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HALLGARTEN + COMPANY

Sector Coverage

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The Essence of Rare Earths

Dispelling the Myths

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Dispelling the Myths

- + The importance of Rare Earths was first recognized in the boom of 2009-2011, then faded, but it now back with, finally, political recognition of the problem
- + Chinese dominance (particularly in Heavy REEs) is fading, which provides an interesting opportunity to level the playing field
- + Governments in the West are in a panic mode which is refocusing attention (and funding) upon the build out of non-Chinese supply chains
- + If anything can be seen as a positive from the cooling of the EV boom is that it has lessened pressure, and provided breathing space, to source alternative supplies
- ✕ Old myths die hard and the level of ignorance of where REEs come from, how to process them and the (lack of) economics remains as high as in the previous upsurge
- ✕ The obsession with NdPr for the EV and "green transition" goes on, to the detriment of the less well-known but arguably more critical REEs like Erbium and Gadolinium
- ✕ Chinese are still "sitting" on the prices of REEs to dissuade interlopers from evolving new production
- ✕ Dumb things are being done, such as the Australian government funding Arafura while also talking fecklessly of creating a price support/stockpiling policy for a group of minerals that Australian industry does not use
- ✕ Active research into possible applications of the "other REEs" is not being undertaken, particularly as it applies to the prolific REEs such as Cerium and Lanthanum that shall become even more common/cheaper/unwanted as REE production expands
- ✕ There is a misunderstanding of the complexity of the REE separation technology without a supply line of extractors, evaporators, filters, reverse osmosis and even pumps, as well as access to reliable, high-quality and dependable reagents which are difficult and science-intensive in production
- ✕ The financing environment has been tough in the junior explorer space in the last two years, with companies becoming dependent upon government blessing (read, funding) to get a kickstart to development

Crisis Postponed

REEs are back in the headlines, with a vengeance, yet the level of fundamental knowledge amongst the investing public and Rare Earth capital markets mavens is scarcely better than when the last REE boom ended in 2011. Now we have an overlay of governments entering the fray, not just as concerned parties or boosters, but as funders. This is akin to giving a razor to a monkey.

In an attempt to clear the air somewhat we have revisited the theme of “what are REEs?” as all the primers from the first boom seem to have gone the way of all things and it is taken for granted that everyone knows everything about this obscure corner of the Periodic Table.

We may seem somewhat technical, but why not in a sea of unsubstantiated blah, blah, blah on this crucial topic? In this piece we hope to redirect thinking towards fundamentals in REEs rather than focus on the froth,

REEs – From the Mundane to the Weird & Wonderful

Rare earth elements (REE) are elements isolated in the periodic table of Mendeleev as the Lanthanide Series (La, Ce, Pr, Nd, Pm, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu), as well as Scandium (Sc) and Yttrium (Y). In some cases, Promethium (Pm) is excluded from this list because it is radioactive, has no stable isotopes, and is not found in minerals along with other REE. Scandium as a “Rare Earth” is a matter of discussion/contention even in the hallowed halls of Hallgarten & Company.

Lanthanides are conventionally divided into groups according to the stages of the division into Light (La, Ce, Pr, Nd), Medium (Sm, Eu, Gd) and Heavy groups (Tb, Dy, Ho, Er, Tm, Yb, Lu and Y).

All Rare Earths, with the exception of Scandium, are contained together, but in different proportions in various concentrates or minerals. It is quite rare, especially nowadays, to find chemical technology built and based solely on the extraction of REE: most often they are extracted along with the extraction of some other substance or from tailings, waste from other industries: iron, aluminum, calcium, titanium, uranium, phosphates, etc. However, in some cases, there are examples of technologies (e.g. in China) that from the first stages involve the development of deposits and the extraction of minerals containing REE at once.

Scandium technology is usually separated from the technology of other REE, since most often it is not contained together with other REE, although some technological techniques and in many ways the chemistry of Scandium is similar to the chemistry of other REEs.

It can be asserted that the level of economic and technological development of the state can be judged by the amount of consumption of rare earth products and the range of areas of its application. The use of REE in new "green" industries (environmentally friendly modes of transport, wind and solar energy generators, high-tech equipment), as well as in well-known fields such as the production of heavy-duty permanent magnets, special-purpose alloys, polishing powders, catalysts, microelectronics, optics, lasers and ceramics necessitate the production of REE of varying degrees of purity.

About the Chemical Technology of REE

The chemical technology of REE is incredibly complex, expensive, and requires a lot of financial resources, time, and intellectual firepower. Its implementation is the result of the joint coordinated work of several different enterprises. In general, REE technology can be represented by several main stages:

- primary enrichment of raw materials containing REE (for example, flotation, fractionation, granulometric enrichment, etc.)
- extraction of REE concentrate into the liquid phase from primary enrichment products (by leaching, selective heterophase sorption, etc.)
- selective precipitation of the total REE concentrate (with oxalic acid or ammonium carbonate)

The resulting REE concentrate is sent for separation of REE into groups and individual REE, if necessary, additional purification and deep purification of individual REE are carried out to the required purity grades. Deep purification of individual REE is carried out by liquid extraction, ion exchange sorption, chromatography and other methods. The first stages are usually carried out in production at the place of mineral extraction or REE concentrate production, and the separation of the REE group concentrate and the production of individual elements is carried out at another plant. Most often, the final goal of REE separation production is the oxide or carbonate of each rare earth element.

The separation of REE concentrates is a difficult technical and technological task due to the exceptional proximity of the chemical properties of lanthanides. Currently, the main industrial method of separating REE into groups and individual elements is liquid extraction, a high-performance technological process that is relatively easy to model, control, and automate[1].

REE separation is a multistage, high-tech process that includes the selection of an extraction system that provides the highest separation coefficients of neighboring elements, high saturation of the extractant for the target element (this is the maximum concentration of REE in the extractant), effective re-extraction (extraction of metals from the extractant into the aqueous phase). Extraction is carried out on cascades of extractors, 1 extractor – 1 stage. On average, one metal of low (non-marketable) purity can be obtained on one cascade. At least 14 cascades are required to separate all lanthanides, but in reality,

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[1] Extraction is a hydrometallurgical method of separating elements, based on the fact that one or more separable elements are more likely to pass, dissolve better in the non-aqueous phase than the other or other elements during mixing with the initial aqueous phase. In general, two immiscible phases are used for extraction: an aqueous phase containing separable elements and an organic phase. The organic phase is called an extractant. The extractant, in particular, is characterized by selectivity with respect to one of the separable components. The phases are thoroughly mixed and separated, and after separation, the organic phase contains more of the element to which it is selective. This is a better extractable component, and the component that remains more in the aqueous phase is called a worse extractable component. After repeating the mixing procedures, the aqueous phase will contain only a worse extractable component, and the extractant will contain a better extractable component. The aqueous solution after extraction is called raffinate, and the solution used to extract the best extractable component from the extractant is called reextract. The selectivity of the extractant is judged by the separation coefficient, the higher it is, the more the extractant demonstrates selectivity for a particular element, the closer to 1– the worse. If the separation coefficient is less than 1, then it must be raised to (-1) degree and, therefore, the extraction order must be changed. When talking about the extraction separation of several elements contained in one solution, the selected element is compared with the one that shows the greatest selectivity to the selected extractant and, therefore, their separation will be the most difficult. It is impossible to completely separate the elements if there are others in the solution to which the extractant also exhibits selectivity. We are talking only about liquid extraction used in hydrometallurgy.

more than 20 cascades. Each cascade, depending on the separation line and the proximity of the chemical properties of adjacent elements (those elements that follow each other in the periodic table), consists of 50 to 130 steps.

It should not be forgotten that in the technology of rare elements and, in particular, REE, unique (individual) complex expensive equipment is used, the production of which also increases the cost of the entire production. To implement the technology, ion-exchange resins and extractants are used in addition to the use of common reagents such as mineral acids, alkalis, inorganic salts, and organic solvents. The production of resins and extractants is also a very complex and knowledge–intensive and expensive process. Most often, when designing the production of REE, the existing production of extractants and resins in the country is taken into account.: they must be localized and consistently produce products in the required quantity (or have the resource to scale production). In their absence, the production of REE falls under additional dependence on another factor – from foreign suppliers of extractants and resins.

The choice of the technological scheme for separating the REE concentrate also depends on the nature of the mineral acid, which, in turn, is determined by the cost of the acid in the region. If there are plants for the production of mineral fertilizers near the REE separation plant, it is economically advantageous to use nitric acid solutions. At the same time, the waste from the production of REE, purified from impurities of organic compounds, can be returned to the production cycle of mineral fertilizers. If sources of chloride minerals or the production of chloride compounds are located nearby, it is advisable to use hydrochloric acid solutions.

The starting point for a REE production flowsheet, as with anything else, is a feasibility study of the proposed technology. And it, in turn, is mainly dependent upon the main price-forming factors of the initial REE concentrate:

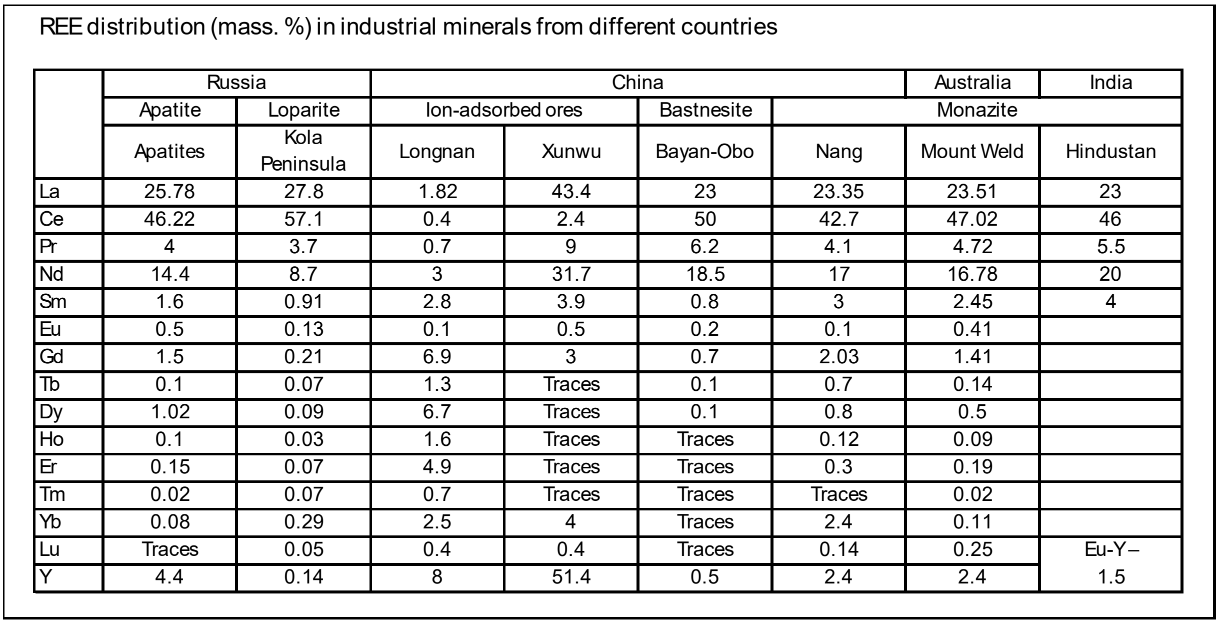
- on the cost and complexity of extraction of raw materials, the depth of occurrence of the REE-containing ore
- the complexity (and cost) of the chemical technology for obtaining REE concentrate from raw materials, tailings or industrial waste
- upon the radioactivity of the raw materials (the higher the concentration of radioactive isotopes, the more radioactive waste there will be and, consequently, the more expensive the entire process of their extraction will be)
- on the concentration of REE and feedstock
- the concentration and ratio of the most expensive REE in the REE concentrate (Tb, Dy, Lu) relative to other REEs

About REE sources

A comparative analysis of the composition of the extracted concentrates indicates that most of the REE concentrates produced in China exceed their global counterparts in terms of the amount of REE of the heavy group and, in particular, Tb, Dy, Lu.

As an example, the table that follows shows examples of the compositions of some concentrates produced in different parts of the world [10-16].

As can be noted from this data, the mineralisation most enriched in Heavy REE is apatite concentrate, which contains an average of 1.47 wt. % of heavy REE (without Y), while concentrates obtained in China from monazite and ion-adsorbed ores contain 4.46% (Nangang), 18.1% (Longnan) and 4.1% (Xunwu) by weight of the amount of heavy REEs.



REE distribution (mass. %) in industrial minerals from different countries

	Russia		China				Australia	India
	Apatite	Loparite	Ion-adsorbed ores		Bastnesite	Monazite		
	Apatites	Kola Peninsula	Longnan	Xunwu	Bayan-Obo	Nang	Mount Weld	Hindustan
La	25.78	27.8	1.82	43.4	23	23.35	23.51	23
Ce	46.22	57.1	0.4	2.4	50	42.7	47.02	46
Pr	4	3.7	0.7	9	6.2	4.1	4.72	5.5
Nd	14.4	8.7	3	31.7	18.5	17	16.78	20
Sm	1.6	0.91	2.8	3.9	0.8	3	2.45	4
Eu	0.5	0.13	0.1	0.5	0.2	0.1	0.41	
Gd	1.5	0.21	6.9	3	0.7	2.03	1.41	
Tb	0.1	0.07	1.3	Traces	0.1	0.7	0.14	
Dy	1.02	0.09	6.7	Traces	0.1	0.8	0.5	
Ho	0.1	0.03	1.6	Traces	Traces	0.12	0.09	
Er	0.15	0.07	4.9	Traces	Traces	0.3	0.19	
Tm	0.02	0.07	0.7	Traces	Traces	Traces	0.02	
Yb	0.08	0.29	2.5	4	Traces	2.4	0.11	
Lu	Traces	0.05	0.4	0.4	Traces	0.14	0.25	Eu-Y– 1.5
Y	4.4	0.14	8	51.4	0.5	2.4	2.4	

Typically, the concentrations of Tb and Dy are low, and the concentration of these elements can also be used to assess the prospects for the development of a particular concentrate; the remaining REE are obtained simultaneously during the division of REE. Nd and Pr are obtained during the division of the light REE group. In this regard, there has been a shift in the "center of gravity" of the REE market towards heavy metals and, in particular, Tb and Dy.

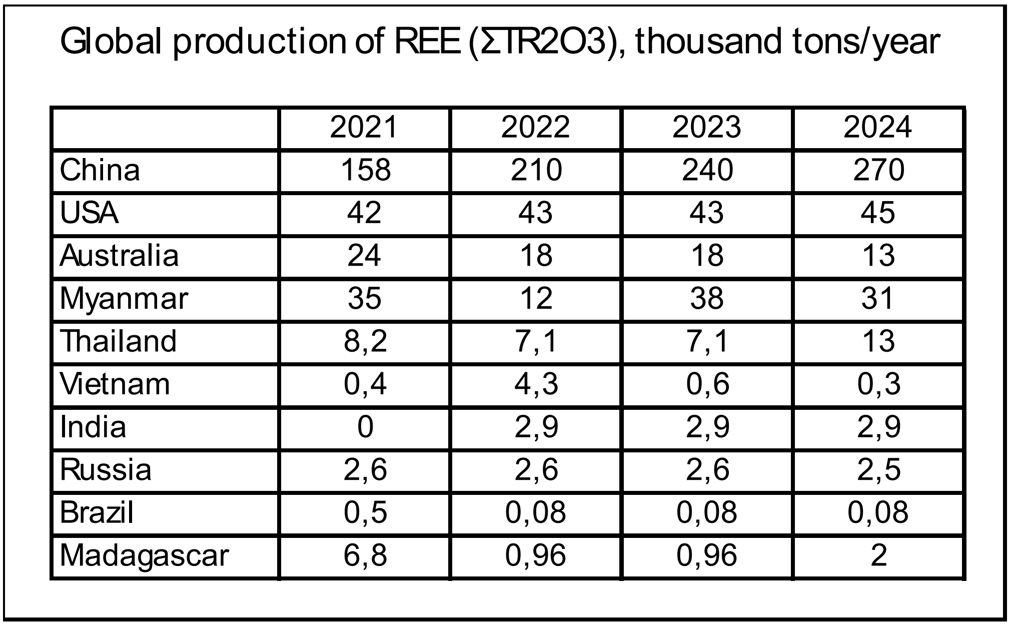
Along with natural raw materials, secondary raw materials can act as a source of REE. With the beginning of active consumption of REE products in various industries, the issue of recycling obsolete vehicles/machinery/devices containing REE has arisen. To date, methods have been developed for the isolation and separation of REE from fluorescent lamps, waste from the production of magnets, obsolete or used magnets, phosphors, catalysts and various types of glasses [17-20]. During the processing of NdFeB magnets, impurities of other REE (Pr, Gd, Tb), as well as Dy, are simultaneously released [21,22].

According to [17, 23], for each device using NdFeB magnets, there are different processing options depending on the amount of additive Dy. A technology for extracting REE from fluorescent lamps, containing from 10% to 20% of various REEs by weight, has also been developed. This allows the reuse of the obtained REEs without prior separation into individual elements [24,25].

Cathode ray tubes of televisions, monitors, and other devices, replaced by less environmentally harmful liquid crystal and plasma screens, are also a secondary source of REE. Methods of recycling obsolete household appliances have been developed, which make it possible to isolate REE [18,26,27].

Production Volumes of REEs

In the last ten years, there has been an increase in the production and consumption of REE. Taking into account the stability of REE production in China over the past twenty years [28-32], the growth is mainly due to Australia, the USA and Myanmar.



Global production of REE (ΣTR2O3), thousand tons/year

	2021	2022	2023	2024
China	158	210	240	270
USA	42	43	43	45
Australia	24	18	18	13
Myanmar	35	12	38	31
Thailand	8,2	7,1	7,1	13
Vietnam	0,4	4,3	0,6	0,3
India	0	2,9	2,9	2,9
Russia	2,6	2,6	2,6	2,5
Brazil	0,5	0,08	0,08	0,08
Madagascar	6,8	0,96	0,96	2

According to estimates [38-39], the actual values of REE production in China differ significantly from official data. The sale of REE products on the black market at discounted prices allows Chinese companies to influence competing companies, increasing the dependence of REE consumer companies on Chinese products, and create stocks that are used both for domestic consumers of China and as a lever of pressure on the REE market. In addition, many global companies (in Africa, Myanmar, Vietnam, etc.) are bound by contracts with Chinese manufacturers of REE products for the sale of undivided concentrate to China. Chinese companies themselves are interested in buying up all the REE concentrates in the world, even at inflated prices. This makes it possible, first of all, to concentrate all production capacities for the separation of REE in China, to prevent the spread of REE separation technology and thereby remain the absolute leader in the production of REE in the world.

In addition, it should be noted that some widely mined ores in China (for example, ion-adsorbed ores, monazite, etc.) are shallow (at the origins of the REE industry in China, ore was mined by local workers and peasants and sold to factories for cash in buckets; now, of course, the situation has changed) and practically non-radioactive. This also affects the final cost of processing raw materials and, consequently, the cost of producing REE.

The privileged position of the PRC in the REE market is due to its de facto monopolization over the past 20 years: any restriction on supplies from this country can have extremely negative consequences for the industry of other countries [40-41]. The active use of monopoly privileges in market conditions allows China to scale production, reduce costs, and accumulate funds, including for research and development. In fact, China has every opportunity to regulate the price policy in the field of REE and has repeatedly used various tools to adjust the cost and increase the economic effect.

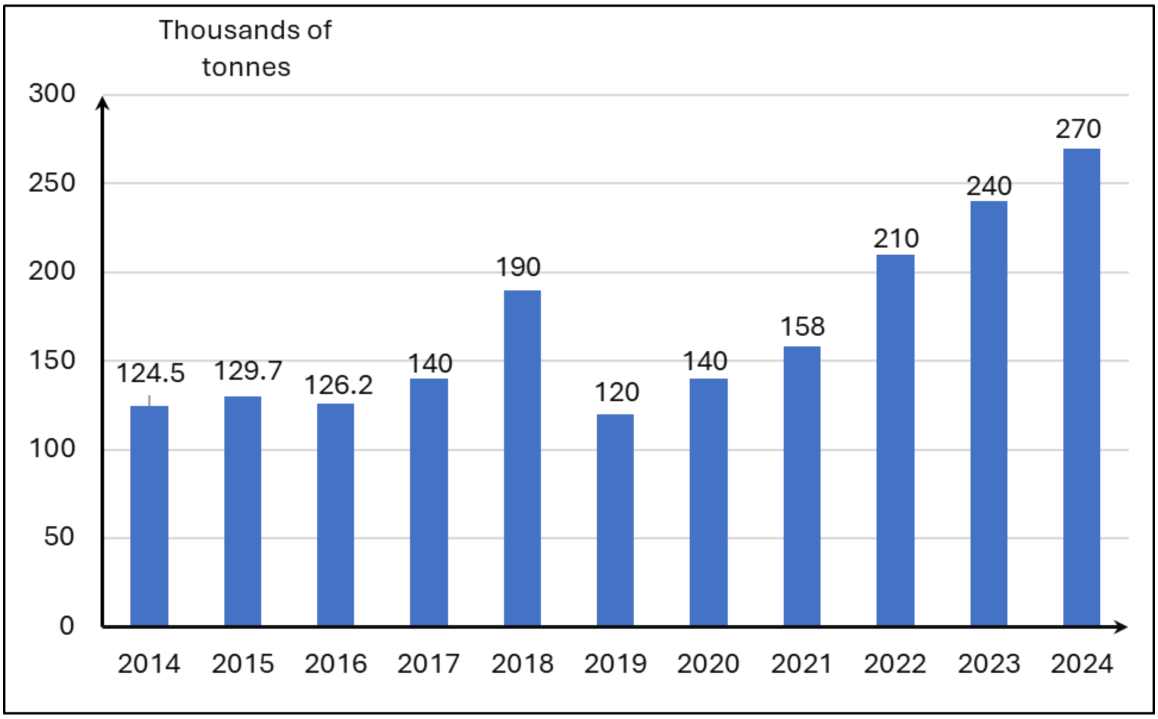


Figure 1 – *The volume of REE production in China.*

The manipulation of export prices by pump & dump techniques, followed by the establishment of monopoly prices, allowed Chinese companies to oust competitors. In practice, these are exports at prices below production costs or sales with financial losses in order to achieve ultra-high profits in the future. The above makes it necessary to develop our own industry for the extraction and processing of REE in other countries.

Applications for Rare Earths

The main consumers of REE are high-tech industries, and the main consumed elements are those used in heavy-duty permanent magnets: Nd acts as the base, Pr, Tb and Dy act as additives. [29, 30, 42, 43].

The ratio of the use of REE of the light and medium-heavy groups in various fields

	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Y
Catalysts	5,0	90,0	2,0	3,0	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
Magnets	<0,1	<0,1	23,4	64,6	4,8	<0,1	2,0	0,2	5,0	<0,1
Polishing powders	31,5	65,0	3,5	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
Other areas	19,0	39,0	4,0	15,0	2,0	<0,1	1,0	<0,1	<0,1	19,0
Metallurgy	26,0	52,0	5,5	16,5	<0,1	<0,1	<0,1	<0,1	<0,1	<0,1
Batteries	50,0	33,4	3,3	10,0	3,3	<0,1	<0,1	<0,1	м	<0,1
Glass	25,0	67,0	1,5	3,5	<0,1	<0,1	<0,1	<0,1	<0,1	3,0
Ceramics	17,0	12,0	6,0	12,0	<0,1	<0,1	<0,1	<0,1	<0,1	53,0
Phosphors	8,5	11,0	<0,1	<0,1	<0,1	4,9	1,8	4,6	<0,1	69,2

Table 4 shows the main applications of some REE.

In Alloys

The use of REE in metallurgy is explained by their high chemical activity. Even small REE additives can remove or bind harmful oxygen and sulfur impurities and change the configuration or distribution of impurity ions. All this helps to improve the mechanical properties of alloys, increase corrosion resistance and oxidation resistance. Mg-REE-based alloys are indispensable components of space equipment and automotive parts due to the high physico-chemical properties, radiation resistance and low density of these alloys.

Due to the peculiarities of the crystal structure, chemical activity and color, REE is used as additives in the production of glass and ceramics.

Optics

REE are used as color agents, protective substances against various types of radiation (infrared, X-ray and neutron radiation), as well as substances for deep cleaning of glass from colored impurities. Er is used as a discoloring agent for high-precision and clean glass (99.0-99.999%) [44]. Erbium and ytterbium are used as alloying additives for optical high-power communication cables. Samarium oxide is used to produce infrared light, while Europium oxide is used to protect against infrared radiation. Er, Eu, Ho, Sm and Tm are used for tinting glasses: additives of a number of REE make it possible to prevent the transmission of light of a certain wavelength [45].

Ceramics

As for ceramics, one of the main applications of high–purity Y (99.999%) is the production of Yttrium-stabilized zirconium containing from 3 to 8% of this element. Ceramics are used in the production of oxygen, fiber optics, thermal batteries in fighter and airplane engines, as well as in medicine, mainly dentistry. In the production of Yttrium-Zircon ceramics, Gd and Sm are used along with Y [21,46].

Phosphors

All REE of the medium-heavy group are used in the production of phosphors. Eu-Tb-Y purity 99.99-99.9999% or Eu-Y-Gd-Lu-Tb purity 99.0-99.999% are used for fluorescent lamps, LED (Light-Emitting Diode, light-emitting diode) and LCD (Liquid Crystal Display, liquid crystal display) lighting. In medicine, phosphors based on Eu-Y-Gd-Tb-Tm (99.99-99.9999%) are used for radiography; Eu-Dy phosphors provide security at airports, shopping malls and other protected facilities [46].

Permanent Magnets

Permanent magnets based on REE are used in the manufacture of acoustic transducers, motors and energy generators, magneto-mechanical devices, magnetic fields and imaging systems. Magnets are also used in amplifiers, smartphones, and the latest electronic devices. One of the main consumers of magnets is the production of wind generators and electric vehicles. Magnets based on REE are used in coolers, the production of which in the future is intended to reduce the energy costs of household and industrial devices [13,48,49].

Despite their cheapness and prevalence, ferrite-based magnets are gradually giving way to NdFeB magnets. NdFeB magnets contain Nd (25-35%), Pr (<10% in the form of an impurity if a Didymic mixture of Nd and Pr was used as the starting material for the production of the magnet), as well as Dy (4.5%), Tb, Ho and Gd to improve the performance of the magnet at high temperatures [50-54]. Sm/Co magnets do not demagnetize at high temperatures, have high performance, corrosion, and oxidation resistance, they are used both in small sensor sensors, and in motors, in the production of magnetic rails. Magnetic cushion trains are most widely used in China [55-57].

Miscellaneous Other Uses of the Less Well-Known REEs

REE of the medium-heavy group are used in narrowly focused, high-precision and clean technologies: in the manufacture of microwave devices (Y, Gd, Ho, Tm, Er and Yb), as resonators in frequency converters (Y-Gd grenades), in magnetic field measuring devices, adjustable transistors and oscillators [58].

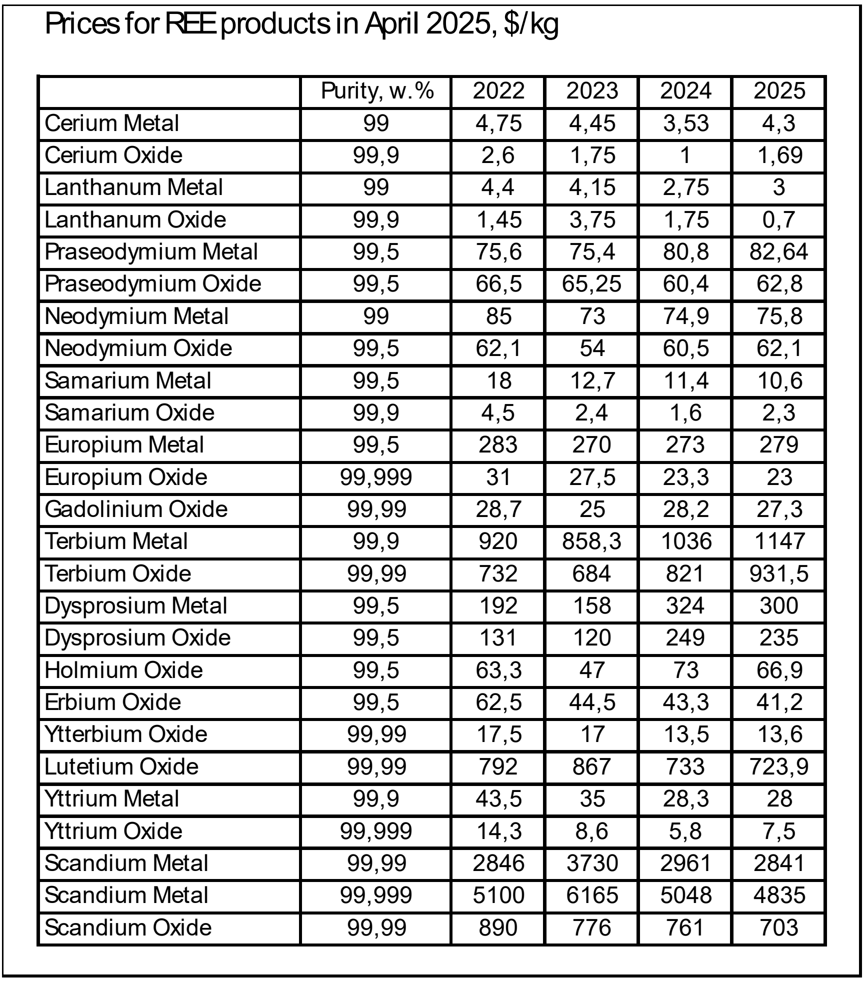
REE with a high thermal neutron capture value (Sm, Gd, Dy, Eu, Er, Y) is used to protect control units, regulate controlled nuclear reactions, and detect radiation leaks [59]. One of the promising, relatively recently developed alloys for nuclear reactor materials is the alloy Dy and B, which demonstrates good performance even at high temperatures [60].

It should be noted that there is an increase in the consumption of REE for medical purposes, both as materials for the latest equipment and as medicines. Europium cations are successfully used as fluorescent probes [61]. Radioactive isotopes of REE are used in the treatment of certain forms of cancer [62-64], in the creation of filters in air purification devices [65,66].

Minor in distribution, but important from the point of view of scientific development, are the areas of application of some REE: samarium – in the creation of strain gauges for measuring mechanical stresses in metal structures; radioactive isotope of europium – in light portable devices for screening and quality control of thin-walled metal vessels; gamma flaw detection based on europium isotopes is much more sensitive than flaw detection based on isotopes of Cesium and cCbalt. Its compounds, which fluoresce under ultraviolet exposure, are used for the analysis of minerals containing europium [21,66,67]. Some Gadolinium salts have strong paramagnetic properties, which is used in obtaining ultra-low temperatures [21,65].

Pricing of Rare Earths

The prices of REE products can be traced according to the data of the global metal market information resources [30-32, 43, 68]. The cost of REE depends on the purity, type of product (carbonate, oxide, metal), demand and complexity of production. The price level is also influenced by external market conditions: the value of the currency, shares of Chinese and Australian manufacturing enterprises, shares of global consumer companies of REE products [29, 42]. Table 3 below shows the prices of the main REE products in April of 2025.



Prices for REE products in April 2025, $/kg

	Purity, w.%	2022	2023	2024	2025
Cerium Metal	99	4,75	4,45	3,53	4,3
Cerium Oxide	99,9	2,6	1,75	1	1,69
Lanthanum Metal	99	4,4	4,15	2,75	3
Lanthanum Oxide	99,9	1,45	3,75	1,75	0,7
Praseodymium Metal	99,5	75,6	75,4	80,8	82,64
Praseodymium Oxide	99,5	66,5	65,25	60,4	62,8
Neodymium Metal	99	85	73	74,9	75,8
Neodymium Oxide	99,5	62,1	54	60,5	62,1
Samarium Metal	99,5	18	12,7	11,4	10,6
Samarium Oxide	99,9	4,5	2,4	1,6	2,3
Europium Metal	99,5	283	270	273	279
Europium Oxide	99,999	31	27,5	23,3	23
Gadolinium Oxide	99,99	28,7	25	28,2	27,3
Terbium Metal	99,9	920	858,3	1036	1147
Terbium Oxide	99,99	732	684	821	931,5
Dysprosium Metal	99,5	192	158	324	300
Dysprosium Oxide	99,5	131	120	249	235
Holmium Oxide	99,5	63,3	47	73	66,9
Erbium Oxide	99,5	62,5	44,5	43,3	41,2
Ytterbium Oxide	99,99	17,5	17	13,5	13,6
Lutetium Oxide	99,99	792	867	733	723,9
Yttrium Metal	99,9	43,5	35	28,3	28
Yttrium Oxide	99,999	14,3	8,6	5,8	7,5
Scandium Metal	99,99	2846	3730	2961	2841
Scandium Metal	99,999	5100	6165	5048	4835
Scandium Oxide	99,99	890	776	761	703

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As can be seen from the table above, the cheapest REE are La, Ce, Sm, and Y, since they are the easiest to separate from the rest, and most REE concentrates are characterized by the highest relative content of these elements [22]. The low cost of Yb2O3 is due to the fact that during the separation of heavy REE concentrate, a mixture containing Yb and Lu is formed at one of the separation stages [68], from which, first of all, Lu is sought to be isolated [69-71].

The most expensive, "critical" elements are Dy, Tb, and Lu, which is associated with the rapid development of their fields of application, including as additives to Nd/Fe/B, Sm/Co, and Dy2O3 magnets [74]. It is also necessary to note the low content of these elements in the initial concentrates, as well as the complexity of their separation technology.

The purity values shown in Table 3 are most in demand by consumers. In this regard, when designing the technology, the REE separation cascades are calculated in such a way as to obtain the necessary product using the least number of cascades. However, liquid extraction does not allow obtaining a high purity product when separating a concentrate containing several elements in a single separation cascade. To obtain a product containing more than 99.99 wt. % of the basic substance, REE concentrate is divided into several cascades: the first cascade is calculated to produce no more than 99.9 by weight. % of the basic substance, on the second and subsequent cascades to obtain ≥99.999%. On average, one cascade can increase the purity of the product by one or two "nines". The required number of cascades and the "length" (the quantity of steps) of each cascade to obtain a product of a given degree of purity is the main criterion for the cost of the entire technology and, consequently, the kilogram of each element.

Industrial variants of schemes of separation of medium-heavy REE

The choice of the technological scheme for separating the REE concentrate depends primarily on the concentration of heavy REE. As noted above, the main purpose of the REE separation technology is to isolate the most expensive elements (Tb, Dy, Lu). Their content in the initial concentrate is usually so low that other elements must be separated before they can be obtained.

Thus, according to the experience of separating the REE concentrate obtained from phosphorites from the Melovoe deposit (Kazakhstan, Mangyshlak peninsula) in the USSR, the separation technology involved separating the light group using TBP (tributyl phosphate) along the Sm/Nd line and the subsequent division along the Dy/Tb line[2]. The resulting light REE group (La, Ce, Pr, Nd) was sequentially divided along the lines Ce/La, Pr/Ce, Nd/Pr. The processing of the raffinate of the previous stage, containing Sm, Eu, Gd, Tb and traces of Dy, involved several conversions of nitrate solutions to chloride solutions and vice versa. The majority of europium was recovered and extracted in chloride solutions, and the mother liquor containing europium residues and other REE of the middle group was converted

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[2] Separation along the A/B line indicates that element "A" is extracted better and later it enters the reextract, the element "B" is extracted worse and goes into the raffinate. In the case of separation of the REE group concentrate, the "A" element goes into the reextract, as well as the elements to the right of "A" in the periodic table, and the "B" element and the elements to the left go into the raffinate. If the better extractable element "B" is listed first, and in the periodic table it stands to the left of "A", then the reverse logic of joint extraction should be applied. For clarity, use the periodic table.

back to nitrate and separated using a synergistic mixture of two different extractants along the Eu/Gd line. The Eu/Gd cascade reextract was re-purified and samarium was obtained. The raffinate of the Eu/Gd separation cascade, containing Gd, Tb, and Dy, was separated using other mixture of extractants and gadolinium and terbium were obtained. After transferring it to a chloride solution, hydrohydrogenic acid was added to the Dy/Tb cascade reextract, Y was separated using special for Y extractant, and the concentrate containing Tb–Lu was separated along the Tm/Er line. Further separation of REE in the reextract using chromatography made it possible to obtain Dy (>99.9%) and Er (<99%). The technology involved expensive evaporation operations, high cost of acids for conversion, and the volume of substandard solutions returned to the process [74].

The improved technology proposed by one of the scientific centers in Russia [75] included the use of three different extractants and proposed to start with the Y separation. Next steps were bound with the separation of light and heavy-medium groups and then individual separation of every REE inside groups. This made it easier to obtain the main REE in demand at that time: Eu and Er.

The composition of the initial concentrate and the demand for a particular element have a significant impact on the separation stages. Since different Chinese enterprises use different concentrates (extracted from ion-adsorbed ores, bastnesite or monazite), the technology of REE separation differs at each plant. Figure 2 shows a separation scheme from hydrochloric acid media of REE concentrate isolated from ion-adsorbed ores, implemented at the Fujian Changting Golden Dragon Rare Earth Co., LTD. plant in China [76] (P_50_7 is widly used China acid extractant, almost all their REE-technologies are based on it).

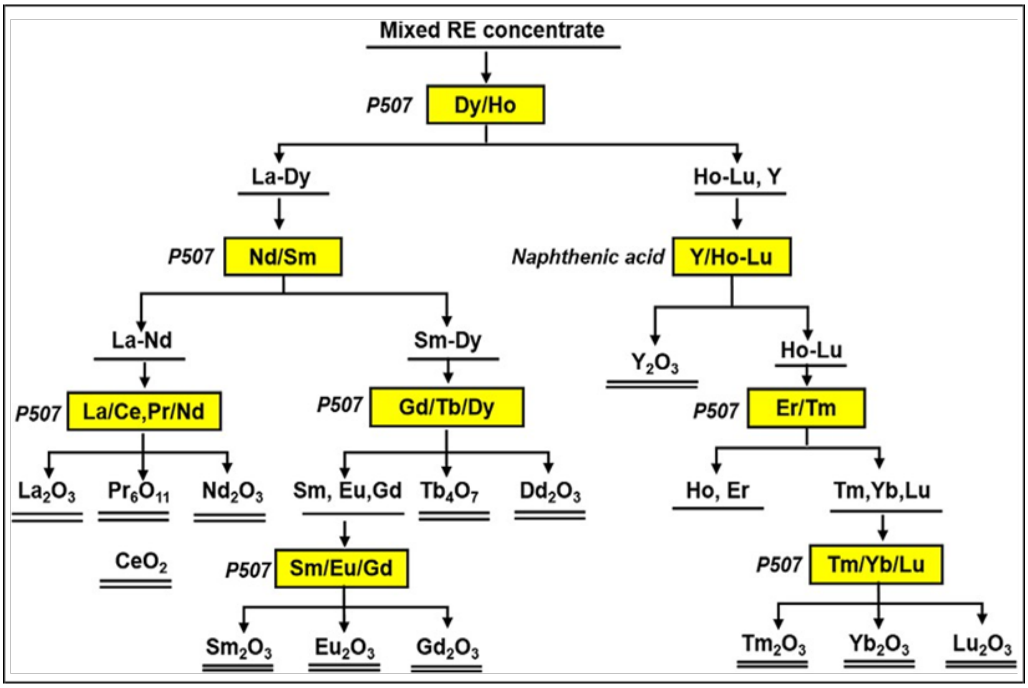

Figure 2 – Separation scheme of the initial REE concentrate isolated from ion-adsorbed ores

A distinctive feature of the technology is the choice of the first Ho/Dy separation line, which makes it possible to isolate a concentrate of heavy REE: Ho – Lu and Y, as well as a concentrate containing REE from La to Dy. Next, the Ho/Dy cascade raffinate is divided along the Sm/Nd line and a light group concentrate is obtained for further separation of light REE and a medium-heavy REE concentrate from Sm to Dy, the subsequent separation of which makes it possible to isolate all its constituent elements.

Y is isolated from the reextract of the Ho/Dy cascade using naphthenic acid and the remaining REE is separated. It should be noted that the entire technology, except for the Y separation, is based on the use of only one extractant, P_50_7, which is manufactured in China.

Due to the low cost and high content of Y in the initial concentrate, they try to separate it at the beginning of the scheme. At the pilot plant site of Ganzhou Rare Earth Group Co., Ltd. In China [77], the efficiency of Y separation was compared at different stages of concentrate separation (Figures 3).

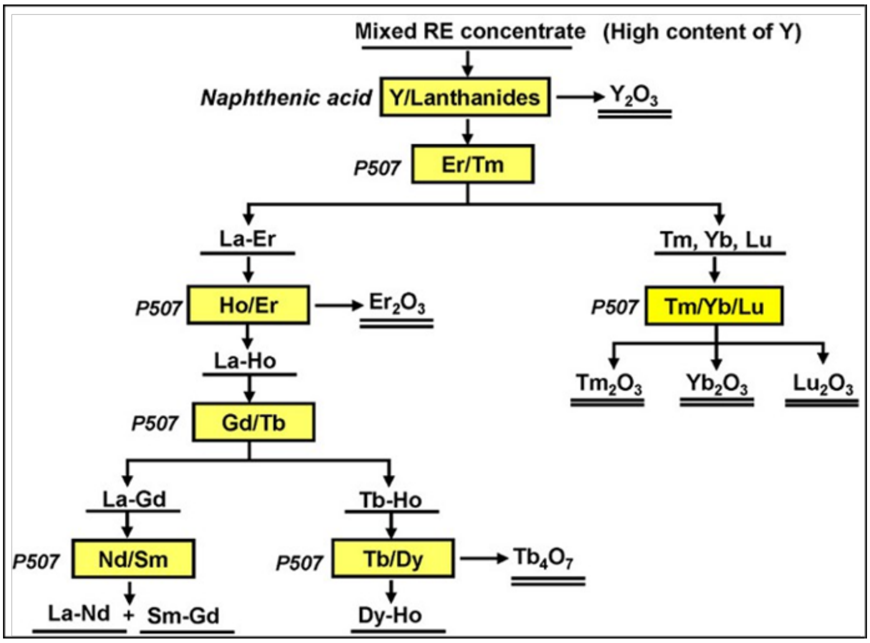

Figure 3 – Scheme of separation of REE concentrate with separation of Y at the beginning of the process along the Y/Ln line

Rationale & Thesis

Several factors contributed to the creation and development of the rare earth industry in China: absolute government support for the sector, shallow occurrence of REE-containing ores and minerals (and for the first time the possibility of extraction directly from the surface), low radioactivity of raw materials, convenient climatic location of mining sites, a large number of low-paid personnel for low-skilled jobs, high concentration of REE in raw materials and Finally, there is a high content of REE of the heavy group. In addition, it should be added that after the collapse of the USSR, many highly specialized specialists in the field of REE technology (chemists, technologists, designers and engineers), as well as technologies and equipment projects operating in Soviet factories, were outbid or recruited to work in China.

Chinese companies, to their credit, have more than taken advantage of the advantages provided, and now they are absolute and uncontested leaders in the field of REE. They use all possible means to consolidate their leadership and prevent the development of REE technologies in other countries. To do this, they use various technical and economic techniques: they buy even low-quality REE concentrates (with a high content of the light group and a low content of the heavy group) and even at inflated prices, dump prices on the global REE market, introduce additional quotas and restrictions on the sale of both REE in the form of oxides or metals, and their compounds. for the purposes of political and economic pressure.

At the same time, with the growth and development of the high-tech industry, the need for REE in the world is steadily increasing. Countries that widely use REE products, but do not produce them, become absolutely dependent on prices and supplies from China. [15, 29, 41, 44]. The monopoly of Chinese companies on the world market necessitates the creation (revival) of production facilities for the separation of REE by other countries.

In conditions of almost complete monopolization of the REE market, creating your own REE production becomes difficult not only from the technical and technological, but also from the political side. As it was noted, having a reserve of REE ore, divided REE, and finances, with government support, Chinese companies can literally bring down REE prices, and a new, newly created REE production will operate at a loss until complete ruin. At the same time, China will sell REE to the domestic market at low prices. From this we can conclude that in the long-term (more than 20 years) reliable support from the state is needed to create the production of REE.

Creating one’s own production of REE is a very difficult task. When planning and designing such a production, it is difficult to take into account all possible factors, both internal and external, that can affect the success of the enterprise. But this needs to be done, and we need to start today, or better yet yesterday.

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