AN AFRICAN RARE EARTH STORY

Derick R de Wit, Venmyn Deloitte
20 October 2015
China started restricting REE exports in 2006 and accelerated it in 2010, by cutting REE export quotas by 40%. They claim:

- conservation and environmental protection. WTO later found industrial policy.
- On 7 September 2010, a Chinese fishing boat collided with Japanese Coast Guard vessels in a disputed territory in the East China Sea.
  - Sensitive kaku occur when Japan detain the skipper. A diplomatic row arose that led to the apparent cutoff of China’s shipment of REE to Japan.
- By mid-2011, panic and speculation drove REE prices through the roof.
What are rare earths?

REEs are a common term describing the 15 chemically similar lanthanide elements which appear together at the bottom of the Periodic Table. Two other elements, yttrium and scandium, have similar chemical properties, and are often also referred to as REEs. REEs can be divided into "light" and "heavy" REEs.

According to the U.S. DoE, "critical" REEs refers to "the stuff you need the most but can't get enough of."

All the REEs have very exotic names:

- lanthanum (La)
- cerium (Ce)
- praseodymium (Pr)
- neodymium (Nd)
- promethium (Pm)
- samarium (Sm)
- europium (Eu)
- gadolinium (Gd)
- terbium (Tb)
- dysprosium (Dy)
- holmium (Ho)
- erbium (Er)
- thulium (Tm)
- ytterbium (Yb)
- lutetium (Lu)
- yttrium (Y)
According to the US DoE, the short term (<5 years) and long term (5-10 years) supply risk of the most important elements are as graphically presented below:

REEs are chemically similar to each other, thus:

- they are always found together;
- they are difficult to separate from each other;
- require complex processing routes;
- need significant capital investments;
- require high operating costs; and
- demand dynamics for one, indirectly affects the others.
REEs are not actually rare, especially in comparison to tin, silver and gold. However, they are usually not concentrated in large veins of minerals the way iron, copper, gold, and other minerals are. Thus, the *scarcity of economically viable deposits* is what classifies these minerals as ‘rare’.

<table>
<thead>
<tr>
<th>Elements</th>
<th>Crustal Abundance (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nickel</td>
<td>90.0</td>
</tr>
<tr>
<td>Zinc</td>
<td>79.0</td>
</tr>
<tr>
<td>Copper</td>
<td>68.0</td>
</tr>
<tr>
<td>Cerium</td>
<td>60.0</td>
</tr>
<tr>
<td>Lanthanum</td>
<td>30.0</td>
</tr>
<tr>
<td>Cobalt</td>
<td>30.0</td>
</tr>
<tr>
<td>Neodymium</td>
<td>27.0</td>
</tr>
<tr>
<td>Yttrium</td>
<td>24.0</td>
</tr>
<tr>
<td>Scandium</td>
<td>16.0</td>
</tr>
<tr>
<td><strong>Lead</strong></td>
<td><strong>10.0</strong></td>
</tr>
<tr>
<td>Praseodymium</td>
<td>6.7</td>
</tr>
<tr>
<td><strong>Thorium</strong></td>
<td><strong>6.0</strong></td>
</tr>
<tr>
<td>Samarium</td>
<td>5.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Elements</th>
<th>Crustal Abundance (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gadolinium</td>
<td>4.00</td>
</tr>
<tr>
<td>Dysprosium</td>
<td>3.80</td>
</tr>
<tr>
<td><strong>Tin</strong></td>
<td><strong>2.20</strong></td>
</tr>
<tr>
<td>Erbium</td>
<td>2.10</td>
</tr>
<tr>
<td>Ytterbium</td>
<td>2.00</td>
</tr>
<tr>
<td>Europium</td>
<td>1.30</td>
</tr>
<tr>
<td>Holmium</td>
<td>0.80</td>
</tr>
<tr>
<td>Terbium</td>
<td>0.70</td>
</tr>
<tr>
<td>Lutetium</td>
<td>0.40</td>
</tr>
<tr>
<td>Thulium</td>
<td>0.30</td>
</tr>
<tr>
<td><strong>Silver</strong></td>
<td><strong>0.08</strong></td>
</tr>
<tr>
<td>Gold</td>
<td>0.0031</td>
</tr>
<tr>
<td>Promethium</td>
<td>43374.00</td>
</tr>
</tbody>
</table>
A South African Rare Earth Story

What are REEs used for?

Around the world, everybody wanted to know “What are rare earths used for?” REEs vital to many modern technologies. Most have no substitutes and are indispensable in many applications.

- consumer electronics
- hybrid motors and batteries
- computers and networks
- communications
- clean energy
- advanced transportation
- health care
- environmental mitigation
- alternative (green) energy
- aerospace and defence
In 2010 the Pentagon wanted to know if the DoD is reliant on REEs and from where?

They found that the US military is 100% reliant on China for 100% REE metals, alloys and magnets - direct and indirectly.

Some of the defence related weapons and equipment that are reliant on REEs are:
A South African Rare Earth Story
REEs in hybrid car manufacturing

- LCD screen
  - Europium
  - Yttrium
  - Cerium

- Glass and mirrors polishing powder
  - Cerium

- UV cut glass
  - Cerium

- Diesel fuel additive
  - Cerium
  - Lanthanum

- Component sensors
  - Yttrium

- Hybrid electric motor and generator
  - Neodymium
  - Praseodymium
  - Dysprosium
  - Terbium

- Headlight glass
  - Neodymium

- 25+ electric motors throughout vehicle
  - Neodymium magnets

- Hybrid NiMH battery
  - Lanthanum
  - Cerium

- Catalytic converter
  - Cerium
  - Lanthanum
Suddenly the world became aware that China, home to some 95% of REE production, had an alarming strategic monopoly. And prices?

Deng Xiao Peng, the liberator of China’s economy, foreseen 30 years ago that China would become the Saudi Arabia of REEs - His vision has proven correct!
• The supply chain for metals starts at a mine, having an ore deposit – with the exception of Bre-X Minerals Ltd.
• A mine is an ore deposit from which metal can be recovered economically, safely and legally.
• For most metals, grade is the deciding factor for economic viability (Mineral Resource > cut-off grade). However, this is not necessarily true for REEs.
• The determining factor for REEs is if applicable technology exists such that the contained REEs can be extracted and separated as high purity compounds at competitive (Chinese) costs.

Bre-X Minerals Ltd. was a Junior Canadian mining company listed on the TSX. It was involved in a major gold mining scandal when it reported acquiring an enormous gold deposit in Indonesia. In October 1995 the company announced significant amounts of gold had been discovered, sending its stock price soaring. Originally a penny stock, its share price peaked at CAD$286.50 in May 1996. However, the company collapsed in 1997 after the gold samples were found to be a fraud.
At a high level REEs are 1) extracted to produce a mix rare earth salt that are 2) separated and purified through a hydrometallurgical (separation) plant
to produce individual high purity REEs i.e. separate high purity La, Ce, Pr, ...Yb, Lu and Y.

Compared to “traditional” metals, overall recoveries are fairly low (<60%).
   • It is more important to produce a feed suitable for separation and purification.

The extraction of rare earths is more akin to a chemical factory than a minerals process plant.

The importance of ore grade and mechanical beneficiation is to reduce the amount of expensive chemicals required.
   • Thus ensuring economically competitive production costs.
Most REE deposits are associated with nuisance elements to produce high purity REEs – i.e. radioactive and metallic elements (Pd, Zn, Cu, and Fe, Mn).

Most challenging nuisance elements are the radioactive (regularly present), acid users and impurity elements.

To produce the desired REE metal, nuisance elements need to be separated from REEs.

REE technology has not been developed outside China and those with it did not share.

The Chinese government prevents REE expertise to be “exported” from China.

Ore characteristics of most “new” deposits prevented use of conventional approaches.

New process flows had to be developed for the “unique” orebodies outside of China.

A race to production occurred with >200 REE projects surfacing with room for <5-6 (including the frontrunners).

Fast-tracking was at the order of the day - everybody tried to secure a place in the leading pack.
Meet Jonathan Goodluck

An African Rare Earth Story

- Junior mining company acquired an “unknown” REE orebody (incl. pulp samples) from a major mining house,
  - “paid” student’s salary – no future royalties, shareholding, options, right, etc.
- Confirmed the Mineral Resource by drilling a “few” confirmatory holes and reanalysing the pulps, and declared a significant Mineral Resource,
  - capable of supplying 10% or the world’s REE demand for >20 years.
- Listed toward the end of 2010,
  - a “few” weeks after the world “discovered” the importance of REEs.
- IPO was extensively oversubscribed,
  - raised more funds than what they ever thought necessary.
- Obtained a further investment by securing a strategic partner.
- Commencing with the study phase they had a good investment in:
  - the second best commodity (after Au);
  - an investor “friendly” country;
  - experienced management;
  - strategic partner and offtake agreement; and
  - funds (> $80m).
The unique characteristics of the new (ex-China) REE orebodies prevents an “one size fits all” approach,
• like in most instances “the orebody dictates”.

The principle of fast-tracking (complex) REE projects lies in securing the associated metallurgical data,
• else the supposed process flow is a mere “fairy-tallurgy”.

“fairy-tallurgy” as opposed to a “geo-fantasy”
Complexity is solved through innovation and creativity.
• In my experience an opposing relationship exists between creativity and structure;
• structure (project management) stifles creativity;
• without structure, creativity does not yield (timeous) practical and techno-economic solutions, thus
• structure and creativity have to be balanced (a difficult act) to effect pragmatic results in a “realistic” timeframe - too keep shareholders and funders interested.
Innovation and creativity necessitates time and money.

Funds were available. However, due to the race to construction, time pressure was a reality.

“Conventional” metallurgical testwork is normally performed by linear (waterfall) approach,
  • e.g. crushing → milling → flotation → leaching.

Agile approach reduces complexity and risk by subdividing project into small manageable cycles e.g. dating and schooling. It is:
  • repetitive and incremental approach;
  • rely on continuous planning and feedback; and
  • is more adaptive.

Development of REE process flow is akin to R&D. Thus, an Agile-type approach were adopted where multiple (worldwide) testwork campaigns were executed that were:
  • parallel: slight changes can yield different results;
  • confirmatory: validation of the results - if not why not?
  • different methods: comparative assessments to quickly change method if preferred one became obsolete.
• The prefeasibility testwork took 3 years with testwork performed in South Africa, Canada, Australia (3 labs), China (2 Labs), Chicago and Germany. During this time:
  • the major beneficiation options were exhausted;
  • both acid and caustic cracking routes were assessed;
  • various processes equipment were tested (i.e. centrifuge, autoclave, micro filtration, dry milling, acid mixing, rotary kilns, FBR).
• Metallurgical expenses totally outweighed geological drilling costs.
• Wealth of data was generated from which the optimum process flow (for the specific ore) was developed.
• The final process route was the resultant of all the testwork with no single solution by one testwork facility.
  • Each lab contributed a piece of the puzzle (mosaic theory).
Patented process route

- The ore beneficiation method was patented and presented a unique process flow for the extraction of REEs from this unique orebody.
- The patented process route was a combination of existing (proven) metallurgical unit processes. However, these were:
  - not previously applied in REE applications; and
  - uniquely configured.
- Advantage is:
  - very low operating costs; and
  - high recoveries.
Key technical attributes that differentiate REE projects are:

- good in-situ REE grades (>4-5% TREO);
- code compliant Mineral Resource estimates;
- significant portion of critical/heavy REEs in distribution;
- clear familiarity (understanding) of deposit mineralogy;
- existing (proven) metallurgical process flow;
- clear definition of final product composition and purity;
- secured offtake agreement;
- low operating cost (incl. separation <$11-$12/kg TREO);
- capital cost <USD200m; and
- competent management and technical team.
China abolished its quotas in 2015, after the WTO declare them illegal. But it may have been a hollow victory.

REE demand is predicted to continue growing.

Magnet based applications is forecast to grow at highest rate (±10% per annum), which implies a doubling in demand for magnet REOs over the next 7 years.

China’s domestic production may be lacking to satisfy ≥2020 domestic demand without major production increase.

In 2015 Molycorp filed for bankruptcy and Lynas’ production is uncertain. Now, no REE shortage exists, with most in surplus.

Currently, the world are still dependent on China, who consolidated control over its REEs and can dictate prices.

Future projections are that certain REEs will be in surplus, while others will be in deficit.
Derick R de Wit
082 381 3517
dedewit@Deloitte.co.za

Deloitte refers to one or more of Deloitte Touche Tohmatsu Limited, a UK private company limited by guarantee, and its network of member firms, each of which is a legally separate and independent entity. Please see www.deloitte.com/about for a detailed description of the legal structure of Deloitte Touche Tohmatsu Limited and its member firms.

Deloitte provides audit, tax, consulting and financial advisory services to public and private clients spanning multiple industries. With a globally connected network of member firms in more than 150 countries, Deloitte brings world-class capabilities and high-quality service to clients, delivering the insights they need to address their most complex business challenges. The more than 200 000 professionals of Deloitte are committed to becoming the standard of excellence.

This communication contains general information only, and none of Deloitte Touche Tohmatsu Limited, its member firms, or their related entities (collectively, the "Deloitte Network") is, by means of this communication, rendering professional advice or services. No entity in the Deloitte Network shall be responsible for any loss whatsoever sustained by any person who relies on this communication.

© 2016 Deloitte & Touche. All rights reserved. Member of Deloitte Touche Tohmatsu Limited