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INTELLIGENCE BULLETIN DELIVERED BY
ICAMCyL Foundation
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INTELLIGENCE BULLETIN #7

Strategic Intelligence Bulletins aim to enrich strategic and managerial decisions and to engage stakeholders based on partners networks

RARE EARTH ELEMENTS (REE) IN MAGNETS

Rare earth elements (REE) are indispensable in modern electronics, and they are also closely associated with many "green" technologies, such as hybrid car engines and wind turbines (Figure 1). Almost everyone on the planet now encounters REEs in their daily lives, as they are used in the production of many common items, like smartphones, laptops, and other electronic devices. Each of these devices contains at least one REE. Today, no company produces high-tech developments without them. For instance, a Toyota Prius battery contains 10 kg of lanthanum, and a wind turbine magnet requires no less than 260 kg of neodymium.

Figure 1. Rare earth metals in the hi-tech industry (conditional visualization)

Rare earth metals are called so not because they are rare in the earth's crust, but because they are rarely found in sufficient quantities to make their extraction economically viable. REEs encompassa group of 17 elements of the periodic table: 15 lanthanides (with atomic weight from 57 to 71 in the periodic table), as well as scandium and yttrium. Yttrium with an atomic weight of 39 and scandium (21) are often considered in the REE group, since they have the same chemical and physical properties and are also found in the same deposits. Cerium, yttrium, lanthanum, and neodymium are the most commonly found in the earth's crust. The fact is that magnets made from rare earth elements are much stronger and lighter than ordinary magnets.

HISTORY

Rare earth became known at the end of the 18th century. It is believed that it was the Finnish scientist Johan Gadolin who discovered the mineral that contained the yttrium, which is now used in televisions. The element is displayed in red on the screen. In parallel, two Swedish chemists, Jöns Jacob Berzelius, and Wilhelm Hassinger (1803), continued their research. However, they were unable to obtain a single metal in its pure form, because the elements were complex oxides. Dmitri Mendeleev, in his work "Fundamentals of Chemistry", described only six rare metals: yttrium, lanthanum, cerium, erbium, praseodymium, and

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neodymium. A hundred years after the discovery of REEs, they were given a distinct place in the periodic table of chemical elements (Figure 2).

VARIOUS APPLICATIONS OF REEs

REEs play a major role in technological advancements, and these resources are necessary to ensure safe progress in the future. Their unique properties have led to widespread application in modern technological processes and strategic industries. Below, according to Naumov, 2008 we outline the main applications in industries where REEs are currently required in various industries:

- Scandium(Sc) High- strength Al- Sc blends, electron ray tubes;

Figure 2. Chemical elements

- Yttrium(Y) Capacitors, phosphors, microwave oven pollutants, spectacles, oxygen detectors, radars, spotlights, superconductors;
- Lanthanum(La) spectacles, pottery, auto catalysts, phosphors, colors, accumulators;
- Cerium(Ce) Polishing maquillages, pottery, phosphors, spectacles, catalysts, colors, misch essence, UV pollutants;
- Praseodymium(Pr) Pottery, spectacles, colors;
- Neodymium(Nd) endless attractions, catalysts, IR pollutants, colors for glass, spotlights;
- Promethium(Pm) Sources for measuring bias, atomic nuclear batteries, phosphors;
- Samarium(Sm) endless attractions, microwave oven pollutants, nuclear assiduity;
- Europium(Eu) Phosphors;
- Terbium(Tb) Phosphors;
- Dysprosium(Dy) Phosphors, pottery, nuclear assiduity;
- Holmium(Ho) Pottery, spotlights, nuclear assiduity;

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- Erbium(Er) Pottery, colorings for glass, optic filaments, spotlights, nuclear assiduity;
- Ytterbium(Yb) Metallurgy, chemical assiduity;
- Lutecium(Lu) Single demitasse scintillators;
- Thulium(Tm) Electron bean tubes, visualization of images in drug;

• Gadolinium(Gd) Visualization of images in drug, optic and glamorous discovery, pottery, spectacles, crystal clear scintillators.

REEs APPLICATION IN MAGNETS

High-tech electric motors and electric current generators, which are used in vehicles, robotic devices, and renewable energy equipment, are built on permanent magnets (Figure 3). They are produced by high-energy-intensive technologies and use high-purity starting components (magnetic powders) with control of their final characteristics, composition, and microstructure.

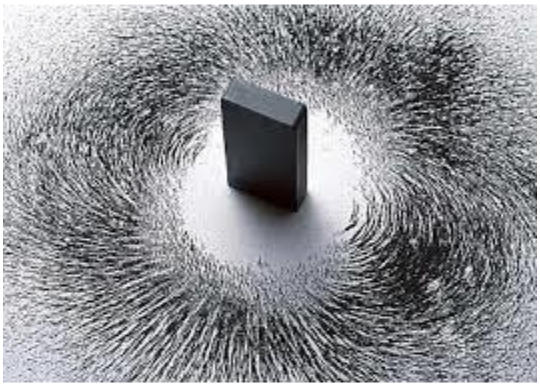

Figure 3. Permanent magnet in action (illustrative image)

RE magnets are powerful permanent magnets made from alloys of RE elements[1]. There are several types of permanent magnets available in the industrial market, each with its own characteristics, quality and price. NdFeB is the dominant permanent magnet compound (Figure 4). Ferrite magnets, on the other hand, primarily consist of iron oxide with small amounts of metallic elements, including strontium, barium, manganese, nickel, and zinc. SmCo magnets are composed of samarium and cobalt, while Alnico magnets are made of aluminium, nickel, and cobalt. Figure 5 summarises the performance and characteristics differences among these permanent magnet types. Specifically, a permanent magnet (PM) in an electrical machine operates at a point in the second quadrant of the B vs. H hysteresis curve The second quadrant is the region where the magnetization and flux density remain positive (M > 0, B > 0), but the magnetic field is negative

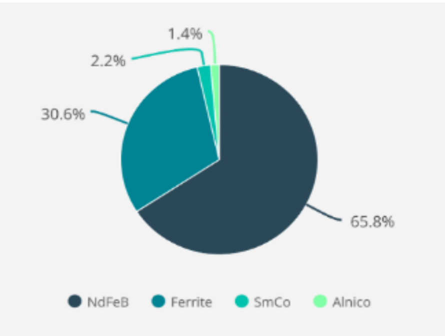

Figure 4. Percentage of NdFeB permanent magnets in current target market

[1] https://www.theassay.com/articles/feature-story/for-rare-earths-its-all-about-the-magnets/

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(H < 0). The PM remains magnetized in the desired direction while the magnetic field strength is working in an opposite direction (Kontos et all, 2020).

Quantity	Symbol [unit]	NdFeB	SmCo	Ferrite	Alnico
Remanence	B_r [T]	1.08–1.49	0.87–1.19	0.20–0.46	0.55–1.37
Intrinsic coercivity	H_{ci} [kA/m]	876–2710	1350–2400	140–405	38–151
Relative permeability	μ_r [-]	1.0–1.1	1.0–1.1	1.05–1.2	1.3–6.2
Energy product	$(BH)_{max}$ [kJ/m^3]	220–430	143–251	6.4–41.8	10.7–83.6
Density	D [kg/dm^3]	7.4–7.5	8.2–8.5	4.9–5.1	6.8–7.3
Electrical resistivity	ρ [nΩm]	12–16	50–60 or 530–900	10^7–10^{11}	470–750
Curie temperature	T_c [°C]	310	720–820	450	800
Maximal operation temperature	T_{max} [°C]	150	250–350	300	500

Figure 5. Some properties of permanent magnets (PMs) relevant to electrical machines, Source: Kontos et all, 2020

Several researchers point out that there is currently a performance gap between ferrite and RE magnets. They suggest that a new magnet with a good price/performance ratio may be able to replace the magnets studied so far, or replace NbFeB and SmCo with other less expensive articles such as Ce. Candidates for such alternatives include FePt, FeNi, Co-carbide, Fe-nitride, ZrCo11, HfCo7, Y2Fe14B and YCo5, as well as Mn-based compounds such as MnBi, Mn2Ga and MnAl. MnAl stands out due to its low cost resulting fromabundant raw materials, good corrosion resistance and low density (5000-5100 kg/m3).

MARKET PLAYERS

From the 20th century until the 1980s, the United States was the undisputed world leader in the extraction of REE. The bulk of production came from the Mountain Pass mine in California, with an annual output of 20,000 tons at one point, which accounted for more than 60% of global production. However, the situation soon changed dramatically when China emerged as a major player.. The rare earths market is currently dominated by China, which produces around 60% of the world's REE (168,000 tonnes in 2021). As a result, the world's largest economies are completely dependent on Chinese supplies. In accordance with preliminary data extracted from the U.S. Geological Survey (USGS), global REE mine production in 2021 is estimated at 280,000 tonnes of REE oxide equivalent, a 17% increase from 2020 (240,000 tonnes).

At the same time, the European Commission estimates that demand for rare earths for electric cars and wind turbines could increase more than fivefold by 2030. The market for these metals is currently dominated by China, a factor that increases the vulnerability of the European industry. The supply of these materials has come under considerable pressure in recent years and is now considered to be the greatest supply risk of all elements. Therefore, the EU plans to stop importing these metals in the nearest future, as most neodymium magnets available on the EU market come from China and third countries. This

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forces European countries to explore domestic mines, and apply green technologies or search for substitutes using alternative raw materials that are available in the EU.

Figure 6. A view of the mine of Swedish state-owned mining company LKAB | Jonas Ekstromer/AFP via Getty Images

Thus, LKAB will mine rare earth metals in the Sweden deposit (Figure 6), one of the largest in Europe. It has already started preparing a strip (horizontal mine) spanning several kilometers long at a depth of about 700m to the new deposit to be able to explore it in detail. The company plans to apply for its development in 2023. However, LKAB estimates that it will take at least 10-15 years to start extracting raw materials and delivering them to the market.

This project will create and shape an entire industry that will provide the necessary materials for aviation, space, the nuclear industry and radio electronics. It is planned to create a production chain - from ore mining to the technology for developing the production of concentrates and metal oxides, which will ensure the production of finished products in the future.

THE ROLE OF PASSENGER

On the other hand, innovations in alloys and materials for REE-free magnets are an important option to replace critical raw materials. A striking example is the PASSENGER project (Figure 7). PASSENGER's proposed materials (namely, improved ferrite and MnAlC) combine key premises to guarantee the achievement of a sustainable permanent magnet solution for Europe. These materials not only minimise the need for any critical raw elements but also utilise constituent elements widely available in Europe. Furthermore, the materials and technologies proposed in the project have reached a sufficiently advanced stage of development, providing a solid basis for a successful transition from the lab to industrial production through the establishment of innovative pilot plants within PASSENGER's timeframe.


Figure 7. PASSENGER project

In terms of sourcing, the improved ferrites targeted by the project will be produced using the same elemental constituents employed in the production of traditional Sr-ferrite. The

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divergence lies in the route of material synthesis and post-processing, which will result in obtaining an improved product with superior performance.

The following results will be pursued:

- Complete substitution of traditional RE magnets with new Mn-Al-C magnets;
- Partial substitution of traditional RE magnets with improved Sr-ferrite magnets;
- Integration and validation of the newly developed RE-free magnets.

CONCLUSION

There is currently a limited number of industry-recommended permanent magnets worldwide. The most common are the so-called rare-earth magnets, which are known to be quite expensive to manufacture and are not without drawbacks. These drawbacks include for example the low stability of magnetic properties under conditions of corrosion, temperature, and mechanical stress. Therefore, it is necessary to search for new compositions based on cheaper initial components instead of rare earths, as well as to develop energy-efficient technologies for their production with a “sparing” effect on the key properties of magnets. In pursuit of these advancements, the PASSENGER project collaborates with teams of physicists, chemists, and materials scientists to carry out research and development. The project provides all the necessary conditions for scientific activities and faciliates the educational process by offering learning resources for different audiences.

Download the **LKABs Press Release dated Jan 12, 2023** here:
Europe's largest deposit of rare earth metals is located in the Kiruna area

Additional information about the **Action Plan to secure access to Rare Earth Elements for European industry** can be found in the “Ensuring access to the raw materials for the European Green Deal: A European Call for Action”

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