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Importance Of Rare Earth Elements In Modern Technologies

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Abstract

Rare earth elements are the most important elements due to their special material properties. In this review article, we aim to highlight the importance of Rare-earth elements. These are used in smartphones, digital cameras, computer hard disks, light-emitting diodes (LEDs), computer monitors, flat-screen televisions, and electronic displays. It is used in the ceramic and glass industry for high-temperature materials for polishing, coating, decolouring, etc. They are also used as a permanent magnet, in X-ray tubes, as phosphors in colour television, for clean energy, and in defence technology.

Key words : Rare-earth elements, smartphones, electronic display, light-emitting diode.

Introduction

Rare earth elements (REE) are a group of seventeen elements of the periodic table. Scandium, Yttrium, and Lanthanides (15 elements with atomic numbers 57 to 71). Scandium and Yttrium are considered REE because they tend to occur in the same ore deposits as the Lanthanides and exhibit similar chemical properties. Lanthanides are divided into two groups: one is the light rare earth elements, and the other is the heavy rare earth elements. The light rare earths are lanthanum through europium, with atomic numbers 57 to 63, and the heavy rare earth elements are those with atomic numbers 64 to 71. The abundance of rare earth elements in our Earth's crust is comparable to many well-known and common elements like silver, tin, tungsten, and mercury. Therefore, their compounds ought to play an important role in our present and future lives[13,16,6,12].

Table 1 presents the average abundance of rare earths in the Earth's crust. For comparison, average crustal abundances for gold, silver, lead, and copper are 0.004, 0.075, 14, and 60 parts per million, respectively[18].

Table 1. Average abundance of REE in the Earth's Crust (in parts per million)

Element	Symbol	Atomic number	Crustal abundance
Lanthanum	La	57	39
Cerium	Ce	58	66.5
Praseodymium	Pr	59	9.2
Neodymium	Nd	60	41.5
Samarium	Sm	62	7.05
Europium	Eu	63	2.0
Gadolinium	Gd	64	6.2
Terbium	Tb	65	1.2
Dysprosium	Dy	66	5.2
Holmium	Ho	67	1.3
Erbium	Er	68	3.5
Thulium	Tm	69	0.52
Ytterbium	Yb	70	3.2
Lutetium	Lu	71	0.8
Yttrium	Y	39	33

This review aims to provide an updated understanding of REE in the global scenario, starting from their occurrence, recycling, and their application in modern technology. Their application in agriculture, medicine, and environmental effects is also presented.

A) Resource & Development :

The Rare-earth elements do not exist as industrially native metals in nature as copper, silver, and gold. They occur in numerous minerals as either major or minor constituents. The principal sources of REE are Bastnasite, Xenotime, commonly found in minerals and deposits, loparite, which occurs in alkaline igneous rock, and monazite. There are over 250 minerals that contain rare-earth elements as important constituents in their chemical formula and crystal structure[5]. Table 2 presents a list of some important rare earth-containing minerals[5].

Table 2. Formula and name of some important REE associated with rare earth deposits.

Minerals	Formula
Allanite	(Y, Ln, Ca) (Al, Fe^{+3} $)_3$ (SiO4) $_3$ (OH)
Apatite	(Ca, Ln) $_5$ (PO_4) $_3$ (F, Cl, OH)
Bastnasite	(Ln, Y) (Co_3) F
Fergusonite	(Ln, Y) NbO_4
Gittinsite	Ca Zr Si_2 O_7
Limorite	Y_2 (SiO_4) (CO_3)
Loparite	(Ln, Na, Ca) (Ti, Nb) O_3
Monazite	(Ln, Th) PO_4
Parisite	Ca $(Ln)_2$ $(CO_3)_3$ F_2
Xenotime	YPO_4
Zircon	(Zr, Ln) SiO_4

The total world reserves of rare earth oxide (REO) by principal countries are estimated at 120 million tonnes. China has 36.67% of the world's resources, followed by Vietnam and Brazil, which have 18.3% each, and Russia has 10%, while India holds about 5.75% of the world's rare earth reserves. (Geological Survey US; 2019-2021).

Table 3. World Reserves of Rare-earth

Country	2019		2020		2021	
World Total(rounded)	120000	**%share**	120000	**%share**	120000	**%share**
China	44000	36.67	44000	36.67	44000	**36.67**
Vietnam	22000	18.33	22000	18.33	22000	**18.33**
Brazil	22000	18.33	22000	18.33	21000	**17.50**
Russia	12000	10	12000	10	12000	**10**
India	6900	5.75	6900	5.75	6900	**5.75**
Australia	3400	2.83	3300	2.83	4100	**3.42**
Greenland	—	—	1500	1.25	1500	**1.25**
USA	1400	1.17	1400	1.17	1500	**1.25**
Tanzania	—	—	890	0.74	890	**0.74**
South Africa	—	—	790	0.66	790	**0.66**
Canada	—	—	830	0.69	830	**0.70**
Malawi	—	—	—	—	—	—
Malaysia	30	0.03	—	0.03	—	—
Other Countries	**310**	**0.26**	**310**	**0.26**	**280**	0.23

China holds the leading position among producers of rare earth oxides, with 140,000 tonnes. The other major producers are Myanmar, Australia, the USA, Russia, and Malaysia, as shown in Table 4 (BGS 2014-2018).

Table 4. World Production of Rare Earth Oxides (By Principal Countries).

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

China owns a virtual stranglehold on rare earth production and processing, with 95% of rare earth oxide mined and 97% of rare earth metal refined in China. The nation is also a leader in rare earth research and development. Now, efforts on several fronts are aimed at boosting REE production outside of China, including plans to reopen REE mines in the US and South Africa as well as develop rare earth deposits in Australia, Canada, and elsewhere.

B) Uses and Consumption :

Due to their pervasive applications in a number of technologies, Rare earth elements have become an essential component of present-day life[14]. Table 4 summarizes the extensive application of rare earths in different areas.

Table 5. Application of rare earth in different areas.

Areas	Application
Electronics	Television screen, computers, cell phones, silicon chips, monitor display, long-life rechargeable battery, camera lens, LEDs, Compact fluorescent lamps (CFLs), marine propulsion system.
Manufacturing	High-strength magnets, metal alloys, stress gauges, ceramic pigments, colorants, plastic, and creations are used as additives for strengthening other metals.
Medical science	Portable X-ray machine, X-ray tubes, magnetic resonance imagery (MRI), Cancer treatment, genetic screening test, and dental laser.
Technology	Lasers, Optical glasses, Fiber optics, Masers, radar detection, nuclear fuel rods, mercury-vapor lamps, computer memory, and high-temperature superconductors.
Renewable Energy	Hybrid automobiles, wind turbines, next-generation rechargeable batteries, bi-fuelcatalysts.

Because of their unique physical, chemical, and magnetic luminescent properties, these elements help to make many technological advantages, such as performing at reduced energy consumption, greater efficiency, speed, durability, and thermal stability.

They are used in industries such as Catalysts, glass production, and metallurgy. However, they play an increasingly important role in the application of high technology, which includes batteries, ceramics, and permanent magnets. Table 6 presents the main uses of rare earth elements. Elements such as lanthanum and Cerium are most often used in mature markets. Dysprosium, neodymium, and praseodymium are used in high technology[3]. Permanent magnets production is the largest and most important use of REE, accounting for over 29% of Total consumption of these elements in 2022[8].

Table 6. Main uses of Rare Earth Elements

REE	Symbol	Application
Scandium	Sc	High-strength Al-Sc alloys, electron beam tubes.
Yttrium	Y	Phosphors for fluorescent lighting and liquid crystal display (LCDs), capacitors, radars, lasers, superconductors, and glasses.
Lanthanum	La	Battery alloys, phosphors, glasses, ceramics, car catalysts, lasers, pigments, and accumulators.
Cerium	Ce	Catalysts, phosphors, ceramics, glasses, pigments
Praseodymium	Pr	Permanent magnets, photographic filters, ceramics, glasses, pigments.
Neodymium	Nd	Permanent magnets, catalysts, lasers, and pigment for glass and ceramics.
Promethium	Pm	Miniature nuclear batteries, phosphors.
Samarium	Sm	Permanent magnet, reactor control rods.
Europium	Eu	Fluorescent lighting and LCDs.
Terbium	Tb	Lighting and display phosphors, permanent magnets.
Dysprosium	Dy	Permanent magnets, laser lighting, nuclear industry.
Holmium	Ho	Magnets, lasers, nuclear industry.
Erbium	Er	Laser, optical fibres, glass colorant, and the nuclear industry.
Ytterbium	Yb	Solar panels, fibre optics, lasers, metallurgy, and nuclear medicine.
Lutetium	Lu	X-ray phosphors.
Thulium	Tm	Magnets, electron beam tubes.
Gadolinium	Gd	Nuclear fuel bundles, medical imaging, and electronics.

As the demand for rare earth metals in a wide range of technology applications continues to increase, efforts to re-establish the mining and production of REE are underway everywhere. Due to the unusual physical and chemical properties of REE. Rare earths have diverse applications that touch many aspects of modern life and culture. Specific REEs are used to make phosphors-substances that emit luminescence for many types of ray tubes and flat displays, in screens that range in size from smartphone displays to stadium scoreboards. Some REEs are used in fluorescent and LED lighting. Yttrium, europium, and terbium phosphors are the red-green-blue phosphors used in many light bulbs, panels, and televisions.

The glass industry is the largest consumer of REE raw materials, using them for glass polishing and as additives that give special optical properties and provide colour. Lanthanum makes up as much as 50 percent of digital camera lenses, including cell phone cameras.

Lanthanum-based catalysts are used to refine petroleum, while cerium-based catalysts are used in automotive catalytic converters.

Magnets that employ rare earths are rapidly growing in application. Rare earth magnets are used in computer hard disks, CD-ROMs, and DVD drives. The spindle of a disk drive attains high stability in its spinning motion when driven by a rare-earth magnet. These magnets are also used in a variety of conventional automotive subsystems, such as power steering, electric windows, power seats, and audio speakers.

Cerium, Lanthanum, neodymium, and praseodymium, commonly in the form of a mixed oxide known as mischmetal, are used in steel making to remove impurities and in the production of special alloys.

Research and studies are going on globally for cost-effective recovery of REE from e-waste[7,19]. These studies include automated approaches and disassembling electronic scrap, as well as chemistry to extract REE from them. Therefore, REEs are consumed in a variety of ways at an unprecedented rate. Since they are extremely important hence these elements are called. "The vitamins of Modern Industry"[1].

REE can affect the growth and development of plants[21]. Rare earths enhance plant biomass by stimulating the uptake of mineral nutrients and promoting the synthesis of chlorophyll[15]. It is also used in agriculture as fertilizer to improve crop growth and production, and therefore leads to a further increase in the concentration of REE in soil[23].

Besides modern technologies with their tremendous need for rare earth elements, their use in medicine has gained prominence in different molecular imaging techniques and radiotherapies. Lanthanides are used in many health and medical applications, such as in anti-tumor agents, kidney dialysis, medicine, and surgical equipment. Due to their optical properties, rare earths have been used in many imaging techniques such as magnetic resonance imaging (MRI)[22,17]. Table 7 summarizes the medical application of REE [11].

Table 7. Medicinal Application of Rare Earth Elements.

REE	Medical Application
La	Lanthanum oxide nanoparticles can be used for MRI.
Ce	Cerium-doped lutetium orthosilicate is a scintillator that has been mainly used for PET imaging, a type of test that reveals tissue and organ function.
Pr	Praseodymium oxide nanoparticles have been used in radiotherapy techniques.
Nd	Neodymium has been used in lasers as a crystal and is employed in the treatment of skin cancer as well as laser hair removal.
Sm	A radioisotope, Sm-153, has been used to treat severe pain in patients whose tumours have advanced into bone tissues.
Eu	Europium presents bio applications due to its optical properties as nanoprobes with an

	emphasis on their heterogeneous/homogeneous bio detection as well as in vitro and in vivo bioimaging.
Gd	Gadolinium enhances MRI images of tumours, and its magnetic properties are also of use in intravenous radio-contrast agents in MRI scans.
Tb	A radioisotope, Tb-149, has been used in targeted cancer therapy.
Dy	A radioisotope, Dy-165, has been employed in the treatment of rheumatoid knee effusions.
Ho	Holmium-based solid-state lasers have been used for non-invasive medical procedures for treating cancers and kidney stones.
Er	Erbium-based lasers have been used in medical and dental practice.
Tm	A radioisotope Tm-167, has been used as a power source in portable X-ray devices.
Yb	A radioisotope Yb-176 can be used to produce Lu-177, which is known to be a promising radioisotope for a medical application.

New medical applications for these elements are being found at an increasing rate, and emerging advancements such as nanotechnology might be used to enhance their use in medicine in the future.

The extensive use of REE in various modern technologies continues to grow despite some knowledge about the environmental concerns of REE as they are getting released into the environment along with radioactive nuclides. Most of the harmful effects of REE exposure to humans and their potential health effects come from the studies of mine workers and others who regularly deal with REE or its products[20]. Therefore, there is a need for the development of more effective treatment technologies will determine the future adverse impact of REE on the ecosystem. There is a great need to understand the toxicological properties of REE as there is a widespread use of their element within agriculture and medicine, and more studies and consolidation are needed to accurately assess the impact of these elements on human health (Givenzi etal, 2018).

Scope of Future Research :

Despite significant advancements in the understanding and application of rare earth elements, there remain several key areas that warrant further investigation. Future research can be directed toward the different domains.

The growing importance of rare earth elements (REEs) in modern technologies presents a wide array of opportunities for future research. One major area is the development of sustainable and eco-friendly extraction and processing techniques. Traditional mining and refining processes are energy-intensive and environmentally hazardous; hence, there is a need to explore green alternatives such as bioleaching and cleaner chemical methods. Additionally, the advancement of efficient recycling technologies for recovering REEs from electronic waste and used magnets is vital. Urban mining and product designs that allow for easy disassembly and material recovery can significantly reduce reliance on primary sources.

Another promising direction lies in the search for alternative materials that can serve as substitutes for REEs in critical applications. Research into nanomaterials, composites, and non-rare earth-based functional materials may offer solutions to reduce dependence while maintaining or enhancing device performance. Geological studies to discover new REE deposits, especially in underexplored or politically stable regions, are also crucial. Emerging concepts such as deep-sea and extraterrestrial mining, though in their infancy, hold future potential.

Geological and geochemical research continues to be important for identifying new terrestrial and extraterrestrial deposits. Deep-sea nodules, hydrothermal vents, and even asteroid mining are being explored as futuristic sources. However, these require detailed environmental risk assessments and international legal frameworks, which in themselves form a new domain of policy-oriented research.

From a geopolitical perspective, future studies must address the monopolization of REE supply chains, particularly the dominance of a few countries. Research can inform policies for international cooperation, the creation of strategic reserves, and the decentralization of supply. Economic models that assess the long-term value of investing in domestic REE industries, subsidies for green mining, and taxation on environmentally harmful practices are also worth exploring.

In summary, the scope for future research in the field of rare earth elements is vast and multi-dimensional. Addressing the scientific, environmental, and geopolitical challenges surrounding REEs will require not only technological innovation but also global cooperation and policy-driven strategies.

Conclusion

Rare Earth Elements (REEs) have become indispensable in the advancement of modern technologies, ranging from consumer electronics and renewable energy systems to advanced defense equipment and medical diagnostics. Their unique magnetic, optical, and catalytic properties make them critical for the development of high-performance, miniaturized, and energy-efficient devices. However, the growing global dependence on REEs also highlights significant challenges, particularly regarding their limited supply, the environmental impact of extraction, and geopolitical vulnerabilities.

Due to the unique magnetic, luminescent, chemical, and physical properties of rare earths, they are an essential part of many high-technology applications. Fast-emerging green technologies, ranging from electric car batteries to solar panels and wind turbines, among others, are widely utilizing REEs. There is a great need to intensify our search for REE resources not only on land but also in the ocean bottom sediments. In essence, the strategic importance of REEs will only deepen in the coming decades, making it imperative to balance technological growth with sustainability and responsible resource management.

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