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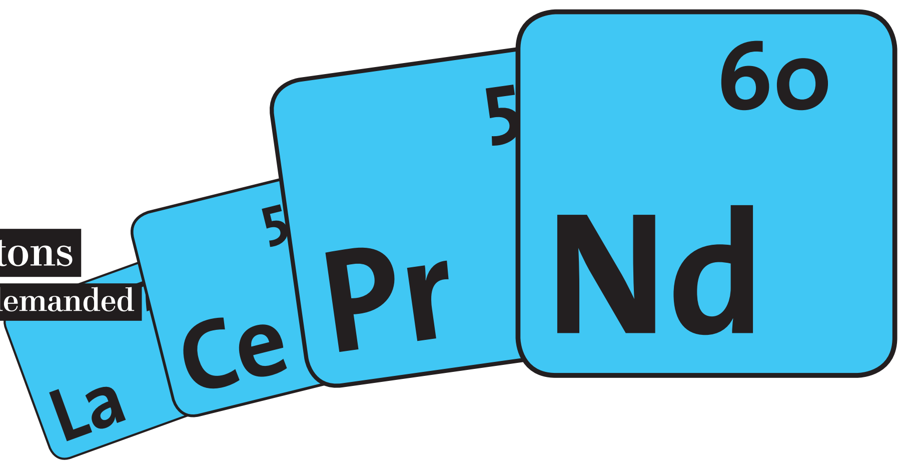
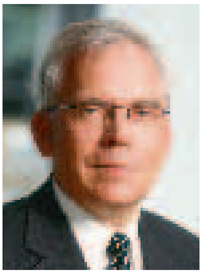
Rare Earths
Metals of the Future



137,000 metric tons of rare earths were demanded globally in 2011.

212 years is how long the world's rare earths reserves of 29,021,000 metric tons will last, if demand remains constant.

Editorial



Dr. Ulrich Hackenberg, Member of the Board of Management of Volkswagen Brand with responsibility for Research and Development.

For many of the technologies that car manufacturers are devel oping today, rare earths are indispensable. In this issue of VIAVISION you will find out everything about these resources, their availability and applications, as well as their recycling.

Happy reading.

Elementary

No High Tech Without Rare Earths

Rare earths are closely connected to future technologies. The metals can be found in mobile phones and electric motors, in wind turbines and LED headlights. They are elementary parts of many such applications. The rising demand for high tech devices causes an increased need for rare earths. However, their exact trading volume can only be estimated: It cannot be said exactly how many metric tons are imported and exported from different countries. The numbers for Germany for example are confidential and are not published.*

137,000 metric tons was the global demand for rare earths in 2011, according to estimates.

Source: Roland Berger (as of 2011)

190,100 metric tons of rare earth metals are expected to be consumed worldwide in the year 2014.

Source: Lynas (as of 2010)

Rare earths – Application examples:

21 Scandium
- in high performance lights for stadium illumination
- in light metal compounds for bicycles

39 Yttrium
- in high-resistance ceramics for lambda probes in car exhaust systems
- in spark plugs

59 Praseodymium
- in strong magnets, for example in e-cars
- as colorant in glasses

60 Neodymium
- in strong magnets, for example for wind turbines
- as colorant in ceramics and glass

61 Promethium
(is barely used, because it is radioactive and decays quickly)

63 Europium
- in television sets as red and blue luminescent material
- in energy saving lamps

64 Gadolinium
- as green luminescent material in radar monitors
- as a contrast agent in magnetic resonance scanners

21 Sc | 39 Y

57 La | 58 Ce | 59 Pr | 60 Nd | 61 Pm | 62 Sm | 63 Eu | 64 Gd | 65 Tb | 66 Dy

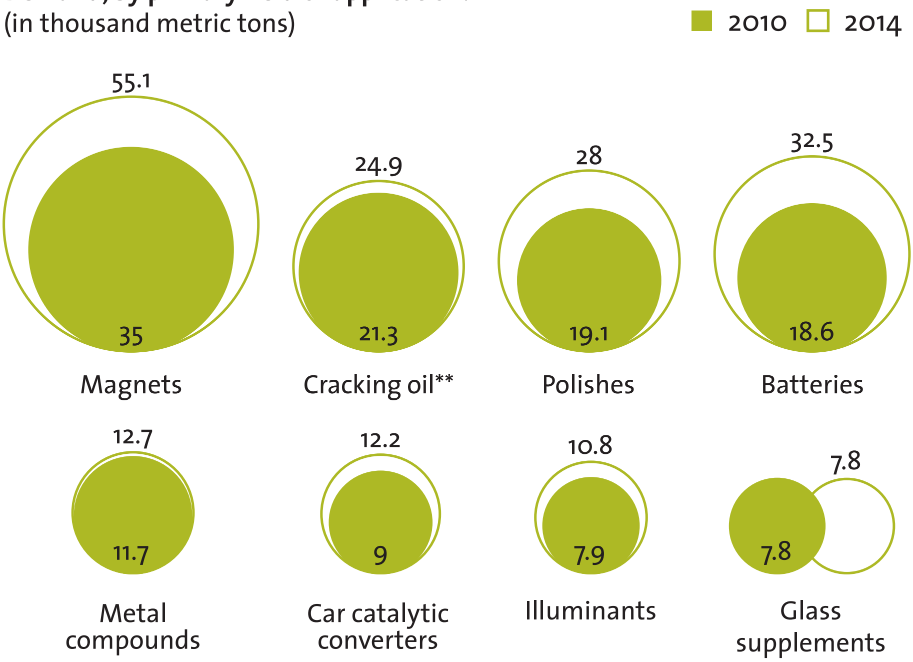
57 Lanthanum
- for hydrogen storage in nickel-metal hydride batteries
- as a catalyst for cracking crude oil**

58 Cerium
- in catalytic converters
- in polishing agents for glass

62 Samarium
- in magnets with especially high temperature resistance
- in lasers

* The numbers circulating for the import and export of rare metals in Germany are wrong, according to the German Federal Institute for Geosciences and Natural Resources.

Demand, by primary field of application:
(in thousand metric tons)



*In 2010, rare earths were most frequently used in magnets, according to estimates. This is expected to be the case in 2014 too. In addition, large quantities of rare earth metals are required for cracking oil**, as well as for polishes and batteries. The demand for rare earths in 2010 was 136,100 metric tons, which includes other applications such as in lasers or animal food supplements. In 2011 demand was 137,000 metric tons, according to estimates, and in 2014 is predicted to be 190,100 metric tons.*

Sources: Lynas (as of 2010); Roland Berger (as of 2011)

65 Terbium
- ➔ as a green luminescent in energy saving lamps
- ➔ in re-writable CDs

66 Dysprosium
- ➔ in magnets with high temperature resistance, for example in e-cars
- ➔ as a shielding agent in nuclear reactors

67 Holmium
- ➔ in high-performance magnets
- ➔ in the control rods of nuclear reactors

69 Thulium
- ➔ as a radiation source for X-rays
- ➔ to activate luminescent materials in television sets

70 Ytterbium
- ➔ in synthetic dental fillings
- ➔ in high quality permanent magnets

67 Ho | 68 Er | 69 Tm | 70 Yb | 71 Lu

68 Erbium
- ➔ for decolorizing glass
- ➔ as a light wave conductor in fiber optic cables

71 Lutetium
- ➔ for tomography in nuclear medicine

*17 chemical elements of the periodic table make up the commodity group known as the rare earth metals, they have the atomic numbers 21, 39 and 57 to 71. In contrast to what their name suggests, they appear relatively often: In the earth's crust there is more yttrium, cerium and neodymium than lead. These three metals, as well as lanthanum, praseodymium, samarium, europium and gadolinium, are the most widely used for industrial purposes. The primary fields of application for the metals are in magnets, lamps, metal alloys and batteries, glass, ceramics and polishing agents, as well as catalytic converters and in the cracking of crude oil**.*

Sources: German Federal Institute for Geosciences and Natural Resources (as of 2011); TRADIUM; Royal Society of Chemistry (both as of 2012)

** The cracking of oil, called Fluid Catalytic Cracking (FCC), is the chemical process by which crude oil is split into gasoline and other products.

Not So Rare

Availability and Production of Rare Earths

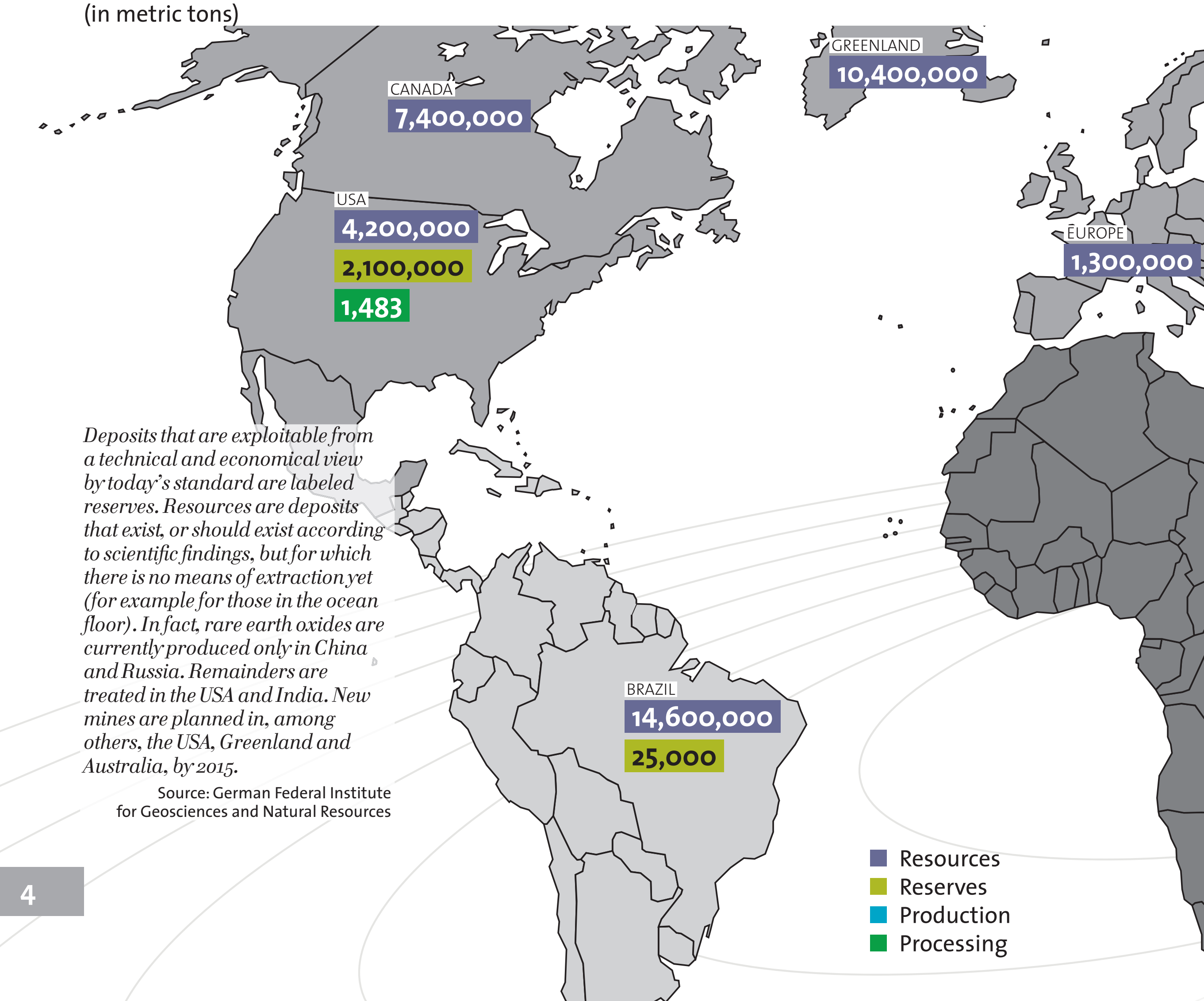
29,021,000

metric tons of rare earth metals were available in 2010. In comparison: Gold availability was 45,300 metric tons.

Sources: ETH Zurich; German Federal Institute for Geosciences and Natural Resources

According to estimates, they are more than 600 times as common as gold but are found in economically feasible quantities in only a few places in the world. Additionally, the rare earth metals are usually mixed with each other after extraction and have to be separated using elaborate chemical processes. They are subsequently purified into rare earth oxides. Many countries publish either no, or contradicting, numbers about the production, export and import of rare earth oxides; and prices are very volatile. One thing however is clear: Global availability will last for many years to come.

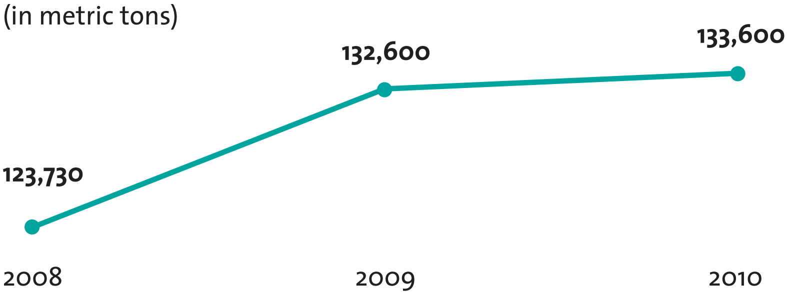
Global resources, reserves and production amounts of rare earth oxides 2011:
(in metric tons)



Deposits that are exploitable from a technical and economical view by today's standard are labeled reserves. Resources are deposits that exist, or should exist according to scientific findings, but for which there is no means of extraction yet (for example for those in the ocean floor). In fact, rare earth oxides are currently produced only in China and Russia. Remainders are treated in the USA and India. New mines are planned in, among others, the USA, Greenland and Australia, by 2015.

Source: German Federal Institute for Geosciences and Natural Resources

Estimated global production:
(in metric tons)



Not every country reveals how many metric tons of rare earth oxides it produces. China's share of total production is currently over 97 percent. This monopoly enables China to significantly influence price development, by temporarily halting sales.

Source: U.S. Geological Survey, Mineral Commodities Summary 2011

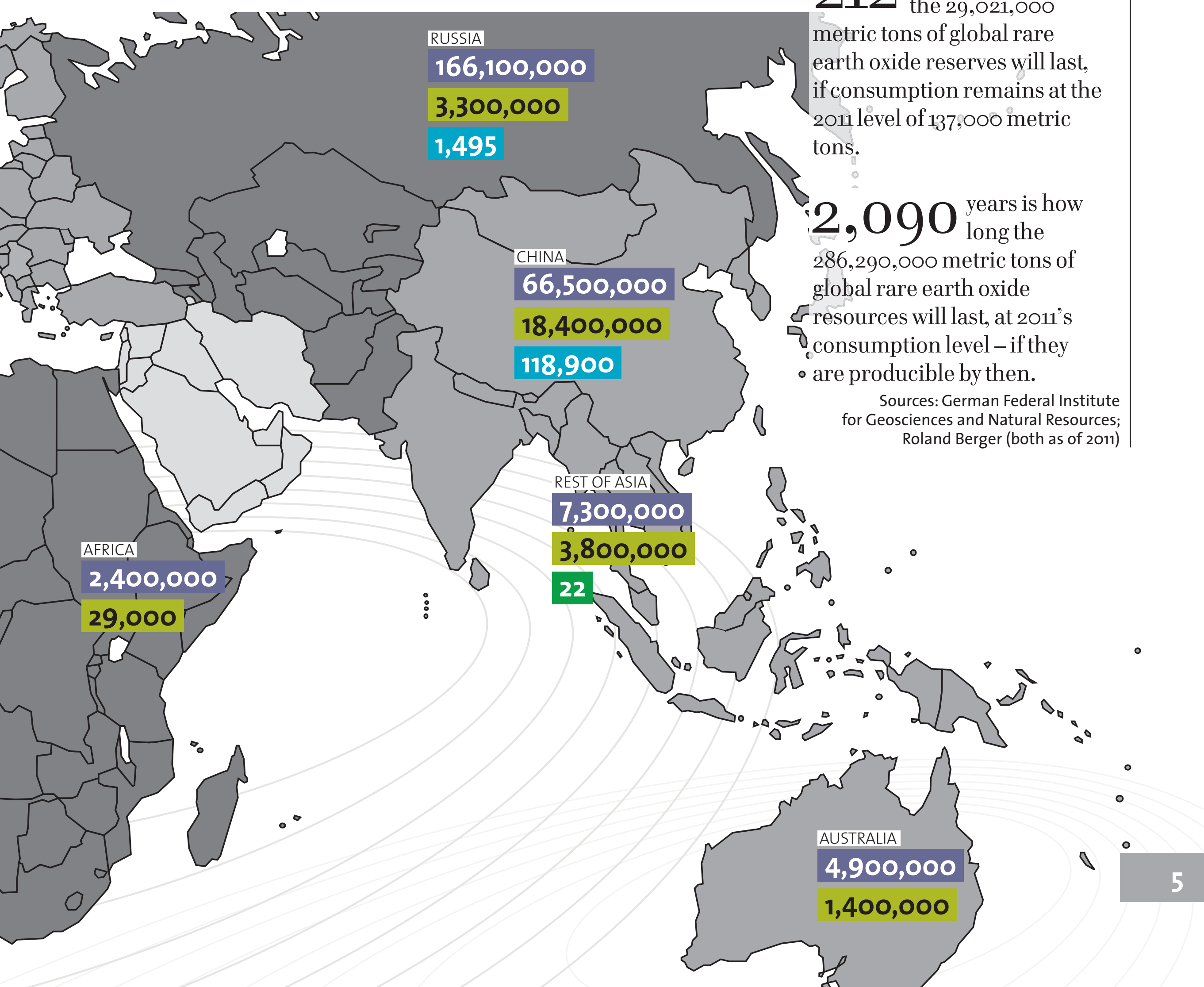
Availability

Concerning sought after resources, the question arises as to how long the deposits will last and from when on substitutes will be needed. The calculation of resource availability is however only a snap shot in time. The actual availability depends on different factors such as changes in demand or technological innovations.

212 years is how long the 29,021,000 metric tons of global rare earth oxide reserves will last, if consumption remains at the 2011 level of 137,000 metric tons.

2,090 years is how long the 286,290,000 metric tons of global rare earth oxide resources will last, at 2011's consumption level – if they are producible by then.

Sources: German Federal Institute for Geosciences and Natural Resources; Roland Berger (both as of 2011)



Enhancer Metals

Rare Earths in Car Manufacture

4 kilograms of rare earths are built into the Touareg Hybrid, mostly in the battery. Only one kilogram of these metals is built into the Audi Q5, because there is a lithium ion battery installed, which works without rare earths. Source: Volkswagen

Hybrid cars, electric motors or LED lights – many automotive technologies of the future would be unthinkable without rare earths. The special metals are found in different car parts. The smallest amounts act like a doping substance on the properties of other materials, making them more magnetic, shinier, or more resistant to heat.

CERIUM

Polishes

Car polishes make dull windows, mirrors and paint shine like new. **Cerium oxide** is responsible for the sparkling effect, its nano-particles only measure about one millionth of a millimeter and are very hard. They allow for the removal of a thin surface layer during polishing. As a result small cracks and scratches can be removed. Sources: Federal Ministry of Education and Research, Nano-Report 2009; SPECTARIS (as of 2011)

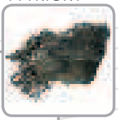
LANTHANUM

Battery

The electric motor in hybrid and e-cars is usually supplied with electricity from a battery. Lithium ion batteries work without rare earths – in contrast to nickel-metal hydride batteries, which store energy in the form of hydrogen. **Lanthanum** helps here, since it can, in combination with nickel, absorb and store large quantities of hydrogen. The energy is released during vehicle operation.

Sources: Fraunhofer Institute for Systems and Innovation Research ISI; TRADIUM (both as of 2012)

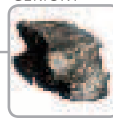
YTTRIUM



Lambda probe

The lambda probe is installed in the exhaust system of cars and measures the oxygen concentration in the exhaust fumes. The integrated control electronics adjust the air-fuel ratio in the motor, according to the signal of the probe, to ensure optimal combustion. The ceramics contained in the probe are made permeable by oxygen ions using **yttrium**, which is vital to this measurement.

Sources: University Karlsruhe, Institut für Theoretische Festkörperphysik (as of 1999); Projekt DaNa (as of 2011)

CERIUM

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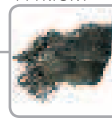

TERBIUM


LEDs

In car headlights LEDs are often used as daytime driving lights. They convert electrical energy into light, for which rare earths are essential: They are in the semiconductors of the light diode, through which the electricity flows. Here the special metals, together with metal phosphates, are responsible for the different colored lights. **Cerium**, **yttrium** and **terbium** which make for a warm, yellow light, are used most often.

Sources: Munich Environmental Institute; Fördergemeinschaft gutes Licht, LED – Licht aus der Leuchtdiode (both as of 2011); *Journal of the Electrochemical Society* (issue January 2011)

NEODYMIUM

CERIUM


Glass

In the production of glass, **neodymium** and **cerium** remove the glass's natural color components: First the cerium converts the iron contained in the glass in such a way that it changes color from an intense blue to a light yellow. Neodymium then absorbs the yellow coloring – making the glass colorless.

Source: Technische Universität Dresden, Institute of Waste Management and Contaminated Site Treatment (as of 2009)

YTTRIUM


Spark plug

The electrodes of the spark plug in a combustion engine can contain **yttrium**. Usually the electrodes wear out over time because with each ignition a minuscule fraction of the material oxidizes, thus releasing particles into the air. Yttrium forms a more resistant surface, which prolongs the life span of the electrode.

Source: Bosch (as of 2011)

CERIUM

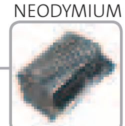
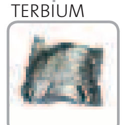
LANTHANUM

YTTRIUM


Catalytic converter

A car's catalytic converter turns the nitrogen oxide, hydrocarbon and carbon monoxide exhaust produced by the combustion engine into nontoxic substances – nitrogen, carbon dioxide and water. This is done as a result of the pollutants either taking in or releasing oxygen. **Cerium** is employed here: Cerium dioxide stores the oxygen for a short time, releases it quickly and thus enables rapid exhaust conversion. **Lanthanum** and **yttrium** aid the temperature stability of the catalytic process.

Sources: Helmholtz Zentrum München (as of 2004); Fraunhofer Institute for Systems and Innovation Research ISI; Technische Universität Bergakademie Freiberg, Institut für Energieverfahrenstechnik und Chemieingenieurwesen (both as of 2012)

NEODYMIUM

TERBIUM

PRASEODYMIUM

DYSPROSIUM


Electric motor

Magnetism is the driving force in the electric motor: The alternating attraction and repulsion of permanent magnets and electromagnets generate movement in the electric motor. The permanent magnets often consist of a compound of **neodymium**, iron and boron. The highly magnetic neodymium increases the energy density of a standard iron magnet, increasing performance by a factor of 76. A greater resistance to heat above 80 degrees Celsius is achieved by adding **terbium**, **praseodymium** or **dysprosium**.

Sources: Fraunhofer Institute for Systems and Innovation Research ISI; TRADIUM (both as of 2012)

Substitute resources

There is an ongoing and vigorous search for natural resources that can replace rare earths. In Germany, RWTH Aachen is searching, in cooperation with Siemens, for such substitute resources. A promising candidate has been found for the permanent magnets already: an iron-cobalt compound with a nano-structure. This material could replace rare earths in magnets in the future without decreasing their performance.

Source: Siemens, *Pictures of the Future* (fall issue 2011)

Use Again

... or Find Alternative Resources

Rare earths are expensive. The recycling of this natural resource could contribute to lowering the costs of technologies, such as the electric motor, as well as protecting the environment against the pollution caused by exploitation and deposition. Presently rare earths are almost never reused. The reason: Because they are mixed with other substances in these products, the chemical separation process is complex. There is strong demand for new methods to reclaim rare earths or for finding substitute resources.

1 percent of all rare earths used are recycled in Germany.
Source: German Federal Institute for Geosciences and Natural Resources (as of 2011)

10 percent of Japanese electronics manufacturer Hitachi's demand for rare earths is scheduled to be provided by recycled materials by 2013. Source: Hitachi (as of 2011)

Recycling of magnets

The permanent magnets installed in an electric or hybrid car contain about 30 percent rare earths, such as neodymium, praseodymium and dysprosium. A German research project is working on different methods of recovering those materials. One of which is melting the ground magnets and dissolving the rare earths out via a chemical process. The renewed use of the magnetic material, without the fractionation of the components, is being tested as well. The results are planned to be presented in 2014.

Sources: Clausthal University of Technology; Siemens; Institute for Applied Ecology, Study on Rare Earths and Their Recycling (all as of 2011)

Recycling of batteries

Nickel-metal hydride batteries consist of between seven and ten percent of rare earths such as lanthanum, cerium and neodymium. Scientists test a recycling method by which the batteries are shredded and presorted using a sieve. The rare earths remain in the finer residues. Heated, and under the effect of chemicals, they are enriched during the fusion stage and can be extracted again later. Currently the project is still being evaluated technically and economically.

Sources: RWTH Aachen; TU Bergakademie Freiberg; Institute for Applied Ecology, Study on Rare Earths and Their Recycling (all as of 2011)

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