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Sub-Sector Coverage

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Rare Earths Primer:
Challenges & Technologies

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Rare Earths Primer

Challenges & Technologies

- + Rare Earth developments are now being driven more by government and end-user needs/wants rather than by stockmarket passions
- + REE have a plethora of uses but the "green transition" is dominating the scene with EVs and wind turbines having narrowed the focus down to four magnet metals, Nd, Pr, Tb & Dy
- + The REE space is constantly evolving with focus swinging to mineralisations, like monazite sands and Ionic Adsorption Clays that did not even stand a chance in 2009-12
- + That said, technologies, more than mineralisations, are now the discriminating factor
- + China is losing control of the Heavy Rare Earths space where it is a net importer and in risk of being a price-taker more than price-maker
- + Governments (particularly the US, Australia & Canada) are putting their money where their mouth is in backing "worthy" projects
- × Rare Earth prices have been pushed lower once again by China in an attempt to choke off development
- × The EV sector is not evolving at the pace that many projected
- × A plethora of "no-hoper" projects continue to crowd the sector and distract attention from those with the essentials for survival

This Time It's Different

The first upsurge in interest in Rare Earths in the period 2009-12 was characterised by a focus on mineralisations with a plethora of different minerals being proposed for exploitation to produce REEs.

Now, with the Second Coming of Rare Earths since 2019, many of those original mineralogies have been discarded and even those still being considered as not as important as the process for extracting the REEs in a timely and efficient manner. The profitability of the process is now paramount, with the other important characteristics being capex and energy efficiency.

In this primer, we shall look at the shift in focus and the technology issues which have become paramount in the Rare Earths world.

Rare Earths at the Crossroads

The first Rare Earth Boom of 2009-12 buried the old shibboleth that Rare Earths were rare. A vast proliferation of wannabes were almost exclusively focused on mining REEs and none that we can recall were looking at new processing technologies but rather accepting the traditional technologies, many of which were little changed since the 1970s. The number of listed companies was whittled down in the intervening years to a couple of dozen survivors by 2020.

While some of the imperatives that had driven interest in 2009-12 have now gone away, others remain or have been exacerbated:

- China dominance of supply & processing
- Chinese dominance of pricing
- The rising interest in wind energy in 2009-2012
- The far greater need (real rather than just mooted) in the 2020s for magnet metals for the HEV/BEV/EV industries
- In 2023/4, there began a trend of increased focus on the military/strategic uses of REEs
- Declining Chinese production of Heavy Rare Earths making them a net importer
- Mineralogies of interest had changed as monazite sands (with their attendant radioactivity) were no longer as daunting and Ionic Adsorption Clays (where meaningful deposits outside China had not been identified) became a realistic alternative to "old" mineralogies
- The REEs of interest had changed from a broad brush of most elements in 2009-12 (including Cerium, Lanthanum and Europium), to a narrower focus on the likes of Nd, Pr, Tb and Dy

While many investors had retreated with their fingers burnt after 2012, there was now a greater interest from governments in the resource security (including defence) implications of on-going China dominance.

The Over-Riding Dilemma

We are now fifteen years into the "rediscovery" of Rare Earths and several things have become clear that were swept under the rug in the first flush of enthusiasm. Firstly, finding and mining the Lanthanide Series minerals was not the hard part. Indeed, it was frighteningly easy to find deposits (even if most were also-ran). Beyond the issue that many REE projects were in isolated locations, the mining was in most cases envisioned rather straightforward open-pit technology, though even the underground deposits presented few challenges.

The real problem (and expense) was in the chemistry. In a mining community, where past difficulties were manifested in refractory gold deposits or laterite nickel deposits, Rare Earths represented a whole new level of trouble altogether. The requirement in most cases to process all the material through a myriad of chemical phases to extract the more valuable components was mind-boggling and expensive. Moreover, it quickly became clear that dealing with substantial amounts of noxious by-products was the price miners would have to pay to achieve commercial product of a desirable product range.

It was once succinctly put that ".. the world needs a better mousetrap to capture REE; one without the toll that comes with wholesale disposal of effluents, reagents and caustic byproducts".

The Current State of Play

Conventional methods used in all REE separation processes are based primarily on solvent extraction (SX), with some efforts being made on ion exchange (IX). These methods unfortunately rank very low relative to their ability to meet stringent standards of clean chemistry, efficiency and economics. In fact, they are responsible, in large part, for severe environmental and human health problems associated with REE mining world-wide. These collateral problems have been particularly evident in China, where for many decades the bulk of REE were mined and processed via low selectivity separation methods. The result of these processes was the discharge of generated waste into surrounding air, water, and land sites. Lax enforcement of existing regulatory laws has only served to exacerbate the problem.

The image below shows the state of the Silmet plant in Estonia around 2010, when it was a key chess piece in the initial REE boom, despite its primitive Soviet-style appearance. At that point beggars could not be chosers.

The Problem with Conventional Methods

In essence, Rare Earth processing is all about Chemistry, Chemistry, Chemistry. This is generally unwelcome talk for mining mavens as they mainly have their minds wrapped up in Geology, Geology, Geology. However, as the five years that Rare Earths have been in investors' minds have shown it's all in the processing and very little to do with the mining.

It's useful to look at the current processing of Bastnaesite (one of the key mineralisations at many REE deposits) to highlight how the current methodology is not only enormously laborious but also expensive in terms of opex, capex and consumables (mainly acid).

In order to reduce the acid consumption, bastnaesite concentrates are typically roasted to decompose the carbonate minerals before leaching with either hydrochloric or sulfuric acid. Cerium comprises about half of the rare earth content within bastnaesite, so removing it prior to solvent extraction dramatically reduces the solvent extraction capacity required for selective separation of individual Rare Earth elements.

At Bayan Obo, the largest producer of Rare Earths in China, the process starts with roasting with concentrated sulfuric acid to "crack" the monazite. The rare earth sulphates formed during this process are then leached with water, and excess acid is neutralized with magnesia and filtered. The leach solution then proceeds to solvent extraction, alternatively a mixed rare earth chloride (for electrolysis to *mischmetal*) could be produced by precipitation with ammonium carbonate, followed by dissolution with HCl and crystallization. Unfortunately, the radioactive element, thorium, is precipitated and reports to the leach residue. It cannot be recovered economically, resulting in both loss of the valuable thorium and potential environmental hazards. HF and sulfur dioxide report to the off-gas from roasting. Large amounts of water or alkaline solutions are needed to remove them, resulting in large volumes of acidic effluents.

All this amounts to an enormous quantity of acid and water employed, not to mention environmental emissions. It is no wonder that Rare Earth companies in the West have found themselves stymied in trying to develop processing flowsheets that tick all the environmental boxes while remaining in the lands of reality in terms of capex.

We all know the names of those companies that have sunk with no survivors from presenting excessive capex numbers in PEAs or PFS's (if they ever got that far). Ucore has eschewed that path, employed lateral thinking and gone outside the box to bring RapidSX into the REE processing equation.

Conclusion

It is said (and has been since the ancient Romans) that: *Sub Sole Nihil Novi Est*, or there is nothing new under the sun. This may indeed have been true for the Romans but sometimes even the repurposing of something already in existence can constitute an innovation. It is somewhat ironic that Rare Earths are referred to as the cutting edge of metals with super high-tech applications and yet the production of the REEs has shown itself to be mired in traditionalism and showing a lack of innovation.

Appendix: Case Study

Ucore Rare Metals

- + Ucore is now technology driven rather than deposit-driven
- + The company has its Kingston, Ontario, demonstration plant in operation and “proof of concept” is behind it
- + Its plant in Louisiana is evolving and is a case of right place at the right time
- + The Federal governments in both Canada and the US are now loosening purse strings to fund viable projects
- × Investors are still not the major funders of projects

Building a Better Mousetrap

Ucore is one of the great survivors of the First REE Boom of 2009-2012 having morphed from a potential developer of a REE mine at Bokan Ridge in Alaska to being focused on REE processing/extraction technologies. As we have often said, REE mining in most instances is akin to a low rent extractive activity, such as quarrying, with the value-added being in the mid- and downstream.

Ucore came to this realization in the middle of last decade and has pivoted towards technology over earthmoving. It turned its mind, in particular, to perfecting a better form of solvent extraction. Through 2019, Innovation Metals Corp. (IMC), a private Canadian-based company, developed the proprietary RapidSX™ technology for the separation & purification of REEs, Lithium (Li), Nickel (Ni), Cobalt (Co), and other critical metals, via an accelerated form of SX with a focus on R&D and process optimization.

In May 2020, IMC became a wholly owned subsidiary of Ucore Rare Metals Inc. and later that year, the commercialization and demonstration facility (CDF) was established in Kingston, Ontario with Kingston Process Metallurgy (KPM), Ucore’s commercialization partner, with detailed engineering, commissioning, testing and demonstration steps.

The ongoing technical transition is leading towards the full-scale REE separation plant at the Louisiana Strategic Metals Complex (SMC), being developed in Alexandria, Louisiana. This will have a capacity of 7,500 tonnes per annum (ex-cerium & ex-yttrium).

The Demonstration Facility

The REE separation demo plant is located within Ucore’s 5,000 square foot RapidSX™ Commercialization and Demonstration Facility at Kingston. The plant is capable of processing all RapidSX splits required to produce individual elements of Praseodymium, Neodymium, Terbium and Dysprosium. It would have a parallel 52-stage conventional solvent extraction (CSX) mixer-settler circuit that will match the RapidSX process configuration and enable direct head-to-head comparison of their performances. Once in commercial operation, this will be one of the first modern technology platforms for separating HREEs and LREEs as a replacement for CSX.

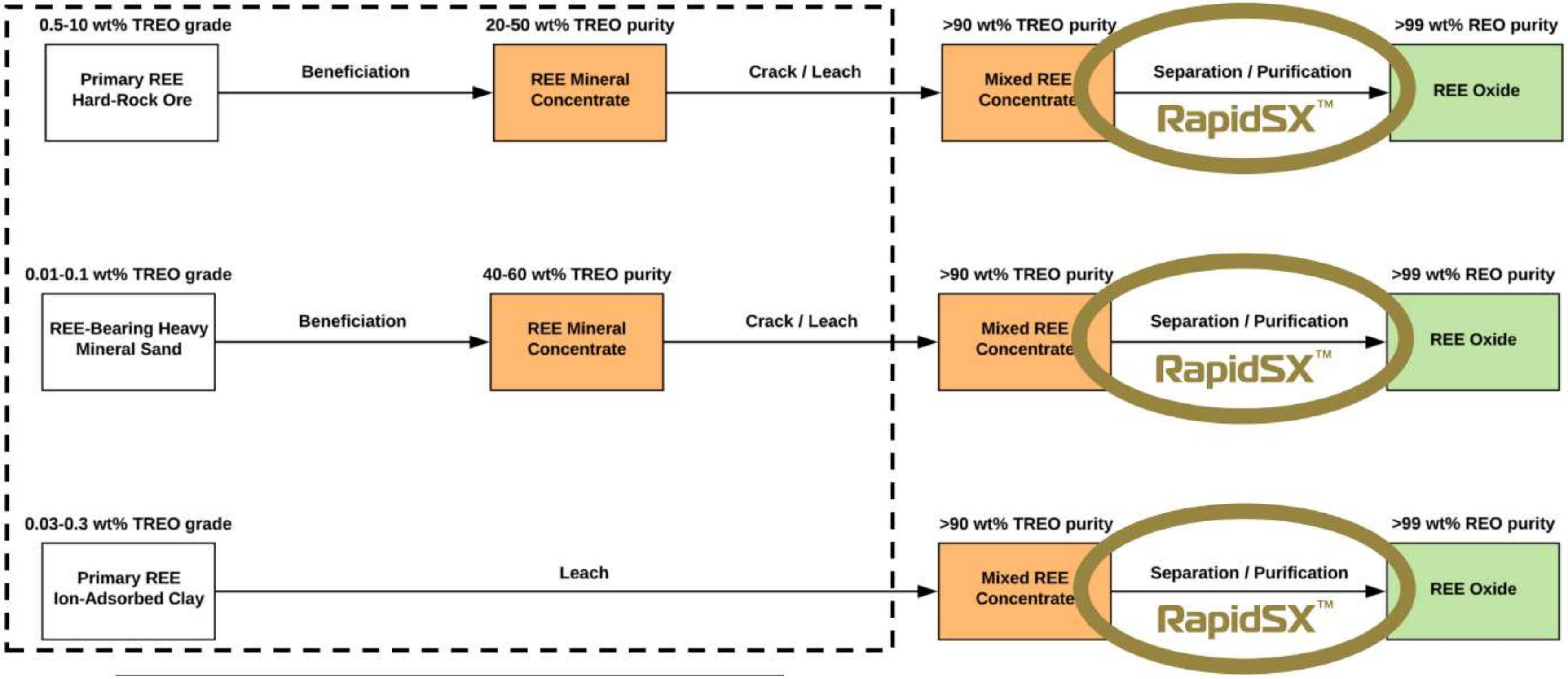
The final engineered layout of the demo plant takes up nearly all of the 465m^2 facility at KPM, thus building a plant within an existing building is the template for the engineering process that the commercialization team will replicate to create the first full-scale SMC. This initial SMC is scheduled to produce 2,000 tonnes of total rare earth oxides (TREOs) by the start of 2026 and 5,000 tonnes by 2027.

The Ucore team's work at the CDF over the past three-plus years has demonstrated a range of significant gains and process benefits of RapidSX™ for separating and purifying REEs. Ucore has qualified these RapidSX™ benefits through an independent 3rd party evaluation, filing a robust intellectual property ("IP") patent to protect the Company's clear process advantages, and embarking on a Demo Plant commercialization, scale-up and technology transfer program

Louisiana Strategic Metals Complex (LA-SMC)

The next phase is the development of a 7,500 tonnes per annum (ex-cerium and ex-yttrium) REE separation plant – the) in Alexandria, Louisiana. The company has been working to precisely quantify the benefits of RapidSX™ through a demonstration program for the US Department of Defense.

Overview of REO Supply Chain

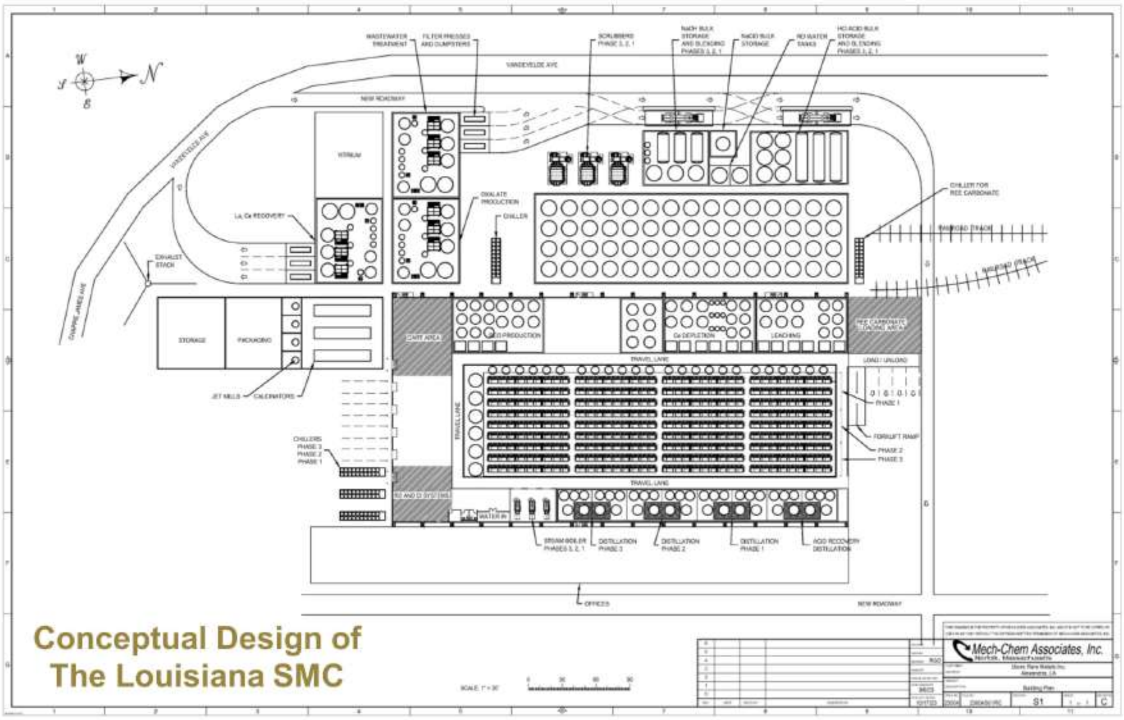


Ucore is preparing for the commercial processing of a broad array of both Heavy and Light mixed REE chemical concentrates at the LA-SMC facility originating from a wide variety of mineralization sources.

To date, three different feedstock sources have been included in the work at the CDF. Noted below are the detailed engineering, commissioning, testing and/or demonstration focus/optimization areas currently underway for each CDF and LA-SMC feedstock.

Ucore is conducting a knowledge "Copy & Paste" transfer from the RapidSX™ development and demonstration work at the CDF in Kingston, Ontario, to its developing multi-staged first commercial-scale REE separation and oxide production facility in Louisiana. The LA-SMC will be sited in this structure.

Below can be seen a site plan for the Louisiana facility:



The Process

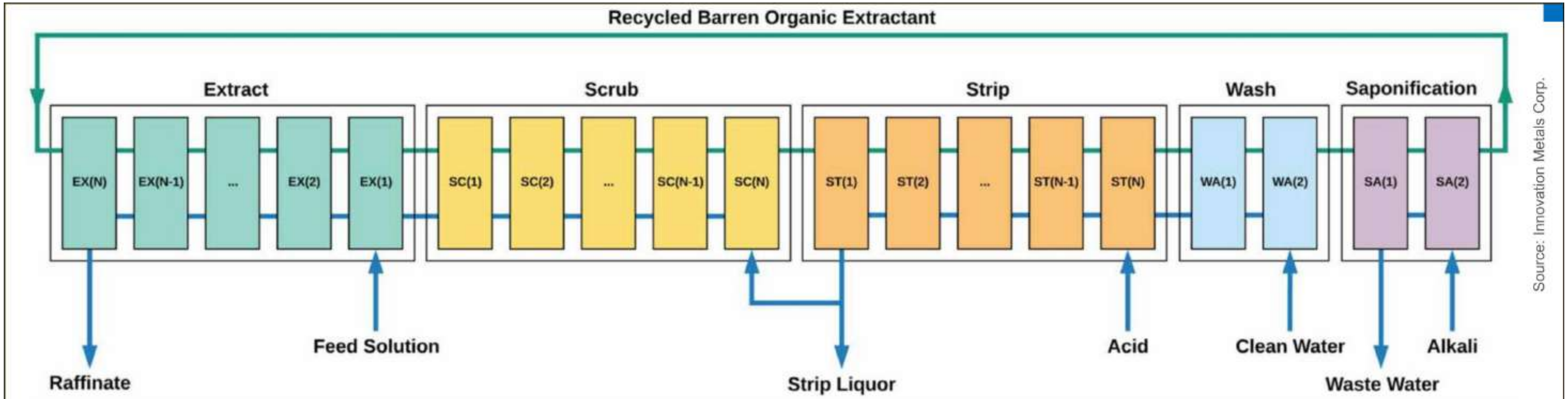
As for RapidSX™ process itself the phases are:

- Cerium Depletion
- Leaching to Produce Pregnant Leach Solution (PLS)
- Yttrium Depletion
- Processing through the 52-Stage RapidSX™ Demo Plant (heavies and/or lights – yielding PrNd, Pr, Nd, Tb, Dy and Y)

On the following page can be seen the phases thru which the concentrate travels before emerging as the end product for offtaker delivery.

To ensure optimum design and engineering of the LA-SMC, work at the RapidSX™ Commercial Demonstration Plant has included the following specific testing, engineering and integration activities:

- Chloride Precipitate Production
- Component Degradation Testing
- Component Non-Destructive & Destructive Testing
- Dynamic Analytical Integration with Control System – on-site TXRF & ICP-MS
- Hydrochloric Acid Recovery & Recycling
- Oxalate Precipitate Production– small batch
- Oxide Production – small batch
- Programmable Logic Controller (PLC) System – feedstock-specific programming for chemistry delivery and feedback from over 600 system sensors
- Radioactive Monitoring and Tracing – potential trace amounts in every product and waste stream
- Scale-Up Demonstration – for LA-SMC commercial plant
- Techno-Economic Engineering – including digital twin modeling
- Ventilation & Fume Scrubbing System
- Waste Water Treatment System



- Extract: transfer of target REE(s) from aqueous to organic phase that contains a specific extractant
- Scrub: removal of impurities from organic phase back into aqueous phase
- Strip: transfer of target REE(s) into new aqueous phase
- Wash: removal of residual species from organic phase
- Saponification: substitution of H+ ions for Na+ ions to reduce subsequent increase in acidity
- Raffinate and strip liquor may become feed solutions for subsequent SX circuits

Conclusion

Ucore has seemingly struck a happy medium in bringing a mold-breaking technology to the REE space and yet at the same time adopting a tried- and tested-technology. One might call this derisked innovation. The RapidSX process is notable in that it uses green chemistry procedures throughout. No pernicious chemicals are used. It is noteworthy that RapidSX uses the same chemistry and chemicals as conventional SX. The difference being that RapidSX has a smaller footprint and uses smaller quantities of all chemicals. Additionally, RapidSX is a closed loop system recycling the acids.

The highly selective separations achieved with the RapidSX process make REE separations and recovery at high purities possible. Conservation of the Rare Earth metals has great importance, especially since large amounts, as much as 30% of these metals, remain unrecovered using Conventional Solvent Extraction.

Ucore holding the intellectual property (patents) for RapidSX creates a whole new vertical for the company. As the technology has applications in other metals as well, Ucore not only will have a whiphand over those in the REE space wanting to employ RapidSX but they shall also have a potential source of diversification of risk away from the REE space. Ucore sees its value-added across a broader playing field in the specialty metals space and this is already starting to manifest itself in the level of inquiries the company is fielding.

Affirmation of the company's technology by the US Department of Defence would be a major boost towards funding the scale up in Louisiana, integrating Ucore into the midstream plans of those both upstream and downstream on Ucore. Nothing can better production as a credibility booster in the REE space. That alone should ensure Ucore is numbered amongst the exclusive group that will survive to cash-flowing status in the REE space.

Important disclosures

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