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Rare Earth Elements (REEs)

Until the late 1990s the REEs were familiar only to a relatively small number of people such as chemists, some geologists and specialized materials and technology engineers. Since then they have gained considerable visibility because of the critical specialized properties that REEs contribute to components in modern day technology, and the near monopoly on the production and supply by China.

As a result, several countries have classified them as 'Critical Minerals' which mean they are, amongst others, "considered essential for the economy, but their supply may be at risk due to geological scarcity, geopolitical issues and trade policy." This reliance on one source (i.e., China) has been one major point of contention in the current trade dispute between the USA and China. In 2018 the USA imported over 80% of its total demand from China.

REEs are a series of 15 elements with atomic number ("AN") ranging from 57 to 71, which are referred to as the lanthanide series on the periodic table. Lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), Samarium (Sm), europium (Eu), and gadolinium (Gd) are referred to as light REEs ("LREEs"); terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (yb), and lutetium (Lu) are referred to as heavy REEs (HREEs). Scandium (Sc) and yttrium (Y), respectively with AN 21 and 39, are considered REEs because they have similar chemical and physical characteristics and tend to occur in the same ore deposits. However, they have different electronic and magnetic properties.

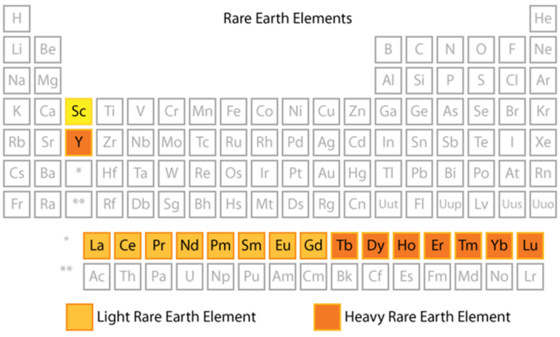
The importance of REEs in the modern day is that approximately half of advanced technologies are reliant on them in some form — from fighter jets, catalytic convertors, fibre optic cables to electric motors. Traditional uses have been in ceramics, glass, and polishing. LREEs are an indispensable component in the permanent magnet sector and substitutes do not exist. If current growth in demand from certain sectors (e.g., electric vehicles ("EV"), wind turbines) is maintained some analysts believe there will be a deficit in supply within the next ten years.

The name REE is misleading as the elements are not rare - except for promethium, all are on average more abundant than silver, gold, or platinum in the Earth's crust. They are "rare" because deposits concentrated to a commercially viable extraction level are unusual. As for "earth" this term was used based on its original definition in comparison with lime or magnesia - 'materials that could not be changed further by sources of heat'.

The first REE, yttrium, was discovered in 1787 in Sweden. However, due to their similar chemical properties it took another 130 years before laboratory techniques were sufficiently sensitive for scientists to be able to finally distinguish the rest.

稀土元素 (REEs)

直到 1990 年代後期，稀土元素才只有相對少數的人熟悉，例如化學家、一些地質學家以及專業的材料和技術工程師。由於稀土元素對現代技術的組成部分做出了至關重要的貢獻，因此從那時起它們獲得了相當的知名度，而中國幾乎壟斷了它們的生產和供應。



Lanthanide series on the periodic table　　*元素週期表中的鑭系元素*
Source: Sciencenotes.org

因此一些國家將它們歸類為"關鍵礦產"，這意味著它們被認為對經濟至關重要，但由於地質稀缺、地緣政治問題和貿易政策等原因，其供應可能處於危險之中。在當前美國和中國之間的貿易爭議中，對單一來源（即中國）的依賴一直是爭論的重點。2018 年美國從中國進口了其總需求的 80%以上。

稀土元素是由一系列 15 個由原子序數 57 到 71 的元素組成，在元素週期表中被稱為鑭系元素。鑭(La)、鈰(Ce)、鐠(Pr)、釹(Nd)、鉕 (Pm)、釤(Sm)、銪(Eu)和釓(Gd)被稱為輕稀土； 鋱(Tb)、鏑(Dy)、鈥(Ho)、鉺(Er)、銩(Tm)、鐿(Yb)和鑥(Lu)被稱為重稀土。 鈧(Sc)和釔(Y)原子序數分別為 21 和 39 一起被認為是稀土元素，因為它們一般發現於相同的礦床中並具有相似的化學和物理特質但不同的電子和磁性特質。

稀土元素在現代的重要性在於，大約一半的先進技術都以某種形式依賴稀土元素，包括戰鬥機、催化轉化器、光纖電纜以及依賴永磁體的馬達。傳統用途是用於陶瓷、玻璃和拋光。輕稀土是永磁體中必不可少的組成部分，並沒有替代品。假如某些行業（如電動汽車、風力渦輪機）的需求保持當前的增長，那麼分析師認為未來十年內供應將出現短缺。

稀土元素的名稱具有誤導性，因為這些元素並不稀少 — 除鉕外，地殼中所有元素的平均含量均高於銀、金或鉑。之所以稱為「稀有」是因為具商業開採價值的礦床並不多。至於「土」是根據其最初的定義，與石灰或白雲石相比，是不能通過熱源進一步改變的材料。

第一個稀土元素 — 釔，於 1787 年在瑞典發現。但由於稀土元素具有非常相似的化學性質，花了 130 年才能夠區分其餘稀土元素。

稀土礦床的地理成因與開採

主要的稀土礦床均在四種地質環境下富集而成的。

(i) 碳酸鹽岩 – 碳酸鹽岩是富含碳酸鹽岩漿的火成岩 其中超過 50%為方解石和白雲石等碳酸鹽礦物。隨著岩漿結晶，稀土集中在礦化的初級階段或後期的岩漿或流體中。高濃度的輕稀土與後期活動有

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Geological Deposition

Enriched deposits of REEs are found primarily in four geological environments.

(i) Carbonatites – These are igneous rocks derived from carbonate rich magmas where >50% of the rock comprises carbonate minerals such as calcite and dolomite. As the magma crystallizes REEs become concentrated in either the primary phases of mineralization or in late-stage magma or fluids. Large concentrations of LREEs are associated with late stage activity. Many of the world's REE deposits are associated with carbonatites, e.g., Bayan Obo, Inner Mongolia, China, and Mountain Pass, California, USA. Mountain Pass was the main global source of REEs until China developed its REE industry. Reported grades at Bayan Obo and Mountain Pass are respectively 6% and 7.98% total rare earth oxide (REO) in weight percentage.

(ii) Alkaline Igneous Systems - REEs have a strong association with peralkaline magmatism, an uncommon kind of magmatism that occurs in tectonic settings near to subduction zones or where there is rifting. These magmas are defined as where the proportion of aluminum oxide is less than sodium oxide and potassium oxide combined. The only active mine in this geological environment is at Lovozero in northern Russia, close to Finland.

(iii) Ion-absorption Clay Deposits (IOA) – These are the world's primary source of HREEs and are found in provinces of Jiangxi, Hunan, Fujian, Guangdong, and Guangxi in southern China. They form in tropical regions with moderate to high rainfall where weathering has destroyed the primary rock mineralogy. The resulting profile consists of kaolinite (clay), quartz, and iron oxides. In areas where the granite bedrock contains soluble REE minerals, the REE can be remobilized into the kaolinite surfaces enriching the minerals up to five times relative to the source rock. To be classed as an IOA deposit 50% of the REE must be ion exchangeable (ie soluble). Concentrations of REEs range from 300ppm to 2,000ppm.

(iv) Monazite Bearing Placer Deposits – these were an important source up to the mid-1960s, but they decreased in prominence owing to the discovery of Mountain Pass. Monazite is recovered as a by product of ilmenite ($FeTiO_3$) and rutile (TiO_2) beach sands. The only active mine is located off the east coast of Brazil, at Buena Norte.

The minerals which contain REEs are numerous (over 200), diverse and often complex in composition. The principal economic REE minerals are bastnaesite ((REE)(CO_3)F), xenotime (YPO_4), monazite ((REE,Th)PO_4), and loparite ((Na,Ce,La,Ca,Sr)(Ti,Nb)O_3).

REE ores often contain radioactive uranium and thorium minerals. Therefore mining, refining and recycling of REEs have serious environmental consequences if not properly managed. Because of this, extraction of monazite from placer deposits has essentially been banned. In contrast the bastnaesite ore from carbonatites and those from IOA deposits are low in radioactive minerals.

REE ores within carbonatite bodies are extracted using conventional open pit mining. Due to the low concentration of REEs, these represent big earth movement operations. In contrast extraction from IOA ores to produce concentrate can be achieved using dilute electrolyte solutions at ambient temperatures. The low energy requirements result in low grade ores being economically viable for REE extraction.

Supply and Processing of REO

REE statistics are usually reported as REO equivalent and by far China has the biggest mine production. Over the last 20 years global production has risen from around 70kt to an estimated 210kt. In 2019 China produced an estimated 132kt REO equivalent or 63% of total global sup-

關。世界上許多大型稀土礦床都與碳酸鹽岩有關，如中國內蒙古的巴彥奧博和美國加州的 Mountain Pass。在中國發展稀土產業之前，Mountain Pass 是全球主要的稀土資源。巴彥奧博和 Mountain Pass 的報告品位分別為總稀土氧化物(REO)重量百分比為 6%和 7.98%。

(ii) 鹼性火成岩系統 — 稀土元素與高鹼性岩漿岩有很強的存在關係，這種鹼性岩漿岩發生在裂谷或俯衝帶附近的構造環境中。這些岩漿定義為氧化鋁的比例少於氧化鈉和氧化鉀的總和。在這種地質環境形成的唯一活躍礦山是位於俄羅斯北部靠近芬蘭的 Lovozero。

REO 稀土氧化物
Source: Smallcaps.com.au

(iii) 離子吸附粘土沉積物(IOA) — 是世界上主要的重稀土來源，在中國南部發現 — 主要分佈在江西、湖南、福建、廣東和廣西等省。這類型的沉積物形成在熱帶地區，降雨量中等至較高，風化破壞了原來的岩石礦物。變成由高嶺石(粘土)、石英和氧化鐵組成。在花崗岩基岩含有可溶稀土元素礦物的區域中，稀土元素可以被轉移到高嶺土表面，使礦物富集到原始岩石的五倍。要被分類 IOA，必須有 50%的稀土元素可離子交換（即可溶）。稀土元素的濃度範圍為 300ppm 至 2,000ppm。

(iv) 獨居石含砂礦床沉積物 — 直到 1960 年代中期，這是重要的來源，但由於發現了 Mountain Pass 礦床，其重要程度有所下降。獨居石是鈦鐵礦($FeTiO_3$)和金紅石(TiO_2)的砂礦副產品。唯一活躍的礦山位於巴西東海岸 Buena Norte。

含有稀土元素的礦物種類繁多(超過 200 種)，多樣而且往往複雜。含經濟價值的主要稀土礦物是氟碳鈰鑭礦((REE)(CO_3)F)、鱗釔礦(YPO_4)、獨居石((REE,Th)PO_4)和鈰鈮鈣鈦礦((Na,Ce,La,Ca,Sr)(Ti,Nb) O_3)。

稀土元素礦石通常含有放射性鈾和釷礦物，所以如果管理不當，稀土元素的開採、提煉和回收將對環境造成嚴重影響。因此獨居石礦床的開採已被禁止。相比之下，碳酸鹽岩和 IOA 礦床的的放射性礦物含量較低。

碳酸鹽岩體的稀土礦石是露天開採的。由於稀土元素的含量低，所以意味著是大型的土方工程。相反，IOA 礦床可以在常溫下使用稀電解質溶液從礦石中提取以生產精礦，低能耗要求令低品位礦石也合乎稀土開採的經濟價值。

供應和加工 REO

稀土的統計數據通常以 REO 當量的形式報告，到目前為止，中國的礦山產量最高。在過去的 20 年中，全球產量已從約 7 萬噸增加到估計的 21 萬噸。2019 年，中國估計產生了 13.2 萬噸 REO 當量，佔全球總供應量的 63%，其次是美國（2.6 萬噸），緬甸（2.2 萬噸）和澳大利亞（2.1 萬噸）。

為了減少對中國的依賴，其他發達經濟體已啟動了勘探計劃，並聯手確定了新的稀土資源並探明了儲量。USGS（2019）估計全球已探明儲量為 1.2 億噸，中國為 44 百萬噸，其次是巴西和越南（各為

ply, followed by USA (26kt), Burma (22kt) and Australia (21kt).

To reduce dependence on China other developed economies, have initiated exploration programmes and teamed up to identify new REE resources and prove reserves. USGS (2019) estimates that there are 120Mt of proven reserves worldwide with 44Mt in China followed by Brazil and Vietnam (22Mt each). Countries are also researching into recycling of REE based products.

Significantly the Chinese REE industry has vertically integrated and dominates the processing and supply of downstream REE products. The vast majority of processed REE concentrate globally is monopolized by six Chinese state-owned enterprises.

REE is normally supplied to end users as concentrate or as compounds. Oxides of cerium, lanthanum and neodymium form the majority of REE demand, accounting for 80%. These are LREEs and China has approximately 90% of global supply.

REE Market

Given their similar chemical nature, many different REEs have related or complimentary uses, thus it is more convenient to describe their uses by application rather than by individual element. In general, the LREEs are cheaper and can be produced in greater quantities and are more extensively used than HREEs.

The uses, applications, and demand for REEs have expanded over the years. The largest and most important REE market is for use in permanent magnets (29% in 2020). For example, in a modern vehicle, there are 200 permanent magnets used for various functions and these collectively require approximately 500g REEs of which 70% would be neodymium. Neodymium is essential for a high-tech device to function effectively.

Catalysts (21%) are another major use of REEs - lanthanum-based catalysts are used in petroleum refining; and cerium-based catalysts are used in catalytic converters to break down heavy hydrocarbon molecules into smaller molecules and to reduce automotive carbon monoxide emissions.

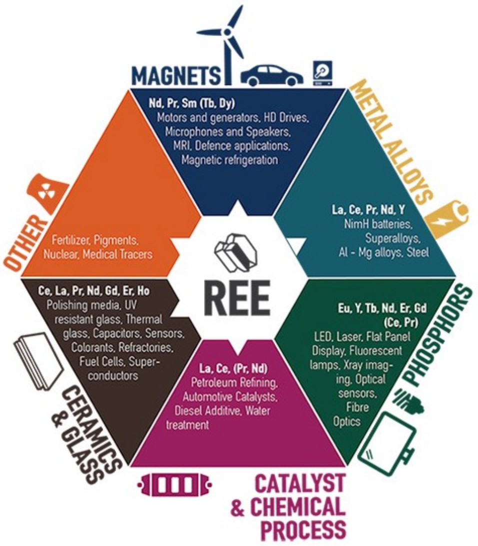
The glass industry (13%) is also a leading consumer of REE raw materials principally for the purposes of glass polishing, and as additives to provide colour and special optical properties to glass. Cerium oxide is used in the production of glass types which require a precision polish whilst lanthanum greatly increases the refractive index of glass.

By 2028 the forecast distribution of REEs made by Roskill (2020) is glass (32%), magnets (21%), Catalysts (17%). Magnets will account for an estimated 68% of end value. EV, wind turbines, fighter planes, ships and submarines are major consumers. A standard motor of an EV consumes ~5kg of REE based magnetic materials, a fighter jet 400kg and a submarine 4,500kg.

Prices vary considerably depending on the REO. Taking cerium and lanthanum oxide (99.9% purity) as example, the average 2019 price according to the USGS was US$2/kg, while terbium oxide was US$510/kg.

22 百萬噸）。各國也在研究基於稀土的產品的回收。

再者，中國的稀土行業已經垂直整合併主導著下游稀土產品的加工和供應。全球絕大多數的稀土精礦均由六家中國國有企業壟斷。



REE applicat ions
Source: Eurare.eu
稀土應用

稀土通常以精礦或化合物形式提供給最終用戶。鈰、鑭和釹的氧化物佔稀土元素需求的大部分，佔 80%。這些是輕稀土，而中國約佔全球供應量的 90% 。

稀土市場

鑑於其相似的化學性質，許多不同的稀土元素都有相關或互補的用途，因此通過應用而不是單個元素來描述其用途更為方便。通常，輕稀土比重稀土便宜，可以大量生產，使用範圍更廣。

多年來，對稀土的應用和需求都在增長。最大和最重要的稀土市場為永磁體(到 2020 年為 29%)，儘管釹僅佔重量和體積的一小部分，但對於高科技設備的有效運行而言，釹是必不可少的。例如，在現代車輛中，有 200 種用於各種功能的永磁體，這些磁體總共需要約 500 克稀土元素，其中 70%為鈮。

催化劑(21%)是稀土的另一主要用途。它們包括用於石油精煉的鑭基催化劑和用於催化轉化器的鈰基催化劑，以將重質烴分子分解為較小的分子，並減少汽車的一氧化碳排放。

玻璃工業(13%)也是稀土原材料的主要消費者，主要用於玻璃拋光和作為添加劑為玻璃提供顏色和特殊的光學性能。氧化鈰用於需要精確拋光的玻璃類型生產，而鑭極大地增加玻璃的折射率。

Roskill 預測 2028 年稀土元素的消耗分佈為玻璃(32%)、磁體(21%)、催化劑(17%)。磁鐵估計將佔最終價值的 68%。電動汽車、風力渦輪機、戰鬥機、輪船和潛艇是稀土元素的其他高用途。電動汽車的標準電動機消耗約 5 千克的稀土基磁性材料 戰鬥機 400 千克和潛艇 4,500 千克。

價格不等。如氧化鈰和氧化鑭(99.9%純度)，根據 USGS 的 2019 年平均價格為 2 美元/千克，而氧化鋱則為 510 美元/千克。

Rockhound is a HK based company set up to serve the minerals industry in the Region. The company offers technical valuations and services in the natural resources sector.

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稀土出口或成中方反制裁王牌 中國稀土真能避險？(節錄)

2020年8月2日 <華富財經>

中美摩擦升溫，稀土出口可能成為反制美國的措施，刺激中國稀土(SEHK:769)股價過去約一個月累升4成，升幅更勝避險資產黃金價格。不過，以稀土概念作為避險投資，可能承擔的風險更高。

避險資產的特質是在遭遇市場出現突如其來的不利因素下，而該資產價格表現堅挺，甚至逆市造好。稀土泛指包含鑭、鈰、鐠、釹等17種化學元素的土壤，用途相當廣泛，包括智慧手機、醫療器材、液晶螢幕顯示、光學鏡頭零件、電動車、航太軍工等。

中國稀土儲量佔全球約35至40%，產量更佔全球超過60%，美國稀土供應在很大程度上依賴中國，因此每當中美關係緊張到「一定程度」，中方便會祭出「稀土供應」這張王牌，如限制進出口等，繼而令稀土價格大漲，令相關概念股急升，當中中國稀土便是其一。

China Southern Rare Earth's offer for terbium oxide soared by 500,000 yuan/mt

25 Nov 2020 <SMM>

China Southern Rare Earth Group announced its latest listing prices for medium and heavy rare earth oxides. Prices of gadolinium oxide increased 3,000 yuan/mt to 176,000 yuan/mt, holmium oxide rose 60,000 yuan/mt to 505,000 yuan/mt, while terbium oxide prices soared 500,000 yuan/mt to 5.8 million yuan/mt.

Prices of many rare earth products increased last week on tight supply. Both offers and actual traded prices of praseodymium-neodymium oxide and neodymium oxide climbed last week on tight supply and firm demand. Meanwhile, rising raw materials costs and shortage of spot cargoes also boosted prices of metal praseodymium-neodymium and metal neodymium.

Prices of terbium oxide, dysprosium oxide and holmium oxide remained firm last week, but trades were moderate as most of the downstream users were cautious about restocking.

SMM expects prices of some rare earth products to rise further in the near term due to limited supply of spot cargoes and demand from downstream magnetic materials producers who held certain orders and kept low inventories.

A US rare earths miner is staging a comeback to take on China (excerpt)

16 Nov 2020 <Quartz>

The Mountain Pass rare earths mine in California's Mojave desert has had its ups and downs through the years.

Once the world's largest producer of rare earths—a group of 17 minerals crucial in the manufacturing of many high-tech products—it was forced to shut in 2002 in part because it was squeezed out by China's low prices. In 2015, its owner went bankrupt. A new owner acquired the mine, and slowly restarted operations. Now that company, MP Materials, is about to go public on the New York Stock Exchange. Its stated mission: restore the full rare earth supply chain to the US and eliminate dependence on China, which currently dominates the global rare earth industry.

Under the arrangement, MP Materials is expected to merge this week with a private-equity backed "blank check" company—known more technically as a special purpose acquisition company—after which it will trade under the ticker "MP" in a $1.5 billion deal highlighting investors' growing interest in the US rare earths industry. MP Materials will net about $500 million in cash to fund upgrades to the Mountain Pass facility, where it's currently mining elements for ultimate use in magnets critical to the manufacturing of electric vehicles.

While Beijing drove the country's rare earths dominance with government subsidies and production and export quotas, companies in the US and elsewhere now hope that markets, together with strategic government rules, can help counter China's sway in the rare earths sector. The SPAC that's helping take MP Materials public, for example, is controlled by Japan's SoftBank group.

Defense Metals Corp. Initiates Pre-Pilot Hydrometallurgical Optimization for its Rare Earth Elements Project (excerpt)

23 Nov 2020 <PR Newswire>

The Defense Metals Corp. ("Defense Metals" or the "Company") (TSX-V: DEFN) (OTCQB: DFMTF) (FSE: 35D) is pleased to announce that it has commissioned SGS Canada Inc. ("SGS") to complete additional pre-pilot hydrometallurgical test work utilizing high-grade rare earth element (REE) mineral concentrate produced during the Company's highly successful 26 tonne flotation pilot-plant that yielded a mineral concentrate averaging 7.4% NdPr oxide (neodymium-praseodymium) (see Defense Metals news release dated September 23, 2020).

Bench-scale hydrometallurgical test work finalized earlier this year and designed to inform operation of a large-scale hydrometallurgical pilot-plant, yielded ~ 90% TREE (Total REE) recovery from concentrate into a chloride-based leach solution, and production of a high-grade 67.5% TREE mixed hydroxide precipitate (see Defense Metals news release dated February 20, 2020).

Wicheeda REE Project

The Wicheeda REE project has indicated mineral resources of 4,890,000 tonnes averaging 3.02% LREO (Light Rare Earth Elements) and inferred mineral resources of 12,100,000 tonnes averaging 2.90% LREO.

About Defense Metals Corp.

Defense Metals Corp. is a mineral exploration company focused on the acquisition of mineral deposits containing metals and elements commonly used in the electric power market, military, national security and the production of "GREEN" energy technologies, such as, high strength alloys and rare earth magnets. Defense Metals has an option to acquire 100% of the 1,708 hectare Wicheeda Rare Earth Element Property located near Prince George, British Columbia, Canada.