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Addressing criticality for rare earth elements in petroleum refining: The key supply factors approach

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ABSTRACT

The group of elements known as the rare earth elements (REEs) is comprised of the 15 lanthanides. REEs are used in a number of technologies including catalysts for automobiles and petroleum refining, magnets for wind turbines and defense technologies, and phosphors in lighting and computer and TV screens. REEs are actually quite abundant in the earth′s crust. The elements are deemed "rare" because they are found in low concentrations and are difficult to extract economically. China holds 48% of the global REE reserves, and until 2012, production of REEs was almost exclusive to China. Over the past decade, China has been steadily decreasing its REE export quotas, reducing the supply of REEs available to the rest of the world. REEs are considered critical materials according to the National Science and Technology Council, which defines critical elements as those serving an essential function in the manufacture of a product, the absence of which would cause significant social consequence. Thus, it is extremely important for consumers of REEs to be aware of and understand the risks facing the supply REEs, as awareness is the first and most important step in developing strategies to mitigate risk. This report presents a mechanism for identifying the risks present in a supply–demand scenario and determining the criticality of an individual rare earth element under specific circumstances.

In "A brief examination of supply and demand in REEs" section we briefly discuss the supply and demand for REEs. "REEs in petroleum refining" section examines the importance of REEs in fluid catalytic Cracking, the largest domestic U.S. use of REEs. "Determining REE criticality: The key supply risk methodology" section presents our key supply factor methodology of addressing the criticality of REEs. In "Scenario analysis" section we apply our methodology to three different possible scenarios affecting U.S. REE markets. "Example of criticality index for cerium considering the increased domestic supply scenario" section contains the results we derive from our methodology. Our conclusions are in "Criticality indexes: Results" section.

Introduction

The group of elements known as the rare earth elements (REEs) is comprised of the 15 lanthanides, atomic numbers 57 to 71, as well as yttrium and scandium, atomic numbers 39 and 21, respectively (Humphries, 2012). REEs are used in a number of technologies including catalysts for automobiles and petroleum refining, magnets for wind turbines and defense technologies, and phosphors in lighting and computer and TV screens, among others (Humphries, 2012). REEs are actually quite abundant in the earth′s crust, ranging in crustal abundance from cerium at 64 parts per million, to thulium and lutetium at less than 0.5 parts per million. The elements are deemed "rare" because they are found in low concentrations and are difficult to extract economically (Emsley, 2001).

China holds 48% of the global REE resources (Gambogi, 2013), and until 2012, production of REEs was almost exclusive to China (Humphries, 2012). Over the past decade, China has been steadily decreasing its REE export quotas, reducing the supply of REEs available to the rest of the world. This became especially problematic in 2010 and 2011, when sharp Chinese quota reductions caused REE prices to skyrocket, in some cases, to more than five times their 2009 prices (Gambogi and Cordier, 2012). Although prices have since fallen, these events alerted the world of the vulnerability of REE supply and the volatility of REE prices. Many countries have taken action to secure a domestic supply of REEs, and in just one year, China′s share of global REE production fell from 97% to about 87% due to new and increased production from countries like the United States and Australia (Gambogi, 2013).

REEs are considered critical materials according to the National Science and Technology Council, which defines critical elements as

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those serving an essential function in the manufacture of a product, the absence of which would cause significant social consequence, and whose supply is vulnerable to disruption (Telleen, 2012). Thus, it is extremely important for consumers of REEs to be aware of and understand the risks facing the supply of each REE, as awareness is the first and most important step in developing strategies to mitigate risk. This report presents a mechanism for identifying the risks present in a supply–demand scenario and determining the criticality of an individual rare earth element under specific circumstances.

In A brief examination of supply and demand in REEs section we briefly discuss the supply and demand for REEs. REEs in petroleum refining section examines the importance of REEs in fluid catalytic Cracking, the largest domestic U.S. use of REEs. Determining REE criticality: The key supply risk methodology section presents our key supply factor methodology of addressing the criticality of REEs. In Scenario analysis section we apply our methodology to three different possible scenarios affecting U.S. REE markets. Example of criticality index for cerium considering the increased domestic supply scenario section contains the results we derive from our methodology. Our conclusions are in Criticality indexes: Results section.

A brief examination of supply and demand in REEs

As with all other economic products, the price of REEs are determined by the forces of supply and demand. Both the supply and demand of REEs, however, make REE markets subject to volatile pricing.

Fig. 1 presents the supply side of the REE market. It is clearly dominated by the People′s Republic of China. Note, however, that China′s production market share of 86% is far above its already large resource share of 48%. Since it takes substantial time to create REE production, this implies that in the short run China may well have substantial power to raise market prices.

Any supply side attributes that lead to the exercise of market power are dependent upon the substitutes for the product at the demand side. If there are easy substitutes for REEs, then China would not be in a position to exercise market power. Thus, a large part of any investigation into criticality involves examining the demand side of the use of particular REE elements.

Fig. 2 reports on a composite index of recent REE prices. The current concern over REEs arises from the 2010 increase in REE prices, brought about by reductions of Chinese supply. The composite index rose by approximately 20 times before peaking about approximately 20 times its 2010 level in 2011. Although prices have fallen since then, the events of 2010–2011 have made it clear that rare earth consumers may be vulnerable to price manipulation by China.

REEs in petroleum refining

The use of REEs in fluid catalytic cracking (FCC) units for petroleum refining is the largest domestic use of REEs (U.S. Department of Energy [DOE], 2011), and FCC catalysts are a refinery′s second highest raw material cost behind crude oil (Baillie and Schiller, 2011). During the FCC process, heavy oils generated from distillation enter the FCC unit and are heated to approximately 1000 °F, at which point the oil begins to vaporize. In the presence of zeolite catalysts, the oil is cracked into smaller, more valuable hydrocarbons (Sadeghbeigi, 2012). Zeolites are solid acids and are the key ingredients in FCC catalysts. The negative charge of the zeolites′ porous framework is balanced by the positive charge of the water molecules and sodium in the pores (Weitkamp, 1999).

In order to enhance activity and thermal stability of zeolites, the sodium content must be reduced. Lanthanum and cerium were discovered to be useful cations for replacing the positively charged sodium in the zeolite structure through ion exchange. The REEs stabilize the aluminum atoms in the zeolite structure, preventing them from separating from the lattice when the catalyst is exposed to the high temperatures of the FCC unit. As a result, REEs increase FCC catalyst activity, as well as the thermal and hydrothermal stability of the zeolites in the FCC process, which ultimately increases the gasoline yield per unit of catalyst and allows the catalysts to remain effective longer (Sadeghbeigi, 2012).

Catalyst activity, or the ability of a catalyst to convert a standard feedstock to gasoline, lighter products, and coke (BASF), is measured using a microactivity (MAT) test. In this test, a standard gas oil is passed over a small-scale cracking reactor containing several grams of catalyst at fixed operating conditions (BASF). The results of a MAT test are influenced by the following factors: catalyst to oil ratio, feedstock quality, reactor temperature, and space velocity (Sadeghbeigi, 2012). Fig. 3 depicts the increase in activity that occurs as the weight percentage of REEs in an FCC

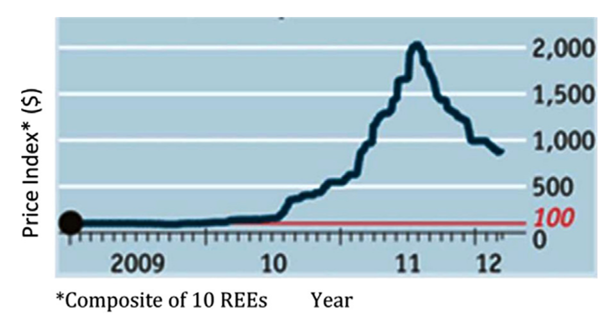

Fig. 2. REEs price index (The Economist, 2012).

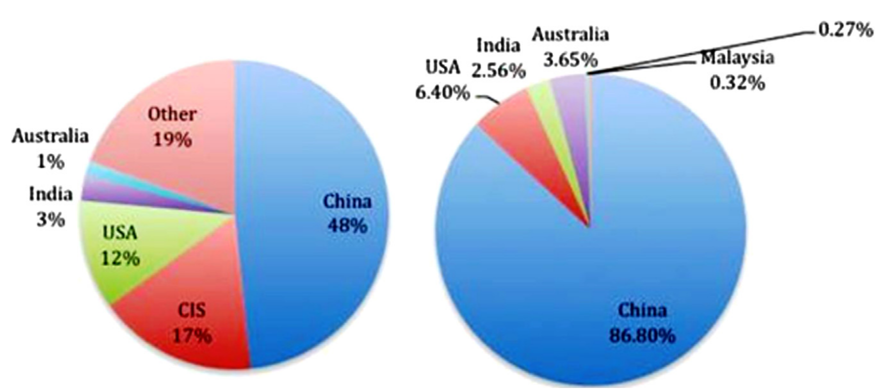

Fig. 1. Current REE resources (left) and production (right) by country (Gambogi, 2013).