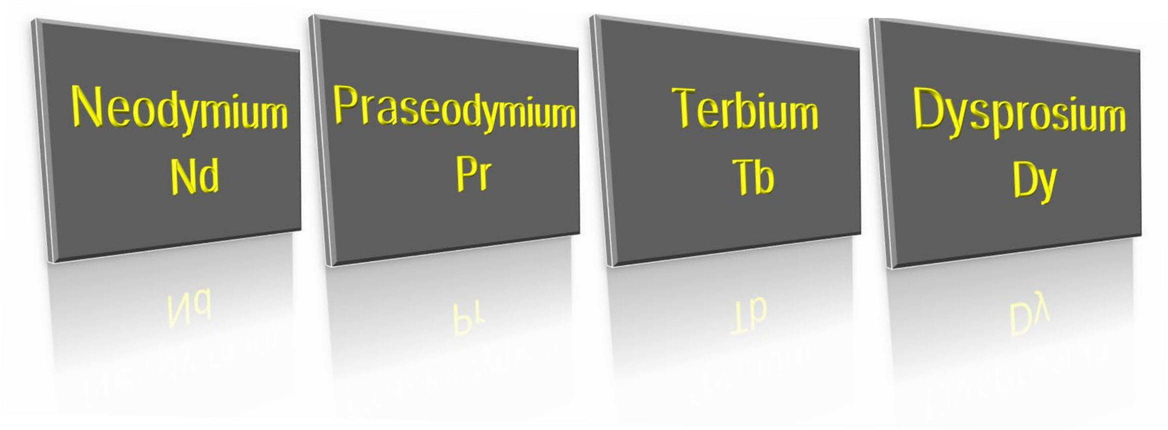
ARK MINES LTD.

FUTURE TECHNOLOGY MINERALS IN SANDS



LOW-COST MINING AND PROCESSING OF RARE EARTHS AT SANDY MITCHELL

Outlining the advantages and benefits of the deposit

30 April 2024

Introduction

The Ark Mines (ASX: AHK) Sandy Mitchell Rare Earths Project (Sandy Mitchell) is a well-advanced prospect boasting both light and heavy rare earths in mineral sands deposits in far north Queensland. Rare earth elements (REEs) are critical in the manufacture of electric vehicles (EVs), wind turbine generators and portable electronics.

The project, part of a portfolio of tenements, is wholly owned by Ark Mines and presents a unique and exciting investment opportunity in the mining-friendly state of Queensland.

The rare earths at Sandy Mitchell are hosted in the phosphate minerals, monazite and xenotime, which are part of a larger mineral assemblage that accumulated as mineral sands by gravity separation during sedimentary processes (in this case, through wave action). Such deposits are known as 'placer' deposits.

Placer deposits generate a very high-grade rare earth mineral concentrate (REMC), the main source of the elements, praseodymium (Pr) and neodymium (Nd), used in the production of light magnets; and often also contain the more valuable elements terbium (Tb) and dysprosium (Dy), used to produce heavy magnets.

Both of these ore bodies were found to be present following an in-depth mineral analysis using quantitative evaluation of minerals by scanning electron microscopy (Qemscan®) in 2010 by the Japan Organization for Metals and Energy Security (JOGMEC). The results are currently being reviewed by Ark Mines to determine a Mineral Resource estimate for the Sandy Mitchell in compliance with the *Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves* (JORC Code, 2012).

Also present are the highly sought after co-products, zirconium (Zr), e.g. zircon used in glass and ceramics manufacture; and titanium (Ti), e.g. ilmenite and rutile, used in the aerospace, automotive and electronics sectors, as well as a wealth of other industries.

Extracting rare earths from placer deposits has many benefits and advantages compared with the other two types of rare earth deposits: hard rock, and ionic clay (IC).

Mining is considerably cheaper than it is for hard rock deposits as the sands are near-surface and readily accessible to standard excavating equipment with no overburden removal, underground development or drilling and blasting involved. Processing, using gravity, magnetic and small flotation circuits, has a low-energy demand without the need for primary and secondary crushing, grinding or high-temperature slurries associated with hard rock.

There is also a far lower environmental footprint, as mining has a low strip ratio (i.e. less waste per unit of ore); processing uses less water that is fully recyclable and only need be of a low-quality; and site rehabilitation is relatively straightforward compared with the high strip ratio, large amounts of water and environmental impacts involved with hydraulic extraction at IC mines.

Rare earth concentrates, along with zircon and ilmenite can be sold to existing refineries in China, as well as developing markets in the USA and Australia, where there are emerging rare earth refineries, to generate intermediary revenue, allowing for the staged development of a processing plant to eventually supply more valuable mixed rare earth carbonates (MREC) and NdPr oxides.

All the benefits and advantages outlined here regarding the mining and processing factors means that the Sandy Mitchell can quickly be developed and start production.

The following report is a metallurgical review and commentary on the Sandy Mitchell placer deposit with comparison to other deposit types. It was commissioned by Harrier Project Management Pty Ltd (Harrier) on behalf of Ark Mines Ltd and independently conducted in April 2024 by Met-Chem Consulting Pty Ltd. The report was prepared to present the REE assemblage and outline the benefits and advantages of mining and processing placer deposits over other rare earth deposit types.

Harrier boasts significant experience with active and significant engagement in large mining projects in Australia and abroad over many years; not least, as the managing firm producing the definitive feasibility study (DFS) for a large rare earths project in Victoria.

Harrier presents this report to provide a platform for an understanding of why Ark Mines continues to develop the Sandy Mitchell given the significance of rare earths within the geopolitical climate.

Harrier
project management

30 April 2024

MET-CHEM CONSULTING Pty Ltd

Metallurgical review and commentary of the Sandy Mitchell Rare Earths Project

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1 Executive summary

The following are the key findings of the commentary.

- The Sandy Mitchell is a typical placer deposit in regard to rare earth product potential.
- The world production of rare earths (REs) is derived from three types of deposits:
  - placer (i.e. mineral sands, as per Sandy Mitchell)
  - hard rock
  - ionic clay (IC).
- Placer deposits have the following advantages over the other two types of deposits:
  - They generate very high-grade rare earth mineral concentrate (REMC), typically ~50% rare earth oxide (REO) which characteristically contains monazite as the main RE host mineral. This is the main source of the 'light magnet' REs, praseodymium (Pr) and neodymium (Nd).
  - They often (but not always) contain the mineral xenotime which contains significant quantities of the high-value 'heavy magnet' REs, terbium (Tb) and dysprosium (Dy).
  - The deposit style of mineralogy is highly amenable to processing numerous products using standard beneficiation processes, such as gravity, magnetic and/or flotation.
  - Due to the natural liberation, comminution (i.e. crushing and grinding) is usually not required.
  - The beneficiation processes used (gravity, magnetic and a small flotation circuit) are significantly cheaper to construct than the whole-ore flotation process usually employed in hard rock deposits.
  - The beneficiation process is also significantly cheaper to operate than hard rock flotation as it does not require elevating the slurry temperature and can use lower quality water which can be fully recycled.
  - Zirconium (Zr), e.g. zircon; and titanium (Ti), e.g. ilmenite and rutile co-products are in demand and have a strong market. While there has been a highly publicised, long-term strategy of the West's desire to free itself of the overwhelming dominance in rare earth mining, as well as dependence on REMC refineries, in China; it is likely that, in the short term, the concentrate will be sold to a Chinese refinery to produce mixed rare earth carbonate (MREC).
  - RE concentrates from placer deposits have traditionally (in recent times) only been sold to China; however, there are emerging RE refineries in Australia and North America that are actively seeking these concentrates as feedstock.
  - These deposits allow for staged development by generating revenue through sales of the zircon, ilmenite and RE concentrates from their beneficiation plants.
  - RE refineries can be constructed at a later time (and location) to maximise RE revenue from either an intermediate chemical product, e.g. a mixed rare earth carbonate (MREC) or separation to oxides (e.g. NdPr oxide for the magnet market).
  - The processing of RE mineral concentrates from placer deposits is well known and technical risks have been reduced significantly in the past 10 years in Australia by good pilot programs and competent engineering design.

- Placer deposits have some disadvantages compared to hard rock and ionic clay deposits, namely:
  - RE concentrate containing high proportions of monazite is very radioactive and this must be taken into account during project design. Furthermore, the concentrate is designated as a 'Class 7: Radioactive material' under the *Australian Code for the Transport of Dangerous Goods by Road & Rail* (ADG Code) administered by the National Transport Commission. It must therefore be transported with a placard and UN (United Nations) number. International transport is particularly expensive as dedicated vessels are usually required.
  - The rare earth host minerals (monazite and xenotime) are refractory and require intense chemical and heat treatment processing routes; namely, acid baking and caustic conversion.
  - These processes are considerably higher in capital expenditure (capex) and operational expenditure (opex) than for non-refractory hard rock RE minerals (such as bastnaesite) and ionic clay deposits.
  - While some placer deposits contain some Tb and Dy due to their xenotime content, their ratios compared with other REs are much lower than pure xenotime hard rock deposits (e.g. Browns Range in Western Australia) and ionic clay deposits in China and South America.
  - The rare earth mineral concentrate (REMC) produced by Mineral Technologies from Ark Mines Sandy Mitchell air core drilling samples indicates a high-grade concentrate of mineralogy that will have many potential off-takers, including domestically, in North America, and in China.
  - The REMC is very likely to be suitable as feedstock for a standard sulphuric acid baking process as being implemented in Australia by Iluka Resources (Iluka) and the Lynas Corporation (Lynas), as well as caustic conversion used in Estonia and being implemented in Canada and the USA.

2 Rare earth global production

Global production of rare earths is approximately 220,000 tonnes per annum (t/a) as rare earth oxide (REO) equivalent. It is estimated that approximately 70–80% comes from hard rock sources, mostly from China, with the balance mainly from the USA at the Mountain Pass Rare Earth Mine and Processing Facility owned by MP Materials; and Australia at the Mount Weld mine owned by the Lynas Corporation.

Ionic clay deposits in China and Myanmar, while accounting for only ~10% of the total REO production, supplies most of the high-value (i.e. in-demand) Tb and Dy for the rapidly growing permanent magnet market for electric vehicle (EV) and wind turbine manufacture.

The balance comes from monazite/xenotime concentrates in placer deposits in China, Thailand and India. While Australia (Iluka, Rio Tinto and Tronox) previously exported these concentrates for processing in France, China and Thailand, this practice has all but ceased in recent years due to environmental restrictions (in France) and the desire to extract value from the contained RE.

3 Hard rock processing

The recovery of RE from hard rock sources is essentially defined by the style of the mineralogy with a particular focus on the RE host minerals.

Essentially, only two host mineral types are commercially treated to recover RE:

- Refractory RE phosphate minerals:
  - Monazite, such as the deposit at the Lynas Mt Weld mine, now in production, and the Hastings Technology Metals Yangibana Rare Earths Project, currently under construction, both in Western Australia. This deposit style is very common in China, particularly in Inner Mongolia (Bayan Obo).
  - Xenotime, such as at Browns Range (also in WA) being developed by Northern Minerals, with an offtake agreement to supply the Iluka refinery.
- Acid-soluble fluorocarbonates of bastnaesite/synchysite, such as the deposits at Mountain Pass (in production). This mineral is also common in China.

4 General hard rock flow sheet

Regardless of the host mineral, all commercial hard rock deposits follow the general process outlined here:

1. Run-of-mine (ROM) feed to stockpile.
2. Comminution via crushing and milling.
3. Beneficiation, usually by froth flotation; however, gravity separation, magnetic separation and/or ore sorting may be used if the mineralogy is amenable. The REMC is usually transported off site (although Mountain Pass is an exception) to a refinery that has good access to chemicals, power, water and logistics. Note that this is a saleable product to existing RE refiners.
4. The REMC is thermally and/or chemically treated to render the RE soluble.
5. Leaching of the treated REMC to dissolve the RE and filter off the solid waste.
6. Treatment of the 'raw' RE solution to precipitate and remove the impurities dissolved during the leaching process.
7. Precipitation of a pure RE chemical intermediate (such as RE carbonate) which is a suitable feed for a separation plant. This is also a value-added product and is a widely traded product in its own right.
8. If RE separation takes place on the same site as the refinery, step 7 above can be excluded and a purified RE solution can be sent directly as a feed to produce individual or (usually) groups of RE products.

The various hydrometallurgical processing flow sheets are presented below, assuming an RE mineral concentrate feed and an RE carbonate product.

5 Monazite/xenotime flow sheet

There are two common flow sheets adopted for processing these types of concentrates, regardless of whether they are from hard rock or placer deposits:

- sulphuric acid baking flowsheet
- caustic conversion flowsheet.

5.1 Sulphuric acid baking

The sulphuric acid baking process is by far the most widely used process for treating refractory concentrates and is employed by Lynas, in both Malaysia and Kalgoorlie, and throughout China (e.g. Bayan Obo). The general stages are shown in Figure 1.

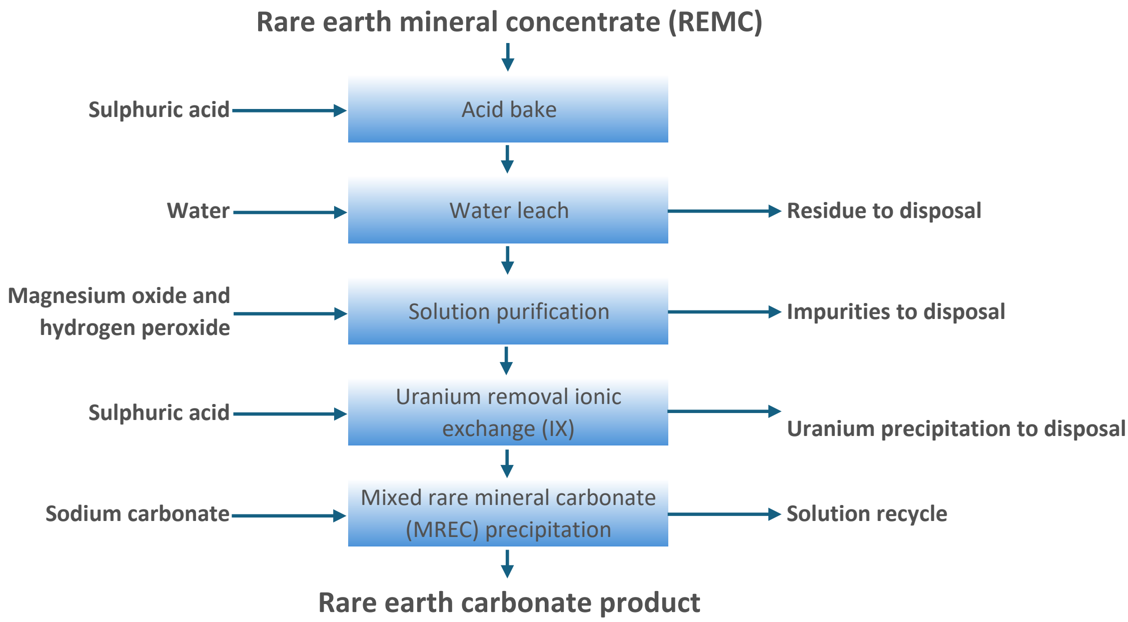

Figure 1: Sulphuric acid baking flow sheet

The process starts with ensuring the REMC is dried then mixed with concentrated sulphuric acid to form a paste. The paste is then added to a kiln (typically a rotary type) and heated to between 250 degrees Celsius (°C) to 300 °C to chemically 'crack' the RE minerals and convert the RE and other impurities to soluble sulphates. The baked concentrate is then water leached in stirred tanks. The insoluble residue, being RE depleted, is filtered and sent to a tailings facility. The 'raw' leach contains RE in solution along with dissolved impurities, such as iron (Fe) and the radioactive elements of thorium (Th) and uranium (U).

The raw leach solution is then purified by raising the pH with magnesium oxide (MgO) and adding hydrogen peroxide (H_2O_2) to precipitate iron and thorium. These impurities are filtered and are usually sent to a separate lined tailings facility due to the radioactive nature of the thorium.

The leach solution is finally sent through an ion exchange (IX) process to remove any residual uranium before going to final precipitation using sodium carbonate (Na_2CO_3) to make a high-purity RE carbonate product. This is the preferred product for RE separation plants.

5.2 Caustic conversion

The caustic conversion process was traditionally the preferred route at Rhône-Poulenc (now Solvay) at La Rochelle in France; although this facility stopped processing mineral concentrates in the late 1990s due to environmental constraints on processing radioactive materials. The process is also used at Silmet, Estonia (Neo Performance Materials) and in China. Importantly, the process is gaining momentum for new plants, such as at Energy Fuels in Utah, USA, and at the Saskatchewan Research Council (SRC) facility in Canada.

The process offers some advantages over sulphuric acid baking, such as:

- a reduced area footprint
- significantly reduced gas scrubbing requirements
- reduced opex as the sodium hydroxide (NaOH) used is recycled
- reduced waste stream volumes
- reduced radioactive elements reporting to the RE carbonate product, particularly actinium (Ac)
- a potentially reduced carbon footprint, as there is no need for drying and baking kilns.

The process has some disadvantages, such as:

- reduced RE recovery from xenotime
- generally, a higher capex.
- costs for the caustic reactor are expensive as a large amount of nickel (Ni) alloys are needed.

The general stages for the caustic conversion process are shown in Figure 2 below.

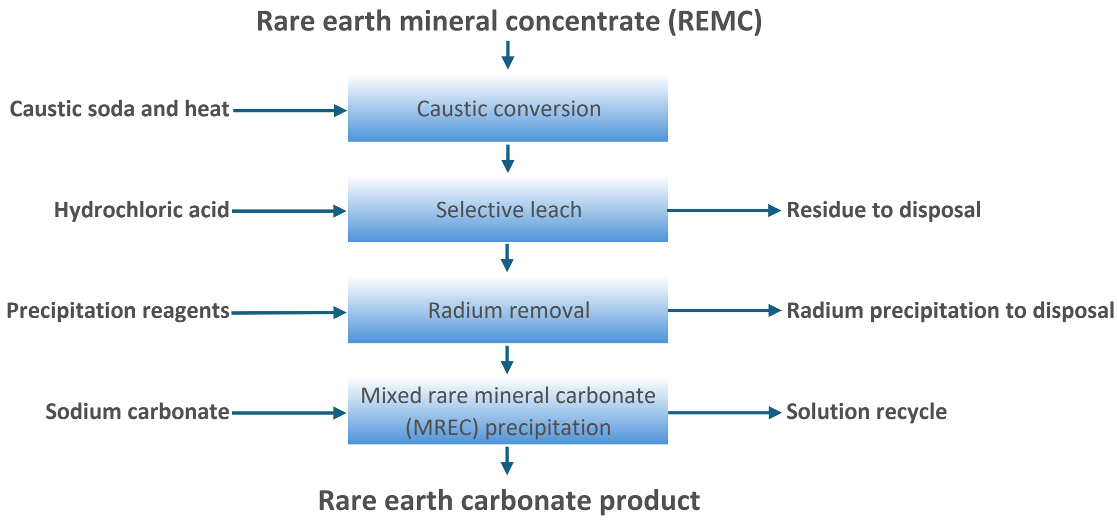

Figure 2: Caustic conversion flow sheet

The caustic conversion process traditionally uses very concentrated solutions of sodium hydroxide at near its boiling point 140–160 °C to crack the RE minerals in the concentrate. This is usually done in heated vessels constructed of alloys containing high levels of nickel.

Post-caustic conversion, the slurry is filtered and the solution containing essentially sodium phosphate is either sent to waste or is treated with lime to regenerate the sodium hydroxide. The solids then go to acid leaching.

The acid leaching can either be done with weak hydrochloric acid (as shown in Figure 2) or strong nitric acid (as per the Solvay's process previously operated in France). It is outside of the scope of this review to discuss the merits of both, but the chemistry is essentially very similar. The slurry is then filtered with the leach residue solids reporting to waste.

The leach solution (particularly for weak hydrochloric acid leaching) is a quite pure RE chloride solution and usually only requires removal of trace (but radioactive) quantities of radium (Ra) which is precipitated by adding two reagents that are then filtered and sent to waste.

The final leach solution is then treated by adding a carbonate (usually sodium carbonate) to precipitate an RE carbonate as per the sulphuric acid bake route.

6 Fluorocarbonate flow sheet

Bastnaesite (and to a lesser extent synchysite) is a significant source of RE worldwide. Well known deposits are Mountain Pass, USA (in production); Bayan Obo, China (in production); the Ngualla Rare Earth Project in Tanzania which is in the front-end engineering and design (FEED) study phase; and Nechalacho, Canada (development suspended).

The host fluorocarbonate minerals are easily soluble in acids; however, most plants choose to calcine to reduce reagent consumption downstream. The general stages of the process are given in Figure 3 below.

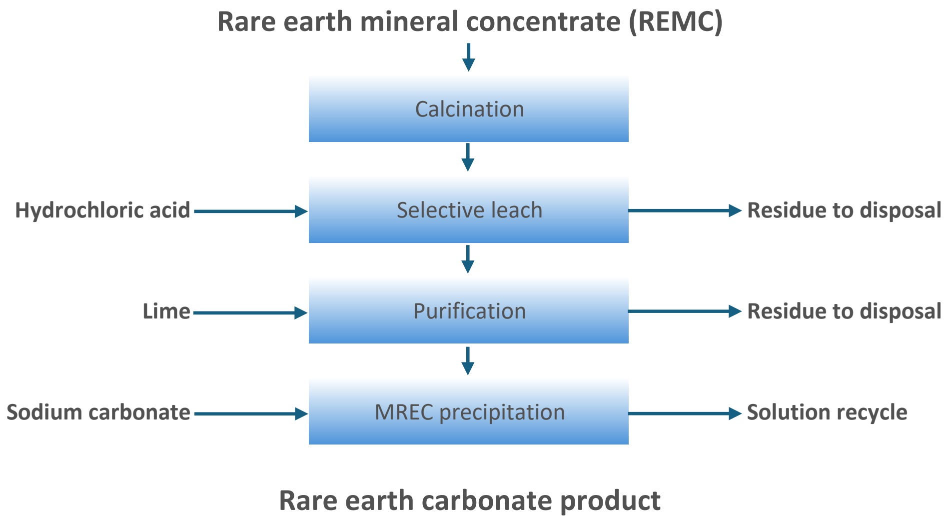

Figure 3: Fluorocarbonate calcination flow sheet

The RE concentrate is first dried then sent to a rotary calciner operated at 600–800 °C to convert the RE fluorocarbonate minerals to RE oxides, as well as iron and thorium.

After cooling, the calcined mineral concentrate is subjected to weak hydrochloric acid leaching. The preceding calcination process has rendered the iron and thorium resistant to dissolution so the majority of these deleterious metals report to the residue solids.

After filtering, the raw RE solution is purified by adding lime to precipitate iron and thorium as per the sulphuric acid baking process. Uranium is normally low in these minerals, so subsequent IX for uranium removal is generally not required.

The final product is produced by adding a carbonate; again, generally sodium carbonate, although ammonium bicarbonate is preferred in China.

7 Ionic clay processing

Ionic clay (IC) deposits have a unique mineralogy in that the REs are weakly adsorbed onto clay minerals such as kaolinite and halloysite. They can be released (desorbed) through contact with stronger solutions, typically, ammonium sulphate solutions are employed, which exchange cations for the REs.

Historically, South China and Myanmar have accounted for all of the IC operations using in situ or hydraulic mining with devastating environmental consequences (see Figure 4).

Figure 4: In-situ leaching pond in South China

In recent times, western projects have started developing in South America which will use counter-current decantation (CCD) tanks – significantly more environmentally suitable than the Chinese methods illustrated.

IC deposits have some inherent advantages over other types, such as:

- a high proportion of high-value Tb and Dy compared to monazite
- cheaper mining costs
- low consumption of a relatively cheap reagent (i.e. ammonium sulphate)

They do have the following challenges:

- a very low grade – typically 0.1% to 0.2% of total rare earth oxide (TREO) meaning high mining rates are required
- they cannot be upgraded via beneficiation, so very large plants are needed

- very large amounts of water which, although it can mostly be recycled, means that very large tailings filters and membranes are required.

Figure 5: A decommissioned hydraulic mine site, also in South China

The mined clays are usually put through a roll/toothed sizer and then to a wash trommel to break up clay lumps. Oversize material (typically >2 mm) is then screened off. The screened undersize material is then sent to a CCD circuit for desorption with ammonium sulphate solution. The tailings then report to thickener/filters before being sent back to the pit for rehabilitation.

The raw leach (desorption) solution is then purified, although typically ammonium bicarbonate is used as the ammonium content is ultimately recycled. The precipitated impurities are generally minor and are sent to a dedicated lined storage facility after filtering. The purified RE solution is then treated with more ammonium carbonate to produce an RE carbonate product which is also recovered via filtration. The final solution undergoes reconcentration via membranes for recycling. Typical IC processing stages are given in Figure 6 below.

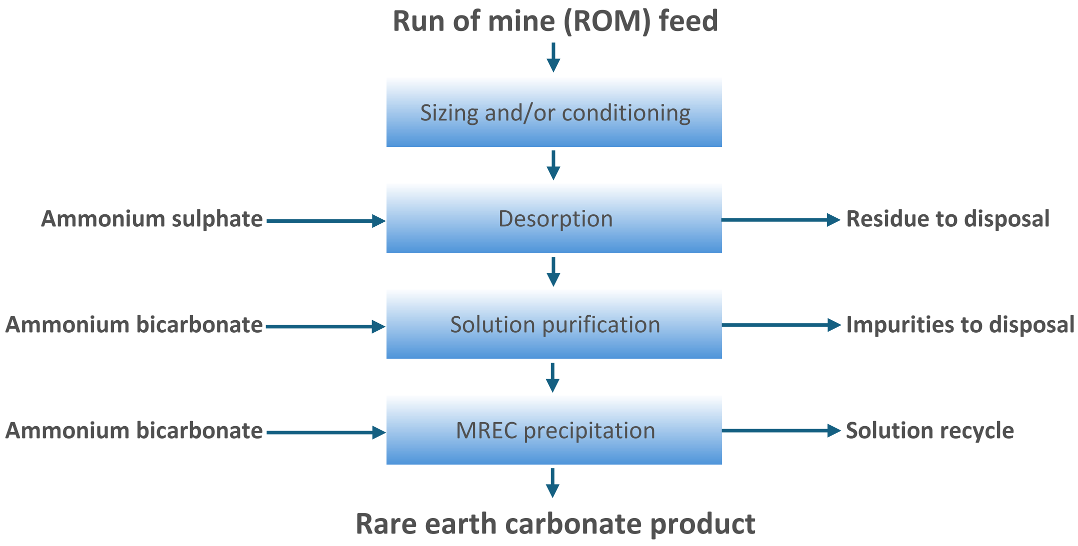

Figure 6: Ionic clay flow sheet

8 Comparison with peer placer deposits

8.1 Rare earth mineral concentrate (REMC) grade

The Sandy Mitchell deposit has been shown capable of making a high-grade REMC through standard beneficiation techniques of screening, gravity, flotation and magnetic separation processes. This was confirmed in the November 2023 report by Mineral Technologies *Metallurgical Characterisation of One Composite Ore Sample* (Report MS 23 / 4443690 / 1) where REMC with a grade of 51.9% REO was produced.

In the report, the REMC is described as having a low content of the high value Tb/Dy elements representing approximately 1% of the total proportion of rare earths present. This suggests that the predominant RE host mineral is monazite with only minor xenotime present, which aligns with the 2010 SGS Australia report commissioned by the Japan Organization for Metals and Energy Security (JOGMEC).

As a comparison, the Tb/Dy proportion will be lower than Iluka's WIMM100 updated Mineral Resource estimate (https://www.iluka.com/media/t5nctvdr/wim100-mineral-resource-estimate-update.pdf) which gives a monazite to xenotime ratio of ~1:4.

However, there are many placer deposits, notably, the Tronox Australia operations at Chandala, Wonnerup and Ginko, that have lower Tb/Dy content than the REMC from the Sandy Mitchell deposit.

8.2 Marketability of mixed rare earth carbonate (MREC)

The TREO grade of the MREC reported in the 2023 Mineral Technologies report will almost certainly be acceptable to existing sulphuric acid bake refiners accepting third-party concentrates (mainly China) and those in Australia under construction (Lynas and Iluka). It is noteworthy that North America is implementing the conversion route at plants being constructed in Saskatchewan, Canada and Utah, USA.

Traditionally, monazite has been traded with pricing reported via such sites as Shanghai Metal Markets (metal.com); however, more recently, price contract structures have become somewhat opaque as the West pushes to secure supply of these critical metals (especially Pr, Nd, Tb and Dy).

9 Refinery options

It is expected that the possibility of adding a refinery to take the REMC through to a value-added RE carbonate product will be considered. The two flow sheets discussed in subsections 5.1 and 5.2 above are both suitable for the expected REMC composition as presented previously. If, however, there is an expectation that the xenotime content will rise then the sulphuric acid bake process may well have the advantage, as this maximises extraction of the high-value Tb and Dy from the xenotime mineral.

10 Recommended forward work plan

The following work plan is recommended from a metallurgical test point of view.

- Continue to build up a geometallurgical model of the resource as is presently being done. This should include continuing to make ‘heavy mineral concentrates’ which can then be sent for XRD mineralogy to determine the ratio of the RE host minerals, monazite and xenotime.
- Once a likely mining plan is identified, make a ROM composite(s) for Mineral Technologies to develop and optimise the process to produce an REMC of grade at least 50% REO. These optimised parameters will feed into a Class 5 scoping study, as defined by the Association for the Advancement of Cost Engineering (AACE).
- Begin desktop batch test work on the REMC bulk sample produced (say, 20 kg minimum) to define parameters suitable for feeding into a scoping study. For this first study, a single process route can be assumed (most likely sulphuric acid bake). Alternative routes can be tested and compared during the prefeasibility study (PFS).

Screen engineering companies to undertake the scoping study, focusing on those with RE experience.

End of the MCC *Metallurgical review and commentary of the*

Sandy Mitchell Rare Earths Project

Conclusion

Having evaluated the metallurgical review, breakdown of deposit types and processing options presented by MCC Consulting, Harrier Project Management has reached a number of conclusions concerning the viability of the Ark Mines Sandy Mitchell Rare Earths Project.

It can be seen that rare earth placer deposits offer a cheaper mining and processing route than is available to hard rock deposits. The work can be achieved effectively by simple excavation and haulage. This is largely due to the ease of accessibility to the mineral sands without the need to remove overburden, or perform any blasting or drilling.

This means that mining construction, development, production and maintenance costs are kept to a minimum as there is no need for the crushing and grinding associated with extracting hard rock deposits. Processing placer deposits also has the advantage of not requiring the very large amounts of water nor the high mining rates that are needed for efficient extraction from ionic clay (IC) deposits. This, in turn, translates to a more environmentally responsible mining footprint that is more readily rehabilitated.

Additionally, the processing options for Sandy Mitchell afford for flexibility and staged development. Acid baking and caustic conversion are deemed suitable if the rare earth mineral concentrate (REMC) composition is as currently expected. But if after further samples and analysis the xenotime content is found to be high enough, then acid baking would be the preferred option in order to optimise high-value terbium (Tb) and dysprosium (Dy) extraction.

The Sandy Mitchell boasts a number of benefits and advantages over other types of deposit. Key takeaways include:

- lower opex and capex due to simple mining and processing requirements
- low power demand
- high-grade REMC production
- highly sought after co-products
- easily accessible deposits, resulting in a low strip ratio
- short development time
- less time to get into production
- earlier payback on investments
- long-term production potential
- low environmental impact with no drilling or blasting
- located in Queensland, an historically mining friendly state
- Australian standards of employment and environmental conditions.

Harrier project management

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on behalf of

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