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TMS Partners in Progress

Challenges in Recycling End-of-Life Rare Earth Magnets

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TMS has forged cooperative agreements with several carefully selected organizations that actively work to benefit the materials science community. In this occasional series, JOM *will provide an update on the activities of these organizations. This installment, by the Center for Resource Recovery & Recycling (CR³), focuses on recycling end-of-life rare earth magnets. The CR³ is a research center established by Worcester Polytechnic Institute, Colorado School of Mines, and K.U. Leuven. Twenty-eight corporations and national laboratories along with support from the U.S. National Science Foundation's I/UCRC program are sponsors of the center.*

At the Center for Research Recovery and Recycling (CR³), an area of interest is the recycling of materials containing rare earth elements. This research field is crucial to the supply of widely needed materials, in particular, strong magnets and phosphors. A previous communication presented a broader view of this area;[1] in this article, we focus on specific challenges for the recycling of rare earths from magnets.

Recently, CR³ has initiated a program geared towards the recycling of rare earth magnets. Two types of rare earth magnets—NdFeB and SmCo magnets—are crucially important to the manufacturing of various products such as hybrid cars, electric cars, airplanes, household appliances, hard disk drives, and wind turbines.[2-4] In most of these applications, the strength of the magnetic field per volume that can be achieved with rare-earth magnets is much larger than with traditional ferrite or Alnico magnets (Figure 1).[5,6] From a fundamental point of view, the extraordinarily strong magnetic properties of rare earth containing magnets are closely related to the capability of the rare earth elements neodymium, dysprosium, and samarium used to stabilize spin states with a large number of parallel electrons. Thus, the use of rare earth elements is crucially important to the function of NdFeB and SmCo materials.

The overall natural abundance of rare earths suggests that, despite their name, rare earth elements are actually not rare in the earth's crust.[7] Thus, a study on the revolutionary demand for rare earth elements by Alonso estimates their long-term supply criticality to be low.[3] However, several other factors influence the availability, and with it, the criticality of these materials. First, all rare earth elements are typically found as a mixture with the heavy rare earth elements such as yttrium and dysprosium being the less abundant, and thus, the more expensive ones. The separation and purification of the elements is quite challenging due to their similar chemical characteristics and is performed through processes which include environmentally questionable extractions and ion chromatography. A second factor influencing criticality is the de facto monopoly of companies based in one country—China—on ore production and processing.[7] This is illustrated by the radical price spikes for rare earth metals in 2011, which can mainly be traced back to changes in Chinese policies and the imposition of stricter export quotas for the rare earth elements.[8] These restrictions and resulting price fluctuations illustrate that consumers and rare earth manufacturers would benefit from a more diversified supply chain.

Recovery and recycling of rare earth magnets can address these challenges, particularly the challenge of rapid price fluctuations. A graphic representation of price data for the recycling of platinum group metals from 1970 on (Figure 2) shows a clear stabilization of the inflation-adjusted price in times of relatively higher recycling rates (>20%).[9-11] [Recycling rate = (secondary production) / (apparent consumption).] An analogous effect can be seen for the price fluctuations of cobalt metal (Figure 3).[12] Thus, we propose in agreement with the literature[3] that similar trends in price stabilization can be expected for rare earth elements through the broad implementation of recycling processes. [Prices were adjusted for inflation to 1970 values using consumer price index

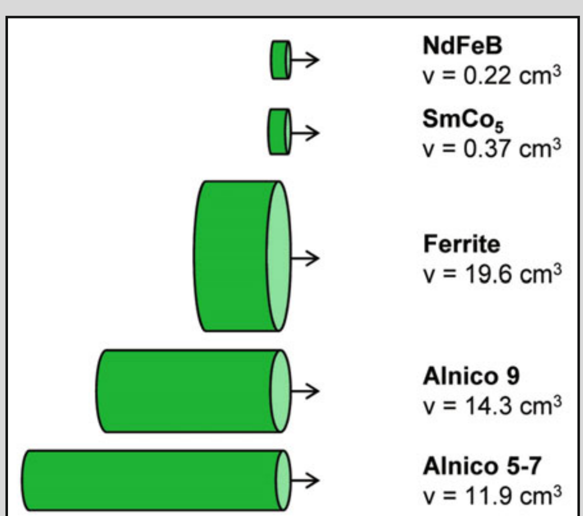

Fig. 1. Relative magnet size and shape to generate magnetic field of 1000 gauss at 5 mm from the pole face of the magnet.

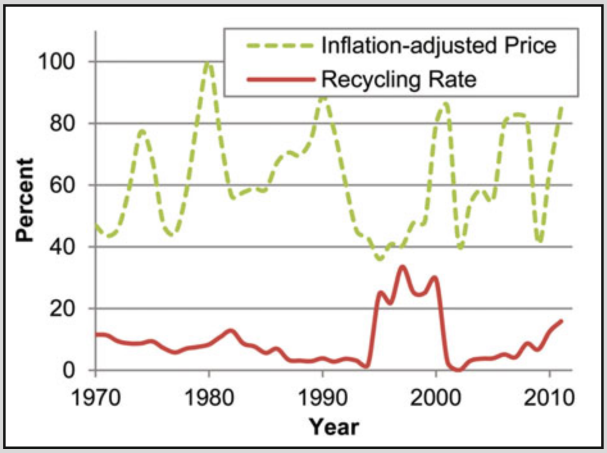

Fig. 2. Inflation-adjusted price and recycling rate of the platinum-group metals (PGMs) since 1970.

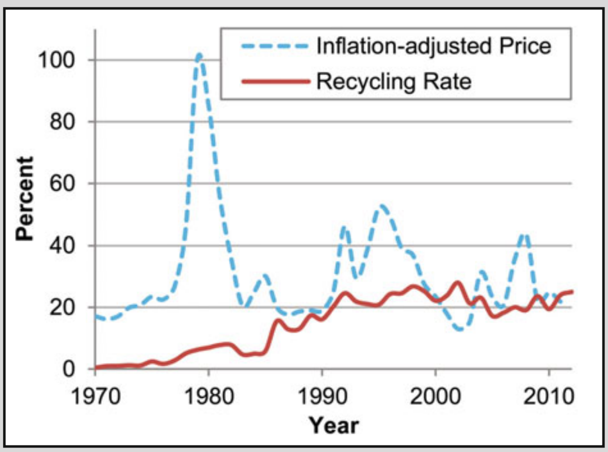

Fig. 3. Inflation-adjusted price and recycling rate of cobalt since 1970.

(CPI) annual averages obtained from the U.S. Bureau of Labor Statistics at www.bls.gov/cpi/tables.htm. Tabulated prices were then multiplied by their respective annual ratios to give the inflation-adjusted price (to the 1970 value) for a year (i) as follows: adjusted price (i) = [price (i) × CPI (1970)]/CPI (i)].].

Despite the positive effect of recycling on price stabilization, no commercial processes are currently established in the United States to recover end-of-life magnets for either reuse or recycling. A major roadblock towards implementing recovery and recycling processes is the lack of data on the end-of-life fate of rare earth magnets. Some studies confirm that rare earth elements can be found in recycled steel and smelter slag,[13,14] but no systematic study towards quantifying the amounts of rare earths in these materials has been performed. Furthermore, it is unclear in which product stream from a shredder plant rare earth magnets typically accumulate. Due to their magnetic properties, rare earth elements might be located in ferromagnetic product streams such as steel chips or copper pickings; however, due to the brittleness of both NdFeB and SmCo magnets, these materials could also contaminate other product streams such as shredder residue. Additionally, cost analyses that quantify the economic opportunity associated with recycling rare earth elements from magnets have not been performed; this type of analysis will be crucially important to judge the feasibility of any developed technology that aims to address the recovery of rare earth elements from magnets. Further complications are introduced by the diversity of products that use rare earth magnets, the lack of incentives for collecting rare earth magnet containing products in centralized locations, and the significant price fluctuations that have been observed in recent years.

All these issues together are highly complex and need to be addressed in a holistic way, using tools of business research, materials engineering, chemistry, and metallurgy in order to achieve significant progress. Importantly, frequent feedback from companies that could be affected by the development and implementation of magnet recycling technologies is required in order to judge the feasibility of all chosen approaches. To this end, CR^3 has initiated research to analyze and quantify the part of the magnet life cycle after the end of their use and a value analysis of rare earth metals in magnets including reasonable future projections, which take their criticality into account. Based on our findings, we will be able to develop technologies for recovery and recycling that are economically attractive, environmentally conscious, and have a high probability of success for implementation in the marketplace.

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