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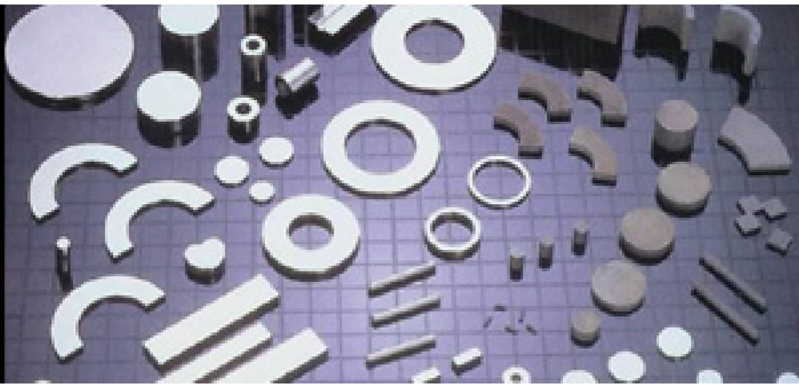
Argus White Paper:

How to build a rare earth supply chain



Rare earths have found their way into just about every area of modern life, from MRI scanners to lasers, jet engines, water treatment, gasoline refining, banknotes, high-speed fibre-optic cables and microchips. But it is their use in the magnets critical to defence, manufacturing, automotive and the transition to electric vehicles (EVs) that is focusing the attention of policy makers around the world. And with concerns mounting about the world's reliance on China for many critical metals, the race is on to establish alternative regional supply chains.

Rare earth magnets

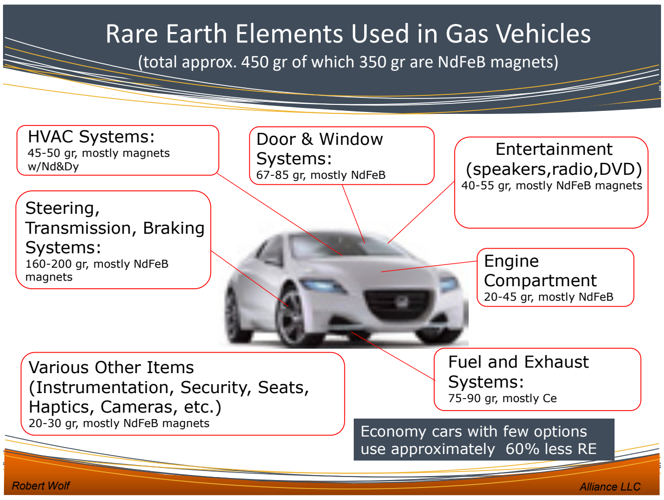
When gasoline prices soared in the US in the 1970s after the Opec oil embargo, carmakers urgently needed to find a way to increase the fuel efficiency of their products. One solution was to reduce the weight of the motors operating the sensors, braking systems, door locks, fuel pumps and all the many other systems in a car – a modern luxury car can have as many as 12 motors just to adjust the two front seats. The hunt was now on for a much more powerful magnet. Samarium cobalt rare earth permanent magnets, which are used extensively in defence and aerospace applications, had already been invented by then. But they were too expensive for mass application.

At around the same time, Japanese manufacturers were searching for a new magnet for their rapidly expanding electronics sector. In the 1980s, Japan's Hitachi invented neodymium iron boron (NdFeB) magnets made by a metallurgical powder process and GM in the US invented rare earth neodymium iron boron permanent magnets made by an alloy melt spinning process. To give an idea of the weight reduction achieved, the magnets in the disc drives of early IBM computers weighed about 90lb. The same NdFeB today would weigh less than 1g.

China today supplies around 80pc of global demand for rare earth magnets — mostly in the form of finished components and EV engines. Japan makes most of the remainder — still using Hitachi's technology — and produces a large share of the world's high-end rare earth magnets (*see Lynas interview below*). Automotive is by far the largest market for NdFeB magnets. But you can find them everywhere — from your phone, to micro-surgery, to heavy industry. The modern world does not work without rare earth magnets.

Enter the EV

EVs need to be light to travel a long way on a single battery charge. That is why they mainly run on rare earth motors, which are far more efficient than conventional electric



motors. They also use a lot more rare earths. It is this growth in demand along with critical defence applications that is leading governments around the world to search for ways to develop a rare earth supply chain that can cope with higher demand and rising political risk.

Listen to the experts

Building an entire supply chain from a narrow base is a huge challenge. But who could be better placed to advise than those few firms already operating successfully in the rare earths sector outside China. *Argus* interviewed three key producers to find out what they think is needed to develop a diversified rare earth supply chain.

Lynas Corporation

When rare earth prices spiked 11 years ago (see price chart) because of a security of supply scare caused when China cut exports and threatened to ban exports to Japan, there were around 300 rare earth mining projects in the world. But you can count the number of western projects that made it through to production on the fingers of one hand. And only one of these managed to transition downstream from mining ore to large-scale commercial rare earth processing and separation to provide the raw material for magnets. Today, Australian mining firm Lynas is the only large light rare earth oxide producer outside China, and is second only to Chinese state-controlled industry group Northern Rare Earth.

Argus spoke with Lynas vice-president of sales and marketing Pol Le Roux. Edited highlights follow:

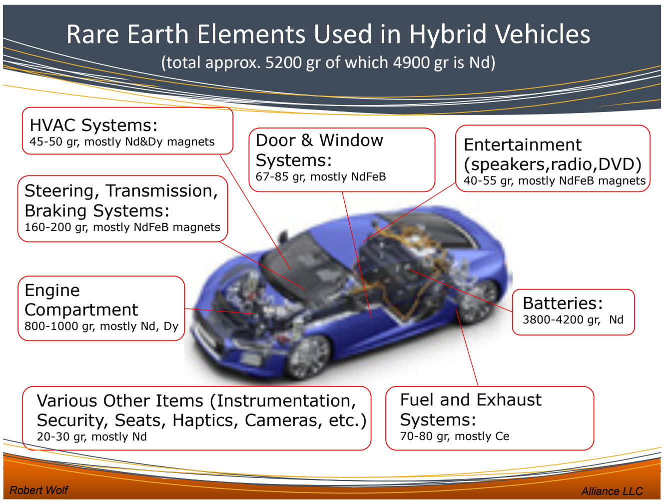
What is the one thing that would be a game-changer for the rare earth industry outside China?

To convince magnet makers and buyers to invest outside China. How can the industry grow if we do not make the end product? Today, the production capacity outside China for light rare earth magnet material is already larger than the consumption outside China, because China is where most magnets are made. The only other large magnet producer is Japan, and Lynas already supplies most of its needs. So where do we expand? In the US and Europe? But there is very little magnet manufacturing there. So if we make more oxides, the only customer is China.

Lynas' involvement with Japan goes right back to the beginning. How difficult was it at the start?

It was very difficult. We started the first mining campaign in Mt Weld in Western Australia in 2011. The concentration unit started in 2012. We started producing rare earth oxides at the plant we built in Malaysia in 2013. We went through really hard times at the beginning. It took three years to resolve all the technical problems. Building a brand new separation plant is so much more difficult than you would imagine.

The support of the Japanese government was really decisive



in the survival of the company. After a very detailed analysis of our situation, they came to the conclusion that we just needed more time, and they gave it to us. They extended a loan to the company by three years and lowered the interest rate, and then the business became a normal business. Then we succeeded in growing our market share in Japan. That also meant that the rare earth industry in Japan was no longer seen as at risk of supply disruption and started to grow. Today, we supply most of the neodymium and praseodymium oxide (NdPr) sourced by Japan.

You know when I knew that Lynas was going to be a success? When we could hire the best experts in the business to come and work with us. The failure rate in this industry is so high that when the best want to come and work with you, you understand that you have a success on your hands.

Why have attempts to develop large-scale commercial magnet manufacturing outside China so far failed?

Cost. In a western business environment everything is structured for small savings every quarter. Let's look at the perspective of the sales guy — if you jog the price by 1¢ and you will get $100,000, why wouldn't you do that? The automotive supply chain is squeezing everything for 10¢. And unless your component cost per vehicle is large, it is hard to get them more interested even though they need the magnets to build the car. And with EVs, the rare earth component will be much bigger.

How did Japan succeed?

They did not let go in the first place. Japan invented NdFeB magnets in the 1980s. To be more precise, Sumitomo in Japan and GM in the US invented the magnets. They then split the technology into two companies. The intellectual property (IP) for bonded NdFeB magnets was held by Magnequench in the US and the sintered magnet technology was held by Sumitomo. Magnequench was taken over by a Chinese company, while Sumitomo sold its business to Hitachi — it went from a Japanese company to a Japanese company. The west was very short-sighted.

And the government also stepped in. During the rare earth crisis in 2010, when a political dispute between China and Japan threatened Japan's entire supply of rare earths, the government got involved and this led to the collaboration between Jogmec [Japan Oil, Gas and Metals National Corporation] and Lynas.

The Japanese also take a different approach to the supply chain. They put a higher value on stability of supply. Let's say you are one of the top magnet makers in Japan, your customers in automotive and other industries will support your business when prices are low like they are today, to ease the financial pain. But if prices spike, your Japanese customer will expect you to support him in the same way they supported you in difficult times. So it is quite different to the western business model.

So how could we develop the magnet industry outside Asia-Pacific?

Investment in new magnet-making capacity outside China would require strong support from a customer or group of customers, with government support, that can commit to a guaranteed offtake agreement for a period of several years, including some kind of price premium and time for a magnet maker to complete its industrial set-up. You know the investment downstream is really more a matter of technology and time than capital.

So yes, the magnets would cost slightly more. But from the perspective of an automotive producer, the cost per car is much smaller than the cost of the catalytic converter to reduce emissions and much smaller than the cost of a battery in an electric car. If you track it back to the price of the rare earth in the magnet and look at the impact of a price increase there — a $10/kg increase in the price of NdPr to $45/kg from $35/kg, where it is today, and a $100/kg increase for dysprosium oxide to $350/kg from $250/kg, would according to my estimates be enough to bring on all the rare earth supply you would need. That price rise would increase the cost of magnets by around $7/kg, or around $15/kg per electric car, with 2kg of magnet per electric car. For a magnet maker, $5/kg can be the difference between living and dying.

Once someone finances your investment or part of it there can be a market place for the products from oxide right through the chain to the magnet. And don't forget that you are creating a market for products that were made to best-practice environmental standards with transparent audits.

Argus' comprehensive China rare earth price offering includes:

- **Cerium**
- **Dysprosium**
- **Europium**
- **Erbium**
- **Ferro-dysprosium**
- **Gadolinium**
- **Holmium**
- **Lanthanum**
- **Lutetium**
- **Mischmetal**
- **Neodymium**
- **Praseodymium**
- **Praseodymium-neodymium**
- **Samarium**
- **Terbium**
- **Ytterbium**
- **Yttrium**

Argus also assesses European rare earth prices for:

- **Cerium oxide 99.5-99.9% cif Europe**
- **Dysprosium oxide min 99.5% cif Europe**
- **Erbium oxide min 99.5% cif Europe**
- **Neodymium metal 99% cif Europe**
- **Neodymium oxide 99.5-99.9% cif Europe**
- **Yttrium oxide 99.999% cif Europe**

Full methodology available on request.

You mentioned heavy rare earth dysprosium, another vital component of magnets, which some see as the biggest opportunity as China is now dependent on imports of heavy rare earth ores.

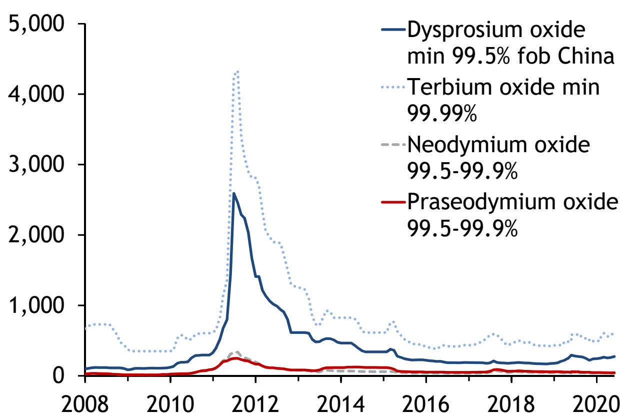
Yes, today most of the dysprosium and terbium produced in China is extracted from ionic clay in southern China and Myanmar (Burma). The mining method is extremely polluting for the underground water supply. So the Chinese government is now restricting mining activity and reducing the availability of the raw material to make dysprosium and terbium oxide, just at the moment that demand for these elements is about to rise.

Why will it rise? Because the greater the power of an electric motor, the higher its temperature. Dysprosium and terbium (DyTb) are used in magnets to improve their temperature resistance. I like to joke that in an internal combustion engine car, the magnet motors move the seats, including those sitting on them, while in an EV the motor has to move you and your passengers including the seats and the car, which requires a lot more power. So as electric cars further penetrate the market, the demand for DyTb will accelerate faster than for NdPr.

Today, there is no commercial separation of heavy rare earths outside China and several years ago we began to look at this opportunity. After all, we are already the only large separator of light rare earths outside China. Our Mt Weld deposit in Australia is basically a light rare earth resource, but it also has some dysprosium and terbium and there will be more when we start to exploit the Duncan deposit nearby. Today, we produce a small amount of heavy rare earth concentrate.

Last year, we set up a joint venture with Texas-based rare earth compound producer Blue Line to build a heavy rare earth separation plant in Hondo, Texas. I have known Blue Line for 15 years. They really know their rare earths — they supply rare earth compounds to many industries in the US, including the oil sector. They have no separation experience, but that is where Lynas comes in.

Rare earth magnet oxides, monthly average $/kg



Less Common Metals (LCM)

Twenty-five years ago, the predecessor to LCM, which is based in northern England, supplied magnet makers in the UK. Today, there is only one magnet maker for the automotive sector left in Europe, Germany's Vacuumschmelze. Two years ago LCM, with a staff of just 41, expanded into magnet metal and is now the only producer of neodymium metal outside Asia-Pacific.

Argus spoke with managing director Ian Higgins. Edited highlights follow:

How easy was it to start out in the rare earth industry and expand from alloy into metal?

Not easy at all. In 27 years, LCM has had three changes of ownership, two relocations and migration to ISO quality and environmental standards. We've enjoyed good periods of rapid growth but also hard times. And as for adapting the process for making neodymium metal to meet western health and safety standards, you could say that a 1,000-mile march starts with a single step.

How can the industry grow outside China?

Integration in some form or another and the low cost of raw materials are two fundamental considerations. To make the six stages of the process economically viable from raw material to oxide to metal to alloy right through to rare earth magnet, we must find a way to stop all of the stages stealing margin from one another until the whole thing collapses and is financially unsustainable. Remember, if you go to a tier-one OEM [original equipment manufacturer] in the automotive industry, they will say why should I pay $50/kg for magnets when I can get it for $45/kg from another supply chain in China?

Let's look at two aspects — the cost of raw material and the cost of transparency and environmental standards.

In the Chinese model, they primarily have the initial light rare earth feed as a by-product of Inner Mongolia iron ore processing. I do not know how they do their accounting but they put it on the iron ore side of life. This means they start with a low-cost or zero-cost feed.

Now for heavy rare earths, the cheapest mining method is extremely polluting and has now been mostly shut down, which is why China is dependent on importing more heavy rare earth ore from Myanmar [Burma], which creates a different cost equation. Overall, part of the lower cost that China is able to achieve is the result of less stringent environmental health and safety standards, but it is not the overriding factor. Chinese processing is efficient anyway. It would not quadruple the price if you had improved health and safety.

Historically, production of rare earth concentrates, especially in northern China, has been extremely polluting, creating a

legacy of toxic dumps. Transparency about these upstream processes is essential. Let's say you are making a light mixed rare earth concentrate and the cost is $2.50/kg and your cost is $3/kg because you processed it ethically at a plant in say, Thailand, and water treatment added 50¢/kg to the cost because your requirement is that the radioactive nuclides are in a safe form. That cost must be communicated to the end consumer.

How can industry help policy makers navigate such a complex industry?

If you look around the world there are around 50 prospective rare earth ventures with varying levels of credibility. I am working with a project for the European Institute of Innovation and Technology to develop a methodology for cataloging and tracking all these prospects and putting the information in a form that makes it possible to take objective decisions, with oversight from independent experts.

There are similar discussions under way in the UK. No one country can or will have everything needed to become supply independent. There are also about half a dozen disruptive technologies trying to challenge the incumbent technology for separating rare earths.

I think it is clear at this stage that if you really want to build a rare earth supply chain outside China, there will have to be co-operation between countries and some kind of mix of public funds and private capital.

LCM is involved in a project with one of the technology disruptors, REEtec in Norway?

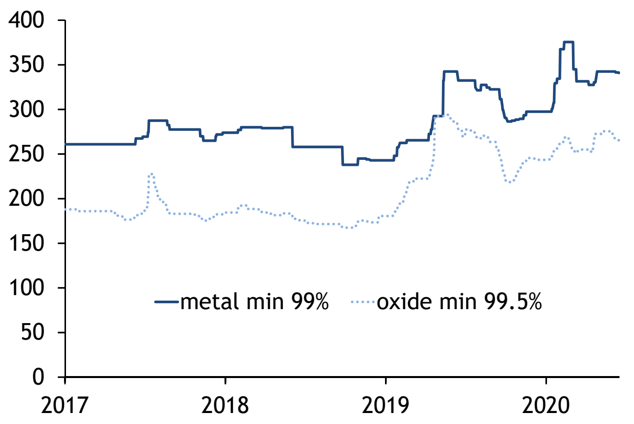
Yes, the SecREEts project, which is part-funded by the EU Horizon 2020 project, unites Norwegian fertiliser producer Yara, which would supply rare earths as a by-product to REEtec, which will then use its proprietary technology to produce rare earth oxides that LCM would then make into metal. We think we are the closest to market, although we are not there yet.

The SecREEts project is small in commercial terms. Are there larger opportunities for using by-products to produce rare earths?

Yes certainly, there are a lot of untapped resources all around the world. The minerals monazite and xenotime are good examples. These occur as by-products of heavy mineral sands processing globally. Both contain rare earths together with radioactive nuclides. The problem is how they can be processed ethically. My very first job out of university was with the UK Atomic Energy Authority, where radioactive materials are handled and processed in a responsible manner.

A simple example is the mining of beach sands in India in Tamil Nadu on the east coast. They mine a titanium bearing mineral ilmenite and natural garnet, which they sell and

Dysprosium metal and oxide fob China $/kg



grade, along with small amounts of zircon. By the time they have finished, all they are left with is silica (sand) and monazite. Because of Indian state rules about radioactive minerals, they take out the monazite and stockpile it and put the silica back on the beach. The monazite is stuck in a stockpile. Does it sit there forever?

One way forward would be for the Indian government to change policy to allow responsible processing of this valuable resource by private enterprises. Alternately, to advance processing of global stocks of monazite and/or xenotime, could the UK play a role through the creation of a government-controlled repository for radionuclide by-products under the control of the UK Atomic Energy Authority, in the same way it controls nuclear fuel processing in the UK?

MP Materials

The Mountain Pass mine in California, developed in the 1950s, was once the world's largest supplier of rare earths. The mine was bought out of insolvency in July 2017 by the MP Materials consortium comprising US investment funds JHL Capital Group and QVT Financial along with minority non-voting shareholder Chinese firm Shenghe Resources.

MP Materials restarted production at Mountain Pass in January 2018, producing a light rare earth concentrate marketed and sold to China. The company produces over 36,000 t/yr of light rare earth oxide contained in concentrate.

Argus spoke with James Litinsky, co-chairman and controlling shareholder of MP Materials. Edited highlights follow:

MP Materials is one of the more recent entrants to the rare earths industry. What was it like to start out?

I never expected to be in this position. We purchased the Molycorp distressed debt in bankruptcy. Not a single credible strategic or financial buyer showed up to buy Mountain Pass. It was days away from reclamation, and we could not watch such an important national asset disappear.

We put in some money to keep the site going and figured out a plan. I had no idea how hard it would be. I hope people years from now will look back and feel the same pride I feel about the job our team out there is doing.

'Build it and they will come will never work for rare earths,' a commentator said recently. Do you agree?

I disagree, although I think that is certainly the perception of many people looking at the history of the industry. But something material has changed for the prospects going forward — the use cases for rare earths are really accelerating with modern technology, specifically for EVs, but also eventually other 5G motion and transport technologies.

I think the game has changed for us all commercially. The automotive supply chain is $700bn of GDP and 10mn-14mn jobs, and with EVs going from 2pc to, pick your timeframe over the next 30 years, maybe 90pc, that is too much capital for there to be a single point of failure in the global supply chain. It wouldn't matter if it was China or the UK. The automotive supply chain will contract around single points of failure if they have a choice. We will build it, and they will come.

But the US imports car engines from China. What is the difference in terms of who makes the magnets?

China has very intelligently and strategically taken over a significant chunk of the automotive supply chain. That is why our sector is so critical. Too much GDP is at risk for the west.

China utilised rare earths to take over the magnet industry. They could do this because there has been no rare earth supply chain in the western hemisphere for many years. China will continue to move downstream to compete for greater commercial share.

In June last year you said you would start production of rare earth oxides at the end of 2020. Why the push back to next year?

The import tariff China levied on our rare earth concentrate sales to them [which has now been lifted] and the pandemic have pushed back stage 2 execution by a number of months, but we continue to make great progress.

If you do make oxides, who are you going to sell them to except for China? There is already more production of rare earth oxides outside China than there is consumption.

Multi-billion dollar supply chains do not move overnight. The supply chain transition has to happen, and it will over time. MP is paving the way as a secure and sustainable source of supply based entirely in the western hemisphere. Our company will vertically integrate over time, and our success will help enable more overall western downstream investment.

Some might say that China will never allow that to happen. The new reality of the EV has changed the game though, in that the industry is going to demand an alternative source of supply. China will hopefully recognise that our output is helpful to the global industry, including theirs. It encourages growth and investment. MP's success will help pave the way for a more diverse and competitive supply chain, and also a more expanded overall opportunity set for all.

The current environment must be complex for a large US rare earth producer with a minority Chinese shareholder. How are you negotiating this challenge now and moving forward?

We are an American company with American employees and 100pc shareholder voting rights and board seats held by Americans. We have a minority Chinese shareholder, Shenghe Resources, which is also our distribution partner in China. In the beginning, we asked Shenghe for technical advice.

When we took control of the site at Mountain Pass in 2017, there were eight people. It was in care and maintenance. Today, we have over 200 people, including an outstanding and growing team of engineers, and we command over 15pc of the global rare earth concentrate market. We have single-handedly restored the rare earth industry to the US, despite the many naysayers who said it could never be done.

We have an ore body in the ground in the state of California, and over $1.7bn of invested capital in a processing facility next to it. The Chinese government cannot pick it up and move it to Beijing. Our mission is to restore the full rare earth supply chain to the US.

Many great American companies like Apple, Boeing and Tesla have Chinese shareholders, operations and sales relationships. We hope to be as Chinese as they are one day.

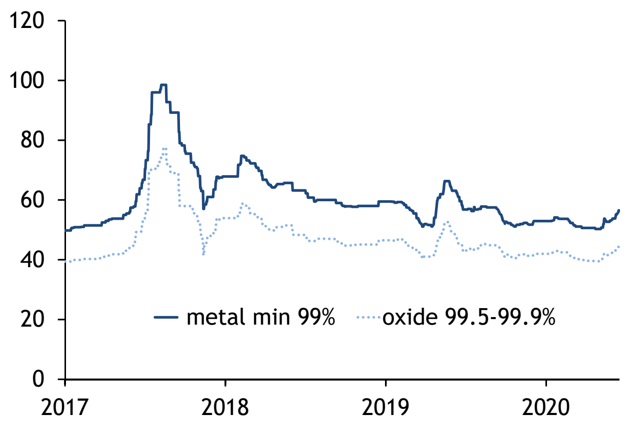
What could government be doing to support the rare earth sector?

The most important thing for the sector is a true level playing field globally. Historically, China has heavily subsidised its rare earth industry via capital and reduced environmental standards. In fairness, China has made some progress environmentally in more recent years.

Yet China continues to completely control the industry because they have smartly utilised a significantly subsidised cost of capital for the sector. We must do the same here. Tax incentives to encourage the domestic supply chain are a great first start. The recent bill proposed by US senator [Ted] Cruz is a great example of how to do it.

Governments, major corporations and global consumers should also continue to shine a light on issues like China's reduced environmental standards. Identifying the challenges, and then responding aggressively to them, requires a long-term approach. That is how China is doing it. We must do the same.

Neodymium metal and oxide fob China $/kg



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