THE RELEVANCE OF RARE EARTHS TO SOUTH AFRICA

CRITICAL HIGH-TECH MATERIALS FOR THE FUTURE OF SOUTH AFRICAN MANUFACTURING

NATIONAL SCIENCE & TECHNOLOGY FORUM:
ADVANCED MANUFACTURING AND AUTOMATION
13 SEPTEMBER 2019

BRENT C. JELLICOE PR.SCI.NAT. (GEO); P.GEO.; MGSSA
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INTRODUCTION TO THE RARE EARTHS – AKA LANTHANOIDS

17 in total

“Rare” is a misnomer

Also Sc and Y

LREE and HREE

Radioactivity in deposits is typical (Th and U)

= Light rare earths

= Heavy rare earths

= Magnet materials
THE NATURE OF REEs

• 15 elements collectively termed the Lanthanoids (or less precisely, the Lanthanides). The element Yttrium is often included with the Lanthanoids for economic reasons and due to chemical similarity.
• REEs are not “rare”, the total TREO abundance of earth is 220ppm compared to carbon at 200ppm;
• REEs are widely distributed in low concentrations but are typically found all together due to having ionic chemistries dependent mostly on the size of the M+3 ion.
• REEs are very reactive and not very noble. They are easy to dissolve and easy to precipitate but are difficult to chemically reduce and separate from each other. They are characteristically trivalent with strong ionic character that allow them to readily form salts with anions. There are different optical and magnetic properties for each REE.
• REEs each have different optical and magnetic properties.
THE COLLECTIVE NATURE OF REEs

• REE diversity in physical and chemical properties defines their individual demand in different applications and, in turn, their criticality. The abundance of REEs vary significantly in their host minerals.

• REE-bearing minerals generally contain most of the rare earths in varying concentrations but tend to be biased toward either LREE or HREE. In general terms, light REE are substantially more abundant in REE deposits than the heavy REE.

• REEs occur in over 250 different minerals.

• The abundance of Total REE (TREE, or TREO) within REE-bearing minerals can vary from 10 to 70%.

• 95% of REEs occur in the minerals bastnaesite (LREE-rich), monazite (LREE-rich), and xenotime (HREE-rich).

• It is not possible to selectively target just one specific element of the REE group for mining.

• All REE must be mined together and then be separated through various metallurgical procedures.
EARTH ABUNDANCE OF RARE EARTH ELEMENTS

Atomic Number, Z

Abundance: Atoms of element per $10^6$ atoms of Si

Rock-forming elements

Relative abundance of the chemical elements in Earth’s upper continental crust

Major industrial metals in **Bold**

Precious metals in *Italic*

Rare earth elements

Rarest "metals": Os, Ir
RARE EARTH ELEMENT DEPOSITS

- There are at least 800 known REE deposits in the world, of which 49 have code-compliant resource estimates. (TMR, 2015)
- Carbonatites have been the world’s main source for the LREEs since the 1960s.
- Ion-adsorption clay deposits in southern China are the world’s primary source of the HREEs.
- Monazite-bearing placer deposits were important sources of REEs before the mid-1960s and may be again in the future (i.e., heavy mineral sand)
- Carbonatites, alkalic igneous / metamorphic, and monazite placer REE deposits are common in South Africa.

<table>
<thead>
<tr>
<th>REE DEPOSIT TYPES</th>
<th>NUMBER</th>
<th>EXAMPLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbonatites</td>
<td>107</td>
<td>Mountain Pass, Bayan Obo</td>
</tr>
<tr>
<td>Carbonatites with Residual Enrichment</td>
<td>41</td>
<td>Mount Weld</td>
</tr>
<tr>
<td>Alkaline Igneous</td>
<td>122</td>
<td>Nechalacho, Zeus, Red Wine</td>
</tr>
<tr>
<td>Hydrothermal Iron Oxide</td>
<td>4</td>
<td>Olympic Dam</td>
</tr>
<tr>
<td>Other Igneous Affiliates</td>
<td>38</td>
<td>Hoidas Lake</td>
</tr>
<tr>
<td>Ion Adsorption Clays</td>
<td>19</td>
<td>Xunwu, Jiangxi Province Longnan, Jiangxi Province</td>
</tr>
<tr>
<td>Metamorphic</td>
<td>16</td>
<td>Steenkampsraal</td>
</tr>
<tr>
<td>Placer – Shoreline, Alluvial, Uncertain</td>
<td>372</td>
<td>Australia, US, India</td>
</tr>
<tr>
<td>Phosphorites</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Other – Bauxite, Flourite deposits, Pb Deposits, U Deposits, Uncertain</td>
<td>61</td>
<td></td>
</tr>
<tr>
<td>Uranium Rafinates</td>
<td>?</td>
<td>McArthur River, Cigar Lake, Elliot Lake</td>
</tr>
</tbody>
</table>
These are not fully linear activities, rather they are semi-concurrent depending on the deposit type and metallurgy.
RARE EARTH MINERAL EXPLORATION TARGETS

Bastnäsite, Allanite and Ancylite

- Bastnäsite – (REE)(CO$_3$)$_2$F
- Allanite – (REE,Y,Ca)$_2$(Al,Fe$_{2+}$,Fe$_{3+}$)$_3$(SiO$_4$)$_3$OH
- Ancylite – Sr(REE)(CO$_3$)$_2$(OH) H$_2$O

These minerals are virtually always LREE dominant, even when found to be co-crystallized with other HREE dominant minerals. In rare cases they have been reported as HREE dominant in which case they occur only in trivial quantities.

Exploration Targets for Y and HREE

1) Xenotime – Placers, Granites, Metamorphics
2) Eudialyte and Alkali-zirconosilicates (AZS)
3) Rafinates
4) Complex fine-grained minerals in peralkaline granitic and syenitic complexes
5) Rare heavy mineral niobates with Y and HREE
6) South China Clay-type ion-adsorbed REE, exclusive of China

SOUTH CHINA IONIC CLAYS

Positive Factors
- Only current source of HREE
- HREE dominant
- Low Th
- Well known and low-cost extraction

Negative Factors
- Low Grade
- Environmental degradation
- Requires cheap labour and good infrastructure
- Only deposits currently proven are in China, Madagascar, and Brazil
GLOBAL EXPLORATION FOR REEs

- Bauxite laterites
- Carbonatite complexes
- Ion-adsorbed clays
- Magnetite ore deposits
- Peralkaline igneous deposits
- Placer Deposits
- Uranium deposits
- Vein deposits
- Weathered crust saprolite
- Total amount of global REE resources is 478 Mt REO.
- These resources could supply the global REE needs at the 2017 production rate (130 kt REO) for over hundred years.
- In terms of principle deposit types, the majority of the current global REE resources are dominated by carbonatite, which contains 297.6 Mt REO within 66 deposits, constituting 62% of the total resources.
- China dominates known worldwide REE Resources.

(Source: Zhou et. al., Oct 2017)
Code-compliant Resources of 59 advanced REE deposits represented here is 276 Mt REO, as of Jan 2017.

The ratio of LREE to HREE is 18:1.

Based on REO market prices in China in December 2016, the market value of LREE and HREE, respectively, constitutes 62.5% and 37.5% of the total.

In the LREE resources, Pr and Nd are the most precious, and their value constitutes 77% of the total LREE market value.

Dy, Yb, and Y are the three most prevalent HREE, and their value contributes to 96.7% of the total HREE market value.

The mass of Y constitutes 62% of the entire HREE resources indicating the scarcity of proper HREE like Dy, Tb, Eu, and Lu however, its market value contributes just 23.4% of the HREE value.

Dy is the most valuable element of all REEs.

(Source: Zhou et. al., Oct 2017)
REE DEPOSITS IN AFRICA

(After: Modified from Harmer and Nex, 2011)
### REE Deposits in Africa

<table>
<thead>
<tr>
<th>REE Deposit</th>
<th>Host/source</th>
<th>Mineralisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kangankunde</td>
<td>Carbonatite</td>
<td>Magmatic-Hydrothermal</td>
</tr>
<tr>
<td>Songwe</td>
<td>Carbonatite + fenite</td>
<td>Magmatic-Hydrothermal</td>
</tr>
<tr>
<td>Nkombwa Hill</td>
<td>Carbonatite</td>
<td>Magmatic-Hydrothermal</td>
</tr>
<tr>
<td>Wigu Hill</td>
<td>Carbonatite</td>
<td>Magmatic-Hydrothermal</td>
</tr>
<tr>
<td>Lofdal</td>
<td>Carbonatite?</td>
<td>Hydrothermal</td>
</tr>
<tr>
<td>Ngualla Hill</td>
<td>Carbonatite</td>
<td>Epigenetic- residual soil deposit</td>
</tr>
<tr>
<td>Mrima Hills</td>
<td>Carbonatite</td>
<td>Epigenetic- residual soil deposit</td>
</tr>
<tr>
<td>Zandkopsdrift</td>
<td>Mica-carbonate breccia &amp; “REE carbonatite”</td>
<td>Epigenetic- residual soil deposit</td>
</tr>
<tr>
<td>Xiluvo</td>
<td>Carbonatite</td>
<td>Epigenetic- residual soil deposit</td>
</tr>
<tr>
<td>Glenover</td>
<td>Carbonatite + pyroxenite</td>
<td>Epigenetic- karst solution breccia</td>
</tr>
<tr>
<td>Tantalus</td>
<td>Syenite + skarn</td>
<td>Epigenetic- adsorption clays</td>
</tr>
<tr>
<td>Gakara</td>
<td>Carbonatite??</td>
<td>Vein</td>
</tr>
<tr>
<td>Steenkampskaal</td>
<td>Unidentified magmatic? metamorphic?</td>
<td>Vein</td>
</tr>
</tbody>
</table>

(Source: Harmer, and Nex, 2016)

**Figure 20:** Plot of contained in situ REO against TREO grade for the 11 African deposits with declared resources. The vertical dashed lines mark 100,000 and 200,000 tonnes of contained REO, respectively, which would provide a 20 year life of project at annual production/extraction rates of 5,000 and 10,000 tonnes per annum, respectively (discussed in text).
REEs have diverse defense, energy, industrial, and military technology applications.

The use of REEs in magnets is a rapidly increasing application.

Nickel-metal hydride batteries use anodes made of a lanthanum-based alloys.

Neodymium-iron-boron magnets, which are the strongest known type of magnets, are used when there are space and weight restrictions.
Global production of REE was 126,000 metric tons of REO in 2016.

Comprised of China (84%) and Australia (11%), and the remainder distributed among Malaysia, Brazil, India, Russia, and Vietnam.

In addition, considerable illegal production is carried out mainly in Southern China that is estimated to reach 20% of the legal production in China.

The total value of worldwide products containing REE is at least $1.5–2 trillion US dollars (US$)
MANUFACTURING OF HIGH-STRENGTH REE PERMANENT MAGNETS

- Permanent magnets contribute to most of the high-technology REE applications including Green Energy generators and utiliser.
- The permanent magnet industry became the largest sector (26%) of total global rare earth oxides (REO) use in 2015.
- In 2019, magnets represent >90% by value, and 20% by mass of all REE production.
- Permanent magnets dominate consumption and growth with increases of 6-12% pa
- Annual magnet market is ~US$20B
- Major use of Critical Rare Earth Oxides (CREOs) including Nd, Pr, Dy, Tb, and Sm.
- Global REE supply is expected to increase exponentially to contribute to meeting current and future global demands from REE-dependent technologies and applications.

(Source: Arnold, 2016; Strnat, 1990; as shown in Zhehan, 2016)
## USE OF REEs IN MANUFACTURING

### Rare Earth – Key Applications

#### Magnetics
- Nd, Tb, Dy, Pr
- Computer Hard Drives
- Disk Drive Motors
- Anti-Lock Brakes
- Automotive Parts
- Frictionless Bearings
- Magnetic Refrigeration
- Microwave Power Tubes
- Power Generation
- Microphones & Speakers
- Communication Systems
- MRI

#### Phosphors
- Nd, Eu, Tb, Y, Er, Gd, Ce, Pr
- Display phosphors - CRT, LPD, LCD
- Fluorescent Lighting
- Medical Imaging
- Lasers
- Fibre Optics

#### Metal Alloys
- Nd, Y, La, Ce, Pr
- NimH Batteries
- Fuel Cells
- Steel
- Super Alloys
- Aluminium / Magnesium

#### Catalysts
- Nd, La, Ce, Pr
- Petroleum Refining
- Catalytic Converter
- Fuel Additives
- Chemical Processing
- Air Pollution Controls

#### Ceramics
- Nd, Y, Eu, Gd, Lu, Dy, La, Ce, Pr
- Capacitors
- Sensors
- Colorants
- Scintillators
- Refractories

#### Glass & Polishing
- Nd, Gd, Er, Ho
- La, Ce, Pr
- Polishing Compounds
- Pigments & Coatings
- UV Resistant Glass
- Photo-Optical Glass
- X-Ray Imaging

#### Defense
- Nd, Eu, Tb, Dy, Y, Lu, Sm
- LREOs
- Satellite Communications
- Guidance Systems
- Aircraft Structures
- Fly-by-Wire
- Smart Missiles

### CREOs
- HREOs
- LREOs
USE OF REEs IN MANUFACTURING

Computers and Cell Phones

- Hard drive
  - Voice Coil Motor (VCM)
  - Spindle motors
  - ~500 million drives/year
    - 6,000 tons of Nd/year
    - Comparable to Mtn. Pass output
  - Shrinking magnets

Source: Western Digital
Mining REE Ore – Testing, Feasibility and Authorisations

**Specialist Studies:** Drilling & Sampling & Testing, Geology, Geotech, Engineering and MET, Hydrogeology, variety of Environmentals, Archeology

**Infrastructure:** Water, Reagents, Power, Transport, Skills,

**Mine Feasibility:** MRE, mining plan, Capex & Opex, BFS, Engineering optimisation, construction, financial success indicators

**Permits and Authorisations:** DEADPE BAR/EIA/EMP, WULA, LUPO, MWP

**Municipal Support:** Social and Labour Plan (SLP) = training, upliftment, contributions to local economy and quality of life.

**Radioactive Ore:**

- Determine radiation from NORMs affecting worker health, public health and environment
- Registration and authorisations: COR NNR, DOE, PRWSA/PRPSA for Radiation Design Criteria
- Disposal of waste materials
  - Separation and safe storage of radioactive elements and minerals from the tailings & waste streams,
  - Separation of environmentally deleterious materials for appropriate disposal.
Processing REE Ore

The geological and mineralogical complexity of REE deposits, variable mining, beneficiation, refining configurations, and the recovery efficiency of REE for a specific mine are governed by:

- Its geological features such as ore grade, mineralogy, deposit type, HREE and LREE proportions, etc.), economic drivers,
- Technical challenges (e.g. by-/co-product makeup, hazardous impurities removal, and difference in the desired end products, etc.), and
- Environmental footprint; human capital; social and economic constraints

Every mine has a unique metallurgy and process flow based on the ore characteristics, REE mineralogy, deleterious elements, and extraction needs.
MINE TO MARKET CONCEPT

- Over-used term, often abused, and rarely attained.
- Mine to Market Concept = Full REE Supply Chain
  = REE Value Chain
- This concept embraces the physical and chemical processing routes and steps necessary for turning ore into high-purity REE metals and REOs
- This value-add chain is absolutely essential for success in today's China-dominated REE market.

MtoM is what non-China REE companies need and must aspire to ....

As this is what China has already gradually established over the last few decades and now completely dominates.
This was the right idea by a now ex-junior exploration company. Point being, it is easy to conceptualise, but immensely difficult to implement successfully. Why is this so?
Neodymium, dysprosium, terbium, europium, and yttrium are strategic, critical rare earth elements that possess unique magnetic, catalytic, and luminescent/optical properties,

They are key resources needed to manufacture products for the deployment of clean energy technology for continued growth of a clean energy economy.

These materials are critical to the technologies that enable wind turbines, solar panels, electric vehicles, and energy-efficient lighting.

The CREE content of the REE deposit will define the marketability and potential production revenue stream.

Figure sources:
Lower: USA Material Criticality Matrix for Medium Term Supply 2015-2025 (USDoE, 2011)
REE BASKET PRICING AND ORE REVENUE

What REEs you can produce and sell, and what you get for it!

• Based on selection of which critical REEs (CREOs) can be put in your basket, projections can be made on demand drivers and changing supply dynamics over the Life of Mine (LoM).
• Individual REO prices are calculated and extrapolated on 3-week trailing averages and then combined into gross $/tonne revenue.
• Obviously, upstream and downstream business units are separated and must economically stand-alone within an overall Mines to Market production model to feed products downstream.
• The existence of agreements with potential customers is critical and can influence the REE basket makeup, price and marketing policy of the mining company. Having a fixed, long-term pricing deck on customer-specified products (either oxides or mix concentrates) will define the feasibility prospects of the REE project in a more secure manner.
• Typically, the type of product and advance marketing agreements will contribute information for reserve calculations, financial modeling, and derived financial parameters including NPV and IRR.
• REE products available for downstream value-add processes are as follows:
  • RE-enriched mineral concentrates [usually to at least 55% of targeted mineral(s)],
  • RE Carbonate (solid), RE salts (solid), RE-chloride (liquid)
  • Separated or partially separated Rare Earth Oxides (REOs)
  • Purified REOs
  • Rare Earth Metals
  • Custom Rare Earth alloys
GLOBAL REE RESOURCES – ORE VALUE AND BASKET PRICE FOR ADVANCED STAGE REE DEPOSITS

Missing from Chart:
- Kangankunde, Malawi
- Nkombwa, Zambia
- Gakara, Burundi

(Modified from Source: Zhou et. al., Oct 2017)
REE Supply Chain Issues

Four main issues to discuss:

1) *The Broken REE Supply Chain*
2) *The REO Balance Problem*
3) *Environmental Impacts*
4) *The China Issue*
REE Supply Chain Issues – The Broken REE Supply Chain

• The actual problem is the absence of a robust and fully integrated value chain with sufficient capacity to translate the ore coming out of a REE mine into valuable end-products such as smart phones, wind turbines and electronic components for defense systems.

• This vertical integration consists not only the mining and primary beneficiation of REE but also the separation and purification of the individual REO and their refining to meet specific downstream technology applications. Eight years after the REE crisis, it is now common ground that the separation of the individual elements is the most fundamental part of the overall supply chain, since it is both technically challenging and expensive to build and operate.

• China is currently the only country that has developed this complete value adding chain; comprising numerous independent companies dedicated to REE research and production, each providing highly differentiated technologies, processing, formulation, or component-specific applications.

• On the other hand, the processing potentials of rare earths outside of China are limited with respect to the separation of LREE and almost none concerning the efficient separation of HREE (Barakos, 2017; Machacek & Fold, 2014).

• Hence, when it comes to the chemical separation of the individual REO, it can be accomplished by China and only a handful of non-Chinese service providers.

(Source: How potential mines can connect to the global REE market, Aug 2018)
REE SUPPLY CHAIN ISSUES – THE REO BALANCE PROBLEM

- REEs are found together, mined together, and processed together. Furthermore, selective separation of high-demand HREEs is difficult without first separating LREEs.

- Over the past decade, rare earth producers globally have sacrificially overproduced certain low-value rare earth elements such as Cerium in order to keep up with rapidly growing demand for other high value rare earth elements, such as neodymium.

- Forecasts that global annual demand for neodymium oxide and dysprosium oxide (or oxide equivalents) will substantially exceed global annual production by 2030, leading to the depletion of historically accumulated inventories and, ultimately, shortages of critical magnet materials.

- Massive over-production of Ce and La to meet end-user demand for CREOs (Nd, Eu, Dy, Tb, and Y) results in stockpiling and flooding of the market. This exacerbates the imbalance between production and demand of other rare earth elements, such as cerium oxide. This of course depresses LREE market prices.

(Figures and forecasts sourced from Adamas Q2 2019 Rare Earth Elements: Market Issues and Outlook)
The REE industry is characterized by potentially severe environmental impacts. Gaining the necessary permits to run a mine including the social licence to operate is a challenge for all mining operations but is a difficulty for REE producers if ores contain NORMs and if they will produce radioactive waste. Waste disposal areas are often exposed to weathering conditions and have the potential to pollute the air, soil and water if adequate monitoring and protection measures are not utilized (Barakos et al., 2015).

The use of dangerous chemicals and toxic compounds during the processing of REE can also result in negative environmental effects. Lax compliance with the regulations has resulted in severe environmental consequences and illegal mining in China (Ali, 2014), while overly strict environmental regulations forced REE mining operations in Mountain Pass to stop production (Barakos, 2017).

However, the mineralogy of the dominant minerals from carbonatite and alkaline intrusion REE deposits influences the environmental character of their mine waste. The paucity of sulfide minerals, including pyrite, minimizes or eliminates concerns about acid-mine drainage for carbonatite-hosted REE deposits and alkaline-intrusion-related REE deposits. The low acid-generating potential of these deposits is further offset by their high acid-neutralizing potential, particularly for carbonatite deposits, which are dominated by acid-neutralising minerals.

(Source Modified from: How potential mines can connect to the global REE market, Aug 2018)
REE Supply Chain Issues — Environmental Impacts

• In terms of trace elements, the REE ore minerals factor most prominently in the environmental character of the ores and mine wastes. Due to similar chemical affinities, the Actinoids Th and U tend to follow the Lanthanoids in certain REE minerals. The main ore minerals currently processed for REEs - bastnaesite, monazite, and xenotime all contain appreciable amounts of uranium and thorium.

• The Chinese pollution problem, which is due to lax legislation that is now costing China hundreds of billions of dollars to correct is to be avoided at any cost. However, due to the current regulations on extracting and storing NORMs, many mines dump material containing REE in stockpiles or include in their waste products, despite the high value of such material (Kennedy, 2015). A corporation with the express purpose of extracting and storing radioactive materials like thorium could result in having a new REE source without the cost of mining them.

• The thorium and uranium contents of the ore minerals and mine waste represent one of the biggest environmental challenges that must be managed during mining, ore processing, and mine closure.

• Mining companies must develop, implement, and monitor NORMs through an enforceable detailed Radiation Management Plan.

(Source Modified from: USGS Rare Earth Elements Professional Paper 1802-0, 2017)
REE Supply Chain Issues – REE Balance & Environmental Impacts

One answer to alleviate the environmental problem is to Diversify Supply

• Recycle REEs,

• Improve the economics of processing existing sources,

• Identify new uses for co-products and by-products that do not currently contribute to the economics of materials production - - *REE substitution!* For example, Ce + Co to replace Nd

• Use REEs to develop better and more widely applicable green energy solutions, and

• Identify alternative element solutions that have lower environmental impacts.
What was happening from the mid-80’s onward?
The answer is: “The inexorable rise of digital technology and new opportunities!”

The controversial Chinese export policy for critical commodities was epitomized in a maritime border dispute with Japan in September 2010 that resulted in the REE crisis and price spike of 2011.

This helped initiate exploration for REE deposits all over the world. In just a few years, more than 400 projects were identified and initiated to explore REE deposits outside of China.

Prices for REE dropped rapidly in 2012 leading to a prolonged period of low REE prices and continued dominance of the market by China.

More recently, China has threatened to cut off the REE supply as trade frictions mount, prompting US President Donald Trump on July 22 to give the Pentagon an executive order to find other sources of the crucial elements.

In addition, “Prices of some of the critical REE elements soared in Q2 from around mid-May to end of June 2019, likely as a result of the trade dispute between the United States and China,” explained Luisa Moreno, managing director of Tahuti Global.

(Source: Rare Earths Market Update H1 2019 in Review, July 2019)
CHINA-BASED PROCESSING, PRODUCTS, AND MARKETS (IN A NUTSHELL)

Ore – Bastnaesite/Monazite/Eudialyte...

Crushing/Grinding/Floatation

Concentrate

Acid Leaching ± Roasting etc

Mixed REE Chloride or REE sulfate

Precipitate

Mixed REE Carbonate

Dissolve in Acid

Mixed REE Chloride

Solvent Extraction

Single REE Chloride

Precipitate with NaCO₃

Individual REE Chloride

Heat

Individual REE Oxide

Electrolysis

Individual REE Metals

China sells less-processed REE products to domestic industry only and high value-added products to the RoW

Sale in China

Sale in China

Sale in China

Sale in China

Sale in China

Sale in ROW

Sale in ROW
The China Issue Becomes the China Syndrome

• In recent years, China’s share of global rare earth mine production has fallen slightly as a handful of new rare earth mines have come on stream outside China. Chinese domestic REE production is subject to consolidation, much more stringent environmental regulations, and depletion of reserves.

• While the nation’s share of mine production has fallen, China’s share of downstream value-adding capacity to convert rare earth mine outputs to oxides, metals, alloys and magnets has continuously expanded, addressing the nation’s growing focus on dominating the downstream production where profit margins are greater, and activities are cleaner and more environmentally acceptable.

• Growing investment in, and control of, foreign ore sources by China supports their policies of retaining domestic production for domestic use, while pushing growth in the downstream value-adding industries and manufacturing.

(Source: Adamas Q2 2019 Rare Earth Elements: Market Issues and Outlook)
The China Issue Becomes the China Syndrome

• For a producer bringing online a new rare earth mine outside of China in the coming years – be it in Greenland, Canada, Australia or anywhere else – there is a high probability that your rare earth mine outputs are going to flow through China’s value chain, leaving you as a producer, and your investors and your customers subject to a higher degree of opacity and uncertainty than some may be comfortable with.

• In conclusion, until the rest of the world starts investing in the critical downstream linkages that take rare earth mine outputs and upgrade them into market-desired materials, such as NdFeB magnets, end-users outside of China will remain reliant on (and vulnerable to) China’s monopoly into the foreseeable future – irrespective of how many new mines are brought online elsewhere.

Source: Adamas Q2 2019 Rare Earth Elements: Market Issues and Outlook

The so-called proof in the pudding is captured in this recent headline …

“Chinese rare earth magnet producer to expand as EV demand booms”

Bloomberg News | June 24, 2019 | 9:33 am Battery Metals China Rare Earth
THE CHINA ISSUE BECOMES THE CHINA SYNDROME

“Not only has China taken the lead on rare earth production over the last 20 years and now holds a dominant position in the whole supply chain from mining to consumer end-products, it has a clear policy to secure other deposits elsewhere in the world and enhance that dominance.” (ICOA, 2017)

“China’s dominance of the markets for rare earths, and for some specific rare metals, will continue with the clear public statements by the Chinese Government of the intention to maintain and expand China’s advanced manufacturing capabilities.” (ICOA, 2017)
REE DEMAND DRIVERS

• Global market: 149,500 metric tons in 2019, valued at $4.5 billion.
• 3-4% annual growth estimates
• 85%-90% REE produced by China

- Permanent magnets dominate consumption and growth of 6-12% pa
- Annual magnet market is ~US$20B
- Major use for CREOs Nd, Pr, Dy, and Tb
- >90% by value, 20% by volume

• Growth in other REEs for special metal alloys and ceramics

Source: Modified from IMCOA 2016
1) China Manufacturing 2025 is targeting 70-80% domestic supply of REEs by 2025 for key high value markets.
   - Critical supply risk: REEs and zirconium chemicals as China supplies 90+% of world supply.
   - 20-50% of China’s rare earths supply is non-quota or illegal.

2) Export & supply of rare earth magnets threatened.
   - High growth rates for magnet production and demand in China will reduce REE exports with preference given to Chinese companies.

3) China’s rare earth industry is US$3-5 billion, with a US$30 - 40 billion environmental clean up legacy.
   - Rare earth prices will need to double in order to pay environment clean up costs over 10 years.

4) China will invest in, and exploit, new international REE resources to feed their expanding domestic industries and market, in order to sell value-added products to the RoW.
REE Market Overview

• The rare earth elements (REE) market is expected to register a Compound Annual Growth Rate (CAGR) of around 8%, during the forecast period. The major factors driving the growth of the market are the high demand from emerging economies, the dependency of 'Green Technology' on rare earth elements, and companies focusing on R&D for products requiring miniaturisation.

• Major output increases are also expected in Australia as Lynas continues to ramp up production. However, junior mining companies will struggle to obtain investments for new ventures as rare earth prices remain depressed. Prices are expected to remain weak, due in part to rampant illegal mining in China.

• By volume, permanent magnets and catalysts were collectively responsible for over 60% of global TREO consumption in 2018. However, by value, permanent magnets alone were responsible for over 90% of the total value of global TREO consumption last year (see Figure 3) and this share is poised to expand further as demand (and prices) for neodymium, praseodymium, dysprosium and terbium continue to rise strongly in the years ahead.

• The rare earth metals segment dominated the market in 2019 and will continue to do so in the next 5 years.

Key REE Market Trends

• Magnets stand to be the largest application for rare earth elements. Magnets find extensive applications in various industries, such as electronics, automotive, power generation, medical, etc.

• Industries, such as automotive, electronics, and healthcare, have been witnessing innovation and development, which are driving the production and growth in such industries.

• Though automotive production declined during 2018, the future of the market is positive, as the market growth is likely to be driven by the continuous innovation efforts being taken toward the development of new, lightweight, hybrid, and electronic vehicles.

• In electronic industries, the innovation of advanced technologies and upgradation of existing ones has been driving the growth of the market.

• China will continue to account for the majority of rare earths mining output through 2019 to 2024, although its share of total production is expected to drop as new projects in Canada, Tanzania, South Africa, and other countries begin commercial production.

A REE SUPPLY VALUE CHAIN DEVELOPMENT STRATEGY FOR SOUTH AFRICA

PROPOSAL

Can South Africa spearhead, develop, build and support a Full Supply and Value Chain for African REE Mines based on Provision of Toll Separation and Metal Making Services?

“THE QUESTION IS: WHY NOT SOUTH AFRICA?”

(Thank you Mintek, for the presentation, “REE Processing | A South African Perspective” in 2011)
Prospective Resource Bases

Targeted REE Resources in South Africa include:

- Zandkopsdrift carbonatite - REE phosphates (monazite & apatite derivatives)
- Steenkampskraal Monazite Mine - REE monazite
- Glenover carbonatite - REE phosphates and REE carbonates
- Naboomspruit pegmatite - REE phosphates, oxides, and silicates
- Namaqua Sands HM tailings - REE monazite
- Richards Bay HM tailings - REE monazite
- Phalabora Phospho-gypsum waste dumps - REE phosphates and sulphates

Possible Southern Africa Targets include:

- Nine other advanced REE projects or new mines that could use value-add REE process services
- **Gakara, Burundi; Mrima Hill, Tanzania; Wigu Hill, Tanzania; Ngualla, Tanzania; Nkombra, Zambia;**
- Kangankunde, Malawi; **Songwe, Malawi; Xiluvo, Mozambique; and Lofdal, Namibia**
Process Technology Research and Lab Centre

- R&D for development of tailored REE recovery technologies.
- Development of process flow sheets for REE recovery, removal of deleterious elements and other impurities, REE separation methods.
- Development of Green Energy and magnets technology.
- Provision of wide-ranging technical support and expertise for metallurgical/process facilities onsite at operating mines.

Onsite REE Beneficiation and Concentration

- Onsite preparation and beneficiation to create a Physical REE mineral concentrate.
- Onsite flotation and Hydrometallurgical processes to make a chemical REE concentrates such as REE carbonate and REE chloride.
- Transport to central facility.

(Source: REE Processing - A South African perspective, Mintek 2011)
RSA Centralised Refinery and Smelter Facilities
- REE separation and conversion to oxides +/- purification
- Conversion of REO to metals
- Make Custom REE-Alloys

Requirements for an RSA Centralised REE Facility
- World class laboratory, research, and metallurgical staff,
- Economy of scale Processing Facilities,
- Infrastructure, safe and dedicated reagent and other chemicals supply,
- Established and secure industrial location with access to both continental transport and marine shipping,

Close Connections for:
- Collaboration with African Mining Companies
- Governmental support (President on downwards)
- Infrastructural support (President on downwards)
- Wastes and radioactive materials storage (NNR and DOE)
- Creating trade, tax, and royalty incentives for utilising the facility
- International agreements for transport of REE concentrates and REE oxides
- Process and smelting industry “knowledge sharing” with non-China experts (Solvay, Vacuum Smelters, LCM, TRU Group, etc.)
A REE SUPPLY & VALUE CHAIN DEVELOPMENT STRATEGY FOR SOUTH AFRICA -
CONCEPTUAL CENTRALISED REE FACILITY

Issues

▪ Complex technology requirements and capital intensive
▪ The science of REE separation, thermo-metallurgy, and alloy making must be consolidated, tested, and perfected.
▪ Centralisation must be cost-effective for the stakeholders.
▪ In order to be globally competitive, need to develop Economy of scale in excess of 20,000 tpa TREO production.
▪ Success of the Facility is dependent on sufficient REE feedstock; planning of the feed supply is critical => •
▪ Must secure off-take agreements
▪ Prices for REE materials can be volatile and may be difficult to market timeously potentially leading to mine financial issues.
▪ Facility development and execution will need equity financing by the key partners/stakeholders with substantial strategic national investment.
▪ Transport, disposal and storage of radioactive waste
▪ Probable direct competition with China
Benefits of a Centralised REE Facility

• The Facility can attract world-class experts for design of REE separation processes.

• Economies of scale in costs for services, reagents, processing, and sophisticated operational support.

• Access to reagent production & recycling facilities.

• Developed infrastructure with qualified, skilled laboratory and plant staff.

• Avoid a substantial portion of large Capex costs for REE mine construction and supporting infrastructure for onsite high-tech processing Plants.

• Toll REE costs will be incurred by the mining company during revenue generation.

• The Facility can develop close ties with a state-sanctioned long-term, storage facility for radioactive waste materials. Reciprocal agreements for may be possible with Steenkampskraal Monazite Mine under through their Certificate of Registration (COR 23) and under approval by the NNR & DOE.
A REE SUPPLY & VALUE CHAIN DEVELOPMENT STRATEGY FOR SOUTH AFRICA -
CONCEPTUAL CENTRALISED REE FACILITY

More Benefits of a Centralised REE Facility

• May facilitate positive financial success parameters for new REE mine ventures that otherwise would have been uneconomical. May also assist with recruiting international Joint Venture partners for mining ventures and corresponding Venture Capital.

• Social & Labour benefits from work opportunities, training, community assistance, municipal tax-base support, and general positive economic benefits for associated support and entrepreneurial services.

• Creates a major manufacturing centre of excellence.

• Provides an in-country foundation for Value-Add manufacturing industries utilising REE materials such as a spin-off South African magnet industry, and manufacturing of Green Energy hybrid and electrical vehicle components.

• Provides a REE Value Chain strategy for South Africa by Southern Africa stakeholders.
AND LASTLY,

• "South Africa is certainly on par with any other country that would lay a claim to being able to supply rare earths elements to meet this increasing demand," said expert mineralogist Deshenthree Chetty at Mintek, a government mineral and metallurgy research department.

• She added that it would be "a great deal for our country to be able to supply, and we are in a position to do so, as long as those markets are favourable."

• Mosa Mabuza, CEO of the Council for GeoScience told AFP that "We have an abundance of rocks in which rare earth elements are found“.

• Diego Oliva-Veleza, commodities analyst with Fitch Solutions in London, cautioned “The rare earth sector in South Africa is largely undeveloped, and could easily fall behind the US, Australia, India, Russia and Vietnam which all have "significantly larger proven reserves of rare earths". (Response, “that was then, this is now” said Brent Jellicoe)

(Source: South Africa’s rare earths mine hopes for boost from US-China feud; AFP, 25 August 2019)

• Thus, we now have some greater understanding for ...

THE RELEVANCE OF RARE EARTHS TO SOUTH AFRICA
THANK YOU FOR YOUR ATTENTION
ITS’ BEEN REEEly GOOD BEING HERE!