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DEFENCE AND CIVILIAN APPLICATIONS OF RARE EARTH ELEMENTS

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INTRODUCTION

The many strategic uses of Rare Earth Elements (REEs) have made them a centrepiece of contemporary geopolitics, in view of their application being in both military and civilian fields. Given their growing importance in every aspect of technological advancement, it is not surprising that nations are trying to secure their supply of these resources. The world has witnessed the demand for rare earth metals skyrocketing and it is projected to reach 315,000 tonnes by 2030 and so is their supply risk, due to factors like the dominance of China on the rare earth supply chain; the growing global shift towards clean technologies like electric vehicles, wind and solar power; the economic importance of these metals, and so on.¹

It has been increasingly difficult to balance the abundance of rare earth ores and their production as per their demand in the market. In order to clarify the strategic importance of these elements, this paper aims to elaborate on their applications in detail, ranging from hard power driven defence technology to the soft civilian-based technological needs.

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1. Poul Due Jensen, "Collective Action to Save Our One and Only Earth", *Grundfos*, June 5, 2022, at <https://www.grundfos.com/about-us/news-and-media/news/collective-action-to-save-our-one-and-only-earth>. Accessed on June 20, 2022.

The term ‘rare earth elements’ is somewhat of a misnomer or misleading, as these elements are available in abundant amounts in the earth’s crust. In fact, some elements are more abundant than common elements like copper, lead and gold. The adjective ‘rare’ for these elements is used due to the rare production and refining capacity of these elements.

WHAT ARE RARE EARTH ELEMENTS?

According to the International Union of Pure and Applied Chemistry (IUPAC) definition, rare earth metals are a family of 15 elements in the periodic table, which starts with lanthanum and ends with lutetium, known together as the ‘Lanthanides Group’. Because of their unique electronic configuration with “ $4f^0$ to $4f^{14}$ ” orbital electrons cells ($[Xe]4f^0$ to $[Xe]4f^{14}$), their physical and chemical properties are comparable and occur in nature under similar physico-chemical conditions. Two more elements from Group 3A, yttrium (Atomic# 39) and Sc (Atomic# 21), are also often included as REEs because of their similarity in

physical and chemical properties and geochemical affinity with REEs.² The term ‘rare earth elements’ is somewhat of a misnomer or misleading, as these elements are available in abundant amounts in the earth’s crust. In fact, some elements are more abundant than common elements like copper, lead and gold. The adjective ‘rare’ for these elements is used due to the rare production and refining capacity of these elements. These 17 REEs were discovered in the late 18th-19th century, with yttrium being the first in 1794 and promethium the last in 1947. Of these REEs, Pr (Promethium At# 61) does not occur in nature.³

In 1794, the term ‘rare earth’ was first introduced by Johann Gadolin by observing their availability in the earth’s crust in a small amount, and their having an earthly appearance—looking like soil or rock. Thulium and lutetium are nearly 200 times more abundant in the earth’s crust than gold. The total

2. Stefania Massari and Marcello Ruberti, “Rare Earth Elements as Critical Raw Materials: Focus on International Markets and Future Strategies”, *Resource Policy*, 38, pp. 36-43.

3. Ibid.

content of REEs in the earth’s crust averages about 154 mg/kg¹, and in the soil, it is 100-200 mg/kg.⁴ These elements have been subdivided into Heavy REEs (HREE, At# 65 to 71)) and Light REEs (LREE; At# 57 to 64) based on their atomic weight. However, the exact boundary between heavy and light is often not well defined. It has been observed that the light rare earth elements are much more abundant or available in the earth’s crust than the heavy ones, which makes HREEs critical. Among LREEs, Neodymium is the most critical one as it is extensively used in all mobile phones, medical equipment and electric vehicles. In addition, the permanent magnets used in wind turbines and data storage systems use neodymium as an essential ingredient. HREEs like dysprosium, yttrium and cerium are critical for clean energy technologies. However, due to their limited supply, they have a small market⁵ (see Table 1).

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Table 1: The Seventeen Rare Earth Elements

Rare Earth Name	Discovery Year	Atomic Name & Number	The Chemist who Named it	Light/ Heavy REE	Critical/ Uncritical	Abundance in the Earth’s Crust (Parts per million)	Usage
Yttrium	1788	Y-39	Sweden- Johan Gadolin	Heavy	Critical		Metal Alloys and Night Vision Goggles

4. Science History Institute, “The History and Future of Rare Earth Elements”, at <https://www.sciencehistory.org/learn/science-matters/case-of-rare-earth-elements-history-future>. Accessed on June 10, 2022.
5. Shiv Padhy, “Rare Earth Metals: Heavy vs Light”, *Rare Earth Investing News*, 2017, at <https://investingnews.com/daily/resource-investing/critical-metals-investing/rare-earth-investing/investing-in-rare-earth-heavy-vs-light/>. Accessed on September 30, 2021.

DEFENCE AND CIVILIAN APPLICATIONS OF RARE EARTH ELEMENTS

Cerium	1803	Ce-58	Europe- John Jacob Berzelius	Light	Excessive	60.0	Automobiles
Lanthanum	1839	La-57	Sweden- Carl Gustaf Mosander	Light	Uncritical	30.0	Optical Glasses, Night Vision Goggles
Erbium	1842	Er-68	"	Heavy	Critical	2.1	Fibre and Optic Cables Machine
Terbium	1843	Tb-65	"	Heavy	Critical	0.7	Visual Display and Fuel Cells
Ytterbium	1878	Yb-70	Sweden- Jean-Charles Galissard	Heavy	Excessive	2.0	Stainless Steels
Holmium	1878	Ho-67	Sweden- Per Teodor Cleve	Heavy	Excessive	0.8	High Strength Magnets and Glass Colouring
Scandium	1879	Sc-21	Scandinavia- Lars Fredrik Nilson	Heavy	Critical	16.0	Defence Equipment
Samarium	1879	Sm-62	France- Paul-Émile Lecoq de	Light	Uncritical	5.3	Nuclear Reactors
Thulium	1879	Tm-69	Sweden- Per Teodor Cleve	Heavy	Excessive	0.3	Lasers, Portable, X-ray Machines
Praseodymium	1885	Pr-59	Germany- Carl Auer von Welsbach	Light	Uncritical	6.7	Lasers
Neodymium	1885	Nd-60	"	Light	Critical	27.0	Laser Ranger Finders Communication
Dysprosium	1886	Dy-66	France- Paul-Émile Lecoq de	Heavy	Critical	3.8	Permanent Magnets

Europium	1886	Eu-63	Europe- Eugène- Anatole Demarçay	Heavy	Critical	1.3	Optical Fibres
Gadolinium	1886	Gd-64	Sweden- Johan Gadolin	Heavy	Uncritical	4.0	X-ray and Scanning
Lutetium	1907	Lu-71	Austria- Carl Auer von Welsbach and Georges Urbain	Heavy	Excessive	0.4	Petroleum Refining
Promethium	1947	Pm-61	America- Jacob A. Marinsky, Lawrence E. Glendenin, and Charles D. Coryell	-	-	10 ⁻¹⁸	Doesn't exist like earth, but its isotopes are available in the radioactive elements.

Source: Rose Ragsdale, "Rare Earth Metals see New Medical Uses", *Metal Tech News*, June 27, 2020, at <https://www.metaltechnews.com/story/2020/04/29/tech-metals/rare-earth-metals-see-new-medicaluses/217.html#:~:text=Holmium%20lasers%20emit%20at%202.1,problems%20with%20a%20thulium%20laser>. Accessed on July 16, 2021.

EVOLUTION OF RARE EARTH ELEMENTS APPLICATIONS

Stage I: Since their first industrial application, the geological knowledge and production of rare earth elements have involved contentious politics. The emergent problems in the urbanised zones to produce light in an inexpensive way and continue the production after dark mostly during long nights, motivated chemist Carl Auer von Welsbach to invent gas mantles in Northern Europe, which initiated REEs' industrial usage in the 1880s. The large RE waste left from the production of mantles was further used by Carl for his second invention in 1930s, which was an attempt to deal with the continued difficulties in igniting the gas mantles. He blended this RE waste with 30 per cent iron to develop the

alloy called 'mischmetal' and patented it under the name of 'flintstone'. This mischmetal started to be used for ignition in lanterns, cigarette lighters, and even automobiles.⁶ In this phase, the political life of REEs was shaped by the European companies seeking access to colonial resources, and other developed countries like Germany attempting to expand their weapon sources. This led these countries to expand their base in countries with a high source of REEs such as India, America and Brazil. For instance, in 1905, the German thorium syndicate began exploiting monazite placers in Brazil, and by 1909, the Australian Welsbach company began exploiting monazite placers in India.⁷

Stage II: The global political turmoil of World War I formalised the geological science that soon reached China that had large mineral reserves. The mineral reserve capacity of China began to attract Imperial Japan for access to rare earths, which consolidated Japanese control over the inland of northeastern and southeastern China in the 1930s. After World War I and the Great Depression of the 1930s, Germany also started seeking the cheaper sources of critical minerals in order to revive its broken economy. Thus, Germany's Kuomintang (KMT) also formed an agreement with China, basing these materials as a strategy to resist Japanese imperialism. In order to map the subsoils of Inner Mongolia and Xinjiang, the KMT formed the Northwestern Scientific Expedition Team, including hired German, Swiss and Danish experts. The team identified minerals, fossils, and treasures in the Western Asian Frontier. In 1927, a team of 40 travelled to Baotou and Bayan Obo, China, where the geologist Ding Deoheng discovered the resources. However, the presence of rare earths was demonstrated by chemist He Zuolin after 10 years.⁸

Stage III: The international rare earth politics began to take shape around the faultlines of the Cold War and arms race, and got established

6. Julie Michelle Klinger, "A Historical Geography of Rare Earth Elements: From Discovery to the Atomic Age", *Journal of the Extractive Industries and Society*, vol. 2., July 7, 2015, pp. 572-580, at https://www.bu.edu/gdp/files/2018/02/Klinger-2015-A-Historical-Geography-of-Rare-Earth-Elements_From-Discovery-to-the-Atomic-Age.pdf. Accessed on November 30, 2021.

7. Ibid.

8. Ibid.

as both the input-output parts of nuclear war. In 1939, the neutron-induced nuclear fission of uranium was analysed by German scientists Hahn and Strassman, and they identified rare earth elements as fission products. The US, Russia and Britain began to work and explore international thorium and uranium rare earth resources. The US and Germany were already importing rare earths and thorium from India and Brazil. In 1942, Russia also opened a rare earth thorium-uranium mine and processing plant in the Aktyuz region of Kyrgyzstan. However, India put an embargo on the export of thorium rich monazite to all countries, when Prime Minister (PM) Nehru identified thorium as a source of atomic energy and nuclear weapons in 1948. PM Nehru considered nuclear weapons development as the prime priority for India, which required monazite and thorium. At the same time, the country was struggling with the impact of the famine crisis, and needed economic support. Interestingly, to engage with India, the US State Department reframed its proposal around emergency famine relief for India, titled as “Indian Food Crisis: Opportunity to Combat Communist Imperialism” with US\$ 190 million as a gift. The then US Congressman John M. Vorys claimed, “India needs grain immediately, we have the grain. We need strategic materials from India over a period of years, India has those materials. We should make India a loan which can be repaid in strategic minerals.” But PM Nehru refused the deal, calling the conditionality a violation of the country’s sovereignty. Later, he agreed to provide strategic materials other than monazite. This phase made the US realise the need to work on its domestic rare earth production capacity as a strategy to reduce its dependence on the Asian countries. Thus, US geologist and mining firms began to search for the country’s own deposits, and in 1949, discovered the Mountain Pass rare earth mine in California that continued to dominate global RE production from 1960-2000.⁹

9. James C. Kennedy, “Rare Earth Production, Regulatory USA/International Constraints and Chinese Dominance: The Economic Viability Is Bounded by Geochemistry and Value Chain Integration”, *Journal of Rare Earth Industry*, 2016, pp. 37-55, at <https://www.sciencedirect.com/science/article/pii/B9780128023280000036>. Accessed on March 20, 2022.

The declining US supply chain in the rare earth market was used by China to enhance its REE leadership and gain geopolitical influence. Professor Xu Guangxian, the father of the Chinese rare earth industry, with his research enabled extracting isotopes of uranium in rare earth extraction and development of REEs cutting-edge technologies.

Stage IV: The nuclear arm race started among countries like the Soviet Union, US, Germany, China and others, which began to shape the politics around rare earths until the 1960s. The US established itself as the primary producer in the 1960s and remained so until the 2000s. When China conducted its first nuclear weapon test in 1964, it realised the need to develop research programmes for rare earths and other non-ferrous metals. In 1980s, a regulation was imposed by the nuclear regulatory commission and International Atomic Energy Agency (IAEA) to eliminate extraction of minerals bearing uranium and

thorium. The US rare earth market was dependent on the phosphate ores (Th-U-REE-P) or principally monazite minerals, and the regulation affected its dominance of the supply chain. This brought the Mountain Pass era to an end, while China continued to increase its Rare Earth Ores (REOs) production (most particularly in Baotou in Inner Mongolia) in the 1990s.¹⁰ The declining US supply chain in the rare earth market was used by China to enhance its REE leadership and gain geopolitical influence. Professor Xu Guangxian, the father of the Chinese rare earth industry, with his research enabled extracting isotopes of uranium in rare earth extraction and development of REEs cutting-edge technologies, which contributed to enhancement of the REE exporting capabilities of China.¹¹

Stage V: The growing extraction of rare earths and its environmental impact made the Chinese government work on cleaner production of rare earth

10. Ibid.

11. June Teufel Dreyer, "China's Monopoly on Rare Earth Elements", Asia Program Analysis, Foreign Policy Research Institute, October 7, 2020.

and shift towards greener hydrometallurgy of the bastnaesite. In 2012, the 'Rare Earth Industry Accession Requirements' policy was released by the Raw Materials Office of the Ministry of Industry and Information Technology (MIIT) to uplift production, and stop illegal mining.¹² In order to improve the extraction and separation process, China initiated new leaching processes using roasting-acid oxidation, bake-water sulfuric acid and NH_4Cl roasting. These efforts enabled China to reduce the environmental impacts by taking initiatives like elimination of the waste water discharge having thorium-radioactive solid, fluorine, ammonium nitrogen or high salinity. The 'Implementation Proposal of Cleaner Production Technologies in Rare Earth Industry' issued by the MIIT in 2014 led to the publication of the 'Plan for the Development of Rare Earth Industry' (2016-2020), which generalised the rare earth engineering and reform for cleaner production.¹³ With the increased global commitment towards clean energy transition, the application of rare earth elements has a potential demand growth for the renewable technologies (solar, wind turbines, hydropower), electric vehicles and other clean technologies that require cheaper batteries and reliable electricity generation infrastructure. Rare earth elements have the capacity to facilitate the cheaper development of infrastructure required for renewables.

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12. Jost Wübbeke, "Rare Earth Elements in China: Policies and Narratives of Reinventing an Industry", *Resource Policy* 38 (3), 2013, pp. 384-394.

13. Wang Liangshi, et al. "Towards Cleaner Production of Rare Earth Elements from Bastnaesite in China", *Journal of Cleaner Production* 165 (2), 2017, pp. 231-242.

Table 2: Stages of Rare Element Application

Stage	Timeframe	Usage	Source Countries of REEs
Stage I	Late 19th century due to the invention by Carl Auer von Welsbach	Gas mantle to continue production at night Mischmetal for ignition in lanterns, cigarette lighters, and even automobiles	India, Europe, Brazil and America
Stage II	Early to mid-20th century	Weapon production during World War I and II Nuclear fission and fusion (involving both thorium and uranium)	India, China, Brazil and Belgian Congo
Stage III	Mid-20th century	Nickel-based rare earth alloys and nuclear weapons	USA, China, Soviet Union and Germany
Stage IV	Mid to late-20th century	Permanent magnets and R&D for cleaner REEs production	China
Stage V	21st century	Clean technologies and artificial intelligence	China, USA, Australia, Myanmar and India

These stages reflect how the use of rare earth elements has evolved, from being used as the gas mantle and mischmetal to becoming significant in the production of clean technologies now. Let's look at the application of rare earth elements in the civilian and military sectors in detail.

DEFENCE APPLICATIONS OF REEs

The defence sector relies primarily on permanent magnets, whose production requires rare earth elements. All permanent magnets have their own magnetic field, such as neo magnets that comprise rare earth alloys such as neodymium iron boron and samarium cobalt. The neo magnets are mostly employed in the production of military weapon systems, which include

generators, missile guidance systems, underwater mine detection systems; anti-missile defence systems, radar systems, and satellite communication systems. The permanent magnets can produce strong magnetic power in smaller component parts, even in high temperatures and with no power supply. These features of permanent magnets allow the weapon system to be both smaller as well as more efficient.¹⁴ Besides permanent magnets, other REEs used in the defence sector are lanthanum to enhance the clarity of glass, for use in intelligence, surveillance, and reconnaissance; and europium phosphorescent for LED lights and plasma displays.¹⁵ The US is the highest buyer of permanent magnets for the production of electric motors, starter generators and traction drives.

Table 3: Application of Rare Earths in Defence Sector

Application	Required Rare Earth
Surveillance and navigational aids such as radar and sonar	Gadolinium, Samarium and Yttrium
Communication and display aids such as lasers, monitors and avionics	Dysprosium, Erbium, Europium, Neodymium, Praseodymium, Terbium and Yttrium
Mounting system in armed vehicles and tanks	Europium, Neodymium, Terbium and Yttrium
Precision-guided munition (such as in cruise, anti-ship and surface-to-air missiles)	Dysprosium, Neodymium, Praseodymium, Samarium and Terbium
Guidance system (that controls the targeting of missiles)	Terbium, Dysprosium, Samarium, Praseodymium and Neodymium

14. Ryan P. Carpenter, "The Bottom of the Smart Weapon Production Chain: Securing the Supply of Rare Earth Elements from the U.S. Military", *Public Contract Law Journal*, vol.40 (2), 2011, pp. 411-433.

15. Alyk Russell Kenlan, "The U.S. Moves to Ensure a Robust Supply Chain for Rare Earth Elements—Beyond China's Control", November 1, 2020, at <https://www.airforcemag.com/article/rare-elements-of-security/>. Accessed on February 10, 2022.

Electronic high-power equipment (that uses permanent magnets)	Yttrium-iron-garnet, Terbium, Dysprosium, Samarium, Praseodymium and Neodymium
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Source: Redakcja Naukowa and Andrez Trytek, "Materials, Technologies, Constructions: Special Purpose Materials", 2019, at https://www.mdpi.com/journal/technologies/special_issues/construction_materials_technologies.

Table 4: Application of Rare Earth in Weapon Systems

Element	Technology	Function/ Application	Selected Examples
Nd, Pr, Sm, Dy, Tb Neodymium, Praseodymium, Samarium, Dysprosium, Terbium	Compact/ powerful permanent magnets	Guidance and control electric motors and actuators	Tomahawk cruise missile, smart bombs, joint direct attack munitions, joint air-to- ground fin actuator, predator unmanned aircraft
Numerous	Energy storage/ density amplification	Electronic warfare, directed energy weapons	Jamming devices, electromagnetic railgun, Ni metal hydride battery, area denial system, long range acoustic device and area denial systems loaded on the "Stryler" vehicle
Y, Eu, Tb Yttrium, Europium, Terbium	Amplification of energy and resolution	Targeting and weapons	Laser targeting, air based lasers, laser avenger (counter-IEDs), Saber shot photonic disrupter, FCS vehicle with laser weapon

Nd, Y, La, Lu, Eu Neodymium, Yttrium, Lanthanum, Lutetium, Emporium	Amplification, enhanced resolution of signals	Radar, sonar, radiation, and chemical detection	Sonar transducers, radar, enhanced λ ray radiation detection, Multipurpose Integrated Chemical Agent Alarm (MICAD)
Nd, Pr, Sm, Dy, Tb Neodymium, Praseodymium, Samarium, Dysprosium, Terbium	Compact/powerful permanent magnets	Electric drive motors	CHPS future combat, integrated starter generator, hub mounted electric traction drive, Zumwalt DDG 1000, joint strike fighter and more electric aircraft

Source: Larry M. Wortzel and Kate Selley, "Defense Technology Program Brief: Breaking China's Stranglehold on the U.S. Rare Earth Elements Supply Chain", American Foreign Policy Council, No. 22, at https://www.afpc.org/uploads/documents/Defense_Technology_Briefing_-_Issue_22.pdf 2021.

AEROSPACE SECTOR

Aerospace involves the use of metallurgy that involves magnesium alloys in combination with REE elements for steel strengthening and ductility of iron. The metallurgy increases the resistance of magnesium-based alloys in aerospace engineering. The fighter jet aircraft use the rare element rhenium alloyed with molybdenum and tungsten.

Rare Earth Elements Crucial to Defence

The US has identified 35 metals or minerals crucial for its industrial base. Some of these are given in Table 5.

Table 5: Application of Rare Earths in Air Power

Name	Properties	Aerospace Uses
Gallium	Superconductivity	Computer chips, light-emitting diodes
Neodymium	Extremely powerful, durable magnets	Missile guidance systems

Samarium	High-temperature magnetism, absorbs	Nuclear reactor control rods, lasers
Praesodymium	Makes stronger, more heat-tolerant alloys, permanent magnets	Aircraft engines, satellite components
Yttrium	Alloy strengthener, glass clarifier	Microwave emitters, optical coatings, LEDs
Promethium	Low radioactivity	Long life batteries for missiles
Lanthanum	Glass clarifier, reacts with hydrogen	Optics and lenses, night-vision goggles, fuel cells
Europium	Phosphorescence	LEDs, plasma displays

Source: Alyk Russell Kenlan, "The U.S. Moves to Ensure a Robust Supply Chain for Rare Earth Elements—Beyond China's Control", November 1, 2020, at <https://www.airforcemag.com/article/rare-elements-of-security/>.

CIVILIAN APPLICATIONS OF RARE EARTH ELEMENTS

The world has very limited knowledge about the applications of rare earth elements, which are important not only for military equipment but also civilian needs ranging from mobile phones, transportation systems to even the lens we use to see a clear world. Our everyday routine, be it the mirror we see our faces in; the television or radio or earphones we use for our entertainment; our transportation to work; medicines or medical equipment; and lighting in the night—everything requires REE contents.

Let's look at the sector-wise civilian applications of REEs:

(a) Industrial Applications of REEs

The industrial sector, most particularly electronics, demands rare earth elements in large amounts due to the continuous increase in the production and adoption of new electronic devices. For instance, as per the data of the international telecommunication industry, cellular telephones reached

103.4 per cent of total global population consumption in 2017, from just 5.3 per cent in 1998.¹⁶

Two types of REE products are used in industries: (a) mischmetals, that are a mixture of rare earth oxides, and (b) high purity compounds, that contain 90 per cent of an individual REE. The four main industrial outputs that involve a mixture of REEs are: (i) **Ceramics**, that involve REEs for temperature compensation or balance the input-output of electricity in spark plugs. (ii) **Glass**, that involves REEs as mixed compounds and separated high-purity materials, which helps further in the coating, polishing, and colouring or decolouring of glass, that is called the fluorescence process. (iii) **Permanent Magnets**, that are the most important industrial output using majorly two rare earth elements with mixtures, which are *samarium-cobalt magnets* and *neodymium-iron-boron-magnets*. The former helps in reducing the size and weight of magnets that get used in televisions, microwaves, watches, computer communications, and even in radar or missile systems; and the latter are used in motors, computer devices, and automobiles. (iv) **Phosphors**, a mixture involving REEs, used for cathode-ray tubes, X-ray screens, lamps and lasers. The use of REEs in the phosphors helps in emission of different colours wavelength light, for instance, cerium gives ultra-violet light; dysprosium gives yellow light; thulium gives blue light; europium gives red light; samarium gives orange light; terbium gives green light; neodymium gives infrared light.¹⁷

(b) REEs Applications in Transportation

Internal Combustion Engine (ICE) Vehicles

The conventional ICE vehicles that require oil rely on REEs for the Fluid Catalytic Cracking (FCC) of oil. REEs are used as diesel fuel additives

16. Keith Kirkpatrick, "Electronics Need Rare Earths", *Communications of the ACM*, vol. 62 (3), 2019, pp. 17-18, at [https://cacm.acm.org/magazines/2019/3/234917-electronics-need-rare-earths/fulltext#:~:text=Some%20of%20the%20rare%20earth,%2C%20and%20dysprosium%20\(66\)](https://cacm.acm.org/magazines/2019/3/234917-electronics-need-rare-earths/fulltext#:~:text=Some%20of%20the%20rare%20earth,%2C%20and%20dysprosium%20(66).). Accessed on February 21, 2021.

17. G. Morteani and C. Preinfalk, "Industrial Applications of Rare Earth Elements", *Lanthanides, Tantalum and Niobium*, 1989, pp. 359-370.

EVs are significant in achieving the world's decarbonisation targets considering their energy efficiency and ability to reduce CO₂ emissions in the long term.

providing their catalytic properties in small concentrations, mostly lanthanum.¹⁸ REEs as petroleum cracking catalysts consist of three parts: silica-alumina refractory binder, inert filler, and a rare earth element-containing zeolite. The mixture of La, Nd and Pr is used in petroleum cracking catalysts, and Ce is used in self-cleaning ovens as a polymerisation catalyst. Srikantharajah, Baillie, Zahnbrecher and Wache state, "Rare earth metals had played an important role in the refining industry since the 1970s to stabilize the zeolite-Y component of fluid catalytic cracking in the fuel to provide higher activity, as well as being used to influence product selectivity."¹⁹ In other words, the application of REEs in fuel enhances the efficiency of transport activities.

Electric Vehicles (EVs)

EVs are significant in achieving the world's decarbonisation targets considering their energy efficiency and ability to reduce CO₂ emissions in the long term. The Clean Energy Ministerial (CEM), a group of 30 industrialised countries such as the USA, Europe, Brazil, Australia, Japan, and others,²⁰ launched the 'EV@30' initiative at the 8th Clean Energy Meeting (CEM) meeting. This initiative is currently being supported and followed by 15 member countries, including India, China, Canada, Chile, Finland, France, Germany, Japan, the Netherlands, New Zealand, Norway, Poland, Portugal, Sweden, and the United Kingdom.²¹ The production of Hybrid

18. Ibid.

19. S. Srikantharajah, C. Baillie, B. Zahnbrecher and W. Wache, "Evaluation of a Low Rare Earth Resid FCC Catalyst", *Digital Refining*, March 2012, at <http://www.digitalrefining.com/article/1000266>. Accessed on January 10, 2022.

20. "Clean Energy Ministerial (CEM), Members and Imperatives", at <https://www.cleanenergyministerial.org/about-clean-energy-ministerial>.

21. International Energy Agency, "Electric Vehicles Initiative: Accelerating the Introduction and Adoption of Electric Vehicles Worldwide", at <https://www.iea.org/areas-of-work/programmes-and-partnerships/electric-vehicles-initiative>.

Electric Vehicles (HEVs) and plug-in EVs was assumed to increase from 2.3 million units in 2016 to over 10.1 million units in 2026, as almost all major automotive industries have developed their EV models.²²

However, the contribution of EVs to the political economy and decarbonisation has been a debated area, as the experience with EVs varies across countries based on the availability of electricity generation resources. A country with coal-dominant power generation might find the use of EVs inefficient to reduce CO₂ emissions. For instance, India's Faster Adoption and Manufacturing of Electric Vehicles- I (FAME-I) programme failed due to the absence of alternative electric power generation and continuous high dependency on coal for electricity generation.²³ Thus, although EVs are a significant agent of decarbonisation, the generation of electricity is an area of concern. The generation of electric power goes through energy conversion processes characterised by high efficiency, guided by the fundamental laws of thermodynamics. The essential energy supply chain involves power stations that utilise primary energy sources such as coal, natural gas, natural uranium, or renewable sources such as solar, wind, or geothermal, then converts them into secondary energy sources or carriers, commonly, electricity.²⁴ In order to make the EV more efficient, the need is to shift from non-renewable sources of electricity generation to renewable sources. This need for a shift brings rare earth elements into the frame.

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22. Kathryn M. Goodenough, Frances Wall and David Merriman, "The Rare Earth Elements: Demand, Global Resources, and Challenges for Resourcing Future Generations", *Natural Resources Research*, 2017, pp. 1-16.

23. Subhash Dhar, Minal Pathak and Priyandarshi R. Shukla, "Electric Vehicles and India's Low Carbon Passenger Transport: A Long Term Co-benefits Assessment", *Journal of Cleaner Production*, S0959-6526(16) 30583-2.

24. W.D. Judge, Z.W. Xiao and G.J. Kipouros, "Application of Rare Earths for Higher Efficiencies in Energy Conversion", *The Minerals, Metals, & Materials Society*, pp. 37-45.

Fig. 1: Use of REEs in the Parts of a Car



Source: Steve Constantinides, "Rare Earth Elements in Transportation", *Arnold Magnetics*, 2017, at <https://www.arnoldmagnetics.com/wp-content/uploads/2017/10/Rare-Earth-Elements-in-Transportation-Constantinides-MST-and-COM-2013-psn-lo-res.pdf>.

REEs provide critical functionality and sustainable mobility to EV technologies. REEs can be used not only to produce EVs but also to enhance clean and emission-free electricity generation. REEs are used in EVs as magnets, catalysts and additives.²⁵ EVs are mostly dependent on the 'batteries', that can be filled or charged from drive engines or plug-in charging. EVs use different types of batteries such as Li-metal (V), Li-ion (Mn, Ni and Co), Na NiCl, NiMH (AB2 and AB5), NiCd, PbA. These batteries use potentially scarce metals or groups of metals such as lithium, nickel, cobalt, vanadium, cadmium, lead and mischmetal (rare earth elements). Lanthanum and cerium are used as power sources in the hybrid EVs, and as battery electrodes in nickel metal hybrid batteries. Neodymium Magnets (NdFeB) are used for the motors, speakers, doors and windows of vehicles. The fluorescent powders for lightning in the EVs use europium and yttrium; glass and alloys require

25. Ingrid Rade and Bjorn A. Andersson., "Requirement for Metals of Electric Vehicle Batteries", *Journal of Power Sources*, vol. 93, pp. 55-71.

the unique additive properties of REEs.²⁶ The traction drive motors are the other important requirement for EVs manufacturing. These are of two kinds: (a) embedded magnet synchronous reluctance motors; (b) induction motors. Both these motors require permanent magnets for temperature management, with dysprosium and terbium mostly preferred over samarium and neodymium.²⁷

(c) Nuclear Applications of REEs

REEs as Uranium By-Product: Nuclear power plants are mostly dependent on uranium, and the world has 6.1 million tonnes of known recoverable uranium resources. The deposits of rare earth elements are seen as unconventional resources of uranium and even called a by-product of uranium production. In the process of REEs' extraction and production, the REE-uranium gets produced only from the mines using a flotation circuit. The extracted REE-uranium involves rare earth oxides, zinc concentrate and fluorspar by-product, which then go through a leaching process using aluminium sulfuric acid to produce the uranium oxide by-product.²⁸ Gadolinium oxide is used as a burnable poison in boiling water reactors of nuclear fields, which improves the efficiency of energy with its high neutron absorption and reduces the consumption of uranium. Samarium, europium and dysprosium are used as neutron absorbers in fast breeder reactors. Gadolinium is used in nuclear engineering industries and neutron radiography as thin converter foils. The sealed-tube neutron generators use thulium and europium, and

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26. Xiang Yang Li, Jian-Ping Ge, Wei-Qiang Chen, Peng Wang, "Scenarios of Rare Earth Elements Demand Driven by Automotive Electrification in China: 2018-2030," *Resources, Conservation and Recycling*, vol. 145, 2019, pp. 322-331.
 27. Steve Constantinides, "Rare Earth Elements in Transportation", Arnold Magnetic Technologies Corporation, 2017, at <https://www.arnoldmagnetics.com/wp-content/uploads/2017/10/Rare-Earth-Elements-in-Transportation-Constantinides-MST-and-COM-2013-psn-lo-res.pdf>.
 28. World Nuclear Association, "Uranium From Rare Earth Deposits", at <https://world-nuclear.org/information-library/nuclear-fuel-cycle/uranium-resources/uranium-from-rare-earths-deposits.aspx>. Accessed on January 15, 2022.

neutron bomb radiation uses gadolinium oxide for military vehicle paints and as a scanning device in nuclear medicine.²⁹

Table 6: Particular Deposits of REE-Uranium

Country	Deposits/Company
Greenland	Kvanefjeld, Ilimaussac complex
Australia	Mount Weld Dubbo Zirconia Project, New South Wales Nolans Bore, Northern Territory
USA	Molycorp, Mountain Pass White Mesa, USA- Energy Fuels Resources Corp (EFRC) Bear Lodge Project, Wyoming Texas Mineral Resources Corporation, Texas Round Top Heavy- Rare Earth Project, Hudspeth
China	Mongolia Baotou Steel Rare Earth Bayan Obo
Canada	Eco Ridge, Ontario Avalon Advanced Materials Inc.
South Africa	Zandkopsdrift project Steenkampskraal
India	Kadapa, Guntur (Andhra Pradesh) Nalgonda (Telangana) East Singhbhum (Jharkhand) Southwest and Khasi Hills (Nagaland) Udaipur and Sikar (Rajasthan) Yadgir and South Canara (Karnataka) Rajnandgaon and Surguja (Chattisgarh) Sonbhadra (Uttar Pradesh) Rudraprayag (Uttarakhand) Una, Shimla and Mandi (Himachal Pradesh) Gondia (Maharashtra) ³⁰

29. C. Morteani and G. Preinfalk, "Industrial Applications of Rare Earth Elements," *Lanthanides, Tantalum and Niobium*, 1989, pp. 59-370.

Russian Federation	Dalur and Khiagda
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Sources: (a) María Victoria Riesgo García, et al., "Rare Earth Elements Mining Investment: It is Not all About China", *Resource Policy*, vol. 54, 2017, pp. 66-76. Accessed on January 2022.³⁰ https://www.researchgate.net/publication/317510617_Rare_earth_elements_mining_investment_It_is_not_all_about_China.

(b) World Nuclear Association, "Uranium from Rare Earth Deposits". <https://world-nuclear.org/information-library/nuclear-fuel-cycle/uranium-resources/uranium-from-rare-earths-deposits.aspx>. Accessed on January 15, 2022.

REE THORIUM BY-PRODUCT

Thorium has the potential application for nuclear fuel, which is 3-4 times more abundant (6-10 g/t) than uranium in the earth's crust. The increasing need for carbon-free energy for nuclear power makes thorium a viable replacement of uranium. The source of thorium comprises valuable minerals such as niobium, rare earth elements, tantalum and/or titanium.³¹ In the extraction of rare earth elements, thorium generation is an exigent factor. The Liquid Fluoride Thorium Reactor (LFTR) has a comparative economic and environmental advantage.³² Thorium is increasingly under consideration for use in nuclear power in the place of uranium, as the reactors powered by thorium can reduce the proliferation risk of nuclear weapons. Thorium generates less dangerous wastes that survive a thousand times less than uranium. Monazite, being the major source of thorium, mostly gets mined for extraction of REEs and ends up with a thorium by-product as well.³³

30. Department of Atomic Energy, "Uranium and Thorium Reserves in the Country", Unstarred Question-Answer, Rajya Sabha, March 25, 2021, at <https://dae.gov.in/writereaddata/rs%20usq%203368.pdf>.

31. International Atomic Energy Agency, "Thorium Resources as Co- and By-products of Rare Earth Deposits", IAEA-TECDOC-1892, 2019, Vienna.

32. Zijie Wang, Alexander T. Brown, Kui Tan, Yves J. Chabal and Kenneth J. Balkus Jr, "Selective Extraction of Thorium from Rare Earth Elements using Wrinkled Mesoporous Carbon", *Journal of the American Chemical Society*, 2018.

33. Mark Halper, "Why Safe Nuclear will Rely on Rare Earth Minerals", ZDnet.com, December 15, 2011, at <https://www.zdnet.com/article/why-safe-nuclear-will-rely-on-rare-earth-minerals/>. Accessed on December 11, 2021.

Table 7: Primary Deposits of REE-Thorium

Country	Deposits and Companies
Australia	Mt Weld, Toongi, Nolans, Lynas Corp.
Brazil	Araxá, Morro dos Seis Lagos, Morro do Ferro, Pitinga, Catalão
Canada	Elliot Lake area, Thor Lake/Nechalacho, Thorium One (Vancouver)
China	Bayan Obo
Greenland (Denmark)	Illimaussaq
India	130 monazite deposits (including 12.73 million tonnes) in Odisha, Andhra Pradesh, Tamil Nadu, Kerala, Maharashtra, Gujarat, West Bengal, and Jharkhand ³⁴
Norway	Fen, Lovozero
South Africa	Steenkampskraal and Rare Earth Extraction Co. (RARECO)
Turkey	Kizilcaören/Eskisehir
USA	Lemhi Pass, Wet Mountains, Iron Hill
France	Rhodia

Source: International Atomic Energy Agency, "Thorium Resources as Co- and By-products of Rare Earth Deposits", IAEA-TECDOC-1892. <https://www.iaea.org/publications/13623/thorium-resources-as-co-and-by-products-of-rare-earth-deposits>.³⁴

Secondary Deposits of REE-Thorium: The heavy mineral sands, most particularly monazite, that get stored along the coasts of rivers and stream environments, also include thorium by-products, which are known as placer deposits.

34. n. 30.

Table 8: Deposits of Thorium By-Product

Country	Deposits
India	Kerala, Tamil Nadu, Andhra Pradesh, Odisha
Australia	Murray Basin SW Coastal East Coastal Eucla Basin
South Africa	Richards Bay Namakwa Sands Dominion Reef Karoo
USA	Florida, Beach Placers North and South Carolina, Stream Placers Idaho, Stream Placers
China	Bayon Obo Th-Fe-REE Deposit Saima U-Th-Nb-REE Deposit (North China Craton) Balingyao or Ba'erzhe Deposit Huayangchuan Deposit (Central China Organic Belt) Xiangshan U-Th Orefield (South China) Maoniuping and Muluozhai (Southwest China) ³⁵

Source: International Atomic Energy Agency, "Thorium Resources as Co- and By-products of Rare Earth Deposits", IAEA-TECDOC-1892, 2019, Vienna.

(d) Renewable and Clean Technologies

The importance of REEs in clean technology developed with growing environmental issues and the Intended Nationally Determined Contributions (INDCs) commitment of the world to the Paris Agreement, which are pushing the world towards clean emerging technologies. REEs

35. J. Zhong, H. Fan, J. Chen, and Y. Meng, "Thorium Resources in China: Spatial Distribution, Genetic Type and Geological Characteristics", Beijing Research Institute of Uranium Geology, 2018, pp. 469-472.

REEs can make the infrastructure development of renewable energy a cheaper process. The 17 REEs have high utility potential to enhance the infrastructure and conductivity of renewables for electricity generation. Among the renewables, only solar and onshore-offshore wind power employs REEs for their production.

can make the infrastructure development of renewable energy a cheaper process. The 17 REEs have high utility potential to enhance the infrastructure and conductivity of renewables for electricity generation. Among the renewables, only solar and onshore-offshore wind power employs REEs for their production, most particularly erbium, neodymium, dysprosium, praseodymium, and yttrium. In 2011, the study entitled “Critical Material Strategy” by the U.S. Department of Energy (2011) analysed the role of REEs in clean energy, together with the supply risk. The most important REEs for the clean energy sector are dysprosium and neodymium.³⁶

(i) Solar Energy

Solar energy requires semiconductors for production and energy conversion: these are getting to be in short supply due to the global semiconductor crisis. The use of REEs can increase the production of inorganic semiconductor photocatalysts that exhibit eco-friendly features, unlike other semiconductors. The presence of REEs, most particularly erbium and yttrium, enhances the efficiency of the Zinc Oxide (ZnO) materials that further enhance the conductivity of solar cells.³⁷

36. International Energy Agency, “The Role of Critical World Energy Outlook Special Report Minerals in Clean Energy Transitions”, May 2021, at <https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions>. Accessed on May 25, 2022.

37. Katarzyna Znajdek, et al., “Luminescent Layers Based on Rare Earth Elements for Thin-Film Flexible Solar Cells Applications”, *International Journal for Light and Electron Optics*, March 2018, at https://www.researchgate.net/publication/323927030_Luminescent_layers_based_on_rare_earth_elements_for_thin-film_flexible_solar_cells_applications. Accessed on May 25, 2022.

(ii) Wind Energy

The adoption of wind turbines has been enhanced due to the International Atomic Energy Agency's (IAEA's) regulation to balance the stabilisation of CO₂ at a consistent level in the atmosphere at a level of 450 parts per million (ppm).³⁸ Wind power production relies heavily on dysprosium and neodymium rare earth magnets. As per the report, the REE content required for a wind turbine using an asynchronous motor is 600 kg per average 3.5 MW turbine.³⁹ Wind power turbines rely heavily on praseodymium, dysprosium, and neodymium for the production of permanent magnets used in their electric generators. As per the report, the REE content required for a wind turbine using an asynchronous motor is 600 kg per average 3.5 MW turbine to enhance the efficiency.⁴⁰ In commercial wind power production, REE contents are required for their direct-drive design system that is used for the installation of wind turbines; their permanent magnets use neodymium rare earth to lower the cost and improve reliability.⁴¹ Wind power ambitions are driven by green technology production and the sustainability of the REE supply chain. The need for wind power installation developed with the growing disruption to the climate. As per the International Energy Agency (IEA) estimation, the global installation of wind power will reach 2,870 Gigawatt (GW) in 2050, which will be five times more than the 592 GW estimated in 2018.

As per the International Energy Agency (IEA) estimation, the global installation of wind power will reach 2,870 GW in 2050, which will be five times more than the 592 GW estimated in 2018.

38. Ibid.

39. Timothy J. Wallington, "Sustainable Mobility: Lithium, Rare Earth Elements and Electric Vehicles," Proceedings of the FISITA 2012 World Automotive Congress (SAE-China and FISITA), pp. 155-166.

40. Paul Veers, Latha Sethuraman and Jonathan Keller, "Wind-Power Generator Technology Research Aims to Meet Global-Wind Power Ambitions", *Joule Previews*, vol. 4, 2020, pp. 1856-1863.

41. Jiashuo Li, et al., "Critical Rare-Earth Elements Mismatch Global Wind-Power Ambitions", *One Earth*, vol. 3, 2020, pp. 116-125, at <https://www.sciencedirect.com/science/article/pii/S2590332220302980>.

Wind turbines are installed both onshore and offshore; they are made of permanent magnet electric generators, whose production requires heavy critical mineral, particularly neodymium, praseodymium and dysprosium, for efficiency. The offshore wind installation relies more on REEs. The expansion of wind power across the world is a result of policies developed by the International Energy Agency (IEA) and the Global Wind Energy Council (GWEC). These policies predicted the rise of REE demand to 105-230 Gigagrams (Gg) by 2050 in comparison to 9 Gg in 2015.⁴² However, it is worth noting that the wind power industry is actively developing innovative magnets such as isotropic, bulk nano-structured, high-flux density generators, nanocomposite magnets, and so on.⁴³

The commercial production of wind power involves primarily two turbine generator designs: doubly-fed induction generators and direct-drive systems. Only direct-drive designs use REE content in high amounts, which is responsible for a greater amount of wind power installation. The direct-drive designs further involve two kinds: one kind uses permanent magnets made of REEs for production, while the other uses electrical generators made of copper.⁴⁴ The permanent magnets part of the direct-drive system includes the use of rare earth elements in aerospace engineering.

(e) REEs in Agriculture

Studies reflect the aspect of REEs in plants, bacteria and some fungi, which helps in disease resistance, enzyme activity, nitrogen fixation, and others.⁴⁵ Experiments have analysed crop responses to REE applications and are reported to be most probable when the soil contains less than ten ppm of available soluble REE extracts. The most common methods of REE

42. Ibid.

43. Paul Veers, Latha Sethuraman and Jonathan Keller, "Wind-Power Generator Technology Research Aims to Meet Global-Wind Power Ambitions", *Joule Previews*, vol. 4, 2020, pp. 1856-1863.

44. Timothy Ault, Steven Krahn and Allen Croff, "Radiological Impacts and Regulation of Rare Earth Elements in Non-Nuclear Energy Production", *Energies*, vol. 8, 2015, pp. 2066-2081.

45. Patrick H. Brown, Anne H. Rathjen, Robin D. Graham and Derek E. Tribe, "Rare Earth Elements in the Biological Systems", in K.A. Gschneidner Jr. E. Eyring, (eds), *Handbook on the Physics and Chemistry of Rare Earths* (Elsevier Science Publisher, 1990), pp 423-449.

application in agriculture are spraying, seed dressing, smearing or soaking, and they are sometimes applied with fungicides as a seed dressing or with herbicides as sprays.⁴⁶

(f) REEs in Medical Sector

The biochemical process doesn't involve the occurrence of natural REEs due to the limited specialised mechanism of the body to deal with these elements. However, this doesn't imply the non-interaction of REEs with the biological system, as they have a role to play in strengthening the immune system, liver function, memory retention and skeletal development. In the biological system, cerium and lanthanum are used in bio-membranes to monitor the movement and deposition within the procurement of both plants and animals; and to develop the role of calcium in the cells. The REEs also shows an anti-microbial effect for the treatment of burns against bacteria and yeast/fungi.⁴⁷

Table 9: Medical Use of Rare Earth Elements

Rare Earths	Medical Use
Lanthanum	To enhance metabolism, lower cholesterol level, blood pressure, blood coagulation risk.
Yttrium	To treat cancer by targeting cancer cells, and yttrium-90 as radiation therapy to give antibodies to arteries.
Samarium	Used as a cancer drug quadramet.
Terbium	Used in alloys for electronic equipment and as a greener phosphor in electronic displays.
Erbium	Used in lasers, infrared light filters and optical fibres, and in dental implant surgery.
Holmium	A soft-malleable white metal found in monazite and gadolinite, used in medical, dental and fibre-optical applications.
Thulium	The rarest REE, used in portable X-ray machines and as a new blood irradiator to avoid early rejection of organ transplant.

46 Ibid.

47 Weijie Weng, Arne Biesiekierski, Yuncang Li, and Matthew Dargusch, "A Review of the Physiological Impact of the Rare Earth Element and Their Uses in Biomedical Mg Alloys," *Acta Biomaterialia*, pp. 1-18.

Promethium	Used as isotope 147 in nuclear batteries.
Ytterbium	Used as Yb-169 for fighting cancerous cells.
Cerium	Dental ceramics and medicines La-based drug for hyperphosphatemia Ho: YAG Laser for medical surgical procedures.Tm-169 and Yb for portable X-ray machines.
Gadolinium	MRI agents

Source-Rose Ragsdale, "Rare Earth Metals See New Medical Uses", *Metal Tech News*, June 27, 2020, at <https://www.metaltechnews.com/story/2020/04/29/tech-metals/rare-earth-metals-see-new-medical-uses/217.html#:~:text=Holmium%20lasers%20emit%20at%202.1,problems%20with%20a%20thulium%20laser>. Accessed on July 16, 2021.

Table 10: Applications of 17 Rare Earth Elements

Rare Earth Element	Applications
Scandium	Aerospace materials, consumer electronics, lasers, magnets, lighting, sport goods
Yttrium	Ceramics, communication systems, lighting, frequency meters, fuels additive, jet engine turbines, televisions, microwave communications, satellites, vehicle oxygen sensors
Scandium	Aerospace materials, consumer electronics, lasers, magnets, lighting, sporting goods
Yttrium	Ceramics, communication systems, lighting, frequency meters, fuels additive, jet engine turbines, televisions, microwave communications, satellites, vehicle oxygen sensors
Lanthanum	Catalyst in petroleum refining, television, energy storage, fuel cells, night vision instruments, rechargeable batteries
Cerium	Catalytic converters, catalyst in petroleum refining, glass, diesel fuel additive, polishing agent, pollution-control systems
Praseodymium	Aircraft engine alloy, airport signal lenses, catalyst, ceramics, colouring pigment, electric vehicles, fibre optic cables, lighter flint, magnets, wind turbines, photographic filters, welder's glasses
Neodymium	Anti-lock brakes, airbags, anti-glare glass, cell phones, computers, electric vehicles, lasers, MRI machines, magnets, wind turbines
Promethium	Beta source for thickness gages, lasers for submarines, nuclear-powered battery.

Samarium	Aircraft electrical systems, electronic countermeasure equipment, electric vehicles, flight control surfaces, missile and radar systems, optical glass, permanent magnets, precision-guided munitions, stealth technology, wind turbines
Europium	Compact Fluorcent Lamps (CFLs), lasers, televisions, tag complex for the medical field
Gadolinium	Computer data technology, magneto-optic recording technology, microwave applications, MRI machines, power plant radiation leaks detector
Terbium	CFL, electric vehicles, fuel cells, televisions, optic data recording, permanent magnets, wind turbines
Holmium	Microwave equipment, colour glass
Erbium	Colour glass, fibre optic data transmission, lasers
Thulium	X-ray phosphors
Ytterbium	Improving stainless steel properties, stress gages
Lutetium	Catalysts, Positron Emission Tomography (PET) detectors

Source: Julio Navarro, "FuCycle Assessment of the Production of Rare Earth Elements for Energy Applications: A Review", *Frontiers in Energy Research*, vol. 2(45), 2014, pp. 1-17.

Thus, the understanding of the many REEs applications has evolved over time. Today, they are used in both military and civilian technologies (see Table 10). Since the realisation of REEs' applications, the world has been using these for the advancement of weapon systems and military technology. Other applications of REEs continue to be considered a secondary need. The significance of rare earth elements has evolved and even changed in character over the years, to include not only industrial and military applications now, but also for soft power developments of a nation that involve medical and health, clean technologies, and in dealing with human-caused anthropocentric issues. These uses of REEs have been increasingly shaping the geopolitical as well as geoeconomic discourse among countries, thus, enhancing their significance as a determinant of international relations.