Aligned with the Future

Victory through Joint Knowledge

Centre for Joint Warfare Studies

Room No 301, B-2 Wing, 3rd Floor, Pt Deendayal Antyodaya Bhawan

CGO Complex, Lodhi Road, New Delhi - 110003 (INDIA)

Telephone Nos : 011-24364881, 24366485, **Fax** : 011-24366484

Website : www.cenjows.in, **e-mail** : cenjows@cenjows.in

cenjows@yahoo.com

Price in India : ₹200 /-

Printed in India

Printed by
Xtreme Office Aids Pvt. Ltd.
Basement Bhanot Building (Below Syndicate Bank)
Nangal Raya Commercial Complex, N.D-110046
Ph.: +91-7982084106
E-mail: xtremeofficeaids@gmail.com
Website: www.xtremeonline.co.in

RARE EARTH ELEMENTS: STRATEGY FOR ATAMANIRBHARTA

Lt Gen Sunil Srivastava, AVSM, VSM** (Retd) &
Gp Capt GD Sharma, VSM (Retd)

Rare Earth Elements (REEs) due to their unique physical and chemical properties have significant application in high technology products, clean energy, and weapon system. In the coming years, their demand is expected surge with further development and growth in technology. This study is undertaken to examine Indian prospectus of REEs mining, processing and production both for self sufficiency in critical areas of the domestic use as well as for exports.

Ironically, while India holds 5th largest reserve of rare earth it imports the finished product derived from the REE.[1] China currently controls nearly 90% of the world's REE mining and refinement as well as holds supply chains dependent on them. China has a well-established record of using trade as a coercive tool in international diplomacy. In 2009, in the midst of a territorial dispute with Japan, China imposed export quotas on rare earths as a result the prices of the rare earth products sky rocketed. Now Post Covid 19 pandemics, many manufacturing hubs of rare earth were closed by China. Hence, there always remains a danger of supply chain disruption if we remain dependant on a single supplier. Besides, the geopolitical rivalry between US and China and consequent trade

1 Answer to un starred parliament question 2762, 11 Mar 20

war, which is not likely to abate, has further enhanced the possibility of supply chain disruption. As a result, the world has realised the need to develop multiple sources for REEs supply chain as well as the need to ramp up their own production to avoid dependence on others. India too needs to develop a Rare Earth strategy to ward off the supply chain risks both in export of raw material and import of the / refined products[2].

What are REEs?

Rare earth elements are collection of the 17 Metals which though are widely distributed in the Earth's crust are not in mineable deposits forms like other minerals hence, extraction and refinement of the metals is a complex process which also has environmental concerns. (**Annexure-I**) Environmental pollution probably was one of the reasons besides, cost competitiveness that industrialized nations despite possessing technology, exported the raw materials to China for processing and extracting the mineral while importing the mineral in the refined form. China recognised it as opportunity to dominate the production and use it as strategic tool. The famous quote of Deng Xiaoping of 1992 that "Middle East has oil; China has rare earths" gave a clear hint that China eventually will use its dominance in rare earth for strategic leverage.

Why are Rare Earth Elements important? These minerals are used in minute amounts as catalysts and in manufacture of alloys, magnets, solar energy systems and computers. Along with other raw materials such as cobalt and lithium, they are the fundamental metals for future technologies, especially with regard to Industry 4.0 applications.[3] **(Annexure-II)**

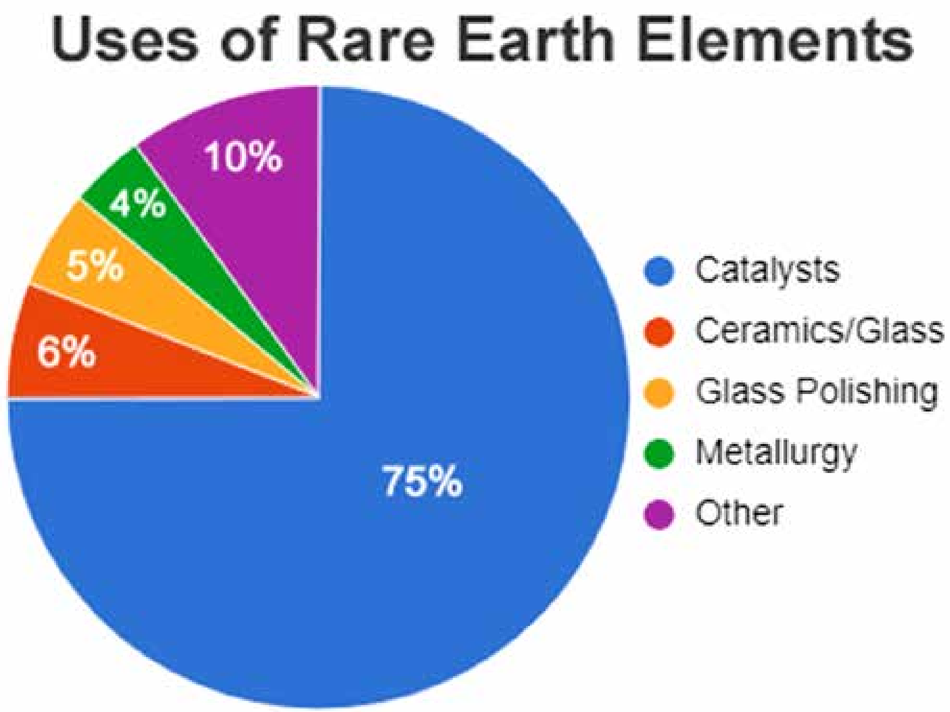
As per the available data, nearly 75% of the REEs are used as catalysts such as in oil industry for separating the constituents of oil i.e., petrol, diesel

---

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

3 https://www.baks.bund.de/en/working-papers/2019/below-the-radar-the-strategic-significance-of-rare-earths-for-the-economic-and

etc. and rest in ceramics, glass polishing, metallurgy and in manufacture of high technology products in civil & defence industry etc.[4] The usage in industrial sector would change with change in focus / growth of the specific industry. In coming days, the imperatives of climate change and carbon free environment, use of electric and hybrid vehicles, pollution free generation of electricity and growth of high-tech industry will boost the demand of REEs Further. clean energy and electric vehicles will be major drivers of this demand[5].



Uses in the United States as reported by the United States Geological Survey Mineral Commodity Summary, 2020

4 https://ibm.gov.in/writereaddata/files/10012020172151RareEarth_2019_AR.pdf

5 https://geology.com/articles/rare-earth-elements/#:~:text=The%20group%20consists%20of%20yttrium,%2C%20ytterbium%2C%20and%20lutetium).&text=Glass%2C%20granite%2C%20marble%2C%20and,polished%20with%20cerium%20oxide%20powder.

Application in Strategic Sectors

Besides high technology manufacturing, the REEs have applications in core sectors such as energy, petroleum, defence, transport, health and nuclear energy:-

(a) **Energy.** For non fossil power generation. (Solar and Wind Turbines)

(b) **Petroleum Sector.** As catalysts for separation & refining of petroleum products.

(c) **Defence Industry**. In manufacture of weapons, sensors, as alloys for engines, platforms etc.

(d) **Transport Sector.** Electric and hybrid vehicles.

(e) **Health Sector.** X rays and Medical Imaging etc.

(f) **Nuclear.** Some of these elements (europium and dysprosium) are incorporated into control rods used to regulate the operation of nuclear reactors or to shut them down should they get out of control (gadolinium)[6].

Defence Applications

The electro-electrical properties of REE make these useful for defence applications. These have uses in night-vision goggles, precision-guided weapons, communications equipment, GPS equipment, batteries, and other defense electronics. Rare earth metals are also key ingredients for making the very hard alloys used in armoured vehicles, aero-space platforms, unmanned vehicles, engines and projectiles that shatter upon impact. Some major uses of REEs in defence sector are explained below: -

6 https://www.britannica.com/science/rare-earth-element/Nuclear-properties

(a) **Guidance, Propulsion and Control Systems**. REEs based Samarium Cobalt (Sm-Co) and Neodymium-iron-boron (Nd-Fe-B) magnets are the strongest magnets that are considered ideal for wide range of defence equipment ranging from the basic electrical motors to fin actuators for guided missiles, munitions, unmanned aerial vehicles etc.[7] Their use also encompasses all conceivable propulsion systems in use today across sea, land and air platforms. Emerging technologies like railguns and Electromagnetic Aircraft Launching Systems (EMALS) all need such powerful magnets. Nd-Fe-B magnets in particular, are also amongst "the smallest, lightest, and most powerful magnets which helps in miniaturisation of the products. This quality in particular makes them very useful in defence industry.

(b) **Optics.** Europium, Ytterium, and Terbium are used as glass doping agents for lasers, night vision, displays, laser targeting systems etc.

(c) **Early Warning Systems**. Lanthanum is used to detect gamma radiation levels and is thus important in early warning systems meant to detect nuclear threats.

(d) **Sensors and Electronic Warfare.** Europium, Ytterium, neodymium, lanthanum and lutetium are used in the production of sonar transducers, radar, and other systems on the electromagnetic spectrum.[8]

(e) **Weapon Platforms**. Large quantities of REEs are needed in modern weapon platforms for example each stealthy F 35 strike fighter requires 920 pounds of rare earth material metal,

7 Rare Earth Elements in National Defense: Background, Oversight Issues, and Options Background, Oversight Issues, and Options assessed at www.crs.gov R41744

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

Each Arleigh Burke DDG-51 destroyer requires 5,200 pounds. An SSN-774 Virginia-class submarine needs 9,200 pounds.[9]

Thus, the demand for REEs will eventually rise as we move forward in 'Make in India' programme of the defence sector. Substitutes can be used in place of rare earth elements in some defense applications; however, those substitutes are usually not as effective and diminish quality and reliability of the equipment.[10] **(Annexure III and IV)**

India's Production of REEs

India has rich deposits of REEs, which remain largely untapped. India's reserves of rare earths, nearly 6.9 million tonnes, are the fifth largest in the world and most of it is in the beach sands of Kerala, Andhra and Odisha.[11] The country holds almost 35 percent of the world's total beach sand a mineral deposit which is significant. **(Annexure-VI)**

The state wise distribution is as under: -

India's Monazite Reserves by State

State Reserves	**(Unit: million ton)**
All India	12.47
Andhra Pradesh	3.69
Gujarat	0.003
Jharkhand	0.021
Kerala	1.84
Maharashtra	0.004
Odisha	3.06

Source: Indian Mineral Yearbook (2019)

9 https://www.airforcemag.com/article/rare-earth-uncertainty/

10 https://geology.com/articles/rare-earth-elements/#:~:text=The%20 group% 20 consists % 20of % 20yttrium,%2C%20ytterbium %2C%20and%20lutetium). & text=Glass%2C%20granite%2C%20marble%2C%20and,polished%20 with%20cerium%20oxide%20powder.

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

The largest feasible deposits for Light Rare Earth Elements (LREEs) in India are to be found in beach sands (monazite). Monazite deposits are located primarily in the coastal states of West Bengal, Kerala, Tamil Nadu, Odisha, and Andhra Pradesh. Some of these are already being exploited in limited capacities. Much smaller deposits are found in inland stream sediments and hydrothermal vents, which contain minerals rich in LREEs as well as xenotime, which contains Heavy Rare Earth Elements (HREEs). Most of these are in Jharkhand and Chhattisgarh. Gujarat and Maharashtra and are reportedly not economically viable for mining.[12] (**Annexure VI)**

In 2014, Indian Rare Earths and Toyota Tsusho Exploration entered into an agreement for exploration and production of rare earths via deep-sea mining. 4000 tons of rare earth oxide was to be mined with effect from 2016[13] but, Deep Sea mining is yet to take off. Given that rare earth is buried nearly 6ooom in the sea bed, Its extraction is technological challenge. India has been allotted 10000km seabed in parts of Central, and South-West Indian Ridges by International Seabed Authority, under UNCLOS.[14] On June 21, Government of India (GoI) has approved a 'Deep Ocean Mission' to explore the ocean for resources and develop deep-sea technologies for sustainable use of ocean resources.[15] Hence, deep sea mining is still in the initial exploratory stage.

Despite possessing substantive REE deposits, India's rare earths production industry is far below its potential.[16]. Against the installed capacity of 11000 the production of the Re oxide in India the last three years is as follows:-

---

12 Ibid
13 https://www.toyota-tsusho.com/english/press/detail/151210_002928.html
14 https://www.jiia-jic.jp/en/policybrief/pdf/PolicyBrief_Chansoria_20200629.pdf
15 https://india.mongabay.com/2021/07/indias-deep-seabed-mining-plans-gear-up-for-a-dive/
16 https://investingnews.com/daily/resource-investing/critical-metals-investing/rare-earth-investing/rare-earth-reserves-country/Top Rare Earth Reserves by Country

(a) 2016-17- 2265 tonnes,

(b) 2017-2018-2724 tonnes,

(c) 2018-2019-4215 tonnes,[17]

(d) 2019-2020 -2900 tonnes.

(e) 2020-2021 -3000 tonnes[18]

These pure RE compounds in oxide form are used to produce RE metal however; the industry for production of such metals is yet to be established.[19]

In India Indian Rare Earth Ltd (IREL) set up in 1950, has monopoly in extraction of REE ore. IREL is under the administrative control of DAE, therefore, IREL mining is guided by priorities of the Department of the Atomic Energy. Presently, India through public sector unit (IREL) is carrying out ore concentration and purification (Upper Stream process) which is exported as we have not established domestic industry for down stream processing for refining and production of pure REE mineral. China US, Japan, Malaysia, Vietnam and Germany are carrying out down stream processing.[20],[21]

India's Consumption of REEs

After economic reforms of 1991, the Indian economy recorded an impressive growth rate. However, the growth has mostly been services

17 Lok Sabha Unstarred question no 2762answered on 11-03 20.
18 https://investingnews.com/daily/resource-investing/critical-metals-investing/rare-earth-investing/rare-earth-metal-production/#:~:text=Despite%20this%20deal%2C%20India's%20rare,MT%20from%20the%20previous%20year.
19 Answer to the unstarred Lok Sabha question 2762 11 Mar 20
20 https://takshashila.org.in/wp-content/uploads/2020/12/A-Rare-Earths-Strategy-for-India_TDD_AK_AP_NR_v1.0.pdf
21 https://takshashila.org.in/wp-content/uploads/2020/12/A-Rare-Earths-Strategy-for-India_TDD_AK_AP_NR_v1.0.pdf

driven. Successive Governments in India have time and again focused to significantly boost the manufacturing sectors from current 16% to about 25% of GDP by 2025,[22] when this happens, the demand for REEs too would increase. REEs are vital for adoption of green technology (solar, wind and nuclear) which is needed especially as we import nearly 85% on fossil energy which is a cause of huge drain on our economy. The oil import bill will double ($181billion) by 2030 and triple ($255 billion[23]) by year 2040[24]. India's effort to move towards green technology and 'Make in India Programme' in defence manufacturing and high technology industry can succeed and sustain only if we are self reliant in critical minerals including the REEs. India presently, is carrying out ore concentration and purification. However, the industry for production of pure metal is yet to be established.[25]

From available data from the India's Mineral book, India's consumption of rare earth has been very small in the industry. For example, 2013 onward the annual consumption of rare earths in the industry was average 31 tonnes[26] which went up to 63.8 tonnes in 2015-16,[27]Thereafter, average 500-650 tonnes are consumed annually which is too little and is directly proportional to our lack of Industrialisation.

Mining and Processing

Most Rare earths minerals in India are imported in finished form, and India remains a low-cost ore concentrate, and oxide provider to the rest of the world.[28]

---

22 https://www.spglobal.com/en/research-insights/articles/the-missing-piece-in-indias-economic-growth-story-robust-infrastructure
23 https://www.reuters.com/business/energy/india-be-largest-source-energy-demand-growth-2040-iea-2021-02-09/
24 https://economictimes.indiatimes.com/industry/energy/oil-gas/indias-fossil-fuel-import-bill-could-triple-by-2040-iea-study/articleshow/80763811.cms?from=mdr
25 Lok Sabha Unstarred question answered on 11-03 20.
26 Source Indian bureau of mines 2018
27 Source Indian bureau of mines 2019
28 Ibid

IREL has an operating plant in Ganjam dist. of Odisha which has installed capacity of 11000 tpa of RE chloride containing about 5000 tpa of RE oxide. IREL has also facilities at Aluva in Kerala for processing 5ooo tpa of mixed RE chloride for production of 2000 tpa of pure individual oxides or compounds (Neodymium, Praseodymium, Samarium, Cerium and lanthanum etc.)[29]

Rare earth compounds found in ore are converted into economically viable forms through a series of electro chemical processes to remove the impurities. These processes are referred to as "**Upstream processes" and "Down stream processes"**. The Upstream process does not require great technological sophistication. On the other hand, the Down-stream process is capital intensive and environmentally toxic. These processes are only performed in a few countries that have the capital, the technological wherewithal, the industrial base, and the environmental regulations that make them viable.[30]. **(Annexures-VIII & IX)**

Critical REEs

Globally, the REE demand is going to increase incrementally with increase in use of clean energy in particular due to the climate change challenges across the world Indian case is no different. Accordingly, with projected increase of their use in lighting market in coming years, supply of Eu, Tb and Y may not be sustained due to anticipated shortage. Due rising demand of the permanent magnet vis- a- vis their supply even Nd and Dy are likely to become more critical.[31]

RE-based permanent magnets are the key ingredient to the sustenance of the 21st century industrial revolution. Presently, India is depended on imports of the REEs value added products. Dependence on imports for permanent magnet will impede our country's growth in Atomic Energy,

---

29 Aanswer to parliament Question 2762 in Lok Sabha on 11-03 20

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

31 Rare Earth Element Resources: Indian Context By Yamuna Singh

defence, space and other strategic sectors. Indigenous capabilities therefore, are of vital importance.

Even if our REEs industry carries out both upstream and down stream process, we can meet only our Light REEs requirements and we will have to be import HREEs since these are particularly needed for the products of Hi-tech in civil and in the Defence Sector . These are gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb) and lutetium (Lu). In these, **Europium (Eu) Terbium (Tb) Dysprosium (Dy) Lutetium (Lu) Yttrium(Y)** are considered critical for manufacturing in the defence sector**. (Annexure IV & V)**

Pricing

Rare earth element prices rely heavily on China due to its dominant position in the supply chain. The prices surged when China imposed quota in export 2010. Though prices moderated later after WTO ruling against Chinese quota system, the prices are still high. The price of Neodymium used in manufacture of permanent magnet is Rs288500/RMB/t and dysprosiums which is used in the nuclear erectors is (1525 RMB/perkg). Gadolinium oxide (used in medical imaging devices and fuel cells) was available at the average price 159,500 RMB/t. Our own demand of REEs will increase with increase in manufacturing and with increased focus on the green technology. This calls for self reliance since in time to come as with passage of time the rare earths will become scarce and expensive.[32] **(Annexure VII)**

Future Industry's Outlook

The major deterrent to follow the down stream processes to extract metal is the toxic processes which have serious impact on the environment. To solve this the scientific community must invent safe processes for extraction of the metal. In this respect, India Rare Earth Limited (IREL)

32 Rare Earth Element Resources: Indian Context By Yamuna Singh

is setting up a plant at Vizag for manufacture of Rare Earth Permanent Magnet (REPM) based on home grown technology developed by DAE and DMRL for use by DAE, Defence and Space sector. The plant will manufacture 3 tonnes per year of the rare earth metal for manufacture of 3 tonnes per year of the permanent Magnet at BARC campus Vizag.[33]

IREL is also working on setting up a “Rare Earths Theme Park” in Bhopal to scale up laboratory-level technologies and “facilitate setting up value chain in the Rare Earth sector.” [34] These projects are expected to take some years to begin operations but, these initiatives seem to indicate a strategy to create a wholly indigenous supply chain for rare earths.

Import of REE

According to the Indian Mines Bureau, India annual imports of REEs minerals has been in the range 500- 600 tonnes. (383.05 tonnes till Dec21). **(Annexure-X)** The 97% of the need is imported from China.[35] Since we have rich reserve of Monazite which is source of light rare earth metals, their can be avoided if we invest in the value chain enhancement. Until sizeable and economically viable deposits of heavy rare earth metals are discovered in India, these would have to be imported for many high tech and defence applications.

Presently, the rare earth metals consuming industry in India is performing only on a moderate scale. Indian economy is growing, and by 2050, it is expected to be the third largest economy in the world with that REEs consuming industries are expected to grow rapidly in India.

Besides, India is implementing one of the largest renewable energy expansion programmes globally with a target of achieving 175GW of

33 http://164.100.236.73/WriteReadData/userfiles/file/EC%20for%20REPM.pdf
34 https://www.irel.co.in/rare-earth-theme-park-bhopal
35 Answer to the Parliament question 2762 ,11 mar 20

renewable energy capacity by 2022 and later up to 450GW by 2030.[36] NITI Aayog has set up target of 70 per cent of all commercial cars, 30 per cent of private cars, 40 per cent of buses, and 80 per cent of two-wheeler (2W) and three-wheeler (3W) in 2030 to be electric.[37]All these would demand high REEs inputs. If the Indian government comes forward for the development of rare earths in earnest, it will also draw more attention from foreign investors from Japan and the US[38]

Bottle-necks in Exploitation

Merely having deposits of rare earths is no guarantee of being able to exploit them. The mining and extraction processes are capital-intensive, consume large amounts of energy, and release toxic by-products, an issue that has caused some controversy in India before.

India today has granted IREL, a government corporation, monopoly over mining the primary mineral Monazite that contains REEs. IREL produces rare earth oxides (low-cost, low-reward "upstream processes")and selling these to foreign firms that extract the metals and manufacture end products (high-cost, high-reward "downstream processes") elsewhere.

Secondly, IREL's which is carrying our REEs mining was essentially established to provide Thorium / Uranium extracted from monazite for the Department of Atomic Energy.

Thirdly, The REEs mining is not open to the private sector. As per the Mines and Minerals (Development and Regulation) Act, 1957, the minerals of the rare earth group containing Uranium and Thorium are categorized as atomic minerals, falling in the first schedule of the MMDR

---

36 https://www.hindustantimes.com/india-news/indiaus-partnership-to-ensure-india-achieves-renewable-energy-target-by-2030-101617852572591.html

37 https://www.business-standard.com/article/pti-stories/rs-12-5-lakh-cr-investment-needed-to-realise-india-s-2030-ev-targets-study-120120800710_1.html

38 Strategic value of Indian rare earth minerals by R.N. Meshram Chief Mineral Economist at Indian Bureau of Mines

Act, 1957. Monazite is the prescribed substance as per the Atomic Energy act of 1962. Accordingly, IREL (India) a public Sector undertaking is the only permitted entity to process the Monazite to produce RE Earth compounds. [39]

Policy Changes for India

Having the 5th largest REE reserve, India is in a position to become the major player in REE extraction, processing and supplier to the global REEs supply chain. According to a US Geological Survey report, China which has about 37 percent of known global REE reserves produces about 60 per cent of global REE. On the other hand, India with about 6 percent of global REE reserves produces just miniscule 1 percent of global supply which is far below the potential. There is also an extremely high possibility of discovery of new deposits along its coastline and hard rock carbonatites that exist all over the peninsula which could further boost our REEs reserves.

Countries along the Indian Ocean too have REE enriched deposit in their sands. India could source the material through partnership with most of the countries since most of these donot possess the technology/ wherewithal to extract the metal themselves.

Unlike India, the REEs in the Indian Ocean Region are largely be explored, mined, processed, and developed in the private sector, the mineral industry largely exists in the private sector while the governments prefer to stay in a regulatory role. India has restricted the mining to the public sector due to nuclear proliferation concern as the raw mined mineral, Monazite has also significant percentage of restricted mineral thorium and Uranium. We could follow the Australian template which allows the private sector to mine with strict guidelines.[40]

---

39 Answer to parliament Question 2782 in Lok Sabha on 11-03 20

40 Assocham Webinar of 26 Nov 2020 assessed at https://www.assocham.org/eventdetail.php?id=2001

China earlier controlled nearly 90% of global rare earth production, posing a vulnerability to manufacturing industries, which the rest of the world is moving to redress and production across the world has commenced. These developments offer India a precious opportunity to set up downstream Industries for refining and become major export market for Rare Earth and Rare Earth Permanent Magnets, and other high value and high technology products with value addition.[41] Reliable domestic supply of these products would also boost our 'Make in India' programme and move towards Atma-nirbhar Bharat.

Mineral exploration is a high-risk business, and the global trend is for governments to withdraw from investing public funds into such high-risk sectors while creating a policy substrate for small entrepreneurs to succeed. We could follow this template under strict guidelines and regulatory mechanism.

NITI Aayog has recognised the need for self sufficiency in REEs. The expert committee constituted by it has recommended a strategy for self sufficiency and develop a road map to harness the domestic and global REE resource. Committees is in favour of overseas acquisition of RE resources and promotion of REEs industry in India, establishing technologies for RE extraction from fly ash, establishing technologies for RE extraction from red mud, strengthening the recycling of e-waste, and establishing the prospects of RE conversion to magnets.[42]

Another study titled "Critical and non fuel minerals resources for India's manufacturing sector: A vision for 2030" by the Department of Science and technology has identified 49 minerals for sustained growth of the Indian economy. Among these 12minerals, Heavy rare earth minerals are identified as critical minerals. To overcome the limitation, Khanij Bidesh India Limited (KABIL) has been established with participation of National

41 https://www.financialexpress.com/defence/rare-earth-elements-ree-and-strategic-metals-security-how-the-best-way-forward-for-india-diverges-from-chinese-model/2226130/

42 http://niti.gov.in/verticals/industry

Aluminium Corporation (NALCO) Hindustan Copper limited (HCL) and Mineral Exploration Corporation Limited (MECL) to acquire, explore and process 12 critical minerals abroad.[43] The KABIL should also interact with private players instead of just with the Government for positive results.

Closed loop Recycling. With an increased focus on the circular economy, recycling could become an important source for REEs especially in products which use large amount of REEs such as magnets. All magnets found in the EV's and turbines can thus be recycled. Such scrap collection and separation, would minimize any longer-term impacts on the environment and can also become assured source for mineral[44].

Strategy for India

Reform REE Policy. Self sufficiency in REEs is critical for our strategic sectors, emerging non-conventional energy generation, and other hi-technology products. India has abundant LREEs due to their occurrence in monazite. A sustainable supply of LREEs can be developed by reforming India's rare earth policy to take better advantage of its reserves and by processing the pure metal.

Import Scarce HREEs. The inland deposits with HREEs are far less easily available and extracting these will be capital intensive and come with major environmental consequences. As such, India may wish to secure these by trading from multiple sources including its strategic partners.[45]Source diversification will avoid future supply chain disruptions.

Allow Private Sector Investment. The key challenge for India today is to scale up in the upstream and downstream processes of the rare earths value chain. India therefore, must open its rare earth sector to

43 https://dst.gov.in/sites/default/files/CEEW_0.pdf
44 https://www.ree4eu.eu/wp-content/uploads/2017/06/REE4EU_Brochure_Digital.pdf
45 https://takshashila.org.in/wp-content/uploads/2020/12/A-Rare-Earths-Strategy-for-India_TDD_AK_AP_NR_v1.0.pdf

competition and innovation and allow private sector companies to process beach sand minerals within appropriate environmental safeguards and strict nuclear proliferation guidelines following Australian template (Australia allows private sector to mine Monazite with strict guide lines on nuclear proliferation).

Indigenous R&D and Innovation key to Self Reliance. For self reliance, it is important to develop indigenous technology. Towards this effort, Bhabha Atomic Research Centre (BARC) has developed a laboratory-scale process for the conversion of RE oxide to RE metal. BARC currently uses this process to produce up to 1.5 kilograms of Neodymium (RE metal), which is then provided to the Defence Metallurgical Research Laboratory (DMRL) for the development of REPMs.[46]

BARC has also developed technology for 99.99% high purity yttrium oxide production, preparation of lanthanum metal and europium doped yttrium vanadate lamp phosphor has been developed and its technology transferred to IREL.[47]

Vizag will soon strategically important, India's first-of-its-kind, Rare Earth Permanent Magnet (REPM) plant that will produce Samarium Cobalt (SmCo). This plant too is based on the technology developed by BARC and DMRL. SmCo magnets have superior qualities in terms of high magnetic strength, corrosion resistance, device miniaturisation capability and stability at high temperatures. This IREL Plant will supply the SmCo magnets in a continuous manner of various strategic projects.[48]

Acquire Mining interests Abroad. We should also explore and acquire the prospective REEs mining interests in the countries bordering the Indian ocean region. Most of these have no capacity to mine and process these elements by themselves.

---

46 http://niti.gov.in/verticals/industry

47 http://www.barc.gov.in/presentations/fddir20.pdf

48 https://pynr.in/article/vizag-soon-to-be-home-to-rare-earth-magnet-plant

Use Alternate Sources to meet the Demand. Apart from the Monazite, explore rare earth production from the alternate sources like Fly ash (by product of coal based thermal plants) and Red mud (by product of Bauxite mining) which has high percentage of rare earth minerals besides recycling from the e waste and closed loop recycling of the magnets.

Incentivize the Private Sector. Incentivize exploration of REEs for encouraging investment by the private sector. This could pave the way for rapid mineral discoveries. Engaging with the few Indian owned companies that are already operating in this space and supporting them would be a major step in strategic metals security for India. GoI could establish a Strategic fund to support Industry in strategic minerals development.

Structural Reforms. The best move forward is to create a new 'Department for Rare Earths (DRE)'to draw exploration, exploitation, refining, and regulation policies. It could be placed under the Ministry of Mines. This DRE should oversee policy formulation and focus on attracting investment and promoting R&D.

Establish an Autonomous Regulator. Also create an autonomous regulator, the Rare Earths Regulatory Authority of India (RRAI), to resolve disputes between companies in this space and check compliance.[49]

Deep Sea Mining. Due to ecological concerns surrounding REEs mining from traditional beach sand deposits and inland sources, it is imperative to explore other alternative sources of REEs that have less negative ecological footprint such as Deep-Sea Mining. Deep Sea Mining involves the extraction of polymetallic nodules from the sea bed. However, the deep diving platforms required to make it a reality are still in experimental stages.

---

49 https://www.financialexpress.com/defence/rare-earth-elements-ree-and-strategic-metals-security-how-the-best-way-forward-for-india-diverges-from-chinese-model/2226130/

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

Extend PLI scheme to REE industry. To encourage REE manufacturing by private sector, the coverage of existing production linked Scheme (PLI) announced for the manufacturing sector should be extended to the REE down stream sector industry as well. Under the scheme, GoI has announced production linked incentive and has allotted the Government's 1.46 lakh crore PLI scheme in Nov 2020.[50]

Identify New Sources of Critical Minerals in India and Abroad

Increasing activity at all levels of the supply chain. A holistic approach is desired i.e. This should include areas like exploration, mining, concentration, separation, alloying, recycling, and reprocessing critical minerals.

Develop and Maintain Digitised Mining Data. The availability and access to digitised and advanced topographic, geologic, and geophysical data within India to the extent permitted by law to the industry will improve understanding and consequent exploitation of the resource. This data base should also include coastal and oceanic data as well.

Transfer of Technology (ToT). Research Agencies and PSUs like DMRL, IREL, BARC should engage and develop better and less toxic processes to extract the pure metal. The improved processing technology must be transferred to the private players on regular basis.

Secure Mining Interests Abroad. Consortium like KABIL should secure REE mining interests abroad.

---

50 https://www.thehindubusinessline.com/opinion/a-metal-in-the-dumps/article33611616.ece

Collaborate with Strategic Partners. Collaborate with US, Australia and Japan for exploring, refining and ToT of down stream processes.

Skilling of the work Force. Carry out skilling of the work force in the mining sector through engineering and research opportunities.

Short and Long-term Solution. Since we still lack capacity to refine minerals for domestic use, we in short term (0 -2.5 -5 years) tie up for imports of REEs from diverse sources including our strategic partners. There is no other alternative than boost our mining and carry out downstream processing following strict environmental guidelines for production of pure minerals forms of the rare earth mineral and attain atma-nirbharta.

Strategic Reserve. Finally, In line with petroleum reserve, we should develop at least two years strategic reserve to cater our domestic needs and to beat the supply chain disruptions. India could coordinate with strategic partners or with groupings such as the Quad, in building up a strategic reserve.[51] After the recent QUAD meeting in Washington on 23Sep21 , the head of the government of the QUAD nations have joined hands to take on the dominance of China in the supply chain.[52]

Our initiatives such as complete switch over to electric vehicles, generation of 450 GW of renewal energy and 100% electrification by 2030 and possibly also lag in industrialisation 4.0 if we are unable to meet critical minerals inclusive of REEs resource crunch in time.

Conclusion

India with its 5th largest world's REEs reserves, has a potential to mine and extract Rare earth minerals for own use as well as exports. REEs

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

52 https://www.livemint.com/news/world/quad-nations-may-build-rare-earths-to-outplay-china-11615478221265.html

has been identified as one of twelve minerals critical minerals for India by a study by the Department of science and technology but, we are constrained by a lack of technical expertise in processing the reservesin a cost-effective manner. Our own consumption of the REEs has been small due to low domestic manufacturing and what ever we needed is imported.

China has started using its capacity of rare earth as a tool to further its strategic goals and in past imposed quotas for supply. World at large is now aware of Chinese long-term intentions therefore, most of the industrialized states have commenced production of the rare earth minerals to reduce dependence on China. We remain depended for 97% of Rare earth needs by imports from China. With China adopting aggressive stance on our Line of Actual control (LAC) with Tibet, we would have strained relationship with China in future. Therefore, dependence on China for REEs is fraught with supply side risks leaving no option for India to mine and process REEs for own requirement and for exports. Any deficiency in REEs and other critical minerals identified by the science and technology will restrict India capacity to take advantage of Industrialization 4.0 and render India vulnerable.

Across the world, countries are developing strategies to secure raw materials required for various economic activities. Diplomatic ties between countries play a crucial role in international trade relation, specifically in the acquisition of overseas mining rights and their development. These can have a telling impact on long-term security of resource supply hence, must be pursued vigorously in addition to the efforts to ramp up own production. [53]

United States is so much concerned that former President Trump ordered the military to update its supply chain for the niche materials, warning that reliance on other nations for the strategic minerals could hamper

53 A report on ‘Critical Non-Fuel Mineral Resources for India’s Manufacturing Sector: A Vision for 2030’.

U.S. defences. A rare earth processing plant depending on the size and location will cost any where between $ 5 to $20 million and to ramp up the REEs production the Army is prepared to even fund two-thirds of the refiner cost.[54] This indicates the gravity of the situation for the US Army, as it would get involved in a civil project after the Manhattan nuclear project of the second world war.

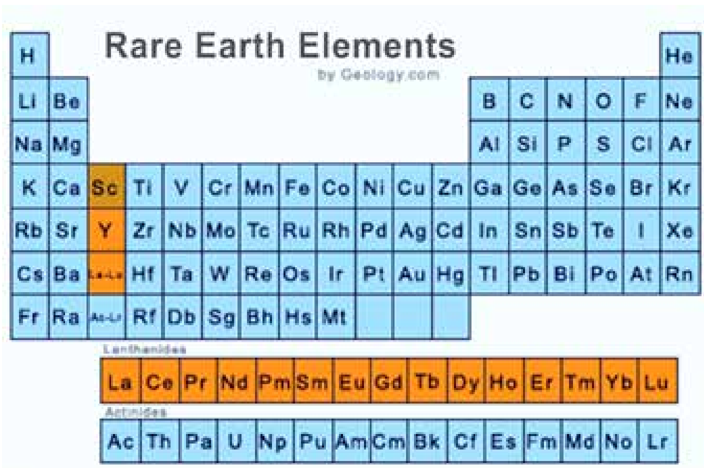
54 https://www.reuters.com/article/us-usa-rareearths-army-exclusive/exclusive-u-s-army-will-fund-rare-earths-plant-for-weapons-development-idUSKBN1YF0HU

Annexure I

RARE EARTH ELEMENTS (REES)

The Rare-earth Elements (REE) are a collection of 17 elements, namely, scandium, yttrium and lanthanides (15 elements in the periodic table with atomic numbers 57 to 71, namely, lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb) and lutetium (Lu).

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). REEs are characterised by high density, high melting point, high conductivity and high thermal conductance.



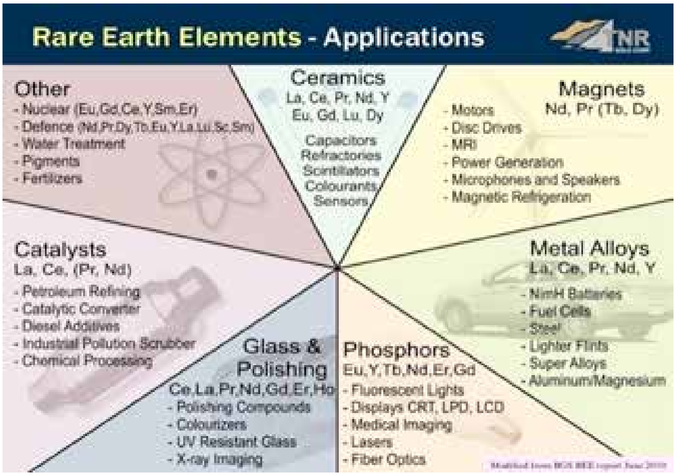
REE Periodic Table: Image by Geology.com.

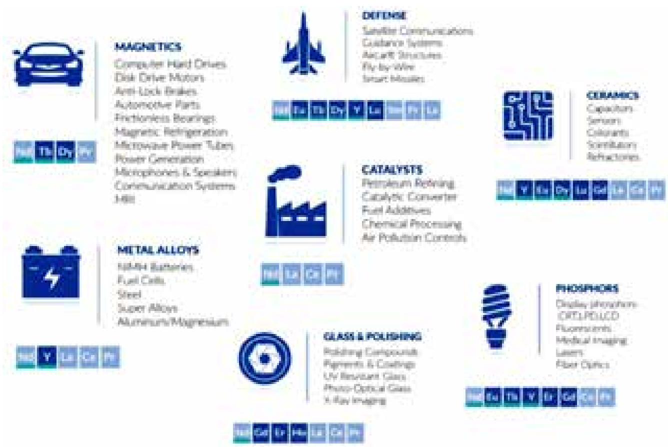
Rare earth elements (REE) are commonly found together in the earth's crust, The estimated average concentration of the rare earth elements in the earth's crust ranges from around 150 to 220 ppm. [55]

55 https://geology.com/usgs/ree-geology/#:~:text=The%20estimated%20average%20concentration%20of,(70%20parts%20per%20million).

Annexure II

RARE EARTH APPLICATIONS[56]





Source: Adapted from National Energy Technology Laboratory, Department of Energy, USA

56 Google.com/search?q=application+of+rare+earth+metals&rlz=1C1CHBF_enCA844CA844&sxsrf=AOaemvI_eTgXvrAcfSjUiR8yfi9Du2VWng:1633078897232&tbm=isch&source=iu&ictx=1&fir=ofQ-WioJJXKR1M%252CU4nMMgQgUGLK-M%252C_%253Bu4TR8Ougfy7_-M%252CaFkBIMYeij8kWM%252C_&vet=1&usg=AI4_-kT_23XyJVMd1-dgNpHE8NI6tzOxLg&sa=X&ved=2ahUKEwjJvrz87KjzAhVhyTgGHSYWCQIQ_h16BAgFEAE&biw=1366&bih=657&dpr=1#imgrc=u6wumXW6l6F2LM

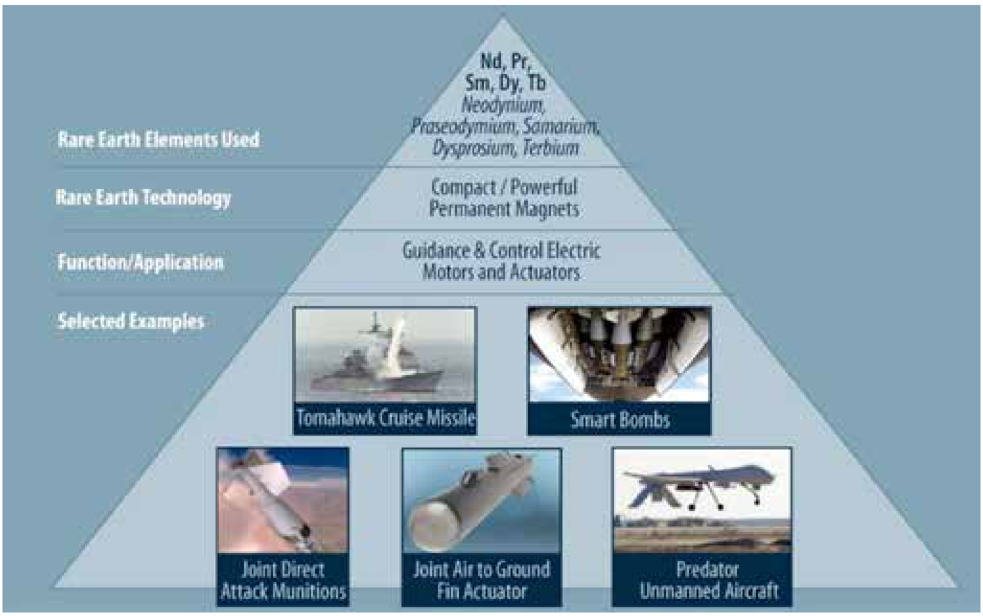
Annexure III

DEFENCE USE OF RARE EARTH

The following illustrations (Figures 1-5) show the use of rare earth elements in a variety of defense-related applications:

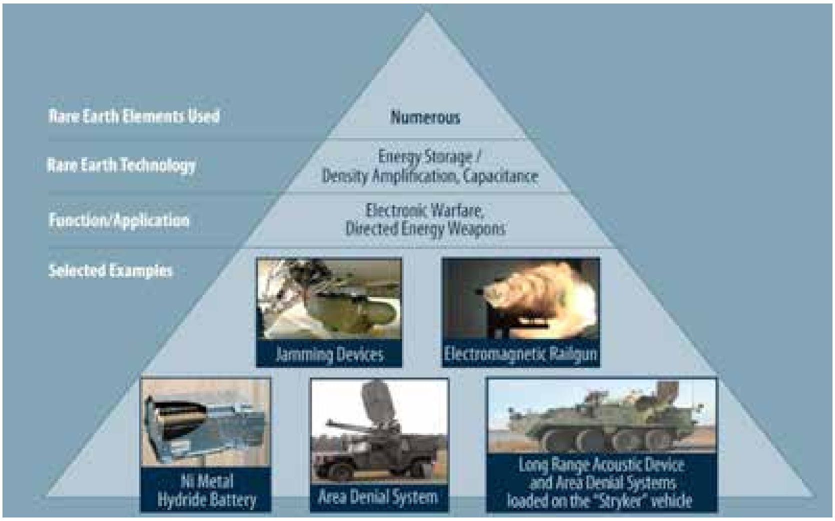
- Fin actuators in missile guidance and control systems, controlling the direction of the missile;
- Disk drive motors installed in aircraft, tanks, missile systems, and command and control centers;
- Lasers for enemy mine detection, interrogators, underwater mines, and countermeasures;
- Satellite communications, radar, and sonar on submarines and surface ships; and• optical equipment and speakers.

Figure 1. Rare Earth Elements in Guidance and Control Systems



Source: Compiled from presentations by the Rare Earth Industry and Technology Association, the United States Magnet Manufacturing Association, and David Pineault, "Global Rare Earth Element Review," Defense National Stockpile Center, spring 2010.

Figure 2. Rare Earth Elements in Defense Electronic Warfare

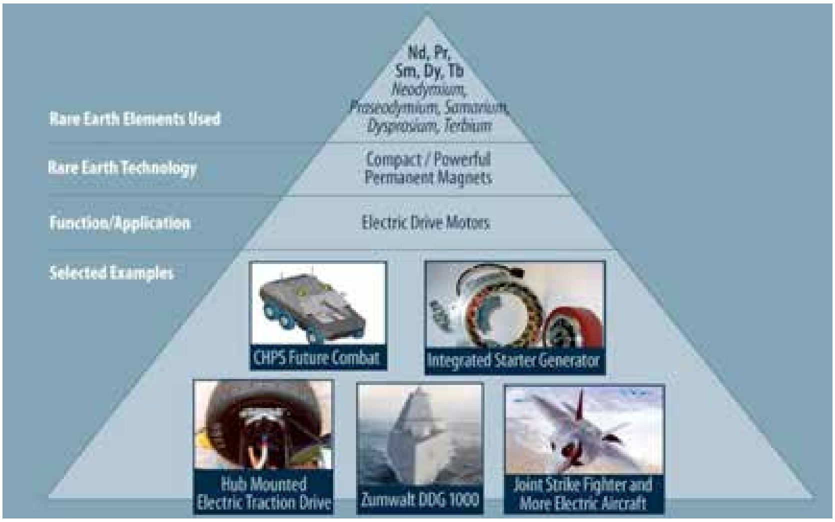


Source: Compiled from presentations by the Rare Earth Industry and Technology Association, the United States Magnet Manufacturing Association, and David Pineault, "Global Rare Earth Element Review," Defense National Stockpile Center, spring 2010.
Rare Earth Elements in National Defense Congressional Research Service 5

Figure 3. Rare Earth Elements in Targeting and Weapon Systems

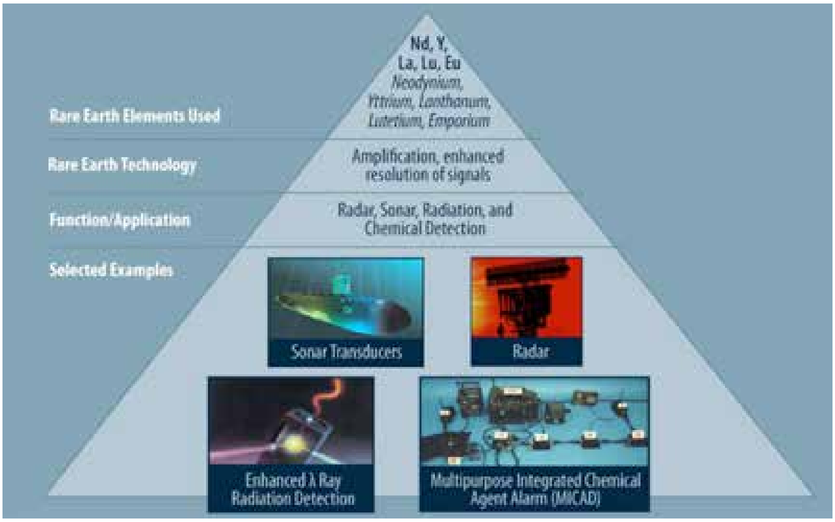
Source: Compiled from presentations by the Rare Earth Industry and Technology Association, the United States Magnet Manufacturing Association, and David Pineault, "Global Rare Earth Element Review," Defense National Stockpile Center, spring 2010.
Rare Earth Elements in National Defense
Congressional Research Service 6

Figure 4. Rare Earth Elements in Electric Motors



Source: Compiled from presentations by the Rare Earth Industry and Technology Association, the United States Magnet Manufacturing Association, and David Pineault, "Global Rare Earth Element Review," Defense National Stockpile Center, spring 2010.

Figure 5. Rare Earth Elements and Communication



Source: Compiled from presentations by the Rare Earth Industry and Technology Association, the United States Magnet Manufacturing Association, and David Pineault, "Global Rare Earth Element Review," Defense National Stockpile Center, spring 2010.

Annexure IV

USES OF REES IN THE DEFENCE INDUSTRY

Yttrium	Microwave, Optical coating and LEDs.
Promethium	Long life batteries for missiles
Lanthanum	Optics, Lenses, night vision goggles, Fuel cells.
Europium	LEDs and Plasma Displays.
Samarium	Lasers.
Praseodymium	Aircraft Engines
Yttrium, terbium and Europium	Displays for TVs and computers

In reality the defence systems require inputs of several REEs in their manufacture. The table below gives their use in various defence systems.

1. Guidance & Control systems, Neodymium, Samarium, Praseodymium, Dysprosium, Terbium.

2. Electronic Warfare, DEWs Numerous.

3. Targeting and weapon systems- Europium, Terbium.

4. Electric Motors Neodymium, Praseodymium Samarium, Dysprosium Terbium.

5. Comn, radar, sonar. Neodymium,Yttrium, Lanthanum, Lutetium, Europium, Erbium.

Critical REES in Defence – Europium (Eu) Terbium (Tb) Dysprosium (Dy) Lutetium (Lu) Yttrium (y),

<u>Annexure V</u>

CRTICAL RARE EARTH MINERALS FOR INDIA

<u>Magnetics</u>	**Neodymium (Nd), Terbium (Tb), Dysprosium (Dy), Praseodymium(pr)**
<u>Metal Alloys</u>	**Neodymium (Nd), Ytterbium(y), lanthanum (La), Cerium (Ce), Praseodymium(pr)**
<u>Defence</u>	**Neodymium (Nd) Europium (Eu)Terbium (Tb) Dysprosium (Dy) ytterbium(y) Lutetium (Lu) Samarium (Sm) Praseodymium (pr) lanthanum (La)**
<u>Catalysts</u>	**Neodymium (Nd) Europium (Eu) lanthanum (La) Cerium (Ce) Praseodymium (pr)**
<u>Ceramics</u>	**Neodymium (Nd) ytterbium(y) Europium(Eu) Dysprosium (Dy)Lutetium (Lu) Gadolinium (gd) lanthanum (La) Cerium (Ce) Europium (Eu) Praseodymium(pr)**
<u>Phosphors</u>	**Neodymium (Nd) Europium (Eu) Terbium (Tb) Yetterbium (Y) Erbium (Er) Gadolinium (Gd) lanthanum (La), Cerium(Ce) (Ce)Europium(Eu) Praseodymium(Pr)**
Glass & Polishing	**Neodymium (Nd) Gadolinium (Gd) Holmium (Ho) lanthanum (La), Cerium(Ce) Praseodymium(Pr)**
<u>Critical REEs</u>	**Terbium (Tb),Europium (Eu) Holmium (Ho) Yetterbium(Y)Erbium (Er)Europium (Eu) Dysprosium (Dy) Gadolinium (Gd)**

Note: All critical REEs are heavy Earth minerals which need importing from external source, Since India does not have economically viable heavy earth metal source with in the country.

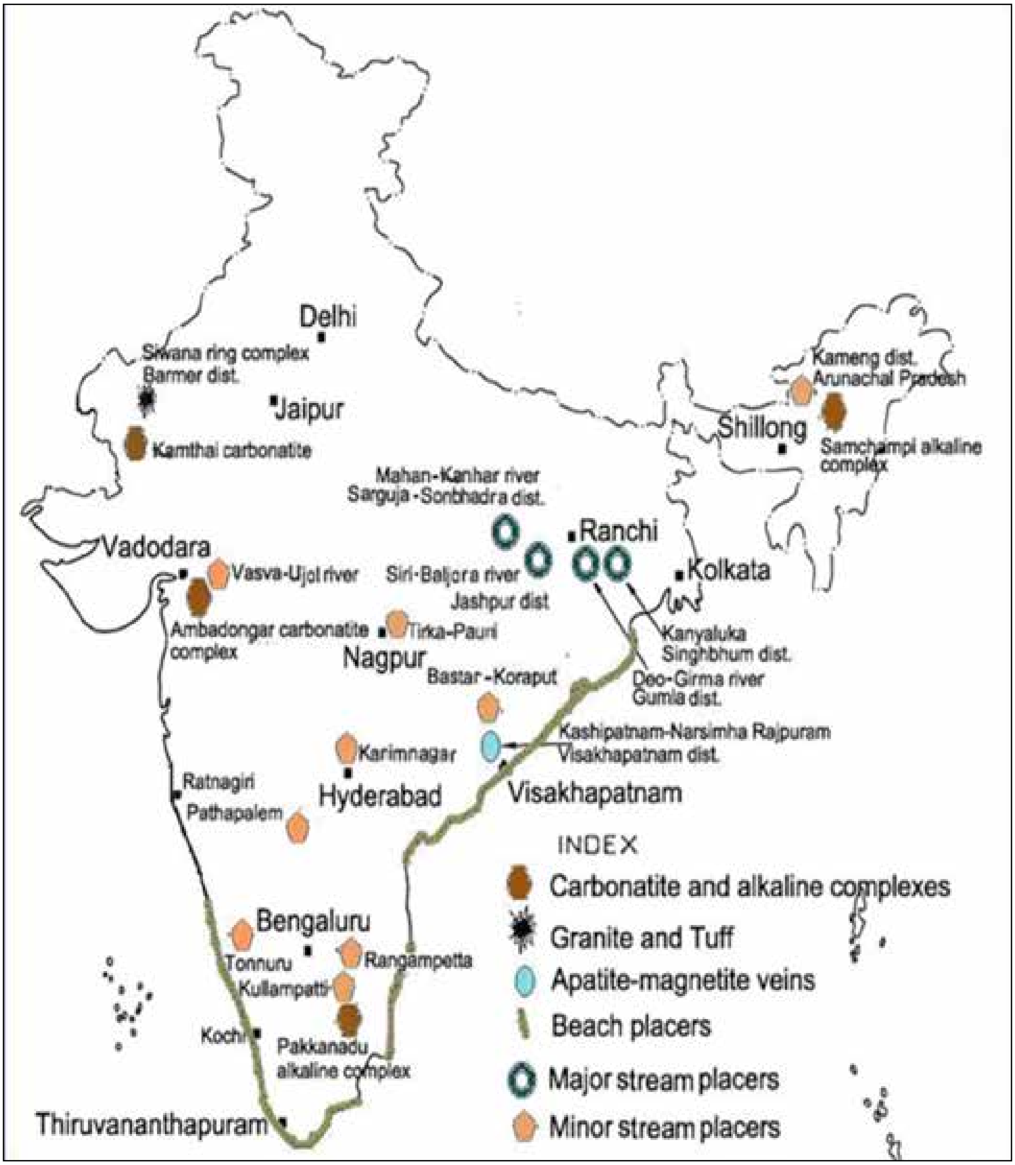
Annexure VI

WORLD RARE EARTH RESERVE AND PRODUCTION[57]

Country	Production (Metric Tons)	Reserves (Metric Tons)
United States	38,000	1,500,000
Australia	17,000	4,100,000
Brazil	1,000	21,000,000
Burma	30,000	N/A
Burundi	500	N/A
Canada	--	830,000
China	140,000	44,000,000
Greenland	--	1,500,000
India	3,000	6,900,000
Madagascar	8,000	N/A
Russia	2,700	12,000,000
South Africa	--	790,000
Tanzania	--	890,000
Thailand	2,000	N/A
Vietnam	1,000	22,000,000
Other Countries	100	310,000
World total (rounded)	240,000	120,000,000

57 https://geology.com/articles/rare-earth-elements/

GEOGRAPHICAL LOCATIONS OF SELECTED REE DEPOSITS/ OCCURRENCES OF INDIA



Annexure VII

INTERNATIONAL PRICING OF THE REES AS ON 2019[58]

Price of selected rare earth oxides as on November 08, 2019

S. No.	oxides	rice range	Average	Unit
1	Lanthanum oxide	12,000–12,500	12,250	RMB/t
2	Cerium oxide	12,000–12,500	12,250	RMB/t
3	Praseodymium oxide	340,000–350,000	345,000	RMB/t
4	Neodymium oxide	287,000–290,000	288,500	RMB/t
5	Samarium oxide	12,000–13,000	12,500	RMB/t
6	Europium oxide	210–220	215	RMB/kilogram
7	Gadolinium oxide	157,000–162,000	159,500	RMB/t
8	Terbium oxide	3450–3480	3465	RMB/kilogram
9	Dysprosium oxide	1510–1540	1525	RMB/kilogram
10	Holmium oxide	325,000–330,000	327,500	RMB/t
11	Erbium oxide	160,000–165,000	162,500	RMB/t
12	Thulium oxide – – –			
13	Ytterbium oxide – – –			
14	lutetium oxide – – –			
15	Yttrium oxide	19,500–20,500	20,000	RMB/t

Source Google.com; price.metal.com/Rare-Earth

Conversion rate of Chinese currency, renminbi (RMB): 1 RMB = Rs. 10.20 on November 8, 2019

---

58 Rare Earth Element Resources: Indian Context By Yamuna Singh

Annexure VIII

MONAZITE COMPOSITION

Composition	%
REEs as Re_2O_3	59.37
P_2O_5	27.03
ThO_2	8.88
U_3O_8	0.35
CaO	1.24
SiO_2	1.00
MgO	0.63
Fe_2O_3	0.32
Al_2O_3	0.12
PbO	0.18
TiO_2	0.36
ZrO_2	0.49

Annexure IX

LIGHT RARE EARTH ELEMENT (MONAZITE) CONSTITUENTS

Lanthanum (La)	22%
Cerium(Cr)	46%
Praseodymium(pr)	5.5%
Neodymium(nd)	20%
Samarium(sm)	2.5%
Gadolinium(gd)	0.2%
Terbium(Tb)	0.06%
Dysprosium(Dy)	0.18%
Holmium(Ho)	0.02%
Erbium(Er)	0.01%
Yttrium(Y)	0.45%

<u>Annexure X</u>

IMPORT OF RARE EARTHS BY INDIA

(IN TONNES)

Industry	2013 to 2015	2015-16	2016-17	2017-2018	2018-2019
Total	31(average)[59]	63.8[60]	519.62	492.41	643.41
	2019-20 (Up to Dec 19)				
	383.05[61]				

As per the Statement of Minister of Science and Technology to an unstarred question 2762 in Lok Sabha on 11 March 20 no Industry has been established for extraction of Pure REEs metal

59 Indian bureau of mines 2018

60 Indian bureau of mines 2019

61 Based on Answer to the Parliament question 2762 11 Mar2020