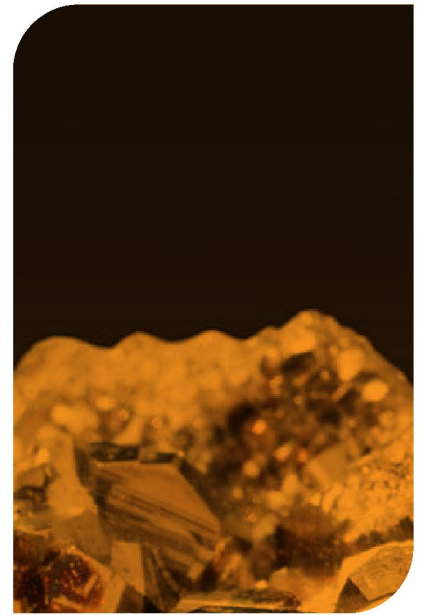
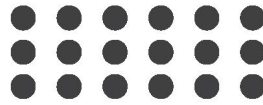




SCIENCE PARK
FINCORD-POLYTECH 2026

RARE-EARTH ELEMENTS: A STEALTH WAR FOR TECHNOLOGICAL DOMINANCE

1. REFERENCE DATA

Rare-Earth Elements: A Stealth War for Technological Dominance//

By O.A. Andrianov, Yu.O. Andrianov

Editors: P.V. Verkhniatskyi, A.I. Yarmolskyi, K.V. Lisovyi, A.A. Topchian

Kyiv, 2026, 127 p.

Notice:

- The personal, non-proprietary intellectual property rights belong to the individual authors. The intellectual property rights to the work are jointly owned by LLC "SCIENCE PARK FINCORD-POLYTECH" and the individual authors, and are exercised jointly by them.
- Any natural or legal person may use this work (including copying, quoting, referencing, and other uses) solely for non-commercial purposes, provided that proper attribution is given to:
 - Rare-Earth Elements: A Stealth War for Technological Dominance;
 - the authors;
 - LLC "SCIENCE PARK FINCORD-POLYTECH", 9Б Mykhaila Hrushevskoho Street, office Д6-3, Kyiv 01021, Ukraine.

E-mail: mail@fctm.com.ua

© LLC "SCIENCE PARK FINCORD-POLYTECH", 2026

© Andrianov O.A., Andrianov Yu.O., 2026

© Verkhniatskyi P. V., Yarmolskyi A. I., Lisovyi K. V., Topchian A. A., 2026

2. AUTHORS



Oleksandr Andrianov

Science Park Fincord-Polytech Expert

An innovative leader with an academic degree, Oleksandr has considerable practical engineering experience and works to promote international cooperation.

Oleksandr has a PhD in Engineering. He has co-authored more than 20 Ukrainian utility model patents and published research in engineering disciplines in professional journals as well as production testing programmes of modern equipment and technologies. He leads research and development in technological innovations and the latest industrial solutions.

Oleksandr studied Equipment and Technology of Welding Production as well as Finance and Credit at the Zaporizhzhia Machine-Building Institute. In 2010, he defended his thesis on *'Optimisation of the process of stabilising the welding of corrosion-resistant steels with alternating current'* at the Kyiv Polytechnic Institute.

He headed a number of commercial and state-owned enterprises for a long time.

Oleksandr is a Board Member and Advisor to the President of ICC UKRAINE on the development of critical raw materials (CRM) and rare-earth metals industry.



Yurii Andrianov

Yurii has built his career at the intersection of engineering, industry, and economics, focusing on the introduction of innovations into industry.

Yurii has a PhD in Economics. He is also a co-founder and General Director at Peretvoruvach Research and Development Institute LLC, which manufactures electric motors and electronic equipment and conducts research and development in the natural sciences and engineering. He has co-authored multiple research and engineering papers for professional journals and developed programmes and methodologies for various industries.

Yurii has two academic degrees in widely different fields. He studied International Economic Relations at the Zaporizhzhia National Technical University and Law at the Zaporizhzhia National University. In 2010, he defended his thesis on *'Assessment and formation of the investment potential of machine-building enterprises'* at the National University Lviv Polytechnic.

Yurii is the Executive Director of ICC UKRAINE in Zaporizhzhia Oblast.

3. EDITORIAL BOARD



Pavlo Verkhniatskyi

Co-founder at Science Park Fincord-Polytech

An expert in sophisticated business intelligence with an international component, Pavlo leads cross-border research and performs geopolitical risk assessment with regard to critical minerals, the defence industry, and other strategic sectors. Drawing on his extensive experience in risk analysis and strategic consulting, Pavlo provides an in-depth understanding of behind-the-scenes particularities of business activities and country specifics with a focus on government–business relations, anti-corruption efforts, sanctions, and secure growth.



Andrii Yarmolskyi

Co-founder at Science Park Fincord-Polytech

Andrii is a lawyer, political advisor, and highly qualified expert in law, national security, public administration, sanctions policy, and economic crime prevention. He has extensive experience in corporate business and government roles, in particular, he served as prosecutor and acting head of two regional administrations, and held senior positions at the National Security and Defence Council of Ukraine. During his tenure at the NSDC, he coordinated the implementation of state sanctions policy and oversaw matters related to the control of critical materials supply chains.



Konstantin Lisovyi

Co-founder at Science Park Fincord-Polytech

Kostiantyn is a strategist and advisor on international cooperation, national security, legislative development, implementation of state programmes, export control, and the defence industry. He has over 20 years of experience in the Foreign Intelligence Service of Ukraine, where he has advanced from entry-level positions to the role of Deputy Head of the Service. Kostiantyn led strategic national security research, contributed to legal and regulatory development, and helped draft intergovernmental security agreements and strategic development programmes for the defence sector.



Ashot Topchian

Co-founder at Science Park Fincord-Polytech

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.

4. TABLE OF CONTENTS

RARE-EARTH ELEMENTS: A STEALTH WAR FOR TECHNOLOGICAL DOMINANCE

No.	Title	Page
1.	Reference Data	2
2.	Authors	3
3.	Editorial Board	4
4.	Table of Contents	5
5.	Abstract	9
6.	Introduction	10
7.	Applications of Rare-Earth Metals	13
7.1.	Utilisation of REMs in Military Technology	13
7.1.1.	REMs in the Military Technology of the United States Air Force	13
7.1.2.	REMs in the Military Technology of the United States Army	14
7.1.3.	REMs in the Military Technology of the United States Navy	14
7.2.	Principal Areas of REM Utilisation in the Civilian Sector	15
7.3.	REM Market Indicators	16
7.4.	Global REM Reserves	17
7.5.	REM Extraction	18
7.5.1.	Principal Indicators and Characteristics of REM Extraction	18
7.5.2.	Countries Extracting REM Ores	20
7.5.2.1.	China	20
7.5.2.2.	United States	21
7.5.2.3.	Myanmar	22
7.5.2.4.	Australia	24
7.5.2.4.1.	Lynas Rare Earths Ltd	24
7.5.2.4.1.1.	REM Extraction and Processing at Lynas Rare Earths Ltd	24
7.5.2.4.1.2.	Lynas Malaysia Sdn. Bhd	25

7.5.2.4.1.3.	Lynas Kalgoorlie Pty Ltd	25
7.5.2.4.1.4.	Export Priorities of Lynas Rare Earths Ltd. to Japan	26
7.5.2.4.1.5.	Risks in the Operations of Lynas Rare Earths Ltd	26
7.5.2.4.2.	Northern Minerals Ltd	26
7.5.2.4.3.	Eneabba Project	27
7.5.2.4.4.	Nolans Project	28
7.5.2.4.5.	Yangibana Project	29
7.5.2.5.	Thailand	29
7.5.2.6.	Vietnam	30
7.5.2.7.	Brazil	34
7.5.2.7.1.	General Situation in Brazil in the Field of REM	34
7.5.2.7.2.	Serra Verde Project	35
7.5.2.7.3.	Caldeira Project	36
7.5.2.7.4.	Monte Alto Project	37
7.5.2.7.5.	Araxá Project	39
7.5.2.7.6.	Tiros Project	40
7.5.2.7.7.	MagBras Initiative	40
7.5.2.8.	REE Extraction prospects in Scandinavia	41
7.5.2.8.1.	Prospects for REE Extraction in Norway	41
7.5.2.8.1.1.	Development Prospects of the Fenn Complex	41
7.5.2.8.1.2.	Prospects for REM Extraction from Phosphate Raw Materials	43
7.5.2.8.2.	Prospects for REE Extraction in Sweden	44
7.5.2.8.2.1.	LKAB's Per Geijer Project	45
7.5.2.8.2.2.	Bastion Minerals Ltd. Gyttorp Project	47
7.5.2.8.2.3.	Leading Edge Materials Corp. Norra Kärr Project	48
7.5.2.9.	Prospects for REE Extraction in Greenland	50
7.5.2.9.1.	General Situation Regarding REE Deposits in Greenland	50
7.5.2.9.1.1.	Tanbreez Project	52
7.5.2.9.1.1.1.	Advantages of the Tanbreez Project	54
7.5.2.9.1.1.2.	General Issues of Mining Projects in Greenland	55

7.5.2.9.1.1.2.1.	Corporate Risks in the Implementation of the Tanbreez Project	55
7.5.2.9.1.1.2.2.	Challenges Facing Mining Projects in Greenland	56
7.5.2.10.	Prospects for REM Extraction in Africa	58
7.5.2.10.1.	Issues in REM Extraction in African Countries	59
7.5.2.10.2.	Tanzania	60
7.5.2.10.2.1.	Ngualla Project	60
7.5.2.10.3.	Kenya	61
7.5.2.10.3.1.	Mrima Hill Project	61
7.5.2.10.4.	Namibia	62
7.5.2.10.4.1.	Lofdal Project	62
7.5.2.10.5.	Prospects for REE Extraction in Morocco	63
7.5.2.10.5.1.	REEs in Moroccan Deposits	63
7.5.2.10.5.2.	REE Extraction in the Process of Phosphoric Acid Production	65
7.5.2.10.5.3.	Geopolitical Risks of Phosphate and REE Extraction in Morocco	67
7.5.2.11.	Prospects for REE Extraction in Ukraine	67
7.5.2.12.	Prospects for REE Extraction in Russia	68
7.5.2.12.1.	Key Points and Indicators	69
7.6.	Technologies for Extracting Pure REEs from Ore Raw Materials	75
7.6.1.	Chloride Technology	75
7.6.2.	Acid-Leaching Technology	77
7.7.	Production of Rare-Earth Permanent Magnets	83
7.8.	Prospects for Expanding REE Production in Democratic Countries	85
7.8.1.	Additional Sources of Rare-Earth Elements and Finished Products	85
7.8.1.1.	General Characteristics of Phosphate Raw Material Sources	86
7.8.1.1.1.	Global Reserves and Production of Phosphate Ore and Fertilisers	86
7.8.1.1.2.	Prospects for REE Recovery from Phosphogypsum	87
7.8.1.1.2.1.	Current Status and Trends in Global Phosphogypsum Accumulation	88
7.8.1.1.2.2.	REE Recovery from Phosphogypsum	89
7.8.1.1.2.3.	Examples of REE Recovery from Phosphogypsum	90
7.8.1.1.2.3.1.	Tunisia	90

7.8.1.1.2.3.2.	Poland	91
7.8.1.1.2.3.3.	Florida, United States	92
7.8.1.1.2.4.	Industrial Implementation of REE Recovery from Phosphogypsum	93
7.8.1.1.2.4.1.	Implementation of Technology by Rainbow Rare Earths	93
7.8.1.1.2.4.1.1.	Profile of Rainbow Rare Earths Limited	93
7.8.1.1.2.4.1.2.	Intellectual Property Protection and Monetisation	94
7.8.1.1.2.4.1.3.	Projects of Rainbow Rare Earths Limited	95
7.8.1.1.2.4.1.4.	Phalaborwa Project	96
7.8.1.1.2.4.1.5.	Foskor Plant	96
7.8.1.1.2.4.1.6.	Technology for REE Recovery from Phosphogypsum at the Phalaborwa Deposit	98
7.8.2.	Recycling of Permanent Rare-Earth Magnets	101
7.8.2.1.	Technologies for Recycling Rare-Earth Magnets	102
7.8.2.1.1.	Traditional Methods of REPM Recycling	102
7.8.2.1.2.	New Magnet Recycling Technologies	104
7.8.2.1.3.	Examples of Practical Application of Rare-Earth Magnet Recycling	107
8.	Conclusions	111
9.	List of References	114

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															Yttrium	Scandium	
Lanthanum	Cerium	Praseodymium	Neodymium	Promethium	Samarium	Europium	Gadolinium	Terbium	Dysprosium	Holmium	Erbium	Thulium	Ytterbium	Lutetium			
57	58	59	60	61	62	63	64	65	66	67	68	69	70	71			
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.

APPLICATIONS OF RARE-EARTH METALS

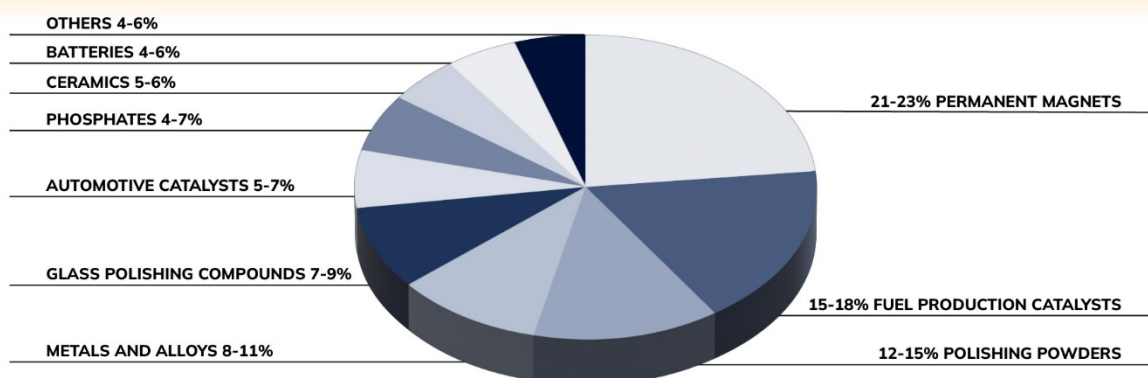


Fig.1 REM application areas, an original diagram based on research materials

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.

REM APPLICATIONS, %

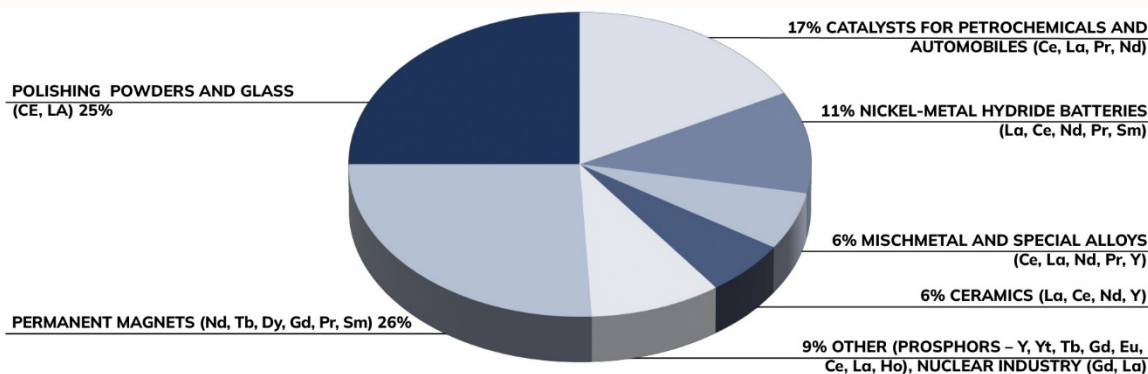


Fig.2 Diagram of distribution of REM applications, according to Argus Agency.

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 Nd₂FeB 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 Nd₂Fe₁₄B-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, Nd₂Fe₁₄B magnets gradually replaced SmCo₅ 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.