Thorium and the rare earth value chain – a nuclear renaissance solution?

Rules covering thorium discharge in many of the world's top rare earths-consuming countries have prevented the development of potentially valuable domestic resources in these regions and helped cement China's monopoly over the sector. *James Kennedy** and *John Kutsch*** discuss the social and economic disadvantages of this situation and outline how a new nuclear strategy could help solve the problem.

International regulations pertaining to thorium have played a significant role in distorting today's rare earths market. The concentration of supply in China has caused severe economic dislocation and national security problems for the US, Japan, Korea, the European Union and other nations.

Private interests worldwide have invested around $6bn in an effort to challenge China's market dominance in rare earths. The governments of Japan, India and Korea have also made direct investments into the sector, but both private and state-backed efforts to develop supply sources outside China have, to date, largely failed.

A solution to this problem is required, but traditional 'free market' strategies are failing. The US Congress has proposed legislation that would resolve this market imbalance through the creation of a multi-national rare earth cooperative and thorium storage, energy and industrial products corporation, with participation in both organisations open to sovereign states, sovereign funds, producers and consumers of such products.

This article examines the situation as it currently stands and examines how the new US legislation could provide an answer.

Regulations and unintended consequences

The rare earths industry was initially built on monazite, a common by- or co-product of placer mining between 1950 and 1964. Thorium bearing rare earth element phosphate ores (Th-REE-Ps), principally monazite, were the primary commercial source of rare earths until the mid-1960s. From 1965 to 1984, these Th-REE-P materials supplied nearly half of the world's rare earths requirements, and nearly 100% of the world's heavy rare earth elements.

Th-REE-Ps and Th-U-REE-Ps (rare earth-bearing apatites from phosphates that typically contain thorium and uranium) are mineralogically superior to low-thorium bearing minerals like bastnaesite because they typically contain recoverable quantities of all 16 rare earth elements (promethium, although included in the lanthanide series, does not occur naturally in the earth's crust). These materials were also typically a low- or no-cost by-product of mining some other commodity, such as titanium, zircon, iron ore or phosphates.

The proliferation of regulations reflecting international standards regarding the definition of "source material" eliminated these high value rare earths from the value chain for most of the world.

Under the US Atomic Energy Act (AEA) Section 11, the following definitions apply to source material:

The term "source material" means (1) uranium, thorium, or any other material which is determined by the Commission (i.e., the US Nuclear Research Council) pursuant to the provisions of section 61 to be source material; or (2) ores containing one or more of the foregoing materials, in such concentration as the Commission may by regulation determine from time to time.

According to the definitions contained in Title 10 Code of Federal Regulations Part 40, Section 40.4 (10 CFR 40.4), source material means:

(1) uranium or thorium, or any combination thereof, in any physical or chemical form or (2) ores which contain by weight, one-twentieth of 1% (0.05%) or more of: (i) uranium, (ii) thorium or (iii) any combination thereof.

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Fears about the safety of nuclear energy have held this industry back, but proposals for a new Thorium Corporation in the US relies on new 'safe' nuclear power taking off.

Under regulation 10 CFR 40.13(c), "Exemptions for low thorium-bearing ores":

Any person is exempt from the regulation in this part and from the requirements for a licence set forth in section 62 of the Act to the extent that such person receives, possesses, uses, or transfers:

(1) (vi) rare earth metals and compounds, mixtures, and products containing not more than 0.25% by weight thorium, uranium, or any combination of these.

The exemptions above fit the project characteristics of the only remaining US producer of rare earths – the Mountain Pass mine in California, now operated by Molycorp Inc. As a precaution, US law specifically exempted this mine's ore from source material classification.

With its higher mining cost and lower value resources, Mountain Pass struggled to compete with China in the 1990s, where most rare earths production was and still is a by-product of iron ore mining.

However, it was a tailings pipeline discharge of thorium that caused Mountain Pass to close in 2002.

The rejection of source material

Beginning in around 1980, refineries no longer wanted to accept monazite as it constituted source material (the natural thorium content of monazite ranges from 3-15%) and the traditional producers of these valuable Th-REE-P byproducts began blending the Th-REE-P ore back into the recently depleted ore-body or dumping it into tailings lakes.

No longer able to utilise Th-REE-P resources, US, Japanese and European value chains were at a disadvantage compared with China. Over the next two decades, most of these refineries and metallurgical facilities were closed, relocated to China or fell into a state of underinvestment.

The Chinese market was unconstrained by these regulations, meanwhile, and filled the breach. The Chinese government elected to actively support the development of its rare earth industry as a National Industrial Policy (Programmes 863 and 973). China's forward-thinking industrial policy included direct and indirect investment and support for rare earth related enterprises, including large scale state sponsored research and development and targeted acquisitions.

Life without Th-REE-P

Rare earth minerals like bastnaesite that do not meet the source material threshold have several disadvantages, including: low-thorium levels that equate to low (sub-recovery) levels of heavy rare earths; the fact that the minerals are directly mined means that 100% of the mining cost must be covered from the sale of the rare earths extracted (versus China, where more than 70% of rare earths production is a byproduct of iron ore mining); and, the typical chemical distribution of bastnaesite is disproportionately apportioned to elements with the lowest economic value, typically >80% cerium and lanthanum.

Today, Mountain Pass and other deposits that are being financed and developed or re-developed are selected for their low-thorium content, but this is not a viable answer to the problem because these types of deposits cannot produce the full spectrum of rare earths (typically only eight of 16 elements).

The primary bastnaesite mineralisation of this deposit has very low levels of thorium, but also lacks recoverable quantities of heavy rare earths (terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium and scandium).

More than 83% of the rare earths produced are lanthanum or cerium, the lowest value rare earths. Historically, these oxides sold at or below cost due to their abundance. Today, these materials are selling at well below cost, offsetting the profits from the more valuable rare earths.

In mid-February, Molycorp's stock wass trading well below $1/share, from a high of $75/share in April 2011 and is at risk of being delisted from the New York Sock Exchange.

The economic prospects for this strategy are not promising. If the disadvantages listed above were not reasons enough for caution, the complete lack of fully integrated refining assets and expansive rare earth value chains outside China is a major concern for buyers of rare earths.

Another recently financed rare earth mining company, Australia-based Lynas Corp., which mines rare earths at its Mount Weld project in Western Australia and processes the ore at a rare earths refinery – the Lynas Advanced Materials Plant (LAMP) – in Kuantan, Malaysia, is also struggling.

For Lynas, concern over thorium prevented the company from starting production for almost a year, causing it to burn through its cash reserves to maintain the non-operational facility while simultaneously fighting legal battles with anti-LAMP protest groups. This required the company to raise additional financing, thereby undermining its capital structure.

The high cost of directly mining a relatively low value ore (>70% lanthanum and cerium) and then shipping it abroad for refining may prove too much for Lynas to sustain.

In June 2014 the company reported that it had less than 60 days of operating cash on hand, before completing a small secondary stock offering to pay down its near-term debt obligations.

In January, the stock was trading below $0.05/share and despite recording positive cash flow in December 2014, the company said that this position was unlikely to be sustained and that its losses look set to continue until prices for light rare earths increase.

Despite these factors, Molycorp and Lynas have both continued to ramp up production of light rare earths, disproportionately expanding the supply of cerium and lanthanum, and thus widening their losses.

Rare earths independence

The economic dislocation and national security concerns resulting from China's monopoly have forced the US Congress to consider ways of overcoming this 'market failure' in the rare earths sector.

The US Congress has considered a number of legislative changes that would reduce permitting and environmental standards for rare earth mines, believing that mine production is the problem.

For example, the following summarises a bill passed by the US House of Representitives in the 2013-2014 session:

H.R. 762 – 113th Congress: *Provides exemptions from federal regulations including the National Environmental Policy Act of 1969 (NEPA) and other federal regulations including governing special areas, all areas of identified mineral resources in land use designations (other than non-development land use designations); apply such exemption to all additional routes and areas that the agency finds necessary to facilitate the construction, operation, maintenance and restoration of the areas of the identified mineral resources; and continue to apply such exemptions after approval of the Minerals Plan of Operations for the unit.*

Recklessly opening new mines with lower environmental standards is not a solution, however.

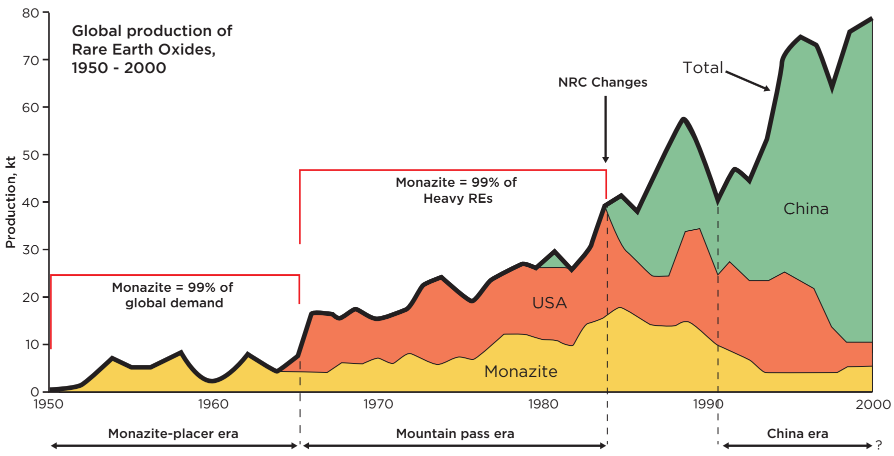
Creating a fully integrated value chain is a much larger and strategically important challenge. China's rare earth value chain is comprised of hundreds of independent companies, spanning two cities almost exclusively dedicated to rare earths research and production, each providing highly differentiated technologies, processing, formulation or component specific applications. Stand-alone mining companies cannot hope to replicate an equivalent value chain.

Molycorp spent over $1bn on its Mountain Pass mine and oxide facilities that generate substantial losses. The company's operational profits are generated inside China, where Molycorp ships all of its most valuable rare earth oxides for refining and value-addition into metals, alloys and magnets.

The protracted political and financial problems that dogged Lynas' LAMP in Malaysia, cost more than $1bn. This facility is also generating sizable operational losses, demonstrating that the financial risks associated with even the first stage of refining rare earths into basic oxides may be too great for any one company.

New producers are likely to expand on Molycorp's model and ship all of their concentrates (or oxides) to China for refining and value adding into oxides, metals, alloys, magnets and industrial components. This would be a step backward for nations hoping

Figure 1: World history of rare earth production



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to rectify economic and national security concerns.

A cooperative solution?

An alternative to lowering environmental standards requires a solution to the thorium problem. Developing a fully integrated rare earth value chain could be met by the formation of a cooperative.

Historically, the US has used cooperatives to overcome market failures in high capital, low margin businesses like farming. Cooperatives were originally developed to spread financial risk, gain access to low-cost capital and expand market access, thus assuring the production and lowering the cost for critical resources and services, such as food or rural electric power distribution.

Recently introduced bills in the US Congress are designed to address the rare earth-thorium problem through a cooperative model.

For example, the National Rare Earth Cooperative Act 2014 (NRECA – HR 4883 & S.2006) is designed to:

- Utilise existing and available Th-REE-P and Th-U-REE-P resources;
- Operate within a federally chartered rare earth cooperative (and thorium corporation);
- Serve as a fully integrated value chain for rare earth materials;
- Be owned and funded by multi-national corporations, defense contractors, sovereign nation agencies such as Japan Oil, Gas and Metals National Corp. (JOGMEC) and Korea Resources Corp. (KORES), sovereign wealth funds, commercial end-user, organisations, and suppliers who commit capital.

By creating an old-fashioned cooperative, the US could solve the very modern problem of meeting its rare earth needs. Rare earth end users from around the world would be able to invest directly in a cooperative value chain, which would be tailored to produce products (oxides, metals, alloys, standardised magnets and components) according to its owners' requirements.

The owner end-users of this cooperative would purchase their value-added rare earth products at market prices (initially set by China, but becoming more dynamic as the industry opens up).

Excess inventory not consumed by the owners would be sold on to external, non-owner customers – again at market prices.

Profits from this system, if any, would be redistributed back to the cooperative's owners and all members would ultimately acquire their value added rare earths goods at prices free from the influences of manipulation and speculation.

Bringing back Th-REE-P

By utilising abundant and available Th-REE-P and Th-U-REE-P resources, the need to make large investments into low-thorium, low value rare earth mines is eliminated. Because the Th-U-REE-P is typically a by-product of some other commodity, the cost of producing rare earths in this way is near zero.

The US mining industry could meet over 65% of today's global rare earth demand with Th-U-REE-P by-products from ongoing non-rare earth mining operations if the source material issue was resolved.

The bill posits a solution of creating a federally chartered Thorium Energy and Industrial Products Corporation that will take all liability and safely store all thorium and associated actinide liabilities from the rare earth cooperative. This facility would comply with all Nuclear Regulatory Commission (NRC) regulations.

The management and safe storage of thorium does not pose any technical challenges and the economic challenge can be overcome by sharing the cost of storage with a number of end user cooperative members and non-members who purchase the finished rare earth products.

The cost of long-term thorium storage would amount to a fractional surcharge on rare earths selling prices, while the storage facility would take ownership of the thorium and be given Congressional authority to develop industrial uses and markets for the material. The commercial prospects should be adequately compelling to attract the level of investment necessary to create new uses for thorium.

The Thorium Corporation would be given Congressional authority to establish a multi-national corporate platform to develop industrial uses and markets for thorium (including decay products), such as alloys, catalysts, medical isotopes and other uses.

It will also be tasked with the commercial development of thorium energy systems that include solid fuels, solid-fuel reactor technology, beam/accelerator-driven reactors and liquid-fuel reactor technology, incorporating electric power, thermal energy, synthetic liquid fuel production, desalination, nuclear waste reduction (actinide burners) and hardened and deployable energy systems. Any uranium by-production would be sold into the nuclear fuel value chain to finance the activities of the Thorium Corporation.

'Safe' nuclear

The Thorium Energy Corporation would be required to seek out direct investment from sovereign entities, sovereign funds, multi-national institutions and the producers and industrial consumers of energy.

Various configurations of high-temperature liquid-fueled reactors (molten salts or metals) or beam/accelerator-driven reactors do not share the risk profile of light water reactors (LWRs), which can be subject to meltdowns and explosive events.

High-temperature thorium liquid-fueled molten salt reactors can eliminate the risk of widespread radiation release (water/hydrogen event) and greatly reduce issues related to long-lived spent-fuel and the proliferation of weapon-grade material.

A lack of constraints over thorium production in China helped the country to build up its monopoly in the rare earths market.

Public concern and perception of what may be termed 'primary risk factors' – meltdowns, explosions, wide spread radiation release and the long term storage of spent fuel (commonly referred to as nuclear waste) may be statistically unfounded or disproportional, but the resulting political response and capital costs are the primary obstacles to the rapid deployment of nuclear energy outside of China.

Safer reactors, not subject to these primary risk factors and the prohibitive capital costs associated with LWRs could be widely accepted and rapidly deployed. The potential benefits of eliminating and/or offsetting greenhouse gas emissions and ocean acidification are greater still.

Why thorium now?

One more high profile nuclear accident could induce other nations to reject nuclear energy, potentially triggering a domino effect which would have profound economic and environmental consequences on the global community.

The nuclear industry does not have a contingency plan for such a scenario or any alternative systems in the pipeline that address the public's primary fears associated with LWR technology.

High temperature, thorium liquid fueled molten salt reactors are technologically obtainable. The US built and operated three liquid fueled reactors at Oak Ridge National Laboratory between 1954 and 1973.

These reactors may also prove to be a socially and politically acceptable alternative to LWRs. Liquid fueled molten salt reactors cannot blow up, melt down, cause wide spread radiation release and can use nearly 100% of the fuel's fissionable energy, greatly minimising spent fuel and waste issues, and can reduce geologic storage requirements by as much as 99.995%. These advantages are also largely obtainable in various configurations of beam/accelerator-driven reactors.

Under the proposed legislation in the US, all stake holders within the nuclear industry, sovereign states and the producers and consumers of energy could share the development costs and economic benefits of thorium energy.

The bulk of research and development costs have largely been dealt with by the Oak Ridge programme, meaning that only a relatively modest investment from each of the potential stake holders is necessary under this collaborative structure.

The successful deployment of next generation thorium-based reactors could greatly augment the economic status of all stakeholders.

Nuclear technology providers and producers and large industrial consumers of energy could economically hedge themselves to benefit from the transitions to a thorium energy based economy.

Even the uranium mining industry could benefit, as the thorium fuel cycle requires fissile isotopes to initiate, and in most applications, sustain the reaction.

A solution to the rare earth problem and prospects for launching a true nuclear renaissance exist and the status quo is not risk free. However, broad international support and participation must be the centerpiece of this effort, as it is only through collective action that the benefits can be shared.

Nuclear energy is arguably the only viable solution to climate change. Yet nuclear energy must also conform to the social and political realities of the world we live in.

The timing of this multi-national platform coincides with enhanced fears about traditional LWR technology, with Germany, Belgium and Japan having seemingly opted out of nuclear energy, at least in its current configuration.

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