Resources, Conservation and Recycling 104 (2015) 76–93

Contents lists available at ScienceDirect

Resources, Conservation and Recycling

journal homepage: www.elsevier.com/locate/resconrec

Full length article

Recycling of rare earths from fluorescent lamps: Value analysis of closing-the-loop under demand and supply uncertainties

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ARTICLE INFO

Article history:
Received 4 June 2015
Received in revised form 3 September 2015
Accepted 9 September 2015
Available online 19 October 2015

Keywords:
Rare earth elements
Energy-efficient lamps
Global production network
Recycling
Resource conservation
Circular economy

ABSTRACT

Rare earth element (REE) recycling remains low at 1%, despite significant uncertainties related to future supply and demand and EU 2020 energy efficiency objectives. We use a global production network framework of REE flows from mine to REE phosphors in energy-efficient lamps to illustrate the potential of closed-loop recycling for secondary supply under different scenarios of primary supply and forecasted demand for LEDs, CFLs and LFLs. We find that different End-of-Life Recycling Rate scenarios for REE secondary supply range between meeting forecasted REE demand and filling primary supply gaps, and competing with primary supply. Our argument centres on diversifying REE sourcing with recycling and the choice between primary and secondary supply. We stress that secondary REE phosphor supply requires further policy support for lamp collection and a discussion of the value of REE phosphor recycling which underlies its economic feasibility.

1. Introduction

With an increase in energy efficiency of 20% to be achieved by 2020 within the European Union (EU), lighting presents a core area of interest. Replacement of inefficient bulbs by 2020 is expected to enable energy savings to power 11 million households a year. In 2009, regulations pursuant to the EU Eco-design Directive introduced stricter energy efficiency requirements for lighting products, which induced a phase-out of incandescent lamps (EU Commission, 2009, 2014a). By 2016 it is expected that a majority of these lamps will be phased out, with similar legislations implemented in other nations including Australia, BRIC countries, Japan, South Africa, and the United States (UNEP, 2014).

The lifetime of incandescent lamps is about four times shorter and their efficiency significantly less than compact fluorescent lamps (CFLs), with 15 lumens of visible light per watt of electricity consumed (lm/W) versus 63 lm/W (Wilburn, 2012). A linear rather than bulb shape characterizes linear fluorescent lamps (LFLs). Fluorescent lamps emit light when voltage is applied to the mercury gas within the glass body, which produces UV light that is transformed to white light by the phosphor powder coating of the lamp (Lim et al., 2013). Light emitting diodes (LEDs) have a lifetime approximately three to six times that of CFLs (Wilburn, 2012). LEDs emit light when electric current passes through a semiconductor chip and they are distinct to fluorescent lights in that they contain minor proportions of phosphor powder and no mercury.

While the market share of LEDs is projected to accelerate, the transition from fluorescent lights will take time partly due to the upfront costs of LEDs in comparison to CFLs and LFLs. McKinsey & Company (2012) expect CFLs and LFLs to remain with a share in the lighting technology distribution until 2020, yet their significance is anticipated to decrease faster jointly with market demand for REE in fluorescent lamps, as envisioned by Solvay and General Electric and illustrated in Fig. 2 (Cohen, 2014). Of central concern to the lighting industry are phosphor powders in these lamps, which contain rare earth elements (REE) used for their luminescent properties and key to producing white light (Binnemans et al., 2013a).

Since the early 1990s, China has gradually emerged as the largest consumer and producer of REE. The country hosts the majority of global mining and processing of these elements and has enacted numerous policies including quotas for mining and export (latter

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http://dx.doi.org/10.1016/j.resconrec.2015.09.005
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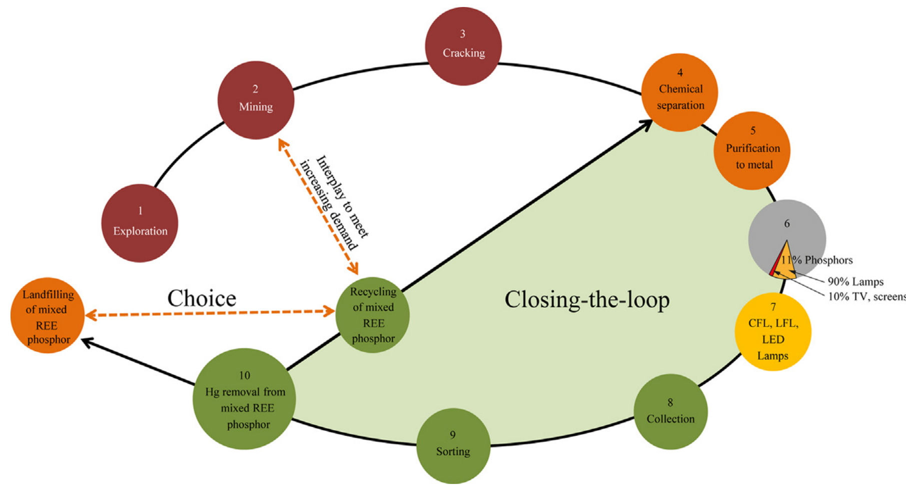

Fig. 1. Global production network of REE phosphor-based, energy-efficient lamps. Source: adapted from Erecon (2014) and Simoni (2013) with % indication of REE phosphor share of total REE market (derived from Castilloux, 2014a) subdivided into estimated 90% of phosphors used in energy-efficient lamps, and 10% for TVs and screens (Balachandran, 2014).

replaced by export licences in January 2015, see Bloomberg News, 2015) and a two-tier pricing system, under which REE cost less in China than in the rest of the world (ROW), introduced by export duties and trading rights, which significantly increases the price of exported REE products (WTO, 2014). Concerns about decreases in REE availability outside China intensified with the price increase of export-destined REE products by up to +600% in 2011 (Massari and Ruberti, 2013). Lawsuits against the REE export policies by China were filed at the WTO (2012) by the EU, Japan and the U.S. and in response to the WTO (2015) Dispute Settlement Body, China removed the application of export duties and export quotas to REEs, and the restriction on trading rights of enterprises exporting REEs. It remains uncertain how subsequent new Chinese industrial policy measures, including new export licences and the ad-valorem tax, will affect the market over the long-term. Strategies to target these concerns address the diversification of REE supply outside China, including re-opening old mines or establishing new mines, and include discussions about whether government intervention would be justified in recognizing the need for integrated value chains (Machacek and Fold, 2014; Tukker, 2014; Zachmann, 2010). Simultaneously, efforts in design to reduce and substitute REE in product components and recycling have surged, aiming to prevent future supply risks.

This study contributes to the discourse on REE recycling with a value analysis of recycled heavy REE europium (Eu), terbium (Tb) and yttrium (Y) from phosphor powders of fluorescent lamps as source of supply at times of EU and U.S. REE criticality classification (EU Commission, 2014b; Richter and Koppejan, 2015; U.S. Department of Energy, 2011). Today, at most 1% of all REE used in different applications are recycled (Binnemans, 2014; Binnemans and Jones, 2014). The role of REE recycling has been explored and critically reviewed in general (Guyonnet et al., 2015; Moss et al., 2013; Schüler et al., 2011; U.S. Department of Energy, 2011) and from the viewpoint of specific REE, laboratory experimentation and product groups (Bandara et al., 2014; Binnemans et al., 2013a; Dupont and Binnemans, 2015; Eduafo et al., 2015; Habib et al., 2014; Kim et al., 2015; Rademaker et al., 2013; Sprecher et al., 2014; Tunsu et al., 2015). While several studies have concluded that recycling of REEs is worthwhile and requires a broader strategy to enable REE processing capacities, including tracing the REE from mine to end of life (EoL) waste (Rademaker et al., 2013; Sprecher et al., 2014), none have provided an in-depth analysis of commercial scale recycling and what is needed to upscale recycling. To this end, this study provides an empirical analysis, using a case study of REE phosphor recycling on a commercial scale and an ex-ante analysis of the market from 2015 to 2020 to assess and discuss the potential for recycling of REE from energy-efficient lamp phosphors. We discuss what factors, including regulatory instruments and rethinking value propositions, are necessary to realize such potential.

2. Methodology

Our conceptual approach involves a qualitatively informed global production network framework to depict value adding, or processing steps from REE-containing ore to REE content in phosphor powders as used in energy-efficient lamps. This is the framework from which we then research the potential for secondary supply and closing the loop for REE in lamp phosphors through a mixed methods approach involving both a case study and modelling. Our case study provides an ex-post analysis of the experience of commercial REE recycling of REE phosphor containing lamps. This and our forecasts of supply and demand of Y, Eu and Tb then underpin the ex-ante analysis of the potential for development of secondary supply of REE phosphors from 2015 to 2020.

2.1. Global production network of rare earths and phosphors

Five steps, depicted in Fig. 1, precede the production of REE phosphors. Investor interest in favourable returns on investment finances prospecting and exploration of REE which enables data

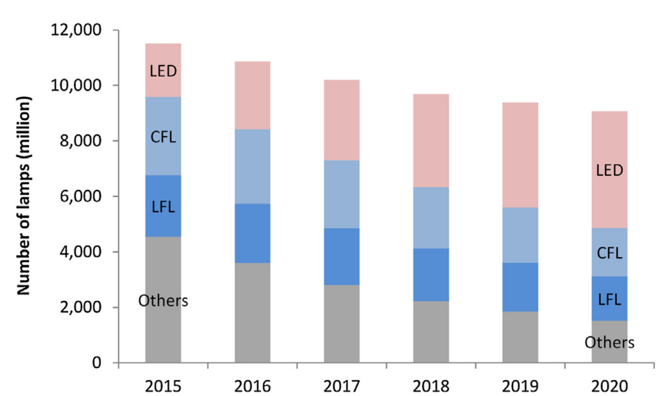

Fig. 2. Forecasted development of the total global lighting market and lamp type shares. *Source*: Adapted from McKinsey & Company (2012).