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Alternative value chains for rare earths: The Anglo-deposit developers

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ABSTRACT

The 2011 peak in rare earth element (REE) prices revealed a vast knowledge gap on the REE-based industry considered to be almost monopolized by Chinese players. A global value chain (GVC) framework is used to provide an understanding of value-adding segments of REE in their transformation from mine to market but inquiries on the currently most-advanced company strategies for alternative REE supplies form the cornerstone of this paper. The Anglo-REE deposit developer strategies are aligned with the value-adding segments and different approaches to integration and co-optation of REE processing competence are uncovered. On this basis the significance of alternative Anglo-REE-developer supplies is discussed and positioned in the perspective of Chinese industrial upgrading.

Introduction

In the third quarter of 2011, free-on-board China prices for products of rare earth elements (REE), a group of 17 non-ferrous metals, surged by up to +600 per cent, caused by Chinese reductions in export quotas and exacerbated by territorial disputes between China and the second largest-REE market, Japan (Metal-pages 2011-2012; Hatch, 2012 and Kingsnorth, 2012). Responses by REE-using markets included varying combinations of stockpiling, end-user firm requests for product redesigns to reduce and substitute REE, and interest in alternative supply of REE via exploration for non-Chinese deposits and recycling.

The Chinese market dominance did not appear overnight: from the mid-1980s to the early 1990s, the Chinese share of global REE production increased significantly from 20 to 60 per cent while the US share remained in the range from 30 and 36 per cent. This share was exceeded between 1992 and 1995 when China took over the majority of global production from the US Mountain Pass mine (Hedrick, 1997; Castor and Hedrick, 2006). Other players included Australia, and smaller actors in Brazil and South Africa which were outcompeted from the mid-1990s until 2000s when China reached 95 per cent of the global production share and Mountain Pass operations ceased. Russia and India remained the only other REE producers next to a small contribution by Malaysia (Castor and Hedrick, 2006).

China also emerged as the largest geographical market for REE, increasingly producing larger shares (68 per cent in 2011) for domestic consumption and augmenting the value-added in its REE products (Kingsnorth, 2012). The remaining part of Asia (with Japan as the single largest market) ranked second with 16 per cent of total world consumption in 2011 while the US market ranked third with 10 per-cent and Europe and other countries consumption was even smaller at around six per cent (Kingsnorth, 2012); hence, most of the REE production and consumption occurs in Asia today. In spite of high unit prices, the total REE market value is low compared to other mineral and commodity markets: in 2012, it was estimated between USD 4 and 6 billion with a total global REE demand of 115,000 t Rare Earth Oxides (REO) with an estimated annual variation of about 15 per cent (Kingsnorth, 2013). REE are mostly used in minor proportions in final end-use products (Kingsnorth, 2012) but they are highly important for both industrialized and emerging economies due to the potential of REE for value added and employment (both directly and indirectly) and induced value creation in new industries (American Chemistry Council (ACC), 2014).

The use of REE in a number of industries (including so-called strategic industries), their importance in high-tech applications and their value-adding potential make them targets of geopolitical interest. In 1992, the Chinese leader Deng Xiaoping suggested that China should become 'the Middle East for REE' and the advances China has made in this industry are surely remarkable: it has monopolized the market by high production volumes and steadily increased the value-added in its REE products by using a set of quotas and duties for production and exports. The system created a two-tier market of lower prices within China and higher prices outside for the same product with the aim to relocate foreign players' downstream production capacity to China. Already in

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2005, the effects of a steep export quota reduction triggered the creation of a black market in China while non-Chinese actors started questioning the organization and dynamics of the industry, the applications relying on REE, and alternative options to resource access (Tse, 2011).

Several research contributions have investigated these trends and processes which require interdisciplinary knowledge to understand the intricate weaving of explanatory factors derived from mining, geochemistry, metallurgy and economics. The contributions focus on criticality of issues involving the global REE market and REE industrial sectors (Korinek and Kim, 2010; Hatch, 2012; Hansen, 2012; Kingsnorth, 2013; Packey, 2013), REE geology and criticality (Eggert, 2011; Chakhmouradian and Wall, 2012; Massari and Ruberti, 2013; Nieto et al., 2013), Chinese industrial policy (Wübbeke, 2013) and the implications of the monopoly for different REE-using industries (Degeorges, 2012; GAO, 2010; Hurst, 2010; Adachi et al., 2010; Kramer, 2010), including specific intermediate products and industries such as magnets (Eggert, 2010; Zepf, 2013). A further stream of research has emerged on aspects related to recycling (Du and Graedel, 2011; Schüler et al., 2011; Binnemans et al., 2013; Harris and Walton, 2013; Habib and Wenzel, 2014) while some contributions address organizational aspects of supply chains (ACC, 2014; Zepf, 2013; Humphries, 2012; Walker, 2010; Eriksson and Olsson, 2011; USDOE, 2011; EU, 2010).

However, the implications derived from the complexity of the REE value chain for the end-user industries and critical appraisals of efforts by REE consumers to encourage alternative supply chains of REE have so far been omitted in academic discussions. The recent contribution on rare earth market developments by Packey (2013) provides a good overview of the industry including insights on two Anglophone REE-miners; while the contribution on REE supply chains by Golev et al. (2014) depicts some of the major non-Chinese actors and is a significant advance towards a more comprehensive understanding of the industry, yet their analytical focus is on geological and recycling aspects of the REEs. In this paper we document the integration strategies of three Anglophone, non-Chinese REE deposit developers, arguably the most advanced projects in terms of providing alternative routes of REE product supply today (Hykawy, 2014a; Kingsnorth, 2012; Lifton, 2012; Silver, 2012). We illuminate their different forms of co-operation and integration with Canadian, Chinese, European and US actors – some of which depend on Chinese REE supply today. Our findings are based on data from an empirical data set of interviews with European REE industry players which were conducted between May 2013 and January 2014 and supplemented with data from the annual reports of the three Anglo-REE-deposit developers.

The paper is structured into five sections. In the next section we describe the input–output structure of the global value chain of REE by depicting the main value-adding segments that transform the REE and we point to specific intermediate and end-user industry requirements of REE. In *Section New supply chains? The rise of Anglo-REE-deposit developers* we delineate the Anglo-REE-deposit developer strategies towards establishing alternative sources of REE supply. Our discussion in *Section Maneuvering between Chinese control of raw materials and efforts to upgrade REE-based filaments: Any changes in global supply patterns?* revolves around the construct of the GVC, the identified periods in the transition of the Anglo-REE-deposit developers and implications of these findings for REE-using industries. The paper continues with the *Section Policy considerations* and ends with the *Section conclusion*.

Upstream processes and products in the REE value chain

Rare earth elements (REE) are a group of 17 transition metals comprising 15 non-ferrous elements of the lanthanides (atomic number 57–71) and also including yttrium (atomic number 39) and scandium (atomic number 21) (Kirk-Othmer, 2005; Ulmanns, 2005). Albeit having chemical similarities, REE display significant differences in their physical properties namely in their reactions to light, electricity and magnetism (Kirk-Othmer, 2005; Ulmanns, 2005). A multitude of appliances from consumer to industrial use appreciate these properties (Roskill, 2011).

REE occur in mineral and not in elemental form, as for example gold. More than 200 different minerals contain REE (Kanazawa and Kamitani, 2006; BGS, 2011), yet only four minerals, namely bastnäsite, monazite, xenotime, and loparite, and ion-adsorption clays, have to date been dominantly used for commercial exploitation (Roskill, 2011 and Walker, 2010). REE-bearing minerals are normally biased towards containing more light REE or heavy REE (BGS, 2011) and the 9 intermediate industries according to our classification (see Fig. 1) demand individual REE from either group or both (Roskill, 2011, Eurare, 2014). Some compositions of REE-containing geological deposits bear geochemical advantages for further processing such as comparably easier and more economically feasible flow sheets (which will be put into context below). As a result, separation from certain REE-bearing minerals will be easier due to factors such as comparably lower content of hazardous, radioactive elements and feasibility of REE production as by-product (BGS, 2011; Rockstone Research, 2014). In addition, the consistency of mineralization will impact tonnage and grade and some deposits are more advantageous due to more favorable and balanced REE distribution; profitability is also influenced by infrastructure and jurisdiction (Rockstone Research, 2014).

By volume and value, the magnet sector is currently the most important within the rare earth industry (Kingsnorth, 2010 and Roskill, 2011). The use of REE in the catalyst market sector is characterized by high volume and comparatively low value as this sector predominantly absorbs light REE. On the contrary, the phosphor market sector rare earth ore consumption in 2008 revealed low volume and high value, due to absorption of predominantly heavy REE.

In comparison to other mineral commodities, the production of REE entails higher complexity and capital intensity since equal focus is required on both mining and chemical processing (Lynas Annual Report, 2013). This is reflected in the so-called 'balancing problem' which summarizes these challenges faced by the REE industry due to REE occurrence in mineral form and the need to separate the REE jointly even if particular industries require only a number of the elements at a time (Falconnet, 1985).

Fig. 2 illustrates the upstream segments of the GVC of REE. *Exploration* is a precondition to finding suitable and commercially viable deposits for exploitation which depends on knowledge about the deposit composition. Thus, value input in form of investments in equipment and labor will result in area surveys, detailed geological maps and rock and mineral samples to be used for laboratory determination of compositional characteristics. The data generated serves the elaboration of flow sheets needed in the forthcoming processing stages. Each REE-mineral bearing rock is different and thus, requires a specific, adjusted flow sheet. The process from resource establishment over preparation of flow sheets, documentation for mining permissions (including progressive feasibility studies and environmental impact assessment) to mine construction is lengthy and can take several years up to a decade and more (Kingsnorth, 2012). Therefore, *mining* does not react rapidly to market demand and large mineral volumes might be mined and come onto the market when market demand has already changed (Falconnet, 1985 and Geoviden, 2012).

In the first (mineral) processing step which usually takes place at the mine, a *beneficiation* is performed by means of crushing, milling and concentration technology, relying on physical processes such as gravity concentration, magnetic and electric separation and flotation techniques. The output from this first processing