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# RARE-EARTH ELEMENTS:
## A STEALTH WAR FOR TECHNOLOGICAL DOMINANCE

# 1. REFERENCE DATA

**Rare-Earth Elements: A Stealth War for Technological Dominance//**
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An innovative leader with an academic degree, Oleksandr has considerable practical engineering experience and works to promote international cooperation.

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### Konstantin Lisovyi

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A graduate of military academies in Ukraine and the United Kingdom, Ashot participated in the reform of Ukraine's defence industry in line with NATO standards and contributed to legislative processes in national security. With experience in commercial organisations, he possesses deep expertise in security risks, international business development, national security protection, and strategic communications. Ashot has also served in the Russian–Ukrainian war as a battalion chief of staff in the Armed Forces of Ukraine.

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# 5. ABSTRACT


In recent years, the critical dependence of democratic countries on China for the extraction and production of rare-earth metals (REMs), in the context of the green transition and the international arms race, has acquired a distinctly geopolitical dimension.

In view of the public escalation of confrontation between China and the democracies in this sphere over the past year, extraordinary measures and mobilisation of all available resources are required. These include securing targeted state funding for new projects, opening and developing promising new deposits, and the rapid launch of waste processing and recycling initiatives for REM-containing materials, generated during manufacturing and use.

What makes the practical implementation of these measures under crisis conditions particularly challenging is the **existential advantage** of authoritarian, mobilisation-based governance and strict state regulation (China, Russia) over the classical market-oriented planning and management methods of the democratic world. This advantage is further reinforced by the traditionally “relaxed approach” of authoritarian states to environmental issues, public health, and public opinion.

Recent active measures undertaken by democratic countries, together with their planned initiatives to develop all segments of the REM industry, are a clear indication that these states recognise the full scale of the strategic threat posed by critical dependence on and technological lag behind China. This awareness offers an opportunity for correction and stabilisation of the situation.

This study examines the broad aspects of the current state and future prospects of international rare-earth metal production and processing, analysing the most widespread technologies and the balance of power, identifying existing interdependencies and structures, and assessing the development prospects of individual industry actors.

To facilitate comprehension, the material is illustrated with **65 figures** and **21 tables**. It is based on the analysis of a large body of industry publications and the processing of information from up-to-date international databases. The list of primary information sources comprises **151 items**.

This material is intended for representatives of public administration bodies, diplomatic staff, as well as analytical and business entities.

# 6. INTRODUCTION

According to the classification of the International Union of Pure and Applied Chemistry (IUPAC), rare-earth metals (REMs) constitute a group of 17 elements. These include 15 lanthanides with atomic numbers ranging from 57 to 71 (lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium), as well as scandium and yttrium (atomic numbers 21 and 39, respectively), which exhibit significant similarities in their chemical and certain physical properties. REMs are commonly divided into two groups, light and heavy, based on atomic weight. However, considering the electron configuration of their atoms, they are often classified into the cerium and yttrium groups. (Table 1) [1, 2]

| CLASSIFICATION OF RARE-EARTH METALS BY GROUP | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| La | Ce | Pr | Nd | Pm | Sm | Eu | Gd | Tb | Dy | Ho | Er | Tm | Yd | Lu | Y | Sc |
| Lanthanides | | | | | | | | | | | | | | | | |
| Lanthanum | Cerium | Praseodymium | Neodymium | Promethium | Samarium | Europium | Gadolinium | Terbium | Dysprosium | Holmium | Erbium | Thulium | Ytterbium | Lutetium | Yttrium | Scandium |
| 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 39 | 21 |
| REM Groups | | | | | | | | | | | | | | | | |
| Cerium Group | | | | Yttrium Group | | | | | | | | | | | | |
| Light | | | | | | | Heavy | | | | | | | | | |

*Table.1 Classification of rare-earth metals by group, an original table based on research*

A notable feature of REMs is that they are not genuinely rare in the Earth's crust; in fact, they are more abundant than elements such as gold, uranium, lead, tin, molybdenum, and tungsten. Nevertheless, deposits containing industrially viable concentrations of rare-earth ores are less common than those present in the majority of other mineral resources. Experts estimate that accessible reserves of REMs exceed current global production by three orders of magnitude. [3]

REMs and their oxides are employed in the manufacture of high-technology products, such as permanent neodymium or samarium magnets, specialised alloyed steels, various catalysts, components of modern electronic devices, polishing materials, phosphors, and other advanced products. The ability of nations and corporations to produce REMs from mineral resources and to manufacture high-technology end products is regarded as a marker of industrial and technological development, comparable to the capacity to produce titanium alloys, aircraft, rockets, nuclear reactors, and aviation engines.

Figure 1 illustrates the principal applications of REMs.

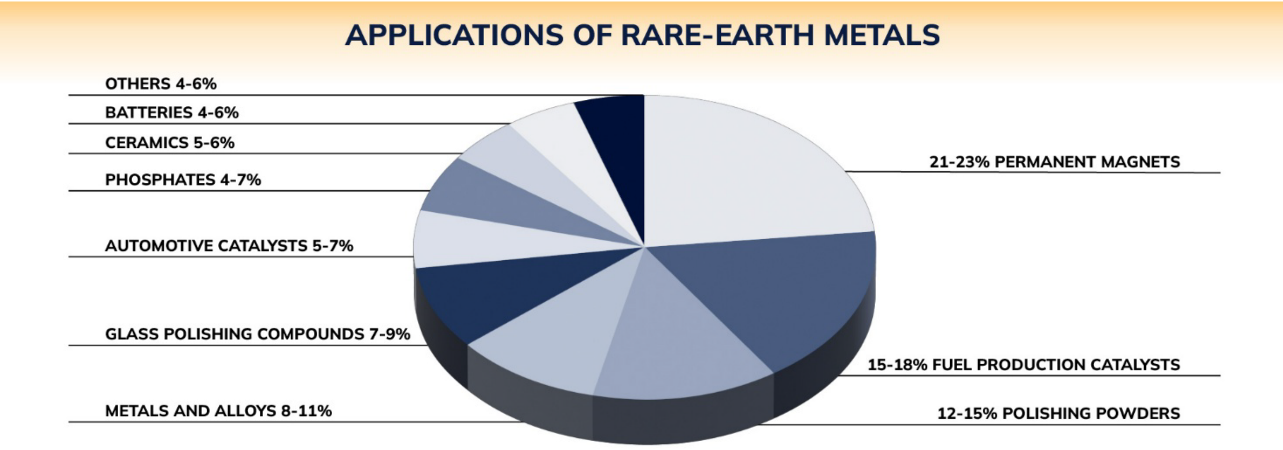


***Fig.1 REM application areas, an original diagram based on research materials***

Table 2 and Figure 2 present the areas of REM utilisation according to Argus Agency as of 2023.

| APPLICATIONS OF RARE-EARTH METALS, ARGUS | | | | | | | |
|---|---|---|---|---|---|---|---|
| AREA | PERMANENT MAGNETS (Nd, Tb, Dy, Gd, Pr, Sm) | POLISHING POWDERS AND GLASS (Ce, La) | CATALYSTS FOR PETROCHEMICALS AND AUTOMOBILES (Ce, La, Pr, Nd) | NICKEL–METAL HYDRIDE BATTERIES (La, Ce, Nd, Pr, Sm) | MISCHMETALS AND SPECIAL ALLOYS (Ce, La, Nd, Pr, Y) | CERAMICS (La, Ce, Nd, Y) | OTHER (PHOSPHORS Y, Yt, Tb, Gd, Eu, Ce, La, Ho), (NUCLEAR INDUSTRY Gd, La) |
| % | 26 | 25 | 17 | 11 | 6 | 6 | 9 |

***Table 2 REM applications in 2023, according to Argus Agency.***

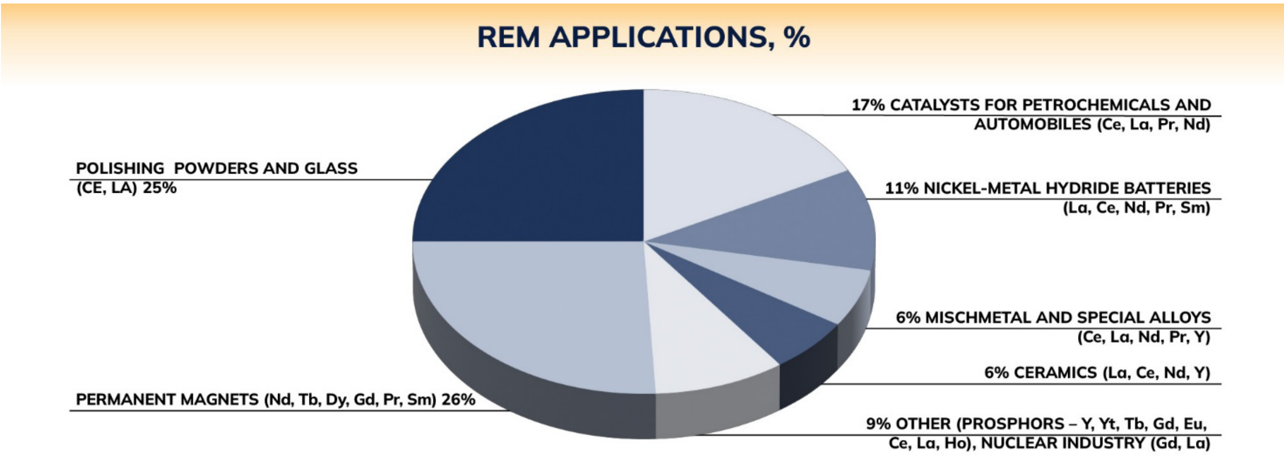


***Fig.2 Diagram of distribution of REM applications, according to Argus Agency.***

According to Argus Agency, by 2033, the share of permanent magnets in REM consumption is expected to rise from the current 26% to 42%.

The history of rare-earth magnets began in the late 1960s, when the United States Air Force Materials Laboratory first identified the distinctive magnetic properties of samarium–cobalt intermetallic compounds ($SmCo_5$ and $Sm_2Co_7$). Their industrial production was initiated in 1970 by Albert Gale and Dilip K. Das of Raytheon Corporation.

Permanent Sm-Co magnets proved to be powerful and highly stable, with excellent performance and compact dimensions. The start of their commercial production triggered revolutionary changes across numerous industries. These magnets became indispensable for electric motors of all sizes, particularly in hybrid engines, wind turbines, and conventional power units. With the introduction of these magnets, devices became both smaller and more powerful.

Over time, the high demand and cost of samarium, coupled with rising global cobalt prices, stimulated research into new magnetic materials. In response to cobalt supply challenges, Hitachi and General Motors developed the neodymium–iron–boron (Nd–Fe–B) magnetic composition, including the $Nd_2FeB$ alloy with a relatively modest REM content. Magnets based on this composition were created in 1983 and rapidly scaled to industrial production. The overall REM content in Nd–Fe–B magnets is approximately 32%, with the majority being neodymium, and smaller proportions of praseodymium, dysprosium, and terbium.

Experiments demonstrated that $Nd_2Fe_{14}B$-based magnets possess twice the magnetic strength of samarium–cobalt products, along with greater resistance to demagnetisation. This opened broad prospects for their use in permanent-magnet electric motors. One of the most significant advantages of Nd–Fe–B magnets is their relatively low cost compared with other magnetic materials. Consequently, $Nd_2Fe_{14}B$ magnets gradually replaced $SmCo_5$ in many devices and, under standard operating conditions, remain unrivalled.

However, although samarium–cobalt magnets are 10–30% weaker in magnetic strength compared with neodymium magnets, they offer several critical advantages. These include high operating temperatures of 300–350 °C (compared with 80–150 °C for neodymium magnets), substantial resistance to demagnetisation, mechanical robustness, and enhanced corrosion resistance (without the need for protective coatings).

These properties make Sm–Co magnets indispensable in applications requiring strength, power, thermal stability, and minimal weight of end products, such as spacecraft, computer technology, miniature electric motors and magnetic couplings, mobile communication devices, as well as aviation, rocketry, and various modern weapon systems.