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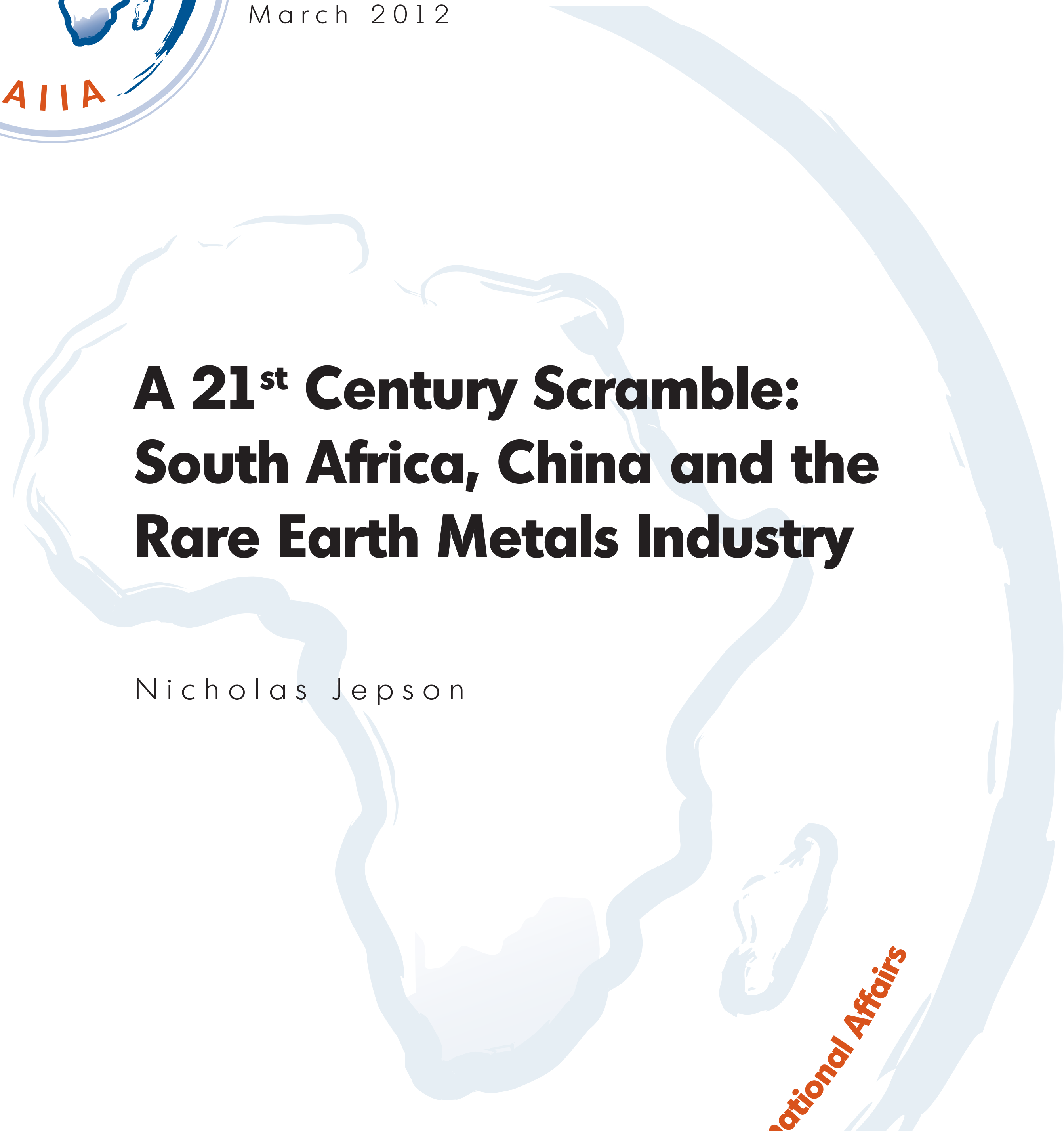

A 21st Century Scramble: South Africa, China and the Rare Earth Metals Industry

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South African Institute of International Affairs

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NORWEGIAN EMBASSY

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ABSTRACT

The paper analyses the peculiar structure of the rare earth elements (REE) industry, a sector dominated by China, and the global implications of current upheavals within the sector, especially as they concern South Africa's (re)emerging rare earths production. REEs are a hitherto obscure group of metals that have now assumed global significance, They are especially critical to modern high-strength magnets and constitute vital inputs for a growing range of mass consumer, 'green' technology and military applications. It is important to understand that REEs altogether comprise 17 different metals which, although found together in various combinations, differ in relative abundance and breadth of possible applications. There are therefore large variations in prices and criticality of supply between the different elements.

The Chinese rare earths industry has secured a 97% share of upstream production by means of aggressive pricing, backed by state support and technology transfer. Beijing is now attempting to consolidate the industry, crack down on illegal mining and restrict and enforce export and production quotas. Official explanations stress renewed concern for environmental issues and the protection of scarce resources from over-exploitation. Also significant, however, is a policy of deliberately using export restrictions to leverage non-Chinese prices, in order to induce foreign downstream producers to relocate production to China. This process is beginning; although there are also two other forms of international response. First, there is demand destruction either through increased efficiency in REE usage, substitution or recycling of rare earths. Secondly – and most widely known – are attempts to restart REE supply chains outside China. South Africa is in the forefront of these efforts through two, globally significant, extractive projects. The refurbished Steenkampskraal thorium and REE mine may be the first non-Chinese new producer to come online, in 2012–2013. The Zandkopsdrift development in Northern Cape is less advanced, but is among the largest prospective new REE mines. Both are joint ventures between Western junior mining companies and East Asian parastatals, respectively from China and Korea. Significant environmental risks seem inherent in the extraction and separation of REEs, especially from thorium waste, although apparently this has not reached the public consciousness in the areas immediately around the South African mines. If these dangers can be avoided or minimised, the new rare earths mines could make a small but significant positive developmental impact at local as well as national level.

ABOUT THE AUTHOR

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ABBREVIATIONS AND ACRONYMS

BEE	Black Economic Empowerment
GWMG	(Canada's) Great Western Minerals Group Ltd
CREO	critical rare earth oxide
DoE	US Department of Energy
Dy	dysprosium
Eu	europium
FCC	fuel cracking catalyst
GQRE	Ganzhou Qiandong Rare Earth (group)
HREE	heavy rare earth element
kg/t	kilograms per tonne
Kores	Korea Resources Corporation
LREE	light rare earth element
MoST	Government of China Ministry of Science and Technology
Nd	neodymium
NdFeB	neodymium-iron-boron
REE	rare earth element
REO	rare earth oxide
ROW	rest of the world [outside China]
Tb	terbium
Vale	Companhia Vale do Rio Doce
WTO	World Trade Organization
Y	yttrium
ZAR	South African rand

PREFACE

The analysis of this paper offers insights into the mining of rare earths, an area that is usually loaded with secrecy and prone to media speculation. The monopoly of China on processed rare earths and the current plans to (re-)open two rare earths mines in South Africa – which used to be a world market leader in rare earths in the 1960s – merit a thorough analysis.

The topic of this research is valuable to analysts and policy makers from at least two key perspectives. Firstly, it is worthwhile exploring the reasons for China's domination in the sector and analysing the policies that inform its exploitation of rare earths minerals. Secondly, it illustrates the need for a better understanding of global dynamics when making costly long-term decisions on investments such as (re)building a mining industry for rare earth minerals in competition with China.

This paper is a parallel publication by the South African Institute of International Affairs and the Centre for Chinese Studies at Stellenbosch. It was written in the context of an internship of Nicholas Jepson at both institutions between July and September 2011. During his stay in South Africa, Nicholas conducted field work, including at the prospective mining sites, in the provinces of Western and Northern Cape in September 2011.

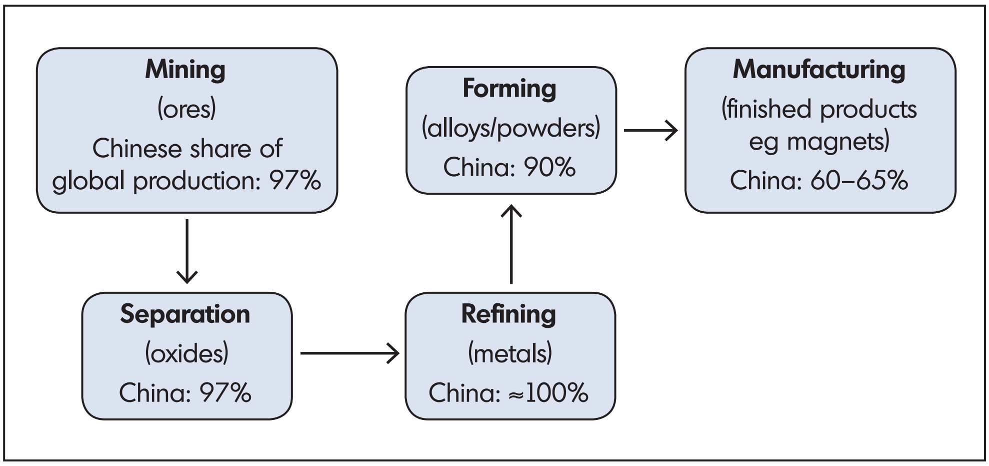
Dr Sven Grimm and Dr Kathryn Sturman
Stellenbosch/Cape Town, January 2012

INTRODUCTION

For the past two years a group of 17 little-known and exotically named metals has been attracting serious public interest. There has been a global scramble for new sources of the materials, fevered speculation driving price rises, and fears for the economic and geo-strategic security of Western nations. The reasons for this upheaval are complex but for many Western journalists, investors and politicians, may be reduced to one word: China. The narrative usually attached to discussion of rare earths is one of aggressive Chinese mercantilism in the service of geo-political goals and apparent Western complacency and vulnerability. It resonates with broader and more general fears in the West of the threat posed by a rising China.

Most articles on so-called REEs point out a salient fact: that, having forced almost all competitors out of the industry through deployment of the familiar Chinese competitive advantages of low labour and environmental costs, China now accounts for 97%[1] of the world's rare earth mining. It enjoys similar dominance at all points of the supply chain up to the manufacturing stage (see Figure 1). China completed its hold over the extraction of rare earths about a decade ago, a time when almost all major non-Chinese mines had closed. Chief among them was Mountain Pass, on the California-Nevada border, which shut down in 2002 due to low REE prices and new environmental restrictions. At that time the loss of the US REE industry seemingly could be written off as a minor episode – the relocation of the dirty and unprofitable end of a minor and unimportant industry that employed few people. Today, the picture has greatly changed. Frantic efforts to restart production outside China are currently under way.

Figure 1: Main stages of the rare earth production process



Source: 'Rare Earth Metals in the Defense [sic] Supply Chain', United States Government Accountability Office, Washington, DC, 2010

Increasingly, REEs are produced for use in high performance magnets, vital to various products for which global demand has skyrocketed over the past decade. These include mass produced goods, for example DVD players and hard drives, and more high-technology consumer items such as iPads and 'smart' phones (see Table 1). The West has woken up to the importance of REEs, however, mainly due to their rapidly increasing use in two sectors of vital future geo-political significance. The first is the manufacture of many 'clean tech' items such as wind turbines, hybrid and electric car batteries, and magnetic levitation ('maglev') trains, at present impractical without the use of rare earth-derived magnets. Secondly and of even more pressing concern to many governments, particularly that of the United States, is the acquisition of REEs for the production of much of their high-technology military equipment, such as armoured vehicle navigation systems, submarine engines and missile guidance systems, and even for refining jet fuel.

Table 1: The importance of rare earths: key applications for the 17 elements

Dysprosium	Nuclear reactors, electric vehicles, lasers, future green tech
Holmium	Generates strongest magnetic fields currently possible, lasers, nuclear reactors
Erbium	Fibre optics, lasers
Thulium	Few current applications, does not occur naturally
Ytterbium	Solar cells, optics, crystals
Lutetium	Petroleum refining, possible cancer treatment, x-rays, computer memory
Yttrium	Phosphors, many alloys, turbochargers, prosthetics, cancer and arthritis treatment
Scandium	Aluminium alloys for aerospace, guns
Lanthanum	Hybrid batteries, computers, fuel cells, electronic vacuums, petroleum cracking
Cerium	Glass polishing, solar panels, light-emitting diodes (LEDs), catalytic converters
Praseodymium	Aircraft engine alloys, super magnets, Computerised Axial Tomography (CAT) scan machines, fibre optics
Neodymium	Electric cars, wind turbines, air conditioning, hard drives.
Samarium	Permanent magnets for defence applications, cancer drugs
Europium	Red and green colours in TV sets, control rods for nuclear reactors, alloys
Gadolinium	High strength alloys, microwave ovens, CDs, computer memory, MRI machines, nuclear reactors
Terbium	Fuel cells, lasers, high technology audio, alloys

Source: Hammond CR, 'Section 4; The Elements', in Lide D (ed.), *CRC Handbook of Chemistry and Physics* (89th ed). Boca Raton: CRC Press/Taylor and Francis, 2009

Along with Australia and North America, Southern and East Africa are among the most promising regions for new sources of rare earths (see Table 2). South Africa in particular appears to have great potential for rare earth extraction. Construction of two new mines in the Western and Northern Cape provinces has already started. The rare earth industry will never become a major driver of national development, but the new mines should bring socio-economic benefits to the communities around them, which are among the most disadvantaged in the country.

In addition, work has started to establish rare earth separation plants (which turn mined ores into oxides) in South Africa, which may position the country as a future regional hub for processing rare earth ores mined elsewhere in Africa. The opportunity to gain a foothold in a sector of such global strategic importance is undoubtedly attractive. There are concerns, however, surrounding the environmental impact of the nascent industry. Rare earth-producing regions in China have been devastated by mining and processing operations that have generated acidic waste water, harmful gases, contaminated groundwater and radioactive tailings. Avoiding such deleterious effects in South Africa will be a major challenge.[3]

Table 2: Current rare earth projects in Africa

Project	Company	Location
Steenkampskraal	Great Western Minerals Group/ Ganzhou Qiandong Rare Earth	South Africa
Zandkopsdrift	Frontier Rare Earths/Kores	South Africa
Wigu Hill	Montero Mining/Kores	Tanzania
Ngualla	Peak Resources	Tanzania
Kangankunde	Lynas Corp	Malawi
Salambidwe	Globe Metals and Mining	Malawi/ Mozambique border
Machinga	Globe Metals and Mining/Resource Star	Malawi
Sangwe	Mkango Resources	Malawi
Nkomba Hill	Rare Earth International/African Consolidated Resources	Zambia
Lofdal	Namibia Rare Earths	Namibia
Hoarusib	Avonlea Minerals	Namibia
Gakara	Southern Crown	Burundi
Mrima Hill	Pacific Wildcat Resources	Kenya
Xiluvo	Southern Crown	Mozambique
Mount Muambe	Globe Metals and Mining/ East China Minerals	Mozambique
Malilongue	Kimberly Rare Earths/ Great Western Mining	Mozambique
Longonjo	Black Fire Minerals	Angola
Moijabana	Impact Minerals	Botswana
TRE	Tantalus Rare Earths	Madagascar

Source: Compiled by author

As regards downstream REE production, the US continues to hold a near-monopoly in fuel cracking catalysts (FCCs), an important end use of REEs, but relatively unproblematic in terms of supply constraints. Rare earth oxides (REOs) are required for refining or 'cracking' crude oil into most kinds of petroleum-based fuels, hence demand for REEs as catalysts largely follows that for oil. Increasingly, however, further demand is likely to come from the greater exploitation of non-traditional sources of crude oil such as those from Canadian tar sands and shale gas, which require larger amounts of REEs to complete the cracking process.[4] Within this sector generally, however, there seems little fear of supply bottlenecks. The rare earths mainly used in catalytic converters and as FCCs are cerium and lanthanum. These two elements have perhaps the widest range of end uses of any of the REEs and are in relatively high demand, with cerium alone projected to make up one-third of total REE sales by 2015.[5] Balancing this, however, is the fact that most REE deposits contain large quantities of both, with almost all the newly discovered non-Chinese deposits having heavy concentrations of the two. Indeed, supplies of cerium and lanthanum are expected to move to permanent surplus when the first wave of new non-Chinese mines opens in 2012–2013[6] (See Table 3).

Table 3: Selected rare earths and projected critical supply problems for oxides

	2011	2012	2013	2014	2015	2016	2017
Lanthanum	○	○	✔	✔✔	✔✔	✔✔✔	✔✔✔
Cerium	○	○	✔	✔✔	✔✔✔	✔✔✔	✔✔✔
Neodymium	✘	✘	○	○	✔	✔✔	✔✔✔
Europium	✘✘	✘✘	✘	✘	○	✔✔	✔✔
Terbium	✘	✘	✘	✘	○	✔✔	✔✔✔
Dysprosium	✘✘	✘✘	✘✘	✘✘	✘✘	○	✔
Yttrium	✘✘	✘✘	✘✘	✘✘	✘	✔	✔✔
CREO	✘	✘	✘	✘	✔	✔✔	✔✔✔

Note: The table assumes a minimum Chinese annual REO production of 118 900 tonnes (the total for 2010).
Note: CREO = oxides of Nd (neodymium), Eu (europium), Tb (terbium), Dy (dysprosium), Y (yttrium).

Source: Hatch GP, *Critical Rare Earths: Global Supply and Demand Projections and the Leading Contenders for New Sources of Supply*. Carpentersville, Illinois: Technology Metals Research, LLC, 2011

Supply as percentage of demand:
✘✘ = 50–74%; ✘ = 75–94%
O = 95–105%
✔ = 106–125%; ✔✔ = 126–150%; ✔✔✔ ≥ 151%

If production quotas are strictly enforced transition points will be later than those indicated above.

Until very recently catalysts made up the largest share of the REE end-use market. Already, however, this sector has been overtaken by that for permanent magnet manufacturing. Rare earth magnets consist of alloys of REEs such as neodymium, praseodymium, samarium, dysprosium, and – to a limited extent – terbium, with other ferro-magnetic metals, usually iron or cobalt. These combinations produce permanent magnets with the highest-strength magnetic fields currently achievable. In consequence, although substitutes may sometimes be available, rare earth magnets make for far more efficient design. For example laptop computers would be half as large again and twice as heavy as current units[7] without the use of rare earths.

The REE magnet market is already large, particularly in consumer electronics such as hard disk drives and smart phones. The most important future component of demand for REEs, however, which is expected to drive double digit growth in this sector (see Table 4), is the use of rare earth magnets in green technology applications. The two most important of these are in electric and hybrid vehicles, and next-generation wind turbines. Although a small quantity of a particular metal is a feature of demand for many REEs, in this case volumes tend to be much larger, with the manufacture of each Toyota Prius hybrid car, for example, requiring 1kg of neodymium and 100–200g of dysprosium. Wind turbines have even greater requirements: at a conservative estimate each megawatt of generating capacity[8] needs150–200kg of neodymium and praseodymium as well as 20–35kg of dysprosium, The growing market for electric scooters in developing countries, particularly China, is also potentially important as a source of demand for REE magnets. Scooters require less REE than electrically powered cars, but their potential sales may be much greater.

Table 4: Projected demand 2010–2020 for rare earths by end use

Application	REO demand by volume 2010 (tonnes)	Projected annual demand growth 2010–2020 (%)
Magnets	26 800	12–14
Catalysts: petroleum refining	7 800	8–10
Catalysts: automotive	16 700	6–8
Alloys: batteries	13 400	2–4
Alloys: non-battery	8 600	4–6
Phosphors	8 500	8–10
Polishes	19 000	4–6
Glasses	11 000	2–4
Ceramics	7 000	6–8
Other	7 000	4–6
Total	**125 000**	**7–9**

Note: Totals may not sum exactly due to rounding.

Source: Otto E, 'Rare Earth Metals', Cormark Securities, 2011, http://www.slideshare.net/RareEarthsRareMetals/cormark-securities-rare-earth-metals-initiating-coverage

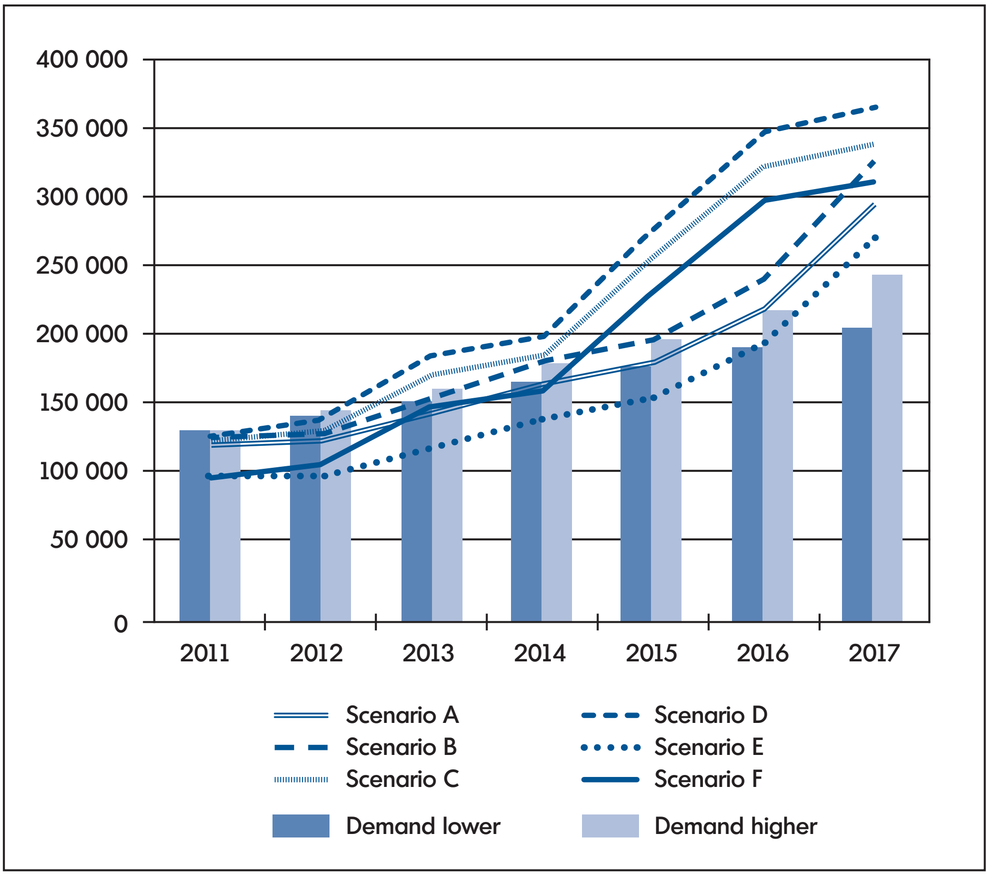
Rare earths are vital for green technologies apart from magnets. Most important are phosphors, used for low-emission lighting and in the efficient thin-film semi-conductors for solar panels. Although some demand for lanthanum also comes from producers of nickel metal hydride batteries (again used in the Prius) it is expected that electric vehicle manufactures will soon switch to more efficient lithium-ion batteries that do not depend on REEs. Designs for hydrogen fuel cells, which may well replace these batteries in the long run, tend to include significant quantities of rare earths, although the large-scale adoption of this technology remains some way off, given the technical and infrastructural difficulties involved.

Demand for REEs across the board is projected to grow by an annual average of 8–11% (see Table 3 and Figure 2), but sectors driven by growth in green technology show greatest potential for market expansion.[9] This has led the US Department of Energy (DoE) to list five rare earths as 'critical', defined as their importance for clean energy (which can be regarded as a proxy for growth in demand) set against risk to supply.[10] In descending order of criticality, these earths are dysprosium, yttrium, terbium, europium and neodymium.

Figures 2 and 3 show potential supply and demand for global REOs (after separation) for the next six years. They show that the issue of supply and demand is very different when critical rare earths are considered separately from REEs as a whole. For all scenarios, global supply is likely to be in surplus for both categories by 2017. The transition point to surplus, however, depends on the extent to which China is willing and able to continue efforts to consolidate its domestic industry and limit production; as well as the speed at which the rest of the world (ROW) producers are able to bring new mines into production. For total rare earths, global supply may exceed demand as early as 2012 (possibly 2017, although most projections show a global surplus by 2015 at the latest). According to current forecasts the transition date for critical rare earths should come between 2014 and 2017, although the supply of some individual REEs may remain critical beyond these dates. All these projections have major implications in terms of the leverage China will hold in attempting to induce foreign downstream producers to relocate production to China. Supply deficits and surpluses will also affect the commercial viability of many new mines currently in development. They will also be affected by the need to identify substitutes for rare earths, which in turn may result in sufficient demand reduction radically to alter these forecasts.

Much of the criticality in supply of individual REEs is determined by the physical nature of global REE deposits. Crucial to that, in turn, is the realisation that given its 17 distinct elements, the rare earth industry behaves very differently from that of other metals. For example, cerium is likely to be produced in large surplus within two years, despite its being the most widely used of the rare earths. It will therefore become largely unresponsive to demand, with concomitant depressed prices, because as noted earlier it tends to be present in almost all REE-containing deposits (which for technical reasons cannot be mined for individual elements). Exploitation of a mine to extract a far scarcer REE, such as dysprosium, is therefore likely also to produce much greater amounts of cerium and of other relatively abundant rare earths, such as lanthanum and neodymium, whether or not there is a commercial reason for so doing. When consideration of this is added to an understanding of likely demand, the key driver of which is green applications, the relevant and relatively complex nexus between supply and demand for each individual metal starts to become clear. This is why, for example, neodymium, the third most common rare earth, is included in the DoE critical list, although cerium is not. It is because large quantities of neodymium are required for the permanent magnets mentioned above.

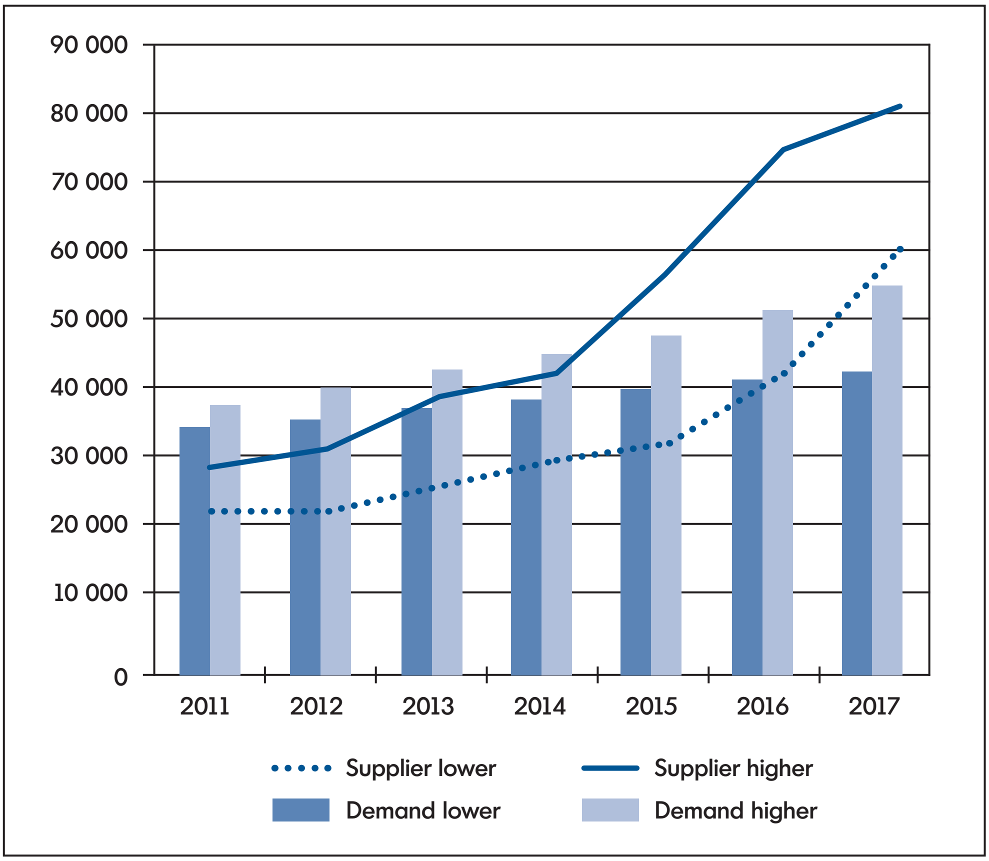
Figure 2: Total global REO supply and demand projections, 2011–2017 (tonnes)



Source: Hatch GP, *Critical Rare Earths: Global Supply and Demand Projections and the Leading Contenders for New Sources of Supply*. Carpentersville, Illinois: Technology Metals Research, LLC, 2011; author's own calculations

Scenario A	Slower expansion of rest of the world (ROW) sources and Chinese supply constant at 2010 level.
Scenario B	Slower expansion of ROW sources and annual 3% growth in Chinese supply.
Scenario C	Faster expansion of ROW sources and Chinese supply constant at 2010 level.
Scenario D	Faster expansion of ROW sources and annual 3% growth in Chinese supply.
Scenario E	Slower expansion of ROW sources and Chinese supply limited to 2011 production quota.
Scenario F	Faster expansion of ROW sources and Chinese supply limited to 2011 production quota.

Figure 3: Total critical rare earths supply and demand projections, 2011–2017 (tonnes) (CREOs: dysprosium, yttrium, terbium, europium, neodymium)



Source: Hatch GP, *Critical Rare Earths: Global Supply and Demand Projections and the Leading Contenders for New Sources of Supply*. Carpentersville, Illinois: Technology Metals Research, LLC, 2011; author's own calculations

Given this complexity it is not hard to see why commentary on the rare earth sector at times seems shrouded in confusion and over-simplification. In many cases all REEs are grouped together as though they were a single commodity, such as copper or gold. Occasionally there is even confusion between the terms 'rare earths' and 'critical metals',[11] as there was in a recent video produced by *The Guardian* that incorrectly identified coltan and cassiterite in the Democratic Republic of Congo as being 'rare earth minerals'. Certainly, many REEs may be considered critical in the broad sense that they are strategically important materials with possible supply bottlenecks. Grouping together such metals, and including with them among others antimony, mercury, tungsten and the platinum group, might make sense for further study, whether for comparison purposes or for considering entire supply chains for economically or strategically important manufactures.[12] Several REEs, however, do not meet the criteria for criticality in terms of economic importance or supply risk.

A further problem arises from some investment advice, which in the absence of much academic writing is perhaps the major source of information on the rare earth industry, other than mainstream media reporting. Again, there is a tendency to consider REEs in the aggregate rather than individually, which makes for poor advice in identifying which rare earth mining ventures are likely to succeed.[13] When differentiation is attempted it often takes the form of highlighting differences between 'light' (LREE) and 'heavy' (HREE) rare earths.[14] There is some logic to this insofar as HREEs tend to be found in much smaller quantities and HREE deposits usually also contain large quantities of LREEs, while the converse does not hold. This approach, however, overlooks projected demand, which is what makes neodymium and sometimes praseodymium appear on lists of critical REEs.

THE RARE EARTHS SECTOR

Evolution towards the current dominance of China

It is perhaps surprising to learn that rare earths, which until recently remained relatively obscure, have been mined commercially since the 1880s. Initially the industry was concentrated in Norway and Sweden,[15] producing first for the new incandescent lamp mantle industry and later for a very small number of other applications, such as lighter flints. Brazil, India and the US joined as producers over the next three decades, extracting REEs from monazite-placer deposits, though a host of technical difficulties stemming from rare earths' mysterious and complex chemical properties limited their commercial exploitation. Indeed, the last REE metal, promethium, was first produced as recently as 1931.

Major advances in separation processing occurred in the late 1940s and early 1950s. They brought down the costs and difficulties associated with REE production and stimulated research into potential end uses for the metals. Until markets for the new applications were fully established, however, the most commercially viable means of producing rare earths was as a by-product of the radioactive element thorium, found in REE-containing monazite and bastnaesite deposits. Indeed, it was waste from the extraction of bastnaesite at Steenkampskraal in the Western Cape that made South Africa the world leader in REE production during the 1950s. Most of the applications for rare earths now regarded as important had not been identified by then, so many of the 17 elements had little more than curiosity value.

The Steenkampskraal mine produced REOs to be used mainly in the optics industry as polishing media, or for colouring glass. The commercial fortunes of the mine, however, were determined exclusively by the thorium market. During initial development of the post-Second World War nuclear power industry thorium, less hazardous and more abundant than uranium, was regarded as having great potential as a fuel source. Steenkampskraal became the United Kingdom's major source of thorium for this use in the 1950s, though production ceased in the early 1960s when uranium (which unlike thorium is suitable for dual civilian and military use), began to be favoured. With this, rare earth production at the site also ended, leaving an abandoned mine and tailings containing both rare earths and thorium.

In the mid-1960s a new phase in the history of rare earths began as a new major application was discovered for europium as the source of red luminescence in colour television sets. This made rare earth production in itself a potentially profitable business, provided it was conducted on a large enough scale. That up-scaling came with the operation that started in 1965 at the huge Mountain Pass mine,[16] dwarfing the previous output of the relatively small Steenkampskraal facility.

The rise of the Chinese rare earth sector

A steady stream of new applications for rare earths continued over the 1970s, crucially including their first use in high-strength permanent magnets. This expanding market caught the attention of Chinese officialdom, aware that in the 1980s China possessed the majority of known global reserves of REEs. A programme of state support for innovation in extraction and processing, combined with low labour costs and a lack of attention to environmental standards, allowed China's rare earth mining industry to grow at an annual average of 40% throughout the 1980s.[17] Clearly, the strategic potential of the sector was recognised early: Deng Xiaoping compared China's REE reserves with Middle Eastern oil in a speech in 1992.[18]

Chinese REE extraction was (and still is) concentrated in two areas. The first is around the huge Bayan Obo iron-niobium-rare earth deposits in Inner Mongolia, the source of about half of China's rare earths and therefore almost half of global REE extraction. Beyond this are ionic clay deposits in Fujian, Guangdong, Guangxi, Hunan, Jiangxi, Shandong, Yunnan and, especially, Sichuan. Though China's output has risen from a 27% share of rare earth ore production in 1990 to today's 97%, growth has not always gone hand in hand with profitability. Mindful of this, throughout the 1990s and 2000s Beijing sought to limit the exploitation of rare earths through production quotas imposed on individual provinces. The provinces' reliance on rare earths as a source of revenue and employment, however, led in many cases to much higher rates of production. Often this has taken the form of illegal and artisanal mining, using basic technology – in some cases simply pumping acids into the ground – which has proved environmentally devastating, particularly in Guangdong, Jiangxi and Sichuan.[19]

Since 1990 rare earths have been an officially protected and strategic sector in China. This status has brought with it a complete ban on foreign investment in mining and its restriction to joint-venture projects with Chinese firms at the separation stage. A further restriction has been in the form of export quotas. Since little existed by way of a Chinese REE industry at midstream or downstream levels until the 2000s, these quotas were relatively relaxed. They became less so after an attempt, beginning in earnest in 2006, to encourage the nascent domestic industry by gradually restricting exports of oxides in an effort to capitalise on what had become almost total upstream dominance.

These export quota restrictions have only generated real media interest since about 2009, when global demand began to approach the limits of Chinese supply. A 40% cut in Chinese exports announced in 2010 piqued Western interest and brought home the vulnerability of rare earth supply lines, in turn creating the conditions for the current scramble to identify and develop new non-Chinese mines. Despite expectations that 2011 export levels would be set much lower, however, they remained more or less unchanged from the previous year.[20] Nevertheless some rare earth alloys were included on the list of restricted products from 2011, which means that in practice quotas are rather tighter than before. Indeed, it is thought that this situation prompted the decision of the Japanese rare earth manufacturer Showa Denko to relocate about 20% of its production to China.[21] The company had been relying on imports of newly-restricted REE-containing ferro-alloys for some of its Japanese operations.

Official export quotas, however, tell only part of the story of China's rare earths strategy. Perhaps more significant is its effort to crack down on illegal mining and smuggling, which in the past may have represented 20% of total rare earth exports.[22] This move is coupled with a renewed drive to reduce and strictly enforce overall production quotas. Legal production of REOs in China in 2010 amounted to perhaps 130 000 tonnes, despite an official quota of 89 200 tonnes.[23] Scepticism that the 2011 target of 93 200 tonnes would not be greatly exceeded seemed justified until a wave of shut-downs, beginning in August, brought the majority of REE firms offline amid reports that the quota had already been reached. This situation initially encompassed a large number of small producers, but has since grown to include three of the eight major firms in Ganzhou, a prefecture responsible for some 40% of Chinese REE output. At the time of writing, China and the world's largest REE producer, Baotou Steel Rare Earth Hi-Tech Co, have announced a month-long suspension of all activities[24] with the explicit aim of boosting prices in the face of the current economic recession. In September *The New York Times* reported that:

> ... most of the country's rare earth factories have been closed since early August, including those under government control, to allow for installation of pollution control equipment that must be in place by Oct. 1 (*sic*).[25]

There appears to have been no official announcement of such a move, however.[26]

The latest development regarding Chinese government efforts to control the sector has been the announcement of its intention to institute a formal system of invoices for REE purchases, in the hope that this will stop the trade in illicitly mined rare earths. This led to a short-term price crash in early November 2011, as suppliers which would find themselves outside the new system attempted to dump their inventory before it was too late.[27] Some prices fell by as much as two-thirds in a matter of days. This temporary flood of rare earths on to the market may assist downstream producers by allowing them to stockpile some material as a buffer against future government-mandated supply restrictions. Since these are mainly illegally mined rare earths, however, it remains unclear how much of this material has been available for the black market in exports, and therefore how far foreign customers have also been able to build up their inventories in the same way. That said, the fact that the announcement of the new restrictions prompted a rush to dump REEs indicates an expectation that the rules will be enforced. This in turn suggests that in the long run China may indeed produce REEs only up to the volume of its official production quotas – a prospect that until now, few analysts have regarded as likely.

Of course, against the background of a still relatively unprofitable, over-producing and polluting industry rapidly depleting a strategic resource that will probably become even more important in future, Chinese attempts to limit production and exports do not necessarily merit the sinister spin placed upon them by much Western analysis.[28] Two major strands of Western fears over rare earths have been first, the US realisation of the vulnerability of some of its key defence supply lines and secondly, a concern that China may begin to use the strategic importance of rare earths as a geo-political bargaining chip. US military equipment tends to be more technologically advanced than that of most other forces and therefore incorporates more REE inputs. This also applies to the US production of arms for export to allies.[29] Any squeeze on REE supply lines would affect a wide range of cutting-edge military hardware, including among many others the Predator drone, the M1 Abrams main battle tank and the Tomahawk cruise missile.

Fears for the dependence of the US on supply chains from what influential circles in the US view as a future geo-strategic competitor were heightened by the fallout from a September 2010 incident in which a Chinese trawler captain was arrested by Japanese coastguards. The incident took place in waters off the Senkaku Islands (called Diaoyu by China), claimed by both Japan and China. Subsequently it was widely reported that China had placed an unofficial embargo on exports of REEs to Japan.[30]

It remains unclear, however, whether this was the case. The story appears to have originated when the Japanese trade, industry and economy minister relayed anecdotal evidence that some Chinese trading firms had ceased exports to Japan.[31] That this conjecture was picked up as fact by *The New York Times*, added to the same newspaper's interpretation that the existing tightening of export quotas worldwide represented a possible widening of the embargo to the US and European Union, suggests that the earlier Japanese story may have also been simply an over-reaction to reduced exports arising from lower quotas. Seen from the Western standpoint this was an apparent sign of Beijing's ability and intent to use its control of REE supply chains in pursuit of geo-political goals. Whatever the reality, China is certainly attempting to leverage its upstream monopoly in its own interest through a programme of export restrictions, lower domestic production quotas, crackdowns on illegal mining and consolidation of the industry into a more manageable number of firms.

Many competing reasons have been posited as to the precise goals of such moves. Officially, efforts to eliminate illegal mining are driven by a desire to secure a scarce resource in the face of rising domestic demand, and to lessen the environmental impact of a notoriously pollutant industry which has laid waste to large tracts of Inner Mongolia and southern provinces.[32] Environmentalism is also cited as the rationale for consolidation of the industry, with smaller firms being folded into larger enterprises should they fail a series of environmental checks (which Western observers tend to assume will be spurious).[33] Furthermore, protection of the environment provides a probable defence in the likely event that a case is brought against China at the World Trade Organization (WTO) over export restrictions on REEs. In 2009 the US, EU and Mexico lodged a formal complaint regarding Chinese export controls on magnesium, manganese, silicon carbide, fluorspar, silicon carbide and yellow phosphorus, with the WTO finding in July 2011 that such restrictions indeed broke global trade rules.[34]

The ruling was keenly anticipated within the rare earths sector, where it was regarded as a test case that could be applied equally to Chinese REEs. As expected, China is appealing against the ruling, a process which may take several years to work its way through the courts. Any analogous complaint with reference to rare earths would be similarly drawn out, which means that China has considerable breathing space to pursue its current rare earths strategy without needing to worry too much about possible sanctions. In any event China may now have a better chance with a defence of its REE policies, since it argues that WTO rules allow it to restrict production on environmental grounds. Given recent moves to slow production for export and domestic markets alike, China is also less vulnerable now to charges that it is unfairly discriminating against exporters.

The question remains as to what drives this policy. As explanations for Chinese moves in the REE sector, environmental concerns appear at least plausible and conservation of resources for domestic use, unarguable. Over-production may have lowered prices to the point of forcing international competition out of business, but it also brought with it decades of exporting large quantities of a strategic mineral at low, and often even unprofitable, prices.

Outside China, however, there is considerable scepticism as to whether this represents the full story. Governmental and buyer firms' concerns revolve around the effect of export restrictions, and greater legal enforcement of them, in effectively instituting a twin-track pricing system for rare earths with a ROW price far higher than Chinese domestic prices.[35] Under these circumstances it hardly seems unreasonable to see Chinese moves as designed to leverage downstream dominance into the expansion of upstream industry within China, either through the development of indigenous firms or by inducing foreign producers to relocate production to China. This is indeed starting, with several Japanese companies planning to relocate some operations. Among them is Hitachi Metals, the world's largest rare earth magnet manufacturer, which plans to move up to 20% of its magnet production to China.[36] From a Chinese perspective the potential for technology transfer is a key issue in such deals, with a former vice president of the China Non-Ferrous Metals Engineering and Design Institute noting that China's stance on rare earths is part of long-standing attempts to trade access to resources for access to technology. This policy was first discussed in the landmark State High-Tech Development Plan (863 Programme) released in 1986.[37]

Today, around 60% of global REE magnet finished components production takes place in China, effectively representing the completion in 2002 of the holus-bolus transfer of the formerly dominant US rare earth magnet industry. Importantly, China's REE magnet industry is twice the size of the next largest, that of Japan.[38] Patents for the most widely used class of REE magnet, neodymium-iron-boron (NdFeB) magnets, were split in the 1980s, after much wrangling, between Hitachi Metals and General Motors' magnets division, Magnequench Inc. This set up dual dominance of the NdFeB magnet manufacturing industry between Japan and the US, until in 1995 Magnequench was sold to a consortium of San Huan New Materials High Tech Inc. and China Nonferrous Metals Import and Export Company, backed by a US investment company.

Surprisingly, perhaps, the deal was not blocked by US lawmakers. Of course, REE magnets had far fewer applications in the mid-1990s than they have today, although the early 1990s incorporation of NdFeB magnets in Joint Direct Attack Munition (JDam) 'smart' bombs would surely have made such technology sensitive even then. The deal was not waved through unconditionally, however; it included a stipulation that the new owners did not remove production or any jobs from the company's Indiana location for at least five years. It now appears that this period was used to experiment with the duplication of the entire magnet production line in China. This proved satisfactory and on the very day of the expiry of the agreement in 2002 the Indiana plant was closed and all its machinery shipped to China.[39] This date coincided with the closure of the Mountain Pass mine, meaning that almost at one stroke the entire US rare earth magnet supply chain ceased to exist.[40]

The Chinese REE sector has faced greater difficulties in its attempts to appropriate for itself the technology of Japan's REE magnet industry. Largely through the acquisition of Magnequench and the removal of US competition, the Chinese magnet industry was able to grow by an annual average of 30% between 1996 and 2006, a pace that approached the astonishing expansion of the downstream REE industry in China over the 1980s.[41] The original terms of the agreement between Magnequench and Hitachi on patents, however, meant that there was less scope to completely out-compete international rivals – in this case largely based in Japan – as had effectively been the case in extraction, separation and refining.

That was because the industry had been split more or less in half. Magnequench acquired patents for a production process known as ‘melt spinning’, and Hitachi took those associated with the rather different technique of ‘sintering’. These two methods produce magnets with somewhat distinct properties which suit them, with some overlap, for different end uses. The two firms have also taken contrasting routes in exploiting their technology. Magnequench (now Neo Materials Technology) sells melt-spun NdFeB powder to magnet manufacturers, mainly in China but also to Europe. Hitachi, on the other hand, produces its own sintered magnets, as well as providing licences to a limited number of other companies to do so. Where possible the Japanese government has attempted to protect its REE magnet industry by requiring that any Japanese manufacturer producing devices containing magnets covered by Hitachi’s patents, must obtain such magnets from Japanese sources.

This approach has had some success in limiting the penetration of Chinese component manufacturers into the Japanese market. More important, until now it has also blocked the possibility of technology transfer to China of sintered NdFeB magnet manufacture. With current supply difficulties engendered by Chinese moves to limit the production and export of REOs, the economic calculus for Hitachi-licensed Japanese magnet manufacturers has changed significantly.

It is no surprise, given the far better prices available within China for REEs, that Hitachi has recently announced plans to move 20% of its production to China, which will involve a joint venture with Chinese firms.[42] Although a diminishing resource base and environmental degradation are undoubtedly concerns for China, the opportunities for technology transfer which these developments bring with them appear the likely motivation behind Beijing’s current moves in the rare earth sector, when viewed in the context of a long-standing policy of strategic expansion at all points of the supply chain.

GLOBAL REACTION TO CHINESE MONOPOLY

Growing worldwide realisation of the implications of China’s REE monopoly, brought into sharp focus by the glut of governmental reports and mainstream media coverage of current supply issues, and combined with price surges for REEs, has provoked contrasting reactions. Attempts to counteract China’s power over the industry can be divided into two forms: projects aimed at reducing reliance on rare earths, and efforts to reinvigorate non-Chinese supply chains.

Japan is currently the most active in attempts to reduce reliance on rare earths, pursuing technological avenues to reduce its need for REE imports from China. This programme involves a $1.3 billion package of spending on projects in pursuit of its stated aim of a one-third reduction in demand for rare earth inputs into Japanese industry.[43] This may take the form of more efficient use of REEs, attempts to recycle rare earths from old electronic equipment, or more ambitious efforts to substitute REE components with other materials. Some progress has been made on all fronts with, for example, Hitachi and Toyota developing ferric oxide-based motors which may in future match the performance of NdFeB units. Getting all these projects to the point where they become widely adopted, however, may take a long time. In its efforts to speed the process Japan has announced that it will co-operate with the US and EU on these matters.[44]

As part of the global response to Chinese-induced supply constraints, however, Japan is also active in the attempt to locate and develop non-Chinese rare earth deposits. Tokyo has reached agreements for exploration rights in Lai Chau province in Vietnam. In a signal that the Japanese government is thinking long-term, $287 million has also been invested in developing a fleet of underwater vessels to identify REE resources on the ocean floor in waters off Japan.[45] Most global attention, however, has focused on the efforts of Western companies to exploit more conventional sources of rare earths worldwide.

Beyond China: The new scramble for rare earths

Surges in rare earth spot prices driven by worries over supplies from China have led to great interest on the part of investors in a ROW rare earth industry that had been all but moribund from 2002 to 2009. This interest in turn has resulted in a new wave of junior mining companies, largely Canadian or Australian, scouring the globe for potential rare earth projects. Many of these are newly-identified deposits, although in other cases firms have bought previously producing mines forced out of business by Chinese competition. A picture is emerging of a scramble between juniors at various stages of exploration, permit acquisition and construction of mines, in an effort to fill the gap in supply left by China's choking off exports as demand continues to rise. Scarcely a week goes by without an announcement of new drilling for rare earth deposits across the globe. Thus far, none of these projects has reached production. The most advanced appear to be the Lynas Corporation's Mount Weld development in Western Australia and Colorado-based Molycorp Inc's attempt to restart the Mountain Pass mine. Both these projects are likely to come online in 2012.

Deposits, however, are geographically widespread, with potential sources of REEs identified in several other locations in North America and Australia, as well as Southern and East Africa, Russia, Central Asia, Vietnam and Brazil (see Table 5). Since rare earths are not tradable commodities, investor interest has been concentrated on opportunities in junior miners' stocks.[46] This has added to fevered speculation fuelled by what often appears a simplistic grasp of industry issues that does not take into account the different conditions of supply and demand for each of the rare earth elements. Most experts seem to agree that the majority of the new projects will never become working mines, though of course for many investors in juniors this was of limited concern, provided that excitement around the REE sector led to higher stock prices before they sold on.[47]

This phase, now referred to as a mini-bubble,[48] appears to have passed. Rare earth miners' share prices have tumbled across the board. In recent months this has been accentuated by the global economic downturn, which has prompted widespread disinvestment from equities across all industries in favour of safer havens. That said, it remains clear from demand projections that a significant market for non-Chinese rare earths will remain, and indeed grow in coming years. Revealingly, prices for rare earths themselves are holding up in the face of economic recession. Based on industry predictions there appears to be space for around five to 10 new non-Chinese rare earth producers. Barriers to entry are high, notwithstanding the unpredictable quality of deposits before drilling, and the difficulties involved in assessing returns given the different supply and demand conditions that apply to each individual metal. New mines require very large capital investments and long development times. Environmental concerns bring further costs and delays, particularly because most mining operations also produce large quantities of radioactive material, mostly thorium.[49]

Clearly, an important aspect of the potential for a venture to become a working mine is the quality of the deposit. As discussed earlier, supply and demand projections for different REEs mean that prospective revenue from any particular mine partly depends upon the mix of elements contained within each deposit. Those with high concentrations of critical rare earths[50] as a percentage of total recoverable ores are regarded as the most attractive. A further complication arises, however, in that deposits also vary in terms of overall material grade, defined in terms of the proportion of total rare earths within a deposit, expressed as kilograms of total rare earths per tonne. While some deposits may contain large quantities of critical REEs, they may have a low material grade; hence a larger tonnage of ore must be mined and processed to produce a given quantity of oxide. This significantly increases production costs. Ordinarily, there is a trade-off between these two metrics, with high material grade deposits tending to contain smaller quantities of critical rare earths as a percentage of the total. Investors therefore face a complicated calculus as to which REE projects are likely to be most profitable. With none of these new ROW mines yet operating, production costs at this stage remain estimates, usually only known to the companies concerned.[51] While, therefore, it is possible to make useful comparisons between the commercial prospects of individual mines, such judgements necessarily contain a certain amount of guesswork.

Along with the over-simplification of REEs into one commodity found in much mainstream and business media coverage of the industry, goes a further common error. This is an overwhelming concentration, often to the exclusion of the rest of the supply chain, on the potential gap in the supply of raw materials created by China's recent rare earths strategy. It remains arguable as to whether new mining firms may be able to make a profit selling at the oxide stage, after separation.[52] Some expert opinion suggests that oxides and alloys must be included on a combined balance sheet if they are to be commercially viable. Certainly it appears that some form of vertical integration beyond separation is necessary. There is the further complication that different end users of rare earths require oxides of specific purities. Put simplistically, this means that the junior miners with the best chance of surviving in a crowded sector are those with at least some idea of their customers' requirements. This realisation has given rise to two business models for potential future success.

The less common of these is a fully integrated supply chain, such as the 'mine to market' strategy of Canada's Great Western Minerals Group Ltd (GWMG). This company already owns two of the few rare earth processing facilities outside China. (One is in the UK and another in the US and both are capable of producing REE alloys and powders.) Through mining ventures in Canada and South Africa it aims to end dependence on Chinese raw material, thereby establishing the first complete REE supply chain outside China since 2002.[53]

Table 5: Selected advanced rare earth projects outside China and Africa

Project	Company	Location	Total REO (tonnes)	Projected production start date
Mountain Pass	Molycorp	US	2 072 037	2012–2013
Bokan	Ucore Rare Metals	US (Alaska)	27 321	Unknown
Hoidas Lake	Great Western Minerals Group	Canada	68 395	Unknown
Thor Lake	Avalon Rare Metals	Canada	4 297 807	2015–2016
Strange Lake	Quest Rare Minerals	Canada	2 098 248	2016
Montviel	Geomega Resources	Canada	3 645 887	2012–2013
Dubbo	Alkane Resources	Australia	651 480	2012–2013
Nolan's Bore	Arafura Resources	Australia	848 000	2014
Mount Weld	Lynas	Australia	1 413 646	2012
Kvanefjeld	Greenland Minerals and Energy	Greenland	6 328 700	2016
Kutessay II	Stans Energy	Kyrgyzstan	46 608	Unknown
Nora Karr	Tasman Metals	Sweden	326 700	Unknown
Salobo	Vale SA	Brazil	Unknown	Unknown

Source: Compiled by author

The second approach is to guarantee a customer base by signing off-take agreements with a partner higher up in the supply chain. For instance, in July 2011 the Luxembourg-based junior mining company Frontier Rare Earths Ltd entered into such an agreement with the Korean parastatal Korea Resources Corporation (Kores) under which the latter would acquire a 10% stake in Frontier and a 20% share in its Zandkopsdrift mine in Namaqualand, South Africa, with the expectation of buying 40% of the REOs eventually produced there.[54]

Important for both strategies is the technical expertise brought by established players in the REE industry, which after a decade-long gap in significant production is in short supply outside East Asia. Those junior miners that currently lack a prospective supply chain extending beyond the ore and oxide stages seem destined either to disappear or to be bought out by other firms, unless they are also able to secure a suitable customer base.[55]

SOUTH AFRICA'S RE-EMERGING RARE EARTHS INDUSTRY

South Africa is one of the more promising possible locations for a reinvigorated REE industry. Several sites have been identified. In September 2011 a new junior miner, Galileo Resources Plc, acquired the Glenover open pit phosphate mine in Limpopo Province. This had been abandoned in 1984, but tests have shown that tailings left at the site contain significant quantities of rare earths.[56] Most attention, however, has centred on two projects often discussed as among the most promising of the new wave of ROW developments. These are respectively Steenkampskraal[57] and Zankopsdrift.

Table 6: Advanced South African rare earth projects (CREOs: dysprosium, yttrium, terbium, europium, neodymium)

Project	Steenkampskraal	Zandkopsdrift	Mountain Pass
Company	GWMG/ Ganzhou Qiandong Rare Earth	Frontier Rare Earths/ Kores	Molycorp
Location	Western Cape	Northern Cape	California
Estimated production start date	2013	2015–2016	2012–2013
Total mineral resource (tonnes)	249 500	43 730 000	31 552 000
Total REO (tonnes)	29 400	945 863	2 072 037
Critical REOs (kg per tonnes) of mineral resource	26.2	4.6	8.1
Critical REOs as % of total REOS to be extracted	22.5	21.4	12.3
Projected life of mine	6–10 years	48 years	104 years
Projected total annual REO production (tonnes)	5 014	20 000	20 000
Projected annual CREO production (tonnes)	1 128	4 280	2 460

Source: Source: Hatch GP, *Critical Rare Earths: Global Supply and Demand Projections and the Leading Contenders for New Sources of Supply*. Carpentersville, Illinois: Technology Metals Research, LLC, 2011

Steenkampskraal

Steenkampskraal is a formerly producing monazite mine that was worked, with some interruptions, from 1950 to 1963. During that time it operated primarily as a thorium mine, exporting the radioactive material as a nuclear fuel source to the UK. Rare earths, with their then limited range of end uses, were mined as little more than a by-product, though this in itself was sufficient to make South Africa an early leader in REE output. Eventually, nuclear technology switched to uranium and in consequence the Steenkampskraal mine was abandoned.

As the number of applications for rare earths grew, two attempts were made to restart mining at the site. The first of these, in 1997, was deemed unviable given the depressed prices of REEs at that time. The second, beginning around 2005, ran into pricing problems in the 2008 global recession.[58] At this point GWMG bought a controlling interest in the project, soon after its acquisition of the UK-based REE powder and alloy manufacturer Less Common Metals Ltd.

Steenkampskraal seemed to offer considerable advantages over GWMG's rare earth extractive projects in North America, not least because as a formerly producing mine it might be expected to require a far shorter restart development time. Though there seem to have been considerable delays in re-commissioning, the fact that GWMG bought a rare earth deposit with the aim of providing for its own manufacturing plant, before the new scramble for rare earths began, gives the company a head start over many rivals. If production begins on schedule in the last quarter of 2012, Steenkampskraal may well be the first of the new ROW rare earth mines to become operational.

Steenkampskraal's status as a former thorium mine creates both advantages and potential problems. From a commercial standpoint the costs of refurbishing and reopening the mine are significantly lower than for comparable projects. Inclusive of the construction of a nearby separation plant, costs are expected to run to $60 million, against an estimated $600 million for Zandkopsdrift.[59] Part of the attraction of the Steenkampskraal site is that a large number of rare earths are contained in tailings from previous operations, left above ground. These come from an era when the only REEs of commercial interest were those with applications in the optical industry, far less important today. There is therefore a much greater concentration of more valuable REEs left in the tailings on site, which compared with other mines gives Steenkampskraal an unrivalled rating in terms of the percentage of critical REEs available for extraction. A further benefit for GWMG is the South African government's waiver of royalty payments, which normally would be 5–7% of gross revenue, in exchange for a commitment to clean up the waste left at the site from previous operations.

This work would no doubt have been necessary in any case, so it is difficult to see the benefit of this aspect of the deal to the local community or to South Africa as a whole. One industry source alleged in an interview that royalties were in fact waived in exchange for especially beneficial terms under Black Economic Empowerment (BEE) legislation. Under this arrangement a mandatory 26% black ownership of the mine will translate into 26% of revenues from mined – as opposed to separated – product accruing to the BEE trust, without requiring any capital in return.[60] The source further maintains that the 26% revenue is roughly equivalent to the 7% royalty on mining and a 5% payment on processes products that the government has waived. If true, this effectively represents a transfer of tax revenues to BEE groups. This situation contrasts with that at Zandkopsdrift, where BEE groups receive a free carry-through on their interest in the mine only until the completion of a full feasibility study, at which point they will be required to pay market value for their stake.[61]

Problems may arise with high levels of thorium present in the Steenkampskraal deposit. An environmental assessment report for the mine is in the process of being prepared, after which South Africa's National Nuclear Regulator will produce detailed guidelines for all activities at the site. (Concern over radiation at the mine is such that employees currently are required to wear protective clothing and carry dosimeters.) Steenkampskraal is an underground (as opposed to open pit) mine, which should limit the release of thorium as dust when mining operations restart, although at present little is known of the effect of radioactive waste that has now lain above ground for almost five decades. The mine is already an approved site for the storage of thorium; GWMG plans to reduce potential hazards by mixing the thorium with concrete and storing it in blocks underground. This is partly in the hope that at some point in the future thorium may again become a sought-after material as a fuel source and possibly also for use in desalination plants.[62]

The idea of exploiting the nation's thorium reserves is not new, given South Africa's well-documented energy generation problems, its reliance on polluting coal power plants and its status as the least energy-efficient nation in Africa. Thorium is a potential alternative to uranium as a nuclear fuel. Indeed it is preferable in many ways due to its more efficient power-generating capacity and shorter half-life.[63] It is also inherently incapable of triggering a meltdown, which makes it an even more attractive proposition in the wake of the March 2011 Fukushima incident in Japan. A government-funded subsidiary of South Africa's electricity utility Eskom, however, spent 10 years and ZAR 15 billion[64] in an unsuccessful attempt to produce a working pebble bed modular reactor using thorium, before the project was cancelled in 2010. Nevertheless, other reactor designs are feasible and, subject to licensing, thorium remains a possible fuel source for planned South African nuclear plants. There is also reported interest from Saudi Arabia, China, the US, UK and South Korea.[65]

Compared with other REE mines likely to become operational in the near future Steenkampskraal is relatively small, with a probable annual output of around 5 000 tonnes of rare earth oxides at full capacity. This is the equivalent of the estimated shortfall created by the production halt announced by Baotou. The Steenkampskraal deposit, however, is thought to contain 26.2 kilograms per tonne (kg/t) of critical rare earths, which would give it the highest material grade of any new REE project currently in development – another factor in lowering production costs. (By comparison the next highest, Mount Weld in Australia, has 16.6kg/t of critical rare earths.[66]) GWMG's mine-to-market strategy is also noteworthy in that it is the first attempt to construct a fully-integrated complete supply chain outside China. The involvement of significant foreign partners also bodes well. Aichi Steel Corporation, part of the Toyota group, which is already a customer for alloys produced by GWMG at its UK manufacturing plant, signed an agreement in April 2011 to continue this arrangement with alloys formed from REOs sourced from Steenskampskraal.[67]

Perhaps more significant from both commercial and political-economic points of view is the heads of terms agreement reached with the Ganzhou Qiandong Rare Earth (GQRE) group of Jiangxi, China. The agreement provides for the formation of a joint venture with GWMG to build a separation plant close to the mine, with GQRE taking a 25% share in the new company. Although the details are still somewhat hazy, it appears that the facility will be able to process more than the probable output of Steenkampskraal. This opens several possibilities. GWMG is conducting further exploration in the area and may be hoping to build enough capacity to handle future sources of REE oxides from the same area. The company may also have designs on processing oxides extracted by the Canadian-based Namibia Rare Earths Inc at its Lofdal project across the Namibian border; or even material from sites further afield in Africa that lack the infrastructure to sustain separation facilities. The latter is seems the more likely, taking into account that the life of the Steenkampskraal mine is unlikely to be longer than 10 years.

The deal is also important from a Chinese perspective as it represents the first such involvement of a Chinese rare earths company with a Western rare earths producer. Steenskampskraal should produce significant quantities of some of the first rare earths that China will need to import (for example, dysprosium), with the transition point perhaps coming in 2014 – or even earlier, given the new domestic production restrictions within China.[68]

Zandkopsdrift

The other major REE site in South Africa is at Zandkopsdrift, some 30km south of Garies on the provincial boundary between Northern and Western Cape. This area has been explored for mineral potential several times in previous decades, most notably in the 1980s by the Anglo American Corporation of South Africa. In 2008 the site, together with data relating to previous exploration work, was acquired by Frontier Rare Earths. The metallurgy at Zandkopsdrift is rather different from that at Steenkampskraal: a carbonite deposit presents greater technical difficulties in extraction and separation, with consequent higher costs. Despite this, the project is sometimes cited as one of the more promising of current REE developments. Partly this arises from its sheer scale. An expected output of 20 000 tonnes a year (beginning in 2015) makes it potentially one of the largest REE mines outside China – perhaps the largest. A relatively low mineral grade is a problem, although a reasonably high proportion of the deposit is of critical metals, particularly europium. Thorium is present, but at much lower levels than at Steenkampskraal.

A major advantage for Frontier has been its partnership agreement with Kores, which is expected to acquire a 10% stake in Frontier, 20% of the mine itself and the right to purchase up to 40% of the oxides produced there.[69] Plans have been mooted for a separation plant to be built at Saldanha Bay, although few details are currently available. Some analysts suggest that, although Zandkopsdrift has a good chance of becoming an operational mine, it may become part of an expected wave of consolidation likely to become a feature of the industry in coming years. One suggestion is a buy-out by Lynas, which owns the Mount Weld deposit that apparently has similar metallurgy to Zandkopsdrift; oxides produced at the latter would easily fit into Lynas's arrangements for separation. If this were to occur it would probably mean that separation would take place outside South Africa, at Lynas's plant in Kuantan, Malaysia. An alternative development might be some form of merger between Frontier and GWMG.[70]

POTENTIAL IMPACT OF THE RARE EARTH INDUSTRY IN SOUTH AFRICA

When assessing the likely effects of the developing rare earth industry in South Africa, it is important to note that the industry will remain small, if strategically important. Although demand looks set to rise in the long run with an increasing number of new technologies incorporating REEs, foreign and domestic production volumes will still be dwarfed by those of heavyweight mining sectors such as gold or platinum. That said, rare earths in South Africa certainly may have significant impacts at the local level in terms of employment, the environment and social and economic development more generally.

One estimate suggests that the Steenkampskraal mine may eventually create at least 100 jobs, with perhaps 80–100 more at the separation plant.[71] Zandkopsdrift should produce around four times more than Steenskampskraal, but this does not mean four times the jobs. In fact, the former project may be more labour-intensive, since it will necessitate mining proportionately larger quantities of mineral resource. Jobs even on this relatively small scale would certainly be a boost for a sparsely populated but economically deprived region of the country, where the negative effects of high rates of unemployment reportedly are evident in a plethora of social problems (see Box 1).[72]

The companies involved insist that the mines will observe the most stringent international safety standards and threats to the mines arising from environmental problems do not seem to worry either them or their investors. Concerns tend rather to centre on political risk, especially the possible nationalisation of mines.[77] Jim Engdahl, CEO and president of GWMG, has argued that nationalisation is simply 'part of the normal political discourse' in South Africa and is unlikely to come about. In any case, he feels that nationalisation of rare earth mines would make little sense, given the lack of profit to be made at the point of extraction and the requirement of a foreign partner for the technical knowledge needed to process beyond the ore stage.[78] While the latter point is valid, examples of governments looking to work directly with foreign partners in the exploitation of nationalised resources are becoming more common; hence nationalisation would not necessarily exclude such arrangements in the South African case.

Box 1: Local impact

People in the towns closest to the two prospective South African REE mines, Bitterfontein and Garies were interviewed concerning the potential impact of the new projects along the Western Cape–Northern Cape border. Most were cautiously optimistic, welcoming any developments which could help alleviate some of the obvious social problems encountered locally. Partly as result of the deteriorating fortunes of older mining sectors, many respondents mentioned high rates of unemployment and associated alcoholism as particular blights on the local community. As one resident commented:

> 'There is nothing for the young men to do here. Once there were jobs in the mines. At the station you can see now there is hardly any stone waiting to be transported, it used to be full. So the men sit, they do nothing, they drink too much, they don't care any more.'[73]

The railhead of a line beginning in Cape Town and also connecting to the port of Saldanha Bay, the town of Bitterfontein once served as a hub for loading stone and ores on trains for transport south but has suffered economic decline in recent years. Previously, most of the freight was granite for export especially to Italy, but the strength of the rand in 2010 and early 2011 brought waning fortunes. The location of Bitterfontein and Garies along the major N7 road route brings some tourists; some are also attracted by the flower season in late August and September, although the fact that the area is only a few hours' drive from

Cape Town limits the number of overnight guests. The impact of the tourist sector seems confined to a handful of guest-houses, with limited economic benefits for the majority of the population.

There was no apparent awareness expressed in personal interviews of plans to develop either rare earth mine. Some older residents of Bitterfontein knew that there had once been mining at Steenkampskraal, although unsure of what had been extracted. Other than one guest-house owner who had hosted engineers working on the redevelopment of the mine, no one interviewed knew of plans to restart production there. In Garies, closer to Zandkopsdrift, a similar lack of knowledge prevailed. When informed of the new mines all responded positively to their employment potential.

The environmental effects of rare earths mining in the region are difficult to predict. Certainly, the record of the REE industry in this regard is not promising. It may be unfair to invoke as a precedent the terrible damage done to the environment in China by the exploitation of rare earths, as it seems unlikely that the same level of negligence would occur in South Africa, given its regulatory safeguards; nor are there comparable mines currently operating outside China for which environmental information is readily available. Two points of comparison appear relevant, however. The first is the earlier incarnation of the Mountain Pass mine in California. The mine was forced to close in part due to huge fines arising from a series of 60 unreported waste-water spills containing radioactive materials, much of which ended up in the nearby Ivanpah Dry Lake. Secondly, radiation from the Bukit Merah rare earth separation plant in Malaysia has been blamed for a high incidence of birth defects and leukaemia among the local population.[74] Public anger over this has resulted in widespread protests against the building of a new plant in Kuantan.[75] With so few separation plants outside China, it remains to be seen whether Bukit Merah will remain an isolated case. There are certainly grounds for concern with regard to South African mines, which lie close to Namaqualand National Park and will incorporate separation plants, potentially more hazardous than the mining itself.

Local residents seemed unaware of the risks associated with radioactive waste at the mines. It is interesting to contrast this situation with that in Malaysia, where large-scale protest, influenced by the Bukit Merha case, has halted construction of Lynas's new separation plant in Kuantan.[76] As regards the new South African operations, more objections may be raised as the projects develop and knowledge of them becomes more widespread; although the desperate need for jobs may well mute any protests.

One high-profile example in this regard is that of Bolivia. More than half the world's known reserves of lithium, used in electric car batteries, lie within its borders. The Bolivian government is attempting to leverage this resource in negotiations with potential partners to ensure that a complete supply chain, up to the manufacture of lithium-ion batteries, is built up within the country.[79] This situation is somewhat different from that of REEs, however, because given Bolivia's control of most of the world's lithium there are no other sources open to companies wishing to guarantee supplies of lithium on the large scale likely to be needed. By contrast, the abundance of possible sites worldwide for rare earth extraction limits the pressure that could be placed upon a foreign partner in negotiations aimed at maximising developmental outcomes. This applies to any demands to locate further stages of the supply chain inside South Africa, and to attempts to increase government revenues in the form of taxes and royalties at each stage of the chain. It is by no means clear, however, that East Asian parastatals such as Kores would be averse to working with a nationalised extractive company rather than a multinational corporation.

The extent to which rare earths can drive social and economic development at the local level is also very difficult to judge. A significant impact on the local area may be felt through the 26% stakes held in both Steenkampskraal and Zandkopsdrift by BEE trusts, although with little information available as to the nature of these bodies the distributional consequences of these income streams are unclear. Revenue estimates are extremely difficult given the volatility of rare earth prices, particularly in the face of continuing global economic turbulence, and shocks within the sector itself such as those now likely to be inflicted by Chinese production shut-downs. Some indication of price volatility is shown by the fact that the scoping report prepared for the Steenkampskraal project in January 2011 gave an annual revenue estimate of $27 million. A rough recalculation of this at prices as of September 2011 would perhaps more than double it, to $55 million.[80]

CONCLUSIONS

Global implications

Out of the complex political economy surrounding the production of rare earths at each stage of the supply chain, a picture is emerging of a three-way scramble that will largely determine the future of the industry. First, Chinese officials talk openly of their hope that under current supply conditions, Japanese hi-tech REE manufacturers, particularly in the magnets sector, will relocate some of their production – and thus their technologies – to China.[81] As noted above, this process is beginning, although it remains doubtful whether China can use its upstream dominance to dismantle the Japanese REE industry in the way it did that of the US in the 1990s. At that time, whether through an ideological commitment to a global free market or simple short-sightedness, the US government was unconcerned with the loss of its rare earths industry. Today, belated recognition that rare earths are geo-strategically important makes Chinese moves more likely to be viewed with something approaching hysteria than with the complacency of the past.

The entrants in the race that garner most attention are non-Chinese sources of rare earths. It seems inevitable that China's share of the global market for REOs and ores will decline rapidly towards the middle of the present decade, as non-Chinese mines begin to come online at significant production levels. In the intervening years, however, China has a window through which to make its play for the greater prize of downstream dominance. On present demand projections China must in any case begin importing REOs within, perhaps, two to five years. By acting now, Beijing can take advantage of its final years of upstream monopoly and in the process clean up and regulate what has been an environmentally debilitating industry. In effect, large parts of the 'dirty' side of the supply chain will be exported, in exchange for a greater share of the high-revenue, hi-tech 'clean' end of the industry.

The final element of the scramble is the least predictable. High spot prices for REEs and the expectation of continued medium-term pressure on supply act as spurs to destruction of demand wherever possible. A new level of international co-operation is evolving on research into alternatives for rare earths, while elsewhere manufacturers are learning to be more efficient in using them. Despite the huge sums spent, especially by the Japanese government and allied firms, it remains unclear how much substitution of rare earths is possible without losses in performance, and how long the development times are for these posited new technologies.

It may well be that a new process or material is discovered that would seriously undermine the need for REEs in a crucial sector such as magnets. It may equally be the case that for the foreseeable future the unique properties of the rare earths will continue to make them indispensible. Just as with the conditions that set this scramble in motion, however, the ultimate result is likely to be complicated and somewhat messy, with no clear winner emerging. Instead, though undoubtedly we are now entering a new phase for the industry, the global rare earths sector is likely to remain keenly contested for some time to come.

Implications for South Africa of the Chinese monopoly

South Africa possesses relative advantages over many of its competitors in rare earth extraction. Although it lacks specialised knowledge, a workforce with a long tradition in mining is available, regionally and nationally, at lower cost than in countries such as Canada or Australia. It is true that South Africa faces challenges in expansion programmes for mining potentially critical metals such as manganese, particularly in road and rail freight capacity; but no such problems are anticipated for rare earths due to the much smaller tonnages involved. Production bottlenecks such as erratic or inadequate electricity generation are also less troublesome owing to the smaller scale of production, despite the relatively energy-intensive nature of the REE separation process. The two mines now under development are globally significant, Steenkampskraal for its high material grade and quick development time and Zandkopsrift for the sheer scale of its projected output and the concentrations of some critical REEs. Both seem likely to become operational mines and in some form to survive the current volatility of the rare earths sector.

One aspect important to local development is beneficiation. The more stages of the production process that can be carried out on South African territory, the better the outcome in terms of revenue, added value and employment. At a minimum it would appear important that separation is handled in South Africa. It is the first stage of the supply chain at which stand-alone production becomes commercially viable, given a market for separated oxides. Indeed, should a South African separation industry develop, the potential exists for that country to become a regional hub for rare earth ores from other African countries that may not possess the necessary resources to separate ores. It is interesting to note that Frontier's joint venture partner Kores also has an interest in the Wigu Hill REE project in Tanzania controlled by Vancouver-based Montero Mining & Exploration Ltd, and is looking to expand further across the continent. The planned South

African separation plant, to be jointly built by Kores and Frontier, will have a capacity equal to the expected output from Zandkopsdrift, hence expansion would be needed should separation of ores from other mines take place. The GWMG-GQRE plant, however, will be designed with extra capacity in mind from the start.

Whether it will be possible to site further stages of production within South Africa remains to be seen. In an interview with *Mining Weekly,* Frontier Rare Earths Chairman, James Kenny, raised the possibility of exploring the options of alloy and magnet manufacturing in South Africa jointly with Kores and other potential partners.[82] Should this happen it is possible that some domestic customers would be available, which would link the two ends of the REE supply chain. For example, Cape Town-based Optimal Energy Pty is in the late stages of producing the country's first electric vehicle, the Joule, initially for the domestic market.[83] Wind turbines will also soon be manufactured at Saldanha Bay.[84] Concerns over the environmental impact of mines, therefore, must also be judged against the contribution that REEs may make to South African clean-tech industries.

Certainly, at the present time and notwithstanding legitimate environmental issues, rare earths have the potential to make a small but significant contribution to South Africa's socio-economic development.

ENDNOTES

1 Small-scale production also currently takes place in Malaysia, Brazil and India.

2 This is notwithstanding the continued importance of catalysts for fuel cracking and automotive applications as an end use, with production of the former still concentrated in North America. This sector, however, is of far less importance than the other major application of REEs in the manufacture of magnets, a process overwhelmingly sited in China, Japan and Korea.

3 US Environmental Protection Agency, *Investigating Rare Earth Element Mine Development in EPA Region 8 and Potential Environmental Impacts*, Washington, 2011, http://www.epa.gov/region8/mining/ReportOnRareEarthElements.pdf.

4 Average annual demand for rare earth inputs for fuel cracking purposes grew 3.5% 2005–2010.

5 Freedonia Group, *World Rare Earths: Industry Study with Forecasts for 2015 and 2020,* Cleveland OH, 2011, http://www.freedoniagroup.com/brochure/27xx/2775smwe.pdf.

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7 Gschneider KA, 'The rare earth crisis – the supply/demand situation for 2010–2015', *Material Matters* 6 (2) Milwaukee, November 2011, http://www.sigmaaldrich.com/technical-documents/articles/material-matters/the-rare-earth-crisis.html.

8 Hatch GP *op. cit*.

9 Mackie Research Capital, 'Rare Earth Horse Race', Toronto, 22 July 2011 http://www.slideshare.net/Tehama/mackie-research-capital-rare-earth-horse-race.

10 US Department of Energy, *Critical Materials Strategy,* Washington, 2010.

11 Domoney R *et al.*, 'Blood, gold and mobile phones', *The Guardian,* 2 September 2011, http://www.guardian.co.uk/world/video/2011/sep/02/congo-blood-gold-mobile-phones-video.

12 British Geological Survey, *Risk List 2011*, Nottingham, 2011, http://www.bgs.ac.uk/mineralsuk/statistics/riskList.html.

13 Miklian J, 'I was a rare earth day trader', *Foreign Policy,* Washington, 21 January 2011, http://www.foreignpolicy.com/articles/2011/01/21/i_was_a_rare_earths_day_trader?page=0,2.

14 Strictly speaking the difference between these two types is defined by their atomic properties. A somewhat different, but overlapping, definition, tends to be used in industry to group together particular elements normally found in deposits together. Put simply, HREEs are more scarce: LREEs will be found in significant quantities in practically all rare earth deposits, though this is not so for HREEs.

15 Scandinavia also being the site of the discovery of the first rare earth, ytterbium, named after the village of Ytterby in Sweden, where in 1787 Captain Carl Axel Arrhenius first obtained a black ore containing the metal.

16 Some small-scale production had taken place at Mountain Pass since 1952, though only as a by-product, in the hope of extracting commercial grades of uranium.

17 Biggs S, 'China rare earths leave toxic trail to Toyota Prius, Vestas wind turbines', Bloomberg, 6 January 2011, http://www.bloomberg.com/news/2011-01-05/china-rare-earths-leave-toxic-trail-to-toyota-prius-vestas-wind-turbines.html; Webster G, 'Rare earth elements, Asia's resource nationalism and Sino-Japanese relations', National Bureau of Asian Research, Seattle, 12 May 2011, http://www.nbr.org/research/activity.aspx?id=137.

18 Wang Z, 'Deng Xioaping's southern tour', China National Radio, 16 August 2008, http://www.cnr.cn/nmgfw/nmzt/60dq/tjnmg/200704/t20070412_504442760.html.

19 Tse PK, *China's Rare Earth* Industry, US Geological Survey, Reston VA, 2011, http://files.eesi.org/usgs_china_030011.pdf.

20 In fact, export quotas for the first half of 2011 were much lower than in the equivalent period the previous year, although a relaxation for the second half of that year brought annual levels for 2010 and 2011 to rough parity. The loosening of exports perhaps reflects Chinese concern for possible WTO sanctions, were Beijing found to be discriminating unduly against production for export.

21 Inoue Y, 'Japanese rare earth users plan Chinese operations', Reuters, 12 August 2011, http://uk.reuters.com/article/2011/08/12/us-rareearth-japan-factbox idUKTRE77B3UO20110812?type=companyNews.

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23 Zhu T, 'Top rare earth miner calls for halt to production as China's quotas exhausted', *Business China,* 2 August 2011, http://en.21cbh.com/HTML/2011-8-2/3MMjM1XzIxMDY3Mg.html.

24 Wei C, 'China Baotou to halt rare earth operations for one month', *Wall Street Journal Online* 19 October 2011, http://online.wsj.com/article/SB10001424052970204346104576638333415825762.html.

25 Bradsher K, 'China consolidates grip on rare earths', *The New York Times,* 15 September 2011. http://www.nytimes.com/2011/09/16/business/global/china-consolidates-control-of-rare-earth-industry.html?pagewanted=all.

26 Nor is it clear from the article what is meant by rare earth 'factories'.

27 *CapitalVue,* 'Chinese rare earth prices collapse', 3 November 2011, http://www.capitalvue.com/home/CE-news/inset/@10063/post/4071543.

28 For instance see 'GTSO seeks to offset threat of rare earth quotas to US energy and defense industries', *Business Wire,* 10 February 2011, http://www.businesswire.com/news/home/20110210005957/en/GTSO-Seeks-Offset-Threat-Rare-Earth-Quotas.

29 This also applies to other modern armed forces, albeit to a lesser extent. The Eurofighter Typhoon, for instance, depends upon rare earth magnets.

30 Bradsher K, 'After China's rare earth embargo, a new calculus', *The New York Times,* 29 October 2010, http://www.nytimes.com/2010/10/30/business/global/30rare.html?pagewanted=all.

31 Hatch GP, 'Focus on the Japan vs China rare earths saga misses the point', *Rare Metal Blog,* 29 September 2010, http://www.raremetalblog.com/2010/09/focus-on-the-japan-vs-china-rare-earths-saga-misses-the-point.html.

32 Hatch GP, 'China's rare earths gameplan part 1', *Technology Metals Research,* Carpentersville IL, 14 July 2010, http://www.techmetalsresearch.com/2010/07/chinas-rare-earths-game-plan-part-1-the-effects-of-reduced-export-quotas/.

33 *Rare Coin Wholesalers,* 'China consolidates grip on rare earths', 26 September 2011, http://www.rarecoinwholesalers.com/blog/35/china-consolidates-grip-on-rare-earths.

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35 Hawes B, 'Japanese magnet producers ponder the move to the mainland', *Rare Metal Blog,* 12 August 2011, http://www.raremetalblog.com/2011/08/japanese-magnet-producers-ponder-the-move-to-the-mainland.html.

36 Gordon J & I Yuko, 'Analysis: Japanese rare earth consumers set up shop in China', Reuters, 12 August 2011, http://www.reuters.com/article/2011/08/12/us-rareearth-japan-idUSTRE77B3TH20110812.

37 People's Republic of China, Ministry of Science and Technology, MoST 2, National High-Tech Research and Development Programme (Programme 863), accessed 20 September 2011, http://www.access4.eu/_img/article/MoST_2_-_National_High-Tech_Research_and_Development_Programme_(863_Programme).pdf.

38 South Korea also possesses a significant rare earth magnet industry.

39 Hurst C, 'China's rare earths industry: what can the west learn?', special report, *Journal of Energy Security,* Institute for the Analysis of Global Security, Washington, 25 March 2010, http://fmso.leavenworth.army.mil/documents/rareearth.pdf.

40 As noted, the US continues to dominate the rare earth fuel cracking catalyst and catalytic converter sectors, although the ready availability of substitutes makes such processes far less important than the magnet industry.

41 In 2005 Magnequench merged with Toronto-based AMR Technologies to become Neo Materials Technology, though 85% of its production remains in China as joint venture projects with Chinese state-owned enterprises. The remaining 15% of lower technology production has been relocated to Thailand.

42 This follows a move by Showa Denko, a large Japanese producer of REE alloys, to move a similar percentage of its production to China.

43 *Taipei Times,* 'Japan to spend US$1.3bn to reduce rare earth usage', 22 February 2011, http://www.taipeitimes.com/News/biz/archives/2011/02/26/2003496801.

44 *Metal-Pages,* 'Japan to deepen ties with Europe on rare earth development', London, 4 February 2011, http://www.metal-pages.com/news/story/52055/japan-to-deepen-ties-with-europe-on-rare-earth-development/.

45 Bromby R, 'Prices down but Japan's REE search continues', *Rare Metal Blog*, 8 October 2011, http://www.raremetalblog.com/2011/10/prices-down-but-japans-ree-search-continues.html.

46 Although new business models are emerging, such as that of Dacha Capital, which is buying up inventories of REE oxides and stockpiling them in anticipation of future price rises. A limited REE exchange, based in Baotou, has also been mooted by the Chinese government, though this would not be permitted to trade in futures.

47 White G & H Kim, 'Here's the truth about the rare earth stocks that are surging right now', *Business Insider,* 28 October 2010, http://www.businessinsider.com/best-rare-earth-companies-2010-10.

48 *Ibid.*

49 Thorium may well again become a viable source of nuclear energy as global stocks of uranium dwindle, although for now it can be considered simply as a particularly hazardous waste product of most REE mining.

50 Most studies take the US Department of Energy definition of critical rare earths as being those most important for green energy technologies: they are neodymium, europium, terbium, dysprosium and yttrium.

51 Even statistics on quantities of critical REEs as a percentage of total REEs within a deposit, contain a simplification, due to wide variations in prices per kilogram for each of the critical rare earths. For instance, dysprosium is found only in very small concentrations in all deposits, if at all, and therefore is priced much higher than most other critical REEs. Hence a relatively large quantity of dysprosium within a deposit, in kilograms, is much smaller than a relatively large quantity of a more common critical REE such as neodymium. In theory, therefore, a deposit containing a relatively large quantity of dysprosium but a relatively small quantity of neodymium would appear unattractive using the common metric of kilograms of (combined) critical REE per ton of total REE. In fact, such a deposit may have excellent profit potential, since a small amount of dysprosium can be sold for the same price as a much larger quantity of neodymium.

52 Hatch GP, 'The Goldilocks mining principle', *Rare Metal Blog,* 8 October 2010, http://www.raremetalblog.com/2010/10/the-goldilocks-mining-principle-right-sizing-rare-earth-mining-ventures.html.

53 See below for a full discussion of GWMG's (Great Western Minerals Group Ltd) Steenkampskraal development in Western Cape.

54 Hill M, 'Frontier signs financing, offtake agreement with Kores for SA rare earths mine', *Mining Weekly*, 22 July 2011, http://www.miningweekly.com/article/frontier-signs-financing-offtake-deal-with-kores-for-sa-rare-earths-mine-2011-07-22. Again, a more in-depth look at Zandkopsdrift follows below.

55 This may take place after the first stage of ore mining: several promising deposits have been discovered in Malawi, although there appears little prospect of the development of even a separation plant inside the country. Instead, off-take agreements are being sought that could possibly lead to shipping to South Africa for this stage of processing.

56 Bulford T, 'A rare earth resource company for the bold investor', *Money Week*, 13 October 2011, http://www.moneyweek.com/investment-advice/penny-shares/why-this-industry-veteran-is-betting-on-rare-earths-55913.

57 This company should not be confused with Great Western Mining, which has an interest in the Malilongue rare earths development in Mozambique.

58 Hatch GP, 'Steenkampskraal: An update', *Technology Metals Research,* 4 March 2011b, http://www.techmetalsresearch.com/2011/03/steenkampskraal-an-update/.

59 Matthews C, 'Rare good news', *Financial Mail,* 6 October 2011, http://www.fm.co.za/Article.aspx?id=155273. Some of this cost difference is associated with the greater technical challenges involved in mining and separation of the carbonite deposit at Zandkopsdrift, as against monazite at Steenkampskraal.

60 Telephonic interview, 3 October 2011.

61 This applies to the Namaqualand Development Trust, which has a 21% interest in Zandkopsdrift. The other 5% BEE ownership stake is held individually by Martin Van Zyl, the former head of Economic Affairs and Tourism in the Northern Cape Provincial Government. It is not clear whether Van Zyl will also be required to pay market value for his stake.

62 Hatch GP, 2011b, *op. cit*.

63 Though thorium still has a half-life of 1 000 years.

64 ZAR is the three-letter currency code for South African rand.

65 Blane S, 'Thorium SA's best-kept energy secret', *Business Day*, 16 February 2011, http://www.businessday.co.za/articles/Content.aspx?id=134440

66 Hatch GP, 2011a*, op. cit*.

67 Hiil M, 'Great Western in rare earths co-operation with Toyota', *Mining Weekly,* 27 April 2011, http://www.miningweekly.com/article/great-western-in-rare-earths-cooperation-with-toyota-2011-04-27.

68 Irvine G, 'China's coming REE imports 2014', *Rare Metal Blog*, 17 March 2011, http://www.raremetalblog.com/2011/03/chinas-coming-ree-imports-2014-.html.

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71 Matthews C, *op. cit.*

72 Personal interviews, Bitterfontein and Garies, August 2011.

73 Anonymous interview with Bitterfontein resident, Bitterfontein, Western Cape, 30 August 2011.

74 Bradsher K, 'Mitsubishi quietly cleans up its former refinery', *The New York Times*, 8 March 2011, http://www.nytimes.com/2011/03/09/business/energy-environment/09rareside.html?_r=1.

75 Lee C, 'Sepa joins battle against toxic plant', *Free Malaysia Today*, 27 May 2011, http://www.freemalaysiatoday.com/2011/05/27/sepa-joins-battle-against-toxic-plant/.

76 Burns S, 'Lynas Malaysian rare earth refining plant construction halted', *Metal Miner*, 5 July 2011, http://agmetalminer.com/2011/07/05/lynas-malaysian-rare-earth-refining-plant-construction-halted/.

77 Anonymous interview with investor, 10 August 2011.

78 GWMG Conference call to investors, 14 September 2011.

79 Schipani A, 'South American scramble: Tapping Bolivia's lithium deposits', *Electric Vehicle Update*, 29 March 2011, http://analysis.evupdate.com/industry-insight/south-american-scramble-tapping-bolivia%E2%80%99s-lithium-deposits.

80 Not enough information is available to make this calculation accurate, since prices for yttrium, for instance, are not readily available, and the scoping report contains a category of 'other' rare earths but does not delineate specific quantities of each, making it impossible to track price changes in this category. The September figure was arrived at by averaging the percentage price

rises of those rare earths for which figures are available, and applying this average rise to the original revenue estimate. The true value is likely to be something in excess of this, though the situation may again change rapidly.

81 Chang-Ram K & E Gibbs, 'China seeks Japan tech in rare earth deals: Reports', *Reuters*, 7 September 2011, http://www.reuters.com/article/2011/09/07/us-china-rareearth-japan-idUSTRE7860S920110907.

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