# Management of the Rare Earth Elements (REE) in the Global Economy: Neodymiun Case Study

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## Abstract

*This study provides an overview of using rare earth elements (REEs) in global economy based on the permanent magnets consuming mainly a mixture of neodymium (Nd), praseodymium (Pr) and dysprosium (Dy), and cerium (Ce), as well as gadolinium (Gd) in much lower quantities. Actually the segment of the magnet market is the largest rare earth market (REM) by volume and will continue to outperform other market segments. In the report on „Rare Earths, Outlook to 2030" presented in Green Car Congress on the 3 February 2021 and developed by Roskill Commodity Research forecast, acquired in June 2021 by Wood Mackenzie, the leading global research, consultancy, and data analytics business powering the natural resources industry, Roskill forecasts that rare earth magnet applications will account for ~40% of total demand by 2030, raising the potential for a tight supply-demand balance for key magnetic REEs. The supply of rare earths on the US, Europe, Japan and Chinese markets is presented and discussed.*

**Keywords:** *management of critical raw materials, rare earths (REEs), rare earth management, neodymium, rare earth magnet market, circular economy*

## 1. Introduction

In recent years, digital transformation and smartization projects in industrial enterprises have become increasingly popular, aiming to increase operational efficiency, productivity and sustainable development. In a situation of limited availability of key raw materials for an innovative economy, such as rare earth elements (REE), including metals used in electronic and energy devices (implementing the green economy), secondary sources of raw materials play an important role.

Smartization aims to effectively optimize resources (of all types) with an emphasis on sustainable development, which is why it can be helpful in achieving goals such as: resource optimization, emission reduction, circular economy integration, compliance with environmental regulations [4].

According to Kumari et al. [11] Neodymium (Nd) is the second most abundant rare earth elements (REEs) found in earth's crust. It is always found in Misch metals [11]. Although Nd rarely exists in nature, its negative impact on human health and environment are cited but involvement of this rare earth in discussion is caused to their wide range of applications, and as Kumari et al. [11] showed Nd's certain intolerable human actions. Moreover, Kumari et al. [11] discussed the role of the Nd in preparing neodymium-iron-boron (Nd-Fe-B) alloy which is utilized in manufacturing permanent magnets. Applications these magnets widely utilized in many areas such as vehicles components, computer hard disks, petroleum industries, wind turbines, loudspeakers, etc. are outlined in Padhan et al. [15], among others. To the best our knowledge, the Research and Markets report (2016), cited by Padhan et al. [15] estimated the global demand of these magnets to increase by 13.2% till 2022 (Research and Markets, [17]).

The JRC study (Moss et al., [13]) examines the use of 14 metals in the six low-carbon energy technologies of the EU's Strategic Energy Technology Plan (SET-Plan), namely: nuclear, solar, wind, bioenergy, carbon capture and storage (CCS), as well as electricity grids will require 1% or more of current world supply per annum between 2020 and 2030 (Moss et al., [13]). These 14 significant metals, in decrease order of demand for tellurium (Te), indium (In), tin (Sn), hafnium (Hf), silver (Ag), dysprosium (Dy), gallium (Ga), neodymium (Ne), cadmium (Cd), nickel (Ni), molybdenum (Mo), vanadium (V), niobium (Nb) and selenium (Se) are presented (Moss et al. [13]).

## 2. Rare Earths

According to Arafura Rare Earths Limited, an Australian mineral exploration company focusing on REEs, headquartered in Perth (ARE, [1]), rare earths (REs) are critical materials and essential to many important products in modern society. Demand for REs is caused by the following trends: (ARE, [2])

- Transition towards more renewable energy
- Advances in consumer electronic technology
- Low emission technology concepts
- Evolution in automotive and future mobility trends (ARE, [2])

## 3. NdFeB Magnet Materials – A Rapidly Growing Market

According to ARE [2] permanent NdFeB magnets, with typical content up to 30% NdPr metal (from NdPr oxide), has an influence on the automotive products and wind power energy generation industry, among others. Moreover. important uses of NdFeB magnets include also: e-bikes, consumer electronics, and robotics (ARE, [2]), air-conditioners and wind power generators (Baba et al. [5]). Most significantly demand for NdPr oxide, in the automotive sector, according to ARE [2], is driving force of growth for permanent magnet electric motors used in hybrid EVs (HEV) and battery EVs (BEV).

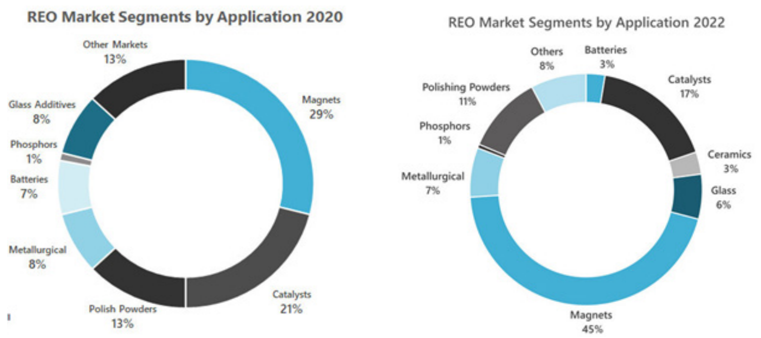


Fig. 1. REO Market in years 2020 and 2022 (Source: ARE, [2])

Rys. 1. Rynek REO w latach 2020 i 2022 (Źródło: ARE, [2])

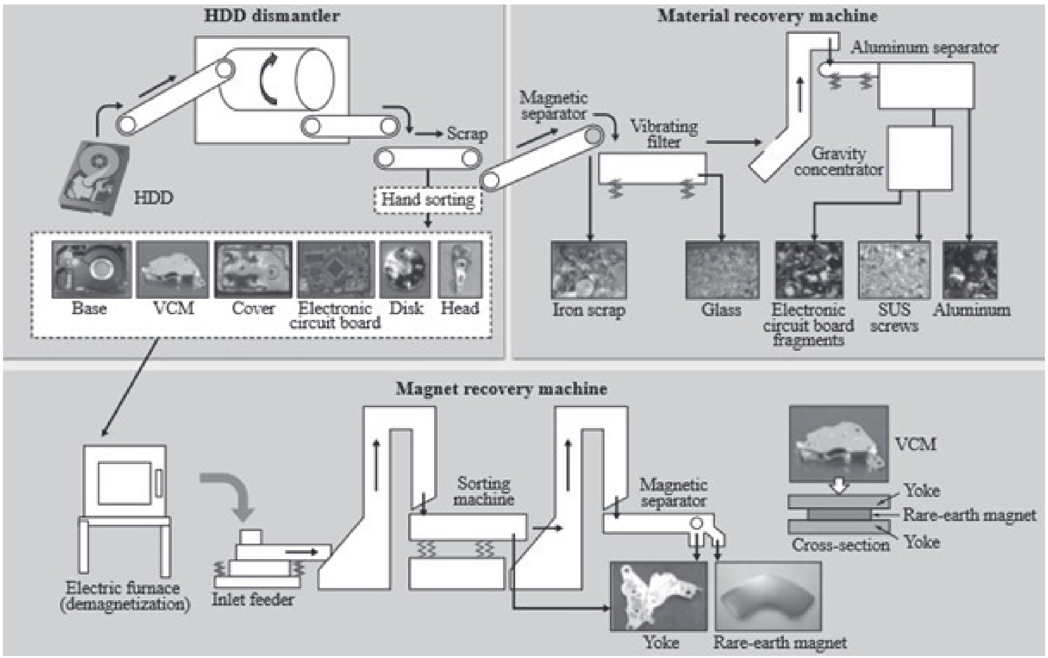


Fig. 2. Process Used to Separate and Recover Rare-earth Magnets from HDDs (where: HDD: hard disk drive VCM: voice coil motor SUS: steel use stainless) (Source: Baba et al. [5])

Rys. 2. Proces stosowany do oddzielania i odzyskiwania magnesów ziem rzadkich z dysków twardych (gdzie: dysk twardy: dysk twardy VCM: silnik cewki drgającej SUS: stal nierdzewna) (Źródło: Baba i in. [5])

Rare-earth magnets are a key material in energy saving and digital equipment such as hard disk drives (HDDs), high-efficiency air conditioners, hybrid vehicles, and wind power generators.

The magnet market segment according to ARE [2] is the largest rare earth market by volume and will continue to outpace other market segments and is expected to account for 40-50% of the Rare Earth Oxides (REO) market by the end of the decade. The REO market segment application respectively in years 2020 and 2022 is shown in Figure 1 (ARE, [2]).

The review addressed the recycling potential of NdFeB permanent magnets, the recycling and recovery of REEs (Nd, Pr, Dy, Tb) from End-of-Life (EOL) and magnets different types of metallurgical recovery methods has been discussed in Yang et al. [23].

Hitachi developed the concept and technologies of rare-earth magnets (REM) recycling and published it as a goal of an Environmental Vision, based on the environment management, and also as continuation activities pointed at the "Prevention of Global Warming", "Conservation of Resources," and "Preservation of Ecosystems". Moreover, the recycling of rare-earth magnets is a part of Hitachi's resource recycling initiatives (Baba et al. [5]).

Regarding the REM recycling and recovery activities, Hitachi has developed magnet recovery machines designed for use with specific products that contain rare earths, namely hard disk drive (HDD) and air conditioner compressors (ACC) (Baba et al. [5]).

The processes used to separate and recover the rare-earth magnets from HDD, and ACC, developed by Hitachi are given in Figure 2, and Figure 3, respectively.

Rare earths used in NdFeB magnets represent the single largest segment by application, accounting for 45%. The use of NdFeB magnets in the automotive, wind turbines and factory automation sectors are the biggest growth applications for NdPr oxide demand. The growth in NdFeB magnets since 2005 is attributed to increased use in the automotive industry, in particular electric drivetrains and electric power steering used in battery, plug-in hybrid and hybrid EVs. Passenger EVs have grown from 450,000 in 2015 to almost 10 million units in 2022 with forecast worldwide expansion of EVs predicted to grow to 34 million in 2030.

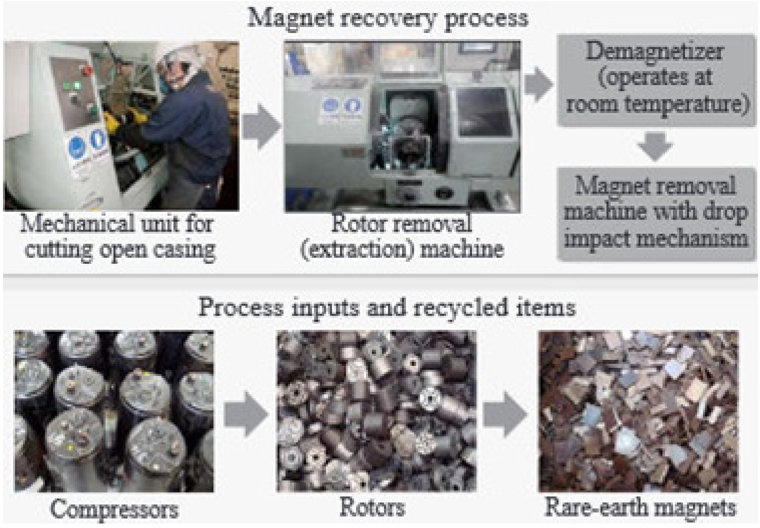


Fig. 3. Process Used to Separate and Recover Rare-earth Magnets from Air Conditioners (Source: Baba et al. [5])

Rys. 3. Proces stosowany do oddzielania i odzyskiwania magnesów ziem rzadkich z klimatyzatorów (źródło: Baba et al. [5])

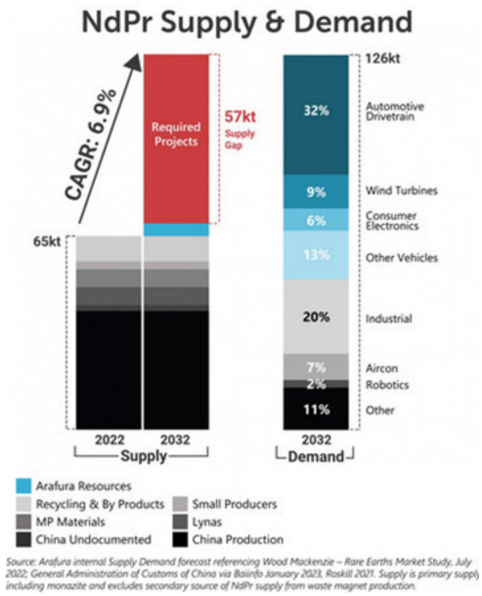


Fig. 4. NdPr supply and demand forecast (Source: WM, [22])

Rys. 4. Prognoza podaży i popytu NdPr (Źródło: WM, [22])

Global consumption of sintered NdFeB magnets in 2022 was 184,000 tonnes. NdFeB magnet consumption is forecast to grow by 5.8% per annum in the foreseeable future with demand reaching 322,000 tonnes in 2032. Use of NdFeB magnets in EVs is forecast to account for 32% of total demand by 2032 (see Figure 3). In addition to the discussion about Rare earth demand, specially Neodymium demand from magnet applications, see "Global rare earths strategic planning outlook in 2023" presented in Wood Mackenzie report (WM, [21]).

Neodymium will remain the primary focal point of the industry as demand from magnet applications grows (WM, [21]).

NdFeB magnets are considered as the strongest permanent magnets with the highest energy product BHmax (200–440 kJ/m3) of all permanent magnets [Jiles]. They are widely used in wind turbines, hybrid electric vehicles, hydro-electric turbine generators, etc. [Coey]. Figure 6 shows the proportion of the different applications around the global NdFeB market (Zhang et al., [24]).

Wood Mackenzie in "Rare earths: vital elements of the energy transition" [22] notes that the: China continues to operate in the downstream segment of the rare earth industry, increasing its share of fast-growing value-added end markets (see Figure 7). PM motors have become the motor technology of choice for many manufacturers, particularly in China, the world's largest electric vehicle market. Most PM motors in an electric passenger vehicle contain 1-3 kilograms of neodymium-iron-boron (NdFeB) magnet material, which should see automotive powertrain applications increase their share of total rare earth magnet consumption from about 16% last year to about one-third of total consumption by 2036.

In this context, the European Commission launched the ERMA Cluster on Rare Earth Magnets and Motors (EU [8]), which is managed by EIT RawMaterials GmbH (ERMA [19]). The key facts presented in the Rare Earth Magnets and Motors Cluster of the European Raw Materials Alliance Report, as results of the Rare Earth Magnets and Motors: A European Call for Action conducted under the auspices of the European

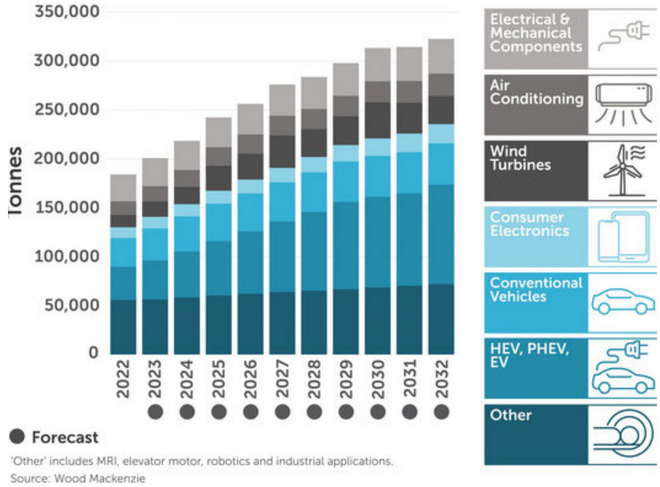


Fig. 5. Forecast NdFeB magnet consumption by segment (Source: WM, [22])
Rys. 5. Prognozowane zużycie magnesów NdFeB według segmentów (Źródło: WM, [22])

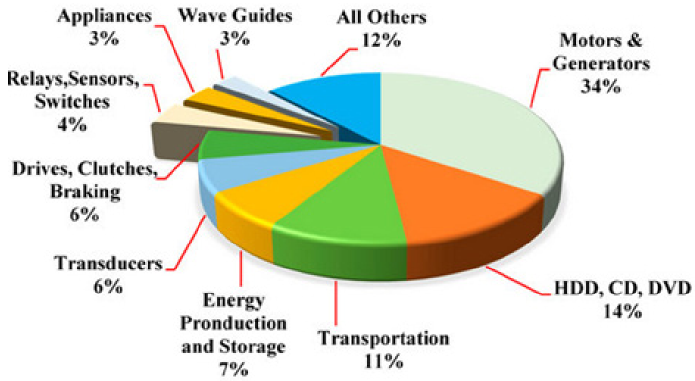


Fig. 6. The proportion of different applications around the global NdFeB magnet market, data from Shaw et al. [18]
Rys. 6. Proporcja różnych zastosowań na globalnym rynku magnesów NdFeB, dane Shaw i in. [18]

Raw Materials Alliance (ERMA) are presented below on the Figure 8 (ERMA, [19]).

Large rare earth metals recovery plants are also being built in Poland. MiningTechnology [20] reports in 2021: Mkango and Grupa Azoty initiated the construction of a rare earth metals separation installation. The new plant will produce separated neodymium/praseodymium oxides as well as heavy carbonate enriched with rare earth elements.

The new plant in Puławy is expected to produce 2,000 tonnes per annum (tpa) of separated neodymium and praseodymium oxides. It will also produce 50 tpa of dysprosium and terbium oxides in a rare earth enriched heavy carbonate [20]. This investment will result in the production of the rare earth separation plant increasing the security of supply of rare earth metals in Europe.

Mkango CEO William Dawes said: "Our integrated 'mine, refine, recycle' strategy, encompassing sustainably sourced light (NdPr) and heavy (Dy/Tb) rare earth from Malawi and rare earth magnet (NdFeB) recycling in the UK, via our interest in HyProMag, is now enhanced by the opportunity to create a rare earth separation and downstream hub in Poland, working with one of Europe's largest chemical and fertiliser companies."[20].

The objectives of the ERMA Cluster are „to secure access to sustainably produced magnet rare earths at competitive costs from primary and recycled sources; to make Europe a global leader in rare earth metal, alloys and magnet production; and to sustain and expand Europe's global leadership in electric motor and generator design. A two-fold approach was followed, that is, to identify promising investment cases as well as to recognize regulatory issues that hinder the growth of the sector in Europe" (ERMA, [19]).

**4. Conclusions**

Rare earth elements (REEs), especially neodymium, are crucial in many fields, especially in the manufacture of permanent magnets. The demand for permanent magnets containing neodymium is expected to increase steadily and significantly in the future due to the demand for permanent magnets used in vehicles, loudspeakers and hard drives, wind turbines, electronics, air conditioning and heating, etc. Markets such as the US, Europe, Japan and China are seeing a steady increase in demand for neodymium magnets until 2036. Due to the high demand and limited supply, it is profitable to obtain Nd from secondary sources in the process of advanced recycling.

The economic analysis of neodymium extraction allows us to understand the complex dynamics associated with this rare earth element. It is crucial to take into account the many factors that influence the market in order to better understand the development prospects, price stability, as well as possible challenges and opportunities that the economic side of the use

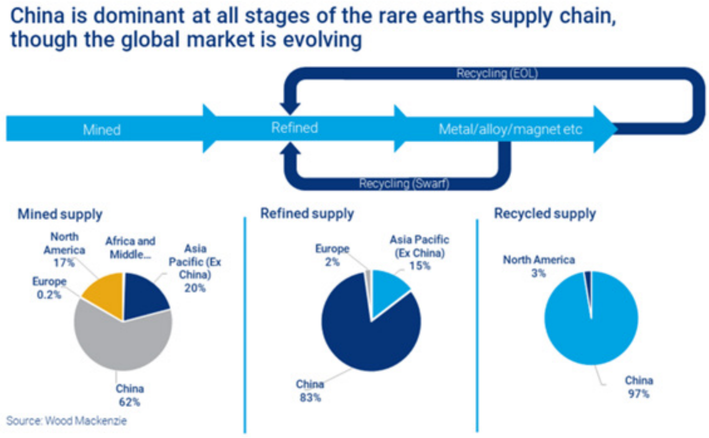


Fig. 7. China dominate on all stage of the rare earths supply chain (Source: Wood Mackenzie in "Rare earths: vital elements of the energy transition", [22])
Rys. 7. Dominacja Chin na wszystkich etapach łańcucha dostaw metali ziem rzadkich (źródło: Wood Mackenzie w "Rare earths: vital elements of the energy transition", [22])

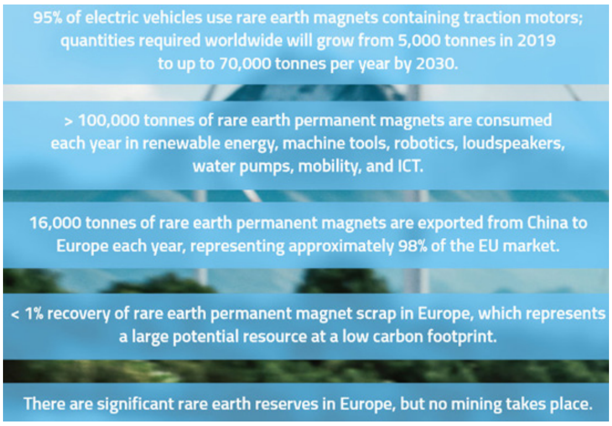


Fig. 8. ERMA Cluster Rare Earth Magnets and Motors: key facts presented in the Rare Earth Magnets and Motors Cluster of the European Raw Materials Alliance Report (Source: EREMA [19])
Rys. 8. ERMA Cluster Rare Earth Magnets and Motors: kluczowe fakty przedstawione w raporcie Rare Earth Magnets and Motors Cluster of the European Raw Materials Alliance (Źródło: EREMA [19])

of neodymium brings. The most awaited development of energy-saving sectors (eco-automotive and eco-energy) forces the acquisition of increasing quantities of NdFeB magnets for the construction and operation of electric vehicles and wind energy generators. For this purpose, clusters and other European initiatives, such as ERMA, are being set up to ensure sustainable access to rare earth elements, including Nd.

In conclusion, the analysis of neodymium as a rare earth element indicates its critical importance for the modern global economy. In the face of rapid technological development, innovation and the growing importance of renewable energy, strategies for managing this valuable resource are becoming crucial to ensure the sustainable and efficient use of neodymium in the future.

Understanding the variety of applications of neodymium and its key role in modern technologies allows us to better predict the directions of development of industries related to it. Further analysis of the impact of these applications on global markets and research into alternative solutions could be crucial for the sustainable management of neodymium resources in the future. It is already important to maintain a balance between the growing demand for neodymium and a balanced supply. In this context, forecasts for the neodymium and rare earth markets are crucial for strategic economic planning.

Increasing demand can lead to challenges in the availability of neodymium, and the lack of effective neodymium recycling systems can lead to increased waste and pressure to access new sources of raw materials. Concentrated production of neodymium in certain countries can lead to strategic dependency and exposure to market volatility, which is why it is important to develop innovative neodymium recycling technologies that reduce the environmental burden and reduce dependence on new sources. Continued research into new applications of neodymium, especially in the area of low-carbon technologies, may open up new markets and boost demand, while strengthening international cooperation in the field of research, production and management of neodymium resources reduces the risks associated with access to this raw material for global industry.

Investments in modern mining and processing technologies can contribute to the efficient use of neodymium resources and reduce environmental impact.

In the face of these challenges and opportunities, the global economy must focus on balancing economic growth with sustainable development, guided by innovation, international cooperation and effective management of neodymium resources.

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## *Zarządzanie pierwiastkami ziem rzadkich (REE) w gospodarce światowej: studium przypadku Neodymiun*

*Niniejsze opracowanie stanowi przegląd wykorzystania pierwiastków ziem rzadkich (REE) w gospodarce światowej w oparciu o magnesy trwałe zużywające głównie mieszaninę neodymu (Nd), prazeodymu (Pr) i dysprozu (Dy) oraz ceru (Ce), a także gadolin (Gd) w znacznie mniejszych ilościach. W rzeczywistości segment rynku magnesów jest największym rynkiem metali ziem rzadkich (REM) pod względem wolumenu i nadal będzie osiągał lepsze wyniki niż inne segmenty rynku. W raporcie „Rare Earths, Outlook to 2030" zaprezentowanym podczas Green Car Congress w dniu 3 lutego 2021 r. i opracowanym przez prognozę Roskill Commodity Research, nabytym w czerwcu 2021 r. przez Wood Mackenzie, wiodącą światową firmę zajmującą się badaniami, doradztwem i analityką danych, zasilającą biznes z branży zasobów naturalnych, Roskill prognozuje, że zastosowania magnesów ziem rzadkich będą stanowić ~40% całkowitego zapotrzebowania do 2030 r., co zwiększy potencjał ścisłej równowagi podaży i popytu w przypadku kluczowych magnetycznych REE. Przedstawiono i omówiono podaż pierwiastków ziem rzadkich na rynku USA, Europy, Japonii i Chin.*

**Słowa kluczowe:** *gospodarka surowcami krytycznymi, pierwiastki ziem rzadkich (REE), gospodarka pierwiastkami rzadkimi, neodym, rynek magnesów ziem rzadkich, gospodarka o obiegu zamkniętym*