CRADLE TO GATE ASSESSMENT OF ENVIRONMENTAL IMPACT OF RARE EARTH METALS

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Abstract

The diverse properties of rare earth elements have seen broad and growing applications that are environmentally benign in traditional and new environmentally benign products such as hybrid cars and wind mills, magnetic refrigeration and so on. This study reports the results of a life cycle assessment study into rare earth elements that has not been given adequate attention. Preliminary results indicate that REEs tend to have very high GHG impacts and resource depletion potential. Also, the numerous waste streams generated in the processing can be toxic and may contain harmful radioactive substances.

Keywords: Rare earth, life cycle assessment, GHG emissions, magnesium alloys

1. INTRODUCTION

The term “rare earth” is applied to a group of seventeen chemically similar elements. RE technically is defined as the lanthanide (La) series of elements with atomic numbers from 57 to 71, and yttrium (Y) series with atomic number 39, and scandium (Sc) with atomic number 21. While the 15 elements in the La series of REs are classified broadly as light and heavy, a more precise classification include light (LREE), medium (MREE) and heavy (HREE) REEs [1]. About 200 RE containing minerals are distributed in a wide variety of mineral classes, such as halides, carbonates, oxides, phosphates, silicates, etc. In actual fact, REs are not rare in natural occurrence; cerium is more abundant in earth crust than is tin, yttrium more abundant than lead, and all of the lanthanide elements are more plentiful than the platinum group metals. However, HREEs are less common.

A variety of rare earth compounds and metal products are currently commercially synthesized. As new products and new applications using rare earths are developed the demand is bound to increase. A number of commercial magnesium-RE alloys have been also developed. High strength properties combined with low density has made magnesium alloys a highly attractive structural material, in particular where weight savings is of concern. An example is the Mg-RE (Ce, Y, Nd) alloys for drive train components [2].

The principal goal of this study is to provide the cradle-to-gate life cycle GHG assessment of REEs produced in Bayan Obo, China. It provides the basic life cycle impact data on REEs for ascertaining the environmental impact of intermediate and final products that use them [3]. Mg- RE alloys and components made from REEs being the product of interest in this study. The LCA study is conducted in two parts. Since the Bayan Obo mining operation essentially produces REOs, the first part assesses the impact of REO production. The second part models the subsequent separation of individual REOs and reduction of REEs that mostly occur elsewhere (such as at the purchasers' site). Combining both, the environmental impact of REEs is computed.

2. LCA STUDY

2.1. Goal and scope

The REEs do not perform a final function on their own, i.e. there is no direct end use except as intermediary materials to produce final products, a reference unit rather than a functional unit is appropriate. The reference unit is defined as 1kg of separated REEs comprising the set of elements in the lanthanide series along with yttrium and scandium. The product system boundary for REE production from cradle to gate, i.e. from ore mining through to separation of REOs (Bayan Obo is a representative system of production) and reduction of each REEs (the reduction of each REO is assumed to occurring in Australia) is shown in Fig. 1.

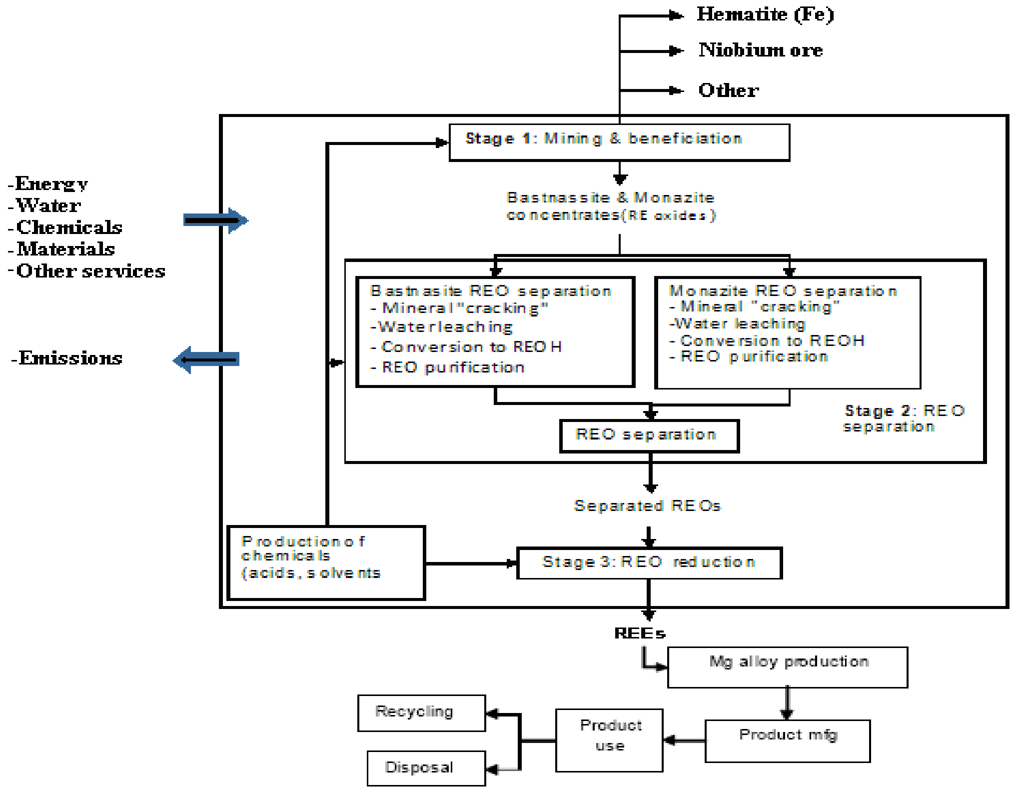

Fig. 1. The "cradle-to-gate" LCA boundary for the production of RE metals

The overall production of REEs is modelled in three separate stages (see Fig. 1). First stage is mining and beneficiation of RE containing iron ore. Beneficiation separates and concentrates bastnasite and monazite mainly using gravity separation, magnetic separation and flotation. This is followed by a cracking process for separating RE oxides (REOs) contained in the ore concentrates (Stage 2 in Fig. 1). The last part models the subsequent reduction of individual REOs to produce REEs. This stage (Stage 3 in Fig. 1) mostly occurs elsewhere (such as at the purchasers' site).

Allocation of impacts to the REEs produced is performed in two steps using mass combined with economic allocation (i.e. price of REE is used as the basis). First step allocates the co-products from iron ore mining - hematite (FeO), Columbite (Niobium ore) and REO bearing ore (i.e.

bastnasite and monazite concentrates). Second is the allocation among the extracted REOs in stage 2. Since the plant produces a mixture of REOs, this would require determination of the composition of REOs, and sharing of the burden according to the share of economic value of the REE produced from corresponding REO. A complex formula for relating the factors that demines the allocation is derived.

2.2. Major assumptions

Major assumptions of this study include the following:

- 45,000 tonnes of REOs are produced per annum from Bayan Obo mineral deposit with 33,750 ton from bastnasite and 11,250 tons from monazite (75% and 25% respectively).
- The REO concentrations in both minerals are 60% with the average grade of REO in mining ore of 6% and final recovery rate of REO of 10% [4].
- Recovery rate for each oxide is proportional to overall oxides compositions in Bayan Obo mineral deposit.
- Treatment process of radio-active wastes (in separating REOs from Monazite concentrates) is considered out of scope.
- The electrical energy used is based on average grid mix for China (75% from coal and 25% Hydro)
- Chemical and other materials used in the processes are assumed to be produced by technologies adopted in Europe.

Nominal representative data is used in this study. The data have been sourced from review of technological processes [5-8], environmental data pertaining to materials and chemicals from LCA databases in SimaPro [9], and combined with modelling and estimation. In computing the environmental impact of REEs, estimates of inputs of energy, materials, chemicals and water at all three stages are combined in an LCA model. The environmental impacts from reduction of only those RE elements used in Mg-RE alloys are considered in this study. These REEs include: light RE: lanthanum, cerium, neodymium, praseodymium; medium: gadolinium; and heavy: yttrium.

3. RESULTS OF THE LCA STUDY

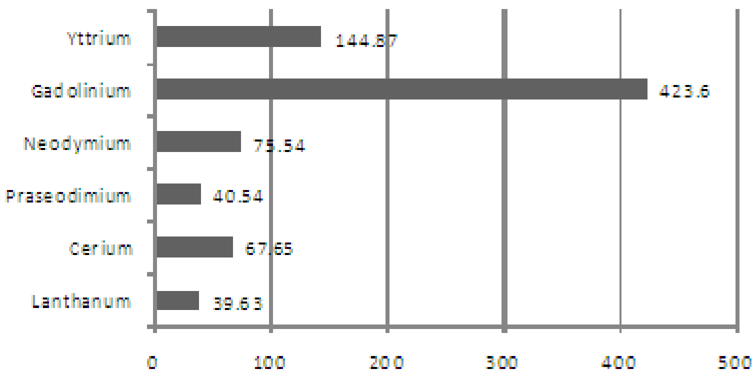

Fig.2. GHG emissions of RE elements (kg of CO2 eq./kg of REE)

Based on materials and energy requirements and effluents and emissions of mining, extraction, separation and reduction stages for production of REE, a corresponding model by using SimaPro 7.1 has been developed. The model computes the environmental impact in terms of GHG, as well as for a set of end point indicators, viz. human health, ecosystem quality and resources depletion. The results of modelling are: the electrical and total overall energy requirement, green house gases (GHG) emission, water consumption and overall environmental impact (based on damage factors: human health, ecosystem quality and resources depletion) from production of 1kg of separated light, medium and heavy RE oxides are presented in Table 1. The presented results (Fig.2 and Table 1) include only those RE elements which mostly used in Mg-RE alloys: light RE: lanthanum, cerium, neodymium, praseodymium; medium: gadolinium; and heavy: yttrium.

Table 1. Environmental impacts from production of 1kg of REE

REE	Energy consumption		Water consumption [kl]	Environmental impact		
	Electr. [MJ]	Heat energy [MJ]		Human Health [DALY*10]$^{-5}$	Ecosystem Quality [PDF*m2yr]	Resources Depletion [MJ] surplus
Lanthanum	91.8±17.8	127.6±27.0	43.5±11.0	7.38±1.32	3.48±0.88	44.3±10.6
Cerium	154.7±29.8	199.5±41.5	75.7±19.1	12.40±2.22	5.89±1.50	74.3±18.2
Praseodymium	91.9±17.9	128.2±27.3	43.4±11.0	7.38±0.33	3.48±0.87	44.3±10.6
Neodymium	173.1±33.3	218.9±45.2	85.5±21.4	13.85±2.47	6.59±1.69	83.0±20.4
Gadolinium	996.4±191.0	1166±235.0	522.3±131.7	79.80±14.19	38.12±9.89	481.6±120.2
Yttrium	331.5±63.6	424.4±86.8	180.7±45.9	26.82±4.77	12.81±3.31	165.7±40.8

4. CONCLUDING REMARKS

The impact of REEs comes from three life cycle stages (see Fig.1): 1) ore mining and beneficiation of Bastnasite and Monazite; 2) REO separation; and 3) REE reduction. Results show that mining and beneficiation has much lower energy and material consumption compared to other stages. Environmental impacts of the elements belonging to light rare earths (La, Ce, Nd and Pr) are generally less than medium (Gd) and heavy (Pr) rare earths. The relative share of impact being based on price and composition of REOs, the impact of REEs need not be in proportion to their occurrence, e.g. Ce has a higher proportion than La, but has a higher impact.

In general, productions of REEs are heavy on chemical processes rather than thermal processes, therefore requiring closer attention to treatment of waste before disposal. Another concern is the large amount of tailings in the extraction of bastnasite and monazite concentrates with naturally occurring radionuclides in the latter, and the release of this to the environment.

Finally, the study estimates a high environmental impact of REEs (though used in small quantities in applications). This combined with low yield and low abundance definitely points to an urgent need for recycling and recovery as individual elements (or oxides) or as alloys that retain their original properties for future use.

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