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DYNAMIC SUBSTANCE FLOW ANALYSIS OF NEODYMIUM AND DYSPROSIUM ASSOCIATED WITH NEODYMIUM MAGNETS IN JAPAN

Nobuo Sekine, Ichiro Daigo, Yasunari Matsuno and Yoshikazu Goto.*

Department of Materials Engineering, Graduate School of Engineering, The University of Tokyo. 7-3-1, Hongo, Bunkyo-ku, Tokyo, 113-8656 Japan, email:sekine@mfa.t.u-tokyo.ac.jp

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ABSTRACT

The recycling of neodymium (Nd) and dysprosium (Dy) is of great interest to industry because of the rapid increase in demand for Nd magnets and the limited availability of the resource. This study characterized the flows and stocks of Nd and Dy associated with Nd magnets in Japan and then evaluated the economic feasibility of recycling Nd magnets. Dynamic substance flow analysis of Nd and Dy in Japan was conducted using data from 1984 to 2010. A bottom-up approach was employed in the analysis to prepare time series of consumption by end use. The results of this study will contribute to the establishment of better recycling systems of Nd and Dy.

INTRODUCTION

Neodymium (Nd) magnets (Sagawa et al., 1984), a type of rare-earth magnet, are the most powerful permanent magnets. Nd magnets are made from neodymium, iron and boron and are used in many products because of their high efficiency and downsizing potential. Moreover, dysprosium (Dy) is added to Nd magnets to improve their heat resistance. Recycling of Nd and Dy is of great interest to industry because of the rapidly increasing demand for and limited availability of these elements (Du & Graedel, 2010). However, Nd and Dy are seldom recovered from end-of-life products, and the recycling potentials of Nd and Dy have rarely been quantified.

Material flow analysis and substance flow analysis (SFA) are useful tools with which to determine the flow of materials and substances. Moreover, we can estimate the stock of a material or substance using dynamic models considering product lifetimes. Shi et al. (2010) conducted dynamic SFA of Dy in Japan by categorizing the end use of Dy into four groups and characterizing the flows and stocks of Dy. The present study determines the flows and stocks of Nd and Dy associated with Nd magnets in Japan through dynamic SFA and quantifies the recyclability of Nd and Dy.

METHODS

Dynamic SFA

SFA is a method for calculating the flow of a specific substance in a defined system. We employed dynamic SFA to calculate the flows and stocks of Nd and Dy in Nd magnets in Japan. The end uses of Nd magnets were categorized as shown in Table 1. We estimated time-series data for the domestic consumption and the entering into use of Nd and Dy in each end-use category for the period 1984–2010 in Japan. A bottom-up approach was employed using the magnet use per product and a range of Nd and Dy contents in the magnets for each end use. In-use stock and discards of Nd and Dy were estimated through dynamic SFA, according to a time series of entering into use and a lifetime distribution for each end use. We did not evaluate acoustic equipment because data were unavailable.

Table 1 Semiproduct and end-use categories

Semiproduct		End use
Motor	Driving motor of HEVs	Automobile
	EPS	
	Other	
		Air conditioner
		Washing machine
		Refrigerator
		Factory automation
Voice coil motor		Desktop computer, laptop computer, cellular phone, camera
MRI equipment		MRI devices
Laser pickup		DVD/BD/CD/ MD recorder/player, CD/MD boom box, micro component system, car navigation system, stereo set, in-car DVD/CD/MD player, desktop computer, laptop computer
Acoustic equipment		Microphone, loudspeaker

*HEV: hybrid electric vehicle, EPS: electric power steering, MRI: magnetic resonance imaging

Evaluation of recyclability

The recycling of Nd and Dy needs to be economically feasible. We evaluated the economic feasibility of recycling Nd magnets. The evaluation considered the costs of recycling processes including collection, separation, degaussing, transportation and refining, and revenues from recovered materials including Nd, Dy steel, and copper. In-use stocks can be regarded as having recycling potential. In-use stocks classified into end uses, which were derived from dynamic SFA, represent the magnitude of recycling potential by end use. We refer to feasible recycling potentials as ‘reserves of the urban mine’. We obtained recycling costs and revenue data and evaluated the economic feasibility of recycling the driving motors

of hybrid electric vehicles (HEVs) and the motors of air conditioners, which account for approximately 50% of the recycling potential.

RESULTS

Dynamic SFA

We characterized the Nd stock and flow for the period 1984–2010 in Japan. The result for 2010 is shown in Figure 1. We estimated the in-use stock of Nd to be between 5200 and 8200 t at the end of 2010; this accounts for about 4%–6% of global in-use stock (Du & Graedel, 2010). We also found that the amount entering into use (680–1200 t/y) was about half the amount of domestic consumption (1700–2200 t/y) because much of the Nd was in final products exported from Japan. Figure 1 also shows the Dy stock and flow. The Dy stock in use was estimated to be 540–1100 t at the end of 2010; this accounts for about 6%–12% of global in-use stock (Du & Graedel, 2010).

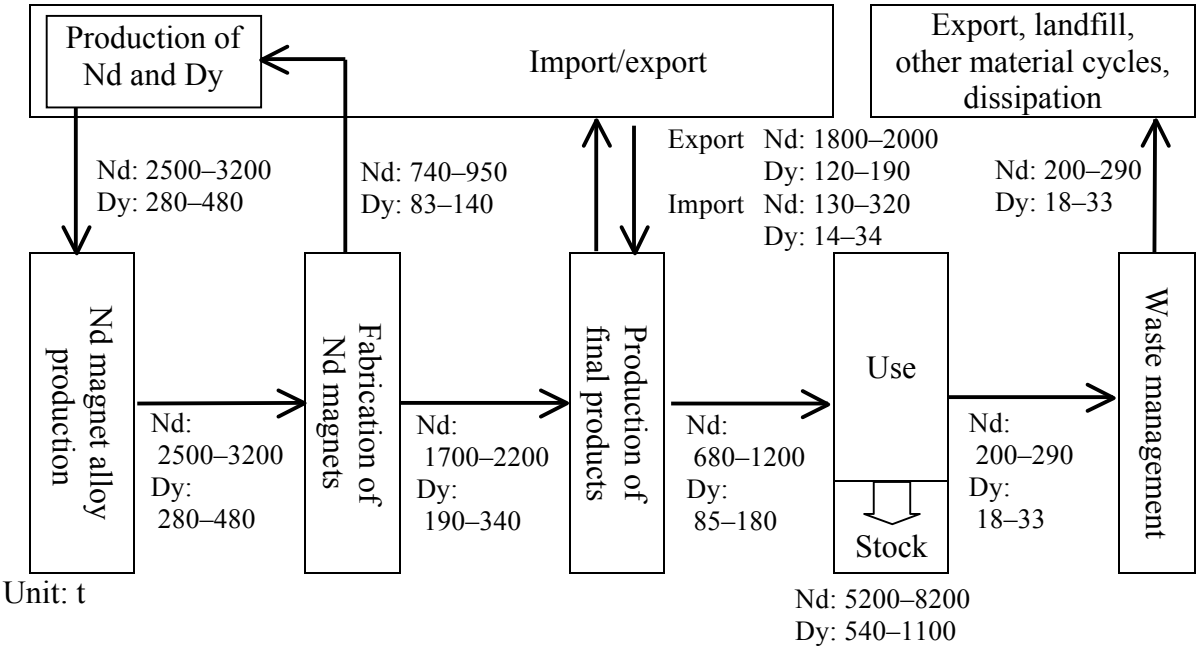

Figure 1 Substance flow of Nd and Dy in Japan in 2010

Evaluation of recyclability

We evaluated the economic feasibility of recycling Nd magnets at the end of 2012 in Japan, as shown in figure 2. We found that recycling the Nd magnets from end-of-life driving motors of HEVs is economically feasible. However, magnets recovered from end-of-life air conditioners cannot be recycled economically. Nd and Dy reserves of the urban mine were evaluated as 290–780 and 100–230 t, respectively.

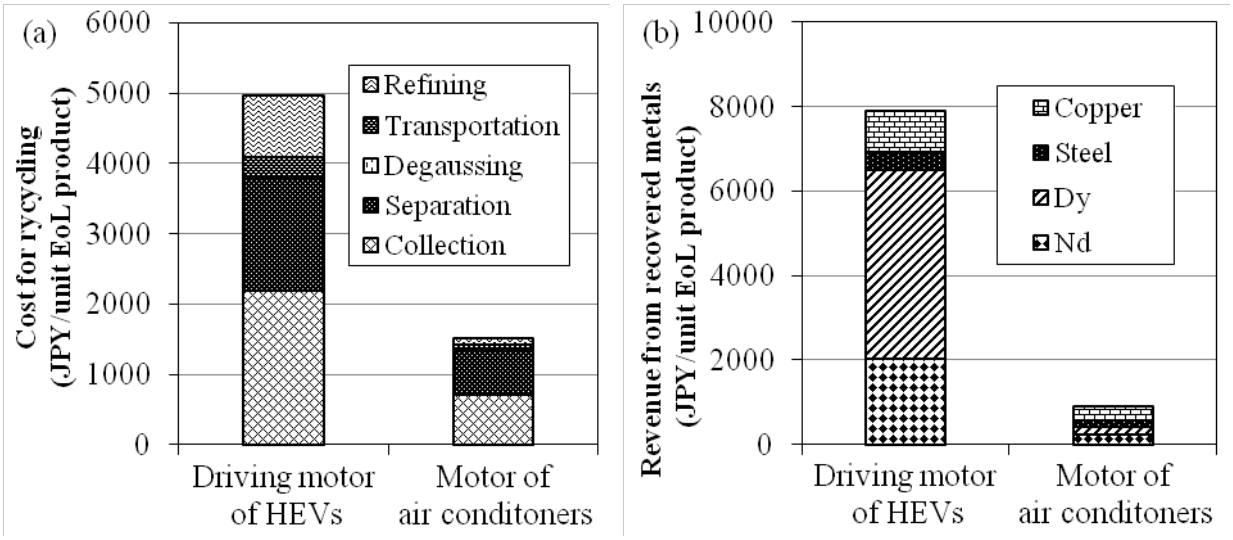

Figure 2 (a) Costs and (b) revenues of recycling products containing Nd magnets

DISCUSSION

Even if all end-of-life Nd magnets were collected and recycled, secondary resources in 2010 (200–290 t of Nd and 18–33 t of Dy) would equate to only about 10% of consumption in the same year. The gap between the consumption and discard may be due to the rapidly increasing demand for Nd and Dy in recent years, with nearly half the consumption of Nd and Dy being in the form of exported semiproducts and finished products.

Nd magnets in end-of-life products are seldom recovered in Japan's present recycling system, although the recycling of Nd magnets from end-of-life driving motors of HEVs was found to be economically feasible. This is because a recycling market for Nd magnets has not yet been established. In the near future, Nd magnets from some end-of-life products may be recovered with an increase in the discard of end-of-life Nd magnets.

CONCLUSIONS

This study conducted dynamic SFA of Nd and Dy and determined the flows and stocks of Nd and Dy. The recycling of driving motors in HEVs was found to be economically feasible. At present, Nd magnets are not recycled because there is no market for secondary resources, which may be because of the low potential of secondary resources. Nd and Dy may be recovered in the future with an increase in the discard of products.

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