance of REE in the entire spectrum of manufacturing sector has been adequately highlighted in preceding Chapters. Over-reliance on China for supply of these critical minerals and its attendant shortcoming has also been adequately elucidated in the foregoing argument. In addition to 2008-10 artificial supply restrictions and Senkaku incident of 2010, the recent events of US-China trade stand-off wherein to create a narrative and exacerbate fear, President Xi Jinping visited the largest REE production unit and the Chinese National Development & Reform Commission (NDRC) released a statement to strengthen its control on export of rare earths[63], is testimonial of China's treacherous intentions of using rare earths as geopolitical tool. When viewed against the basic tenets for sustained economic growth, it is evident that the existing over-reliance on China for supply of critical minerals like REE remains a persistent source of vulnerability and anxiety, and hence needs to be mitigated.

Key Findings.

The key findings which have emerged through the process of the research bring to fore the following facts:-

- **Uniqueness of REEs**. REEs are not as rare as the configured name and are found in fair amount of abundance in the earths crust. The most commonly found rare earth minerals are Bastnasite (carbonate ore), Monazite (phosphate ore) and rare earth adsorption clays. The deposits of bastnasite and monazite are spread across the world with India having sizeable monazite reserves. Rare earth clays are primarily

[63] Schmid Marc, "Rare Earths in the Trade Dispute Between the US and China: A Déjà Vu" , November 2019, Intereconomics, Volume 54, 2019 · Number 6. 378.

found in China. The extraction process of Bastnasite and monazite is a complex and resource intensive process. The purification of the concentrates is carried out in purification plants. The method of purification employed depends on the type of the mineral and the content of rare earth in the mineral (quantity and type of metal). Certain rare earth ores like monazite have traces of radioactive elements like Thorium, hence the purification process involves the steps towards removal of radio activity. Rare earths are characterised by high density, high melting point, high conductivity and high thermal conductance which gives them properties which make them central to large number of emerging technologies.

- **Utility of REE**. REE are essential material inputs for host of contemporary technology products in the entire range of manufacturing sector viz electronics, ceramics, glass industry, Green/ Clean technology including Electric Vehicles (EV), and strategic sectors like military and space. They are also central to all defence applications and are being used for their specific characteristic. The specific areas of Defence Industry which use REEs are night vision devices, laser range finders, guidance systems for missiles, communication systems, fiber optic, permanent magnets with enhanced strength which are stable at high temperatures, stealth technology and precision guided ammunition.

- **Chinas Monopolisation of Supply Chain and Associated Vulnerability**. Presently, China enjoys a near complete dominance over the REE supplies with approximately 80% control over the market. Accordingly, India is mainly dependent on China for supply of REE which accounts over 90 % of total requirement. Kindled by earlier minor disruptions, particularly the Senkaku incident of September 2010 which highlighted the imminent supply chain vulnerabilities of rare earth minerals emanating from singular dominance of China and has brought the issue to strategic limelight. US and several other countries have started addressing the issue and undertaken measures to secure their supply chains with respect to REEs. The models offer good insight into options available to India to ensure strategic independence in the availability of this critical mineral.

- **REE Availability in India** India has the fifth largest deposits of REEs in the world with almost seven million tonnes of reserves yet it imports much of its goods from China. Our production capacity is severely limited, and whatever REE we do produce is very low in the value chain because India mostly does upstream processing (extraction and purification), and India is a minor player in global supply chains, viewed primarily as a source of low-cost ore. Observing global trends, the demand for REEs wall witness a annual growth rate of 8 to 10 % (Figure 7 – 1 below refers).

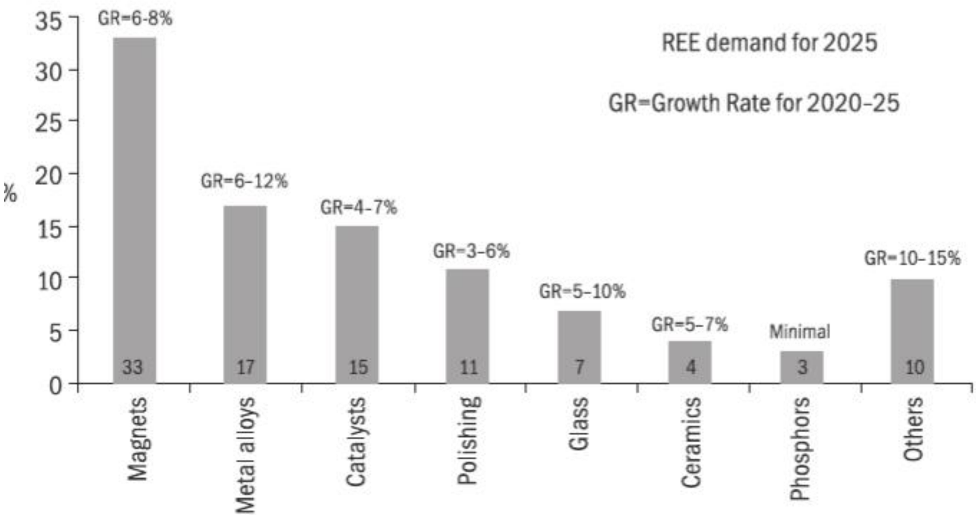

Figure 7 - 1 : Forecast of Global REE Market 2020 - 25[64]

- **Pursuing the REE Growth in India** Indian Rare Earths Limited (IREL) and Uranium Extraction Division of Bhabha Atomic Research Centre, holds control India's rare earth and are responsible for mining and valorization of these Rare Earth metals. Rare Earths have been identified as a strategic sector and yet, there is no

64 Kumar, Parveen & Bharadwaj, Mridula. (2018). Indian Rare Earth Industry: Need and Opportunity for Revival and Growth.

central authority which is pursuing the policies with respect to Rare Earths and measures to ensure strategic autonomy in this sphere. Notwithstanding, Niti Aayog has brought the sector under its review ambit and several measures and studies instituted to pursue them. The minerals vertical of Nitit Aayog is responsible for building a strategic and long-term policy. Several documents provide statistical details and broad policy statements related to mines and minerals which include a 'Strategic Plan For Enhancing REE Exploration In India'; separate sections for REE in the Annual Reports on the websites for India Bureau of Mines, DAE, Atomic Minerals Directorate, IREL and DMRL, contain information with respect to the developments on REEs. Yet, there appears to be a void of a central agency to coordinate the issues.

- **Recent Developments to Address India's REE Challenge**. There have been a slew of activities undertaken to rise up to the domestic requirements of REEs in India both civil and military. A Rare Earth Permanent Magnet (REPM) plant is being set up in Vizag, a Rare Earth and Titanium Theme Park has been set up in Bhopal, there has been an augmentation in the capacity of Rare Earth producing units, mining of beach sands has been further regulated, DMRL has developed the technology for making three different classes of rare earth magnets, a licensing agreement for Transfer of Technology (ToT) has been signed between DRDO and IREL. In addition, to enhance the scope of discovery of REE ore 58,626 square kilometres area has been delineated to be potential for REE occurrences in the country.

- **REE Consumption in India**. The total consumption of REEs during the year 2015 -16 was 31.9 Tons and it increased nearly six times to 1867.9 tons in the year 2016 – 17. At the same time imports of Rare Earth Metals in 2018-19 increased to 643.41 tonnes as compared to 492.41 tonnes in 2017-18. The breakdown of their usage across the defence sector is not available. But there is going to be an exponential increase in the demand and usage or REE and its products as India pursues self reliance in the manufacturing sector.

- **<u>REEs in the Defence Sector</u>**.

  ❖ There has been substantial progress in India's research in the field of magnets for defence application and India is setting up a Rare Earth Permanent Magnet (REPM) plant for production of Samarium Cobalt magnets for use by DAE, Defence and space sectors.

  ❖ To achieve *aatmanirbharta* in defence sector, the government has announced several policy measures. Notable among them which are related to the REE segment are the positive indigenisation list of 209 items, **Indigenisation List on Assemblies,** large infusion of capital, permitting defence exports and lastly permission to increase in FDI in defence sector.

  ❖ Out of the 209 items forming part of the positive indigenisation list, up to 84 systems are likely to use REEs or part of the rare earth value chain in the manufacturing process in a significant manner.

  ❖ Pursuit of self reliance in the Defence Industry is not likely to significantly affect the import basket of REEs by Indian vendors in the short term. In the next five years, in order to achieve the laid down import embargo targets, Indian vendors are likely to perform the role of system aggregators and integrators while importing key components which are not produced within the country.

  ❖ The requirement of REEs in defence manufacture is likely to be met through import for at least the next five years. In the long term however, the success of the Atma Nirbhar Bharat program will depend upon the generation of component manufacture in India and the setting up of downstream industries in the rare earth value chain. This would lead to creation of value chains for items other than defence also and would ultimately lead to strategic autonomy and lesser reliance on the global supply chains.

- There is no public statement on the type and quantity of REEs essential for Indian Defence Manufacturing. The same have been extrapolated from studies carried out in the US and UK in 2013 and 2016 respectively. These reports indicate that availability of seven REEs will be central to *aatmanirbharta* programme in defence sector; namely dysprosium, erbium, europium, gadolinium, neodymium, praseodymium, and yttrium. Of these, except for Yytrium, there is a fair amount of adequacy of ore in the country.

- To secure the value chain for defence manufacture, Inida needs to pursue the downstream industry for the Light REEs and look at import for Heavy REE (Yytrium).

- India currently does not possess the technology or rather the plants to separate materials like Dysprosium and Thorium from Monazite and supplying highly pure Dysprosium to international market, while Thorium could be used for India's future nuclear energy mission for reducing carbon footprints.

Way Ahead and Recommendations

Diversification of Supply Source. The uninterrupted and affordable supply of REE is an imperative for growth of manufacturing sector especially the Defence Sector where interruptions can have disastrous ramifications on the security of the country and its strategic autonomy. The present arrangement of over-reliance on China as a single largest source of REE supply is undoubtedly a source of vulnerability and potential threat to supply chain security. In view of the foregoing arguments, it has become an indispensable requirement to engage with new partners who are emerging as potential sources of REE/ critical minerals. USA, Japan and Australia can be considered for future procurements ex import while at the same time, creating the infrastructure to create the downstream industries domestically.

Mining and Exploration for REEs.

- While the 'Strategic Plan For Enhancing REE Exploration In India' has been arrived at by jointly by the Geological Survey of India and the Atomics Minerals Directorate for Minerals and Research, the recommendations made by the study team need to be pursued in earnest. To exploit the 58,626 square kilometres area which has been delineated to be potential for REE occurrences in the country, due coordination should be carried out between IREL / new nodal agency with the respective State Governments. Additional areas to explore such minerals must continually be undertaken.
- China has used unfair trade practices and subsidised pricing mechanisms to ensure that the REE industry in other countries find it difficult to survive and sustain their activities. India must resist China's methods in order to prevent non-Chinese mining from becoming viable. Only if REE can be collected as a by-product of an industrial operation can the Chinese government's indirect ecological subsidies be matched. The Indian Ocean Region is home to the world's largest such opportunity. The entire geological region surrounding the IOR is rich in REE, resulting from millions of years of natural concentration. REE production from these mineral sands is inexpensive since it is a by-product of industrial mineral mining, and it can readily compete with Chinese REE production, even without a substantial subsidy.
- REE metals are normally found in extremely low concentrations. As a result, these mineral commodities must be explored using modern concepts and tools in order to achieve a breakthrough. This will necessitate significant investments in sophisticated survey and spatial data management technologies in order to produce more detailed data and information from previously unexplored areas and depths.

- **Identification of HREE deposits** and of REE minerals are two of the challenges facing research on REE deposits. The first challenge is to identify and discover deposits which can economically extract HREE, especially since they are relatively rare compared with LREE. There is a need to study deposits that may be enriched in HREE, to include alkali rocks.

Nodal Agency. It is opined that given the strategic nature of these REEs, there is a requirement to create a new department for rare earths (DRE), which would play the role of a regulator and enabler for businesses in this space. As of now, mining and processing has been largely concentrated in the hands of IREL India, under the department of atomic energy. Its progress and capacity to produce rare earths, despite growth, , it is very slow when compared with international REE conglomerates. This slow growth belies its long history, experience and its principal focus is the production of raw materials such as thorium and uranium for India's nuclear energy. The DRE is recommended to look at deregulation of this strategic sector and the promotion of R&D in the field. The primary task of such a department would be to ramp up India's REE production and make India a part of the global supply chain.

Indigenisation of Value Chain.

- India primarily has Monazite and some deposits of Bastnaesite rare earth minerals, both of which fall under the category of LREE. Given the availability profile of indigenous minerals, there should be a systemic approach to encourage manufacturing of products which utilize domestically available raw material/ minerals i.e. LREE. This will enhance self reliance by minimizing dependence on other countries for rare earths and by virtue of increase in demand, provide natural stimulus to domestic production of REE in India. The manufacturing strategy should focus on products utilizing only LREE as priority products; however, to enhance the scope of production, goods which utilize miniscule amounts of HREE can also be included in production inventory as priority two products.

- There is also a need to consider bringing in more companies to the value chain and making it more investment-friendly. While private investments alone may not be enough to cover the costs of upstream processing, this requires a significant amount of capital and government funding. As more efficient procedures are put in place, a public-private partnership can assist attract investment and buyers in downstream processes.

Strategic Reserves. India has no known strategic reserves of REEs while it has been scaling up and accumulating petroleum reserves for emergencies in the recent past. The same logic needs to be applied to rare earths- they're both essential commodities over which India is import dependent. Having Rare Earth Strategic Reserves can help provide a consistent demand environment, as well as a fallback at times of crisis.

Financial Incentives: Various incentives like access to cheaper capital, tax concessions, and providing a sovereign guarantee to corporate bonds floated for strategic mineral facilities can help generate much needed investment into the sector. In addition, exemptions and commercial headwinds already being experienced by key related sectors such as green energy, electric vehicles, specialty chemicals and technology intensive products in India will have a positive ripple effect onto the strategic minerals space if private players enter the fray.

Information Fusion: The Indian Bureau of Mines (IBM) operates as the principal data collector and disseminator in the space. The agency has long experience and the competency to be transformed into a real-time data fusion centre, allowing for instant access to key demand and supply indicators across the value chain. IBM can become the missing link between the demands of the mining sector and the prospects for mines and processors.

Predictive tools and modern data analytics can set the grounds for a transparent and efficient industrial space.

R&D:

- Setting up domestic R&D centres of excellence along with the acquisition of foreign data and talent are necessary for progress in the field. Inclusion of universities, access to mines, industrial linkages, tie-ups with foreign research endeavours, and onboarding former national and international faculty on short tenures is a prudent way forward.
- **Substitution**: For a few years, finding inventive ways to subsidise more vital materials with widely available ones has been a top priority for the west. India, too, should work to reduce its reliance on minerals, particularly in areas where domestic and environmentally benign supply options are limited.

Recycling for REEs: REE and rare metal recycling technologies are still in the premature stages of expansion, efforts are likely to continue to help keep pace with the anticipated increase in demand. Recycling of rare earth containing products needs to be pursued as part of the R& D process after analysis of availability of requisite waste material and technology for economic recovery.

Exports and Imports: India's current practice of exporting away low value ores when such resources are critical to its economy and defence needs to be discontinued immediately. There is a need to focus on domestic value addition using a combination of technology transfers as well as indigenous research.FDI may be invited for the purpose of setting up export-oriented facilities in Public Private Partnership mode- joint ventures with IREL's DRE entity, and with technology transfers. Similarly, a calibrated and dynamic import duty policy is in order. In case of minerals where India is trying to build a domestic supply chain, long-term import duties may prove crucial to incentivise industry efforts.

Rare Earth Quad. The Quad grouping of India, USA, Australia, and Japan have been reportedly set up a 'Critical and Emerging Technology' working group, which subsumes critical minerals' supply chain security. All these countries were either producers of rare earths, or processors, or both. Economic diplomacy can rope in more like minded countries, bringing important capabilities to the table- France, UK, Germany, etc. Their combined efforts and willingness to collaborate can counter China's present monopoly in two important ways- by diluting the monopoly itself as production comes online, and by forming a monopsony (a big buying bloc having a large proportion of global demand). This will not only increase all parties' bargaining power, but allow for a slow decoupling from Chinese dependence.

Conclusion

China is currently a leading global supplier for six out of the 12 mineral resources identified as critical for India by 2030. Over coming years, India will need to strategically develop joint partnerships with existing global players (private firms and governments) to secure assured supplies . China has not been hesitant to weaponize its dominant position to further its gains and geopolitical standing. As China grows increasingly assertive in nature, it is important for the world to jointly act against this de-facto monopoly before it gets too late.

Oil and rare earths are two major input deficits that are threatening the stability of India's fast rising economy. The two restrictions are intertwined: rare earth materials are required for both green energy generation and green technologies such as LEDs and electric vehicles. Aside from energy security, strategic minerals (which includes rare earth minerals) have a slew of essential applications in chemistry, electronics, and defence. In light of the rising worldwide consensus in favour of clean energy, (which will require batteries with REEs as critical components) and demands for diversified supply chains for critical minerals, there is no better time for India to utilise its large deposits of rare earth elements.

The rare earths market is expected to grow at a **Compound Annual Growth Rate** (CAGR) of around 8 per cent during the forecast period of 2019-2024. Domestic R&D efforts and adequate fund liquidity in the production of REMs could create a potential avenue for establishing a competent rare earths industry ecosystem with independence from foreign technology. Likewise, the government also needs to develop a reliable mechanism, commit its sweeping insight into this industry ecosystem. The investments, market and India's huge reserves of raw materials make Research & Development in this segment a highly valuable venture that will boost the development of a large number of strategic hi-tech products and industries.

India needs to develop a national strategy to properly utilize its Rare Earths potential, making it a part of its Make in India initiative. India needs to develop a "Mine to Magnet" supply chain, and it should approach its partners including the US, Japan and Australia, for expertise and technological assistance. A Quad level co-operation on technology sharing, especially in the Rare-Earths domain should be explored. India should invite investments from private firms from these countries to set up processing and manufacturing plants so it can export value-added finished products and emerge as a viable alternate supply chain. This venture would incur a high cost to the Government, but it will be a worthwhile investment. It may eventually become the driver for India's *Aatmanirbhar Bharat* campaign.

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Appendix A

RARE EARTH ELEMENTS AND THEIR APPLICATIONS

REE	REE Applications
Scandium	It finds applications mostly in ceramics, lasers, phosphors and in certain high performance alloys
Yttrium	Due to highest thermodynamic affinity for oxygen, yttrium finds many applications. As for example, its use in ceramics as crucibles for molten reactive metals, in fluorescent lighting phosphors, computer displays and automotive fuel consumption sensors. Yttria-stabilized zirconium oxide is used in high temperature applications, namely, thermal plasma sprays for safety of aerospace component surfaces at high temperatures. Yttrium-iron-garnet (YIG) crystals are required for equipment of microwave communication, whereas crystals of yttrium-aluminum-garnet (YAG) are used with neodymium in a variety of laser applications. Yttria can also enhance the strength of metallic alloys. The Eu:Y2O2S phosphor produces red color in televisions.
Lanthanum	Used in hybrid engines and metal alloys. Lanthanum rich compounds are used as components in FCC catalysts, mainly for making low
Cerium	Cerium finds several commercial applications in glass and glass polishing, phosphors, ceramics, catalysts and metallurgy. The cerium-doped glass to block out ultraviolet light is used in the manufacturing of medical glassware and aerospace windows. It is also used to prevent polymers from darkening in sunlight and to suppress discoloration of television glass. It is used as optical components to improve performance. In phosphors, its role is more as a sensitizer, rather than as

	emitting atom. In the field of ceramics, cerium is used in dental compositions and as a phase stabilizer in zirconia-based products. In catalytic converters it works as a stabilizer, as a promoter of the water-gas shift reaction and as an oxygen storage component. Cerium is added to the dominant catalyst for making styrene from methylbenzene to increase styrene formation. It is used in FCC catalysts containing zeolites to provide both catalytic reactivity in the reactor and thermal stability in the regenerator. In steel manufacturing, Ce finds application to remove free oxygen and sulfur by forming stable oxysulfides and by tying up undesirable trace elements.
Praseodymium	Used in magnets. It is highly useful in ceramics as a bright yellow pigment, in praseodymium doped zirconia. It is also used in the scintillator for medical computed tomography scans
Neodymium	Main applications are in lasers, glass coloring and tinting, dielectrics and, most importantly, neodymium-iron-boron (Nd2Fe14B) permanent magnets. It is used widely in the automotive industry in starter motors, brake systems, seat adjusters and car stereo speakers. Its largest use is in the voice coil motors required for computer disk drives. Permanent magnets are finding progressively more applications in HEVs and EVs and renewable energy generation. Due to its strong absorption band, being centered at 580 nm, which is very close to the human eye's maximum level of sensitivity, Nd is useful in protective lenses for welding goggles. It is highly useful in glass manufacturing for its attractive purple coloring to glass. Neodymium is a component in many formulations of barium titanate, that are needed as dielectric coatings

	and in multi-layer capacitors of electronic equipment. Yttrium-aluminum-garnet (YAG) solid state lasers require neodymium due to its optimal absorption and emitting wavelengths. Nd-based YAG lasers also find applications in various medical fields, drilling, welding and material processing.
Samarium	Samarium is essentially needed in manufacturing of samarium-cobalt permanent magnets. It is also required for laser applications due to its dielectric properties. More expensive platinum-cobalt magnets are replaced by samarium-cobalt magnets. Because of its weak spectral absorption band samarium is used in the filter glass on Nd:YAG solid state lasers to envelope the laser rod to improve efficiency by absorbing stray emissions. Samarium forms stable titanate compounds with useful dielectric properties suitable for coatings and in capacitors at microwave frequencies.
Europium	Due to unique luminescent property europium has special applications. For example, excitation of the europium atom by absorption of ultraviolet radiation results in specific energy level transitions within the atom leading to creation of an emission of visible radiation. For energy-efficient fluorescent lighting, europium yields both red and blue light. Innumerable commercial red phosphors are based on europium for color TV, computer screens and fluorescent lamps. Additionally, its luminescence is also useful in medical, surgical and biochemical fields.
Gadolinium	Gadolinium is utilized for both high magnetic moment and phosphors and scintillated materials. When mixed with EDTA dopants, it is used as an injectable contrast agent for patients undergoing magnetic

	resonance imaging. With its high magnetic moment, gadolinium can reduce relaxation times and thereby enhance signal intensity. The particularly stable half full 4f electron shell with no low lying energy levels creates applications as an inert phosphor host. Accordingly, gadolinium can act as host for x-ray cassettes and scintillated materials for computed tomography
Terbium	Mainly used in phosphors, particularly in fluorescent lamps and as the high intensity green emitter used in projection televisions, namely, variety of yttrium-aluminum-garnet (Tb:YAG). As terbium responds to x-ray excitation, it is used as an x-ray phosphor. Also, terbium alloys find application in magneto-optic recording films and magnets.
Dysprosium	Used mainly in neodymium-iron-boron high strength permanent magnets and hybrid engines. It is also used in special ceramic compositions.
Holmium	Due to highest magnetic moment of any naturally occurring element, holmium is used to create the highest known magnetic fields by placing it within high strength magnets as a pole piece or magnetic flux concentrator. On account of this magnetic property, it also has value in yttrium-iron-garnet (YIG) lasers for microwave equipment. Holmium lasers is also used in a variety of medical and dental fields in both yttrium-aluminum-garnet (YAG) and yttrium-lanthanum-fluoride (YLF) solid state lasers. The wavelength permits applications in silica fibers designed for shorter wavelengths, while still providing the cutting strength of longer wavelength equipment.
Erbium	Erbium is used in phosphors. It has application in glass coloring, in

	lasers for medical and dental use and in eyeware and decorative glassware. It is particularly useful as an amplifier for fiber optic data transfer. Lasers based on Er:YAG are well-suited for surgical applications due to its ability to deliver energy without producing heat in tissue
Thulium	Most of the thulium products are used in making crystals and lasers. In medical area, thulium is used for the production of portable x-ray sources as tools for medical and dental diagnosis; besides in detecting defects in inaccessible mechanical and electronic components. Thulium is also used in magnetic and ceramic materials, like the yttrium-iron alloys, required in the microwave technologies
Ytterbium	Ytterbium is used in several fiber amplifier and fiber optic technologies and in laser. Due to the presence of a single dominant absorption band at 985 in the infrared making, ytterbium is useful in silicon photocells for converting directly radiant energy to electricity. Ytterbium metal increases its electrical resistance on being subjected to very high stresses. On account of this property it is used in stress gauges for monitoring ground deformations from earthquakes and nuclear explosions. It is also used as thermal barrier system bond coatings on nickel, iron and other transition metal alloy substrates.
Lutetium	Lutetium is the best host for x-ray phosphors as it produces the densest known white material, namely, lutetium tantalate. It finds application as a dopant in comparing crystallographic parameters of certain substrate garnet crystals, namely, indium-gallium-garnet (IGG) crystals as it lacks in a magnetic moment

Appendix B

MAJOR UTILISATION OF REE'S GLOBALLY[65]

Area	Applications
Electronics	Television screens, computers, cell phones, silicon chips, monitor displays, long-life rechargeable batteries, camera lenses, light emitting diodes (LEDs), compact fluorescent lamps (CFLs), baggage scanners, marine propulsion systems
Manufacturing	High strength magnets, metal alloys, stress gauges, ceramic pigments, colorants in glassware, chemical oxidizing agent, polishing powders, plastics creation, as additives for strengthening other metals, automotive catalytic converters
Medical Science	Portable X-ray machines, X-ray tubes, magnetic resonance imagery (MRI) contrast agents, nuclear medicine imaging, cancer treatment applications, and for genetic screening tests, medical and dental laser
Technology	Lasers, optical glass, fiber optics, masers, radar detection devices, nuclear fuel rods,

[65] STRATEGIC PLAN FOR ENHANCING REE EXPLORATION IN INDIA, November 2020, November 2020, Geological Survey of India, Ministry of Mines, Govt of India, Available at https://www.amd.gov.in/WriteReadData/userfiles/file/GSI_AMD_Vision_Document_REE.pdf

	mercury-vapour lamps, highly reflective glass, computer memory, nuclear batteries, high temperature superconductors
Renewable Energy	Hybrid automobiles, wind turbines, next generation rechargeable batteries, biofuel catalysts
Others	The europium is being used as a way to identify legitimate bills for the Euro bill supply and to dissuade counterfeiting. An estimated 1 kg of REE can be found inside a typical hybrid automobile Holmium has the highest magnetic strength of any element and is used to create extremely powerful magnets. This application can reduce the weight of many motor

Appendix C

DEFENCE WEAPONS/PLATFORMS ON POSITIVE INDIGENISATION LIST REQUIRING REES IN MANUFACTURING

S.No.	Name of Platform/ Weapon/ System/ Equipment
1	Tracked Self-propelled (SP) Gun (155mm x 52 Cal)
2	Towed Artillery Gun (155mm x 52 Cal)
3	Short Range Surface to Air Missiles (Land Variant)
4	Shipborne Cruise Missiles
5	Multi Barrel Rocket Launcher (MBRL) (Pinaka Variant)
6	Simulators Presenting Smart Ranges and Multi-Functional Targets
7	Battalion Support Weapons Simulators
8	Container-based Simulators for Live Fire Training
9	Tailor-made Simulators for Counter Insurgency (CI) / Counter-Terrorism (CT) based Training
10	Tank Simulators (Driving, as well as, crew gunnery)
11	155mm / 39 Cal Ultra-Light Howitzer
12	Successor of Flycatcher & Upgraded Super Fledermaus (USFM) / Air Defence Fire Control Radar (ADFCR)
13	Missile Destroyers
14	Multi-purpose Vessel
15	Offshore Patrol Vessel
16	Next-Generation Missile Vessels
17	Anti-Submarine Warfare Shallow Water Crafts
18	Water Jet Fast Attack Craft
19	Survey Vessels

20	Anti-Submarine Rocket Launchers
21	Torpedo Tube Launcher for Light Weight Torpedoes
22	Magneto-Rheological Anti Vibration Mounts
23	All Variants of Depth Charges
24	Short Range Maritime Reconnaissance Aircraft
25	Anti-Submarine Rocket
26	Chaff Rockets
27	Chaff Rocket Launcher
28	Integrated Ship's Bridge System
29	Light Combat Aircraft (LCA) MK I A - Enhanced Indigenised Content
30	Light Combat Helicopters
31	Radar Warning Receiver (RWR) for Transport Aircraft
32	Ground-Based Mobile ELINT System
33	Transport Aircraft (Light)
34	GSAT-6 Satellite Terminals
35	Digital Tropo Scatter/ LOS Communication System
36	Low-Level Transportable Radar
37	High Power Radar (HPR)
38	CBRN Detection & Monitoring System
39	Simulators for A Vehicles / B Vehicles
40	Simulators for Towed and Self-propelled Guns of Air Defence
41	Simulators for Correction of Fire by Observers
42	Fixed Wing Mini UAVs
43	Advanced Landing Ground Communication Terminals (ALGCTs) for AGLs
44	Wheeled Armoured Fighting Vehicle (AFV)

45	Inertial Navigation System for Ship Application
46	Conventional Submarines
47	EW Systems
48	ASTRA-MK I Beyond Visual Range Air to Air Missile (BVR AAM)
49	EW Suit for MI-17 V5
50	Communication Satellite GSAT-7C
51	Satellite GSAT 7R
52	Basic Trainer Aircraft (BTA)
53	Small Jet Engines with 120kgf thrust
54	Light Low-Level Terrain Radar (LLWR)
55	Helicopter with All Up Weight (AUW) $\leq$ 3.5Ton (Single Engine Land Variant)
56	Wheeled Armoured Platform (WhAP) – CBRN
57	Next Generation Corvette
58	Mission System for Airborne Early Warning & Control (AEW&C) System
59	Mini UAV for Surveillance (Fixed Wing
60	Helicopter Launched ATGM upto 7 Km
61	Shipborne High Accuracy ELINT system in 0.17 to 40 MHz
62	SDR for Combat Ships (SDR NC)
63	Border Surveillance System
64	Ship borne Surface Surveillance Radar (SSR)
65	Battlefield Surveillance Radar (BFSR) up to 10 KM
66	Through Wall imaging Radars
67	Portable Diver Detection Sonar

68	Multi-Functional Display System (MFDS) for Indigenously Produced Aircraft
69	10 W Power Amplifier (L Band and X Band) for Tropo Upgradation
70	2KW & 4KW Power Amplifiers (L Band) for Tropo Upgradation
71	LED Based Taxy, Landing & Navigation Lights
72	Land Based Medium Power Radar
73	Upgraded Integrated Air Command And Control System
74	Composite Sonar Dome for Ships
75	Land Based MRSAM Weapon System
76	4x2 Armoured Command Post Vehicle
77	Data Network for Ships
78	Thermal Imaging (TI) sight for Small Arms (Aslt Rif, LMG,MMG & RL)
79	Image Intensifier (II) sight for Small Arms (Aslt Rif, LMG,MMG & RL)
80	Day Sight for Small arms including Telescopic & Reflex sight (Aslt Rif, LMG & CQB carbine)
81	Integrated Architecture Display System (IADS) for LCH
82	Automatic Flight Control System (AFCS) for LCH
83	Ship Borne 1 KW High Frequency Trans-receiver
84	Digital Beam Forming based Satellite TV for Ships

Note. The items are numbered as they appear on the Positive Indigenisation Lists.

Appendix D

IMPORT SUBSTITUTION LIST ITEMS LIKELY TO USE REE

Ordnace Factory Khamaria	Proximity Fuze FB-40 for 40mm PFFC Ammn
	Composition NOA-32 Zirconium Nickel Based Ignition Composition
Engine Factory Avadi	Fuel Pump Assy. for UTD-20 Engine
	Automatic Unit B13 Technical Specifications
	Alarm Signalling Unit BAC-6A Assy
	Relay Regulator P15M-3C
	Starter Generator (T90 & T72)
	Optical Sending UnitOD1-1C
	Generator Set, Gasoline Engine Battery Charger 1KW, DC
Ordnance Factory Dehradun	LED Light Source & Luminous Strip
Machine Tool Prototype Factory, Ambarnath	Battery IM002 Catalyst Adycat-8
Opto Electronics Factory, Dehradun	Gyro Stabilizer Aiming Device
Bharat Dynamics Limited	LED 3L107B & Photo diode
	Tandem Warhead with SAM
	Thermal Battery
Goa Shipyards	**12 MCMV vessels**
	Main Propulsion Engine
	Infra-red communication system
Garden Reach Shipbulders	Indigenous Development of Unmanned Surface

& Engineers Ltd	Vessel
	Low Frequency Variable Depth
	Autonomous Underwater Vehicle
	Bow and Stern Thruster
	Under Water Remotely Operated Vehicle

Annexure 1

GOVERNMENT OF INDIA
DEPARTMENT OF ATOMIC ENERGY
LOK SABHA
UNSTARRED QUESTION NO.2762
TO BE ANSWERED ON 11.03.2020

AVAILABILITY OF RARE EARTH METALS

2762. SHRIMATI PRATIMA MONDAL:

Will the Prime Minister be pleased to state:

(a) whether the Government has data on availability of rare earth metals in the country;
(b) the production of rare earth metals inthe past three years inthe country;
(c) the quantum of metals imported andthe names of the countries from which it has been imported; and
(d) the details of ongoing and future initiatives that the Government intends to take in this regard?

ANSWER

THE MINISTER OF STATE FOR PERSONNEL, PUBLIC GRIEVANCES & PENSIONS AND PMO (DR. JITENDRA SINGH)

(a) Yes, Sir. Data on availability of rare earth metals deposit in the country is available. Atomic Minerals Directorate for Exploration and Research (AMD), a constituent unit of Department of Atomic Energy (DAE) is carrying out exploration to augment resources of Rare EarthElements (REE)in several potential geological domains of the country. In addition, AMD carries out exploration along the coastal / inland / riverine placer sands of the country for augmentation of Heavy Minerals which includes monazite (REE and Th mineral) and xenotime(REE + yttrium mineral).

As on January, 2020, AMD has established the following:

12.47 Million tonnes (Mt) of Monazite (containing ~ 55 - 60% total Rare Earth Elements oxide) occurring in the coastal and inland placer sands of the country.

About 2,000t of xenotime bearing heavy mineral concentrate (containing ~2% xenotime) in the riverine placer deposits of Chhattisgarh and Jharkhand.Presently AMD is carrying out recovery of xenotime bearing heavy mineral concentrate in the plant established in Chhattisgarh and has a stockpile of 75.583 tonnes.

3,46,462 tonnes of REE Oxide (inferred category – at 0.5% cut-off) has been estimated in Ambadongar area, Chhota Udepur district, Gujarat.

(b) In India, basic ore for Rare Earths (Neodymium, Praseodymium, Samarium, Cerium, Lanthanum, etc) is Monazite, found along with six other minerals as suite. Monazite is a prescribed substance as per the Atomic Energy Act 1962. IREL (India) Limited (IREL), a Public Sector Undertaking of this Department,is the only entity processing Monazite to produce Rare Earth (RE) compounds. The RE values produced by IREL is in the form of mixed RE chloride and separated high pure RE.

The production of mixed RE chloride by IREL in the last 3 years are given below:

2016-17: 2265 tons
2017-18: 2724 tons
2018-19: 4215 tons

These high Pure RE compounds in oxide form are used to produce RE metal. However, industry for production of such metals is yet to be established.

(c) The data in respect of the import of rare earth metals in the country is maintained by Department of Commerce in the Ministry of Commerce & Industry. As per the data supplied by the Directorate General of Commercial Intelligence & Statistics (DGCIS), the rare earth metal (ITC-HS Code 28053000) imported in the country during the last four years, year-wise and country-wise is given in the Annexure.

(d) Details of the ongoing and future initiatives are enumerated below:

Ongoing initiatives:

IREL have an operating Processing Plant in Ganjam district of Odisha, which has the installed capacity for producing about 11,000 tpa mixed RE chloride, containing about 5,000 tpa of RE Oxide (REO).

IREL has also facilities in Aluva, Kerala for processing of about 5,000 tpa of mixed RE chloride for production of about 2,000 tpa equivalent separated high pure rare earths in the form of individual oxides/compounds (Neodymium, Praseodymium, Samarium, Cerium, Lanthanum, etc)

Future initiatives:

Setting upof a Rare Earth Permanent Magnet (REPM) plant for production of samarium cobalt magnets for use by DAE, Defence and Space sectors. The plant, based on technology developed by BARC and Defence Metallurgical Research Laboratory (DMRL), Hyderabad will be set up in BARC campus, Vizag.

Setting up ofa RE & Titanium theme park for the technologies being developed by BARC in the RE value chain. Pilot scale plants shall be installed in this facility by IREL to attract entrepreneurs to upscale the technologies to commercial scale.

A carbonatite deposit containing REO has been identified in Gujarat. Action has been initiated to ascertain the techno economic feasibility and financial viability for harnessing the deposit.

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Annexure

Import of Rare Earth Metal under ITCHS:28053000 for last three FY and current FY:2019-20 (Up to Dec,19)

ITCHS	DESCRIPTION	COUNTRY	2016-17		2017-18		2018-19		2019-20 (Up to Dec,19)	
			QTY-TON	VAL (US Mill $)	QTY-TON	VAL (US Mill $)	QTY-TON	VAL (US Mill $)	QTY-TON	VAL (US Mill $)
28053000	RARE-EARTH METALS SCANDIUM AND YTTRIUM W/N INTERMIXED/INTERALLOYED	AUSTRIA			0.00	0.00				
		BELGIUM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		CHINA P RP	503.31	1.89	487.01	2.47	623.10	3.66	350.00	1.67
		CZECH REPUBLIC					0.00	0.00		
		FRANCE			0.00	0.00				
		GERMANY	0.00	0.00	0.01	0.00	0.08	0.01	0.00	0.00
		HONG KONG					10.00	0.06	32.00	0.14
		ITALY	0.02	0.00						
		JAPAN							1.00	0.01
		TAIWAN			0.50	0.01				
		U K	0.28	0.02	0.15	0.02	0.03	0.01	0.04	0.01
		U S A	16.00	0.43	4.74	0.14	10.20	0.26	0.01	0.03
Total			**519.62**	**2.34**	**492.41**	**2.64**	**643.41**	**4.00**	**383.05**	**1.85**

Note: Figure pertaining to FY:2019-20, are provisional and subject to change