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STORMCROW

Lithium Prices and Rare Earths Topping Out?

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They've Both Been Rising, Maybe Both are Flattening Out

In this issue we discuss:

- **Lithium Prices Done Their Climb** There was no really strong reason to see lithium prices flying higher, other than restocking post the COVID delays and pre the Lunar New Year break. But now, all lithium prices seem to have topped out, with the exception of spodumene concentrate pricing. Is this it for this mini-run?

- **The Rare Earths Slowing Down Their Pace** With production resuming after the Lunar New Year in China, you'd figure that price appreciation in the rare earth space would be slowing down. And with one exception, you'd be right!

- **Haven't Seen This Done, Thought We Would Take a Swing** I don't believe there is anyone in the battery materials space that doesn't acknowledge that if battery electric vehicles are as successful as the most optimistic analysts want them to be, then critical materials will be in short supply. But what about the rare earths? Frankly, I was a little bemused by the likely answer.

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As a Matter of Introduction…

We've been writing this monthly newsletter for a while now, much more than a year. To be honest, this was a way for a firm that isn't able to publish a lot of the research we do, because it is proprietary and done under NDA, to maintain contact with some readers. The volume of contact and comment is increasing, so that part appears to be working. We hope you enjoy these and find them of value.

And for those who don't know, Stormcrow deals with the markets for critical materials. Generally speaking, what amounts to a critical material is in the eye of the beholder, but we think of them as materials that are essential to making a product with the characteristics intended by its designers, even if those materials are not anything like the highest-cost item on a bill of materials. As an example, think lithium in the battery of your cell phone. That lithium costs pennies as a raw material, but if your cell phone manufacturer was forced to do without it then the resulting cell phone would have a very, very different operating experience than it currently does.

Over the coming months, we are going to deal with our views of the market prospects for some critical materials, and interesting facts about others. We will talk a little about technology and the impact, both good and bad, that it can have on demand for critical materials. We hope you find this interesting and worthwhile! Note that when not writing newsletters like this one, Stormcrow Capital functions as a corporate adviser (capital markets / financing / M&A) in the critical materials sector. We are registered as an Exempt Market Dealer in Canada *(additional disclosures included at the end of this note).*

Another Year, Another Battery Materials Environment

We've just gone though January and Lunar New Year is with us. The period coming into Lunar New Year is always one for restocking, and with that a high point in pricing. For lithium, the restocking has been especially good for prices this year. In 2019, lithium chemical prices were still dropping and some spodumene miners were forced to curtail production, so lithium chemical supplies became even more dependent on a limited stockpile of feedstock in China and the brine producers of South America. Obviously, demand in 2020 was muted due to the pandemic, but prices have been moving strongly higher and we are now seeing something that looks more like a sustainable market.

So, from the end of January to the end of February:

Battery-grade LiOH • H_2O **UP** 11.1%

Battery-grade Li_2CO_3 **UP** 11.0%

Battery-grade $CoSO_4$ • 7 H_2O **UP** 15.2%

Battery-grade $NiSO_4$ • 6 H_2O **UP** 6.8%

Since the end of February, however, both battery-grade lithium chemical prices appear to have completed their climb and leveled off. However, spodumene concentrate prices in China continue to climb. What was USD$400 per tonne at the end of 2020 is now over USD$450 per tonne and continuing higher. Clearly, we are back to demanding real quantities of feedstock in order to make enough lithium chemicals for batteries.

Battery-grade cobalt sulfate pricing rose quickly, reached a peak and now is sliding back a little, so maybe the immediate restocking need has been satisfied. But given that cobalt metal prices remain fairly high, we would not expect cobalt sulfate to become markedly less expensive.

And battery-grade nickel sulfate continues a slower but steady climb. There is always going to be a need for lithium batteries with high energy density, and nickel will play a central role in that for a long time to come.

They Were Never Rare, but We Love 'Em Anyway

Last month we pointed out the odd behavior of a few of the rare earth prices. In particular, we noted that neodymium oxide (a precursor material for making NdFeB magnets) had shown a surprising price increase compared to praseodymium oxide.

Praseodymium oxide was selling for only 0.69x the price of neodymium oxide, 2.3 standard deviations from the average level of 1.26x. Now, with neodymium prices leveling off and maybe falling a little and praseodymium price picking up, the ratio has been rising and is now at levels of 0.74x.

We also noted that, normally, terbium oxide trades at a level of 2.14x the proce of dysprosium oxide. Both can be used to help make NdFeB magnets that can operate reliably at higher temperatures, except that terbium is better at this role, is rarer and has other uses. Last month, that ratio was 3.86, or a whopping 4.3 standard deviations from normal. Since last month, though, that ratio has declined to 3.3, which has shaved more than one standard deviation off the divergence. The same pattern as for the neodymium/praseodymium ratio, in that terbium has leveled off and even fallen a little while dysprosium has gained.

But while those two puzzles might be resolving themselves, one just keeps right on building. Yttrium oxide used to be a darling of the industry. Yttrium is not necessarily rare, but it was a hot material and in huge demand. Remember fluorescent tubes and bulbs? In simplified terms, a fluorescent lamp works by producing an intense ultraviolet light that is then directed onto a phosphor material. In the case of a fluorescent tube, that ultraviolet light is made inside the tube, and it strikes a whitish phosphor that coats the inside of the glass. That phosphor then fluoresces to make the white light that was so hated by so many people trapped in offices lit with them, and by the former President of the United States because it made his orange complexion even more noticeable, and that's saying something.

But I asked whether anyone remembers fluorescent lights for a reason. That reason is we don't use them anymore. They have largely been replaced with light emitting diodes (LEDs). Some LEDs use the same sort of principle and phosphors as the older fluorescent light, except the LEDs are much more energy efficient and ridiculously more efficient when it comes to the amount of critical materials needed. We simply don't need the same amount of yttrium that we used to.

That hasn't been positive for the rare earth industry. In the past, pure yttrium oxide sold for more than $20 per kg, and this was not even during the 2010-2011 "rare earths crisis" (yttrium topped out at near $200 per kg during that period). For the last few years, with weaker demand but plenty of supply, yttrium oxide has been trading at $3 per kg. But over the last few months, yttrium pricing has been on a tear, and yttium oxide is now near $7 a kg. We are trying to find a reason for this beyond some groups getting excited about possible supply disruptions and putting in a stockpile, but so far no one has been willing to shed much light. We will keep you posted.

Will Rare Earths Be a Battery Electric Vehicle Bottleneck?

There has been a lot of media discussion about rare earths recently, mostly around the "issues" that (a) rare earths are absolutely essential to the continued growth of battery electric vehicle penetration, (b) China dominates the rare earth space and is willing to make the entire rest of the planet angry at China by clamping down on rare earth exports (again!) and (c) there is a need to build an alternate supply chain for rare earths outside of China. All of the above makes me think about how it used to be so nice to have someone writing on technology for a major news outlet that actually was a technologist and fundamentally understood the issues being discussed, as opposed to today when everyone is a graduate of a journalism program and most of them can't tell signal from noise when it comes to the thorniest issues facing the subject on which they are writing.

So, in brief, and you can believe me or not but my opinion comes from over a decade of analysis and thought regarding rare earths:

a) The rare earth elements are not "essential" to battery electric vehicles, hybrid electric vehicles, your cellphone, your electric toothbrush or Western civilization. They are nice materials to have if you can get them at a steady and reasonable price with guaranteed availability. As an example that western readers should understand, the Tesla Model S never used a main motor that contained rare earth magnets. It worked and sold just fine. A rare earth main motor would have likely made it a better and more expensive product, but it worked as it was. Where rare earths really are critical, as in some of the phosphors used in making an LED, for example, the amount required per year could be provided by one small company if someone asked and gave them some lead time.

b) China still dominates the global rare earth supply chain, as they did back in 2009 and 2010. In 2010 the ministry in China lowered an export quota on raw rare earth oxides from levels that no one was worried about to levels that scared everybody. It was an ill-conceived quota program, one that treated a tonne of a valuable magnet material and phosphor like terbium oxide exactly the same as a tonne of a low-value polishing compound like cerium oxide. The result was the creation of a circus of Biblical proportions, where the prices for high-value rare earths went way up, but the prices for low-value rare earths soared like an Atlas rocket (because in order to convince a supplier to sell you your desired tonne of polishing powder, you had to pay them not only for the powder but also for the lost profit they could have earned from exporting a tonne of a much higher-value rare earth, instead!). The result was that rocketing prices led to demand collapse as customers learned to thrift use of the rare earths, replace them with another material or replace them entirely using a different technology. So much for "irreplaceable". Prices went so low that the rare earths industry was seriously damaged for many years. The people who participated in that debacle are still around in China. We seriously doubt they want to do that again.

c) However, building an alternate supply chain is always a good idea when there is only one dominant company, nation or region supplying a critical material. The basic argument for doing so is as simple as "you never know". But building that supply chain for magnets is not as easy as digging it out of the ground and selling a mineral concentrate. To make a magnet, you first produce a mineral concentrate by mining. Then you perform hydrometallurgy to separate the rare earths, as a mixed hydrometallurgical concentrate. from the other (mostly) useless elements in that mineral concentrate. Because most of the rare earths are chemically similar enough to make it difficult to do more than just recover them as a jumbled mixture from hydrometallurgy, we then need to separate and purify the individual rare earths using a more-physical-than-chemical technology, like solvent extraction. Then some rare earths, usually now in the form of pure oxides, are put into systems that look like miniature versions of aluminum smelters to convert those oxides to pure metals. In the case of magnet making, we than take some neodymium metal and add it to a lot of iron and a little bit of boron, then sprinkle on some additional metals to taste and need. That mixture of metals then needs to be melted, mixed and cooled at the right rate to make a magnet alloy. These alloys can be ground down and mixed with resins to create a weaker bonded magnet blank or bonded under heat and pressure to create a stronger sintered magnet blank. The blank at this point is not yet magnetized, and will typically be machined into final shape, put into the motor it will bring to life and then magnetized in place with a powerful, externally-applied magnetic field. It's a lot more than just mining.

We might be able to dig the rare earths out of the ground, there is certainly plenty of mining knowledge in the western world. We can definitely make the mineral concentrate from ore. There is no doubt that we can do the hydrometallurgy to get the rare earths out of the minerals. But separating them is knowledge that few in the west have. Making them into metals is even less so. And you can count the non-Chinese magnet makers on one hand at this point. We need a lot of downstream effort to create that non-Chinese rare earth supply chain, something that western governments that want to help don't seem to completely understand.

But all that aside, let's say we get there. So now there are a lot of companies in the west that can extract rare earths, turn them into metals and make magnets out of them. What sort of demand might they face? Well, in 2019 (we will avoid 2020 because of COVID-19 effects) global light-duty vehicle sales were 89.8 million units. Let's assume that sales stay flat, because that makes it easy. By 2030, Guidehouse Insights has suggested that 20% of all light-duty vehicle sales could be electric. So that's 18 million units, which would be spectacular growth from where we are now.

Now, Adamas Intelligence published, in late 2019, that permanent magnet synchronous motors (the basic type of electric motor using a rare earth magnet) require about 1.2 kg of NdFeB magnet per 100 kW of peak power. While there was once hope that this number would decline dramatically, it hasn't moved that much for years. Let's assume that average peak power for electric vehicles, globally, will be only 75 kW per vehicle. That's low by North American standards, especially considering power output of 250 hp (186 kW) or more from gasoline engines in a lot of North American and European vehicles. However, taking into account the efficiency losses in an internal combustion drivetrain, plus the fact that many of these electric vehicle sales will be outside North America and Europe, 75 kW is perhaps low but not outrageously so.

So, if we are selling 18 million vehicles a year with an average 75 kW peak power motor and need 1.2 kg of NdFeB magnet material per 100 kW of peak power per vehicle, then we only need 16.2

million kg of magnet for this purpose in 2030, up from not that much today. 16.2 million kg is, of course, 16,200 tonnes. Way back in 2012, the rare earth magnet market was estimated to be 63,000 tonnes, and it has certainly grown since then. This includes both the NdFeB magnets that are likely to be used in electric vehicles and the SmCo magnets used in military and other very high-stress applications. Given the volume of magnet material currently being used in some pretty low-value places (electric motors in drones, in small appliances, etc.) there would not immediately seem to be a major supply shortage looming, but we should try and drill down to the individual rare earths.

NdFeB is more properly described as $Nd_2Fe_{14}B$, so it's mostly iron, about 72%. But 16,200 tonnes of such magnets would still require 4,325 tonnes of Nd metal. The industry mostly discusses demand in oxide terms, so that is the equivalent of 4,941 tonnes of neodymium oxide. Of course, the major question is whether this is a problem, and to be honest we would have to say likely not, if the capital markets cooperate and provide the necessary backing.

Let's put it this way: in the first half of their fiscal 2021, Lynas Corporation of Australia made 2,709 tonnes of combined neodymium and praseodymium oxide, both useful in magnets. Basically, we are looking for another, single, Lynas, or for Lynas to double its production. Neither of these things is a major challenge to do, other than finding necessary capital.

Now, what is a little more challenging is making magnets that can survive use in an electric vehicle. NdFeB magnets have a significant drawback associated with them, which is that as temperature rises the magnetic field generated by the magnet decreases. Above the boiling point of water, a pure NdFeB magnet begins to decline quickly in field strength and the magnet will essentially cease being a magnet, permanently, at a critical temperature around 310 °C. But it's obvious that an electric motor used in an electric vehicle is very likely to heat up to high temperatures (picture an electric truck hauling a loaded trailer up a long grade in the summer). Needless to say, selling an electric vehicle with a motor that fails under its first big operating load would not be ideal.

The way around this problem is to add either dysprosium or terbium, two other rare earths, to the magnet. Typical modern doping levels would normally be about 3% dysprosium by weight (or a lot less terbium, but terbium is also scarcer and, usually, more expensive than dysprosium, so we will limit this discussion to dysprosium alone). By adding dysprosium, the effective critical temperature at which the magnet fails is raised considerably, and the degradation in field is reduced at higher temperatures.

So, if we need 3% dysprosium in all 16,200 tonnes of magnet we discussed above, we need only a paltry 486 tonnes of dysprosium metal, or 558 tonnes of dysprosium oxide. Problem is, though, that dysprosium is actually rare. Not rare like "rare earths", but rare FOR a rare earth. Terbium is even scarcer than that. Global production of a factor we term "dysprosium equivalent", Dy_{eq} or the amount of terbium oxide and dysprosium oxide produced globally and scaled to a dysprosium oxide-equivalent level for magnet use, was only about 3,200 tonnes in 2019.

An additional demand of 558 tonnes on top of production of 3,200 tonnes doesn't look that bad, until you realize that the current crop of western-world mines are not good for producing Dy and

Tb. Total production in 2019 from both Mountain Pass in California and Mount Weld in Australia was a whopping 370 tonnes Dy_{eq}. Maybe it seems worse to me, because I remember the time and pain required to get just those two mines up and running. Even so, if we get the equivalent of another couple of Mount Weld's and Mountain Pass's into production, then no problem.

Right?

Well, not quite. Rare earth mines produce their rare earths in a fixed ratio. No one can go into a deposit and dig just the terbium and dysprosium out of that one section of the mine. This is part of that whole "the rare earths are chemically very similar" problem. If we need to add a couple more projects of the scale and scope of Mount Weld or Mountain Pass then we have added a lot more neodymium and praseodymium to the market. That is going to bring down the price of neodymium and praseodymium, and rare earth mines live and die on the basis of their return on the magnet materials. Developing the pricing models to tell us what happens to Nd and Pr pricing when that extra material enters the market is precisely what Stormcrow does for a living, and we won't discuss the results openly. But to summarize, lowering the price of Nd and Pr isn't helpful.

So, if rosy projections are right and 20% of all light duty vehicles sold in 2030 are electric and if all of them use rare earth main motors, then we need a couple or three more rare earth mines, or their equivalent from expansions, to be in production. That isn't earth-shattering levels of demand, even the mining industry should be able to keep up. If those mines and the materials from them are not available, then the auto industry could make do with other technologies, even stooping so low as to maybe use induction motors (Tesla did it!).

A bigger problem, though, is the need for more downstream capacity. We need more capability to separate and purify the rare earths, turn the oxides into metals and make magnet alloys and magnets. Right now, the bulk of that expertise belongs to Chinese companies. And Western governments are busy trying to demonize the involvement of Chinese rare earth companies with downstream expertise in Western projects; witness the way MP Materials was treated when it was "discovered" that Shenghe Resources of China was a 9.9% shareholder (gasp!) in April 2020, or that an investment by Baogang Group of China (louder gasp!) into Northern Minerals of Australia was rejected by the Australian Foreign Investment Review Board also in April 2020. Western governments have been beating a drum about Chinese theft of western intellectual property, yet here is a perfectly good opportunity to extract intellectual property from China for the supposed betterment of our society and our governments refuse to seize the moment. It's perplexing, at a minimum.

The long and the short of all this is that rare earths are likely not an impediment to the continued adoption of electric vehicles. More effort and money should definitely be flowing into the downstream portion of the rare earth supply chain rather than simply worrying about digging those rare earths out of the ground, but it's unknown whether any layer of government will figure that out. We do sympathize, though, because it's hard for anyone in government to hear sense when they are constantly being inundated with nonsense about the rare earth market by erstwhile miners and uneducated journalists.

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