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//RARE EARTHS

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WHEN WILL CHINA CUT US OFF?

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- **Misguided Musings** – I continue to read breathless missives about how 'China' will cripple Western society, any minute now, by cutting off our supply of 'essential' rare earths. I would suggest that just about everything in that argument is wrong. But it did inspire me to consider why and when 'the Chinese' might decide to suspend rare earth exports.

- **Not Likely but When?** – In the end, those making these arguments might have a point. The Chinese rare earth industry is now led by state-owned enterprises that can be trusted to make enough material for customers but won't overproduce and damage the market. That's all good. But at the rate demand is rising, courtesy of the wrongheaded attempts to switch the auto industry to nothing but electric vehicles, there might come a point when the Chinese new energy vehicle industry is using most/all of the magnet materials made in China. And if/when that time comes, it's anyone's guess whether anything will be exported, anymore. The question is, when does that time arrive?

- **Pin the Tail on the Donkey Time** - So let's try and figure out when that magic point in time will come and see if the western world has enough warning to try and get its act together with respect to making rare earth. Based on some simple assumptions, my best guess is that we have absolutely nothing to worry about.

- **And Our Hypothetical Supply Chain –** But the above DOES NOT mean that it isn't smart to build a non-Chinese supply chain. Having more than one avenue of supply is never foolish. Companies working on mining and processing rare earths should still have a place within investment plans, just not because China will suddenly cut off supply.

I am a doctor, just not that kind. Or that kind, either.

And it would probably take a psychologist to figure this one out. For some reason understood only by politicians, we've decided that the solution to the global problem of anthropogenic climate change is that everyone should drive an electric car. Now, I completely understand that we need to make sweeping reductions to carbon emissions, something like, say, a 45% reduction by 2030 and with much deeper cuts needed in the years after. But the entire sector known as "Transportation", which includes air, sea, rail and heavy-, medium- and light-duty road-going transport, is only about 14-19% of global anthropogenic carbon dioxide emissions. So even if ALL of the medium- and light-duty vehicles magically became electric vehicles tomorrow (forget heavy-duty, that's a pipe dream simply because 'heavy-duty' vehicles that need to stop to charge for a few hours, every shift, are not 'heavy-duty'), that would knock something like a whopping 5-8% out of all of global carbon emissions. 5% is not more than 45%, or even close, so why focus on this as a 'solution'? But, government seems hell-bent on doing it, and who am I to rain on their parade, am I right?

So, to a more limited and potentially realistic issue…

We've all read what seems like an endless stream of articles on how 'China', a shorthand for the collection of state-owned and private companies working within this industry within China, I think, will destroy Western civilization any minute now by cutting off access to rare earths, an industry that 'they' control to a very high degree. A good example of this sort of fevered argument is "China could shut down our military in a minute if we don't fix the looming rare earths supply crisis", published on a Fox News site on January 26, 2023. It pushes all the psychological buttons of national defense, helplessness, lack of control, you-name-it. In my estimation, it's also so much nonsense, but in a period when Western governments seem to have nominated China to be the Next Great Enemy of America, the argument likely plays well.

More relevant, though, is that estimates tell us that about 90% of modern electrified vehicles use electric motors containing strong permanent magnets made using rare earths, specifically the rare earths neodymium (Nd), praseodymium (Pr), dysprosium (Dy) and terbium (Tb). Nd and Pr are the base materials used in the composition of the magnet, Dy and Tb are additives that improve certain critical operating parameters. While both Nd and Pr can be used to form the bulk of the magnet, the magnet material most commonly deployed in this application is known by the simplified chemical formula NdFeB. The magnets are an alloy of neodymium, iron and boron metal, in the correct chemical proportion of $Nd_2Fe_{14}B$. How or why this works is not really salient to our discussion, it's only important to know that, today, this material is our way of making a magnet that is just ridiculously more powerful than a regular old iron-based fridge magnet, or anything similar. And by using a very powerful permanent magnet in a simple electric motor design, that motor can produce a lot of power from a (relatively) lightweight and physically small package and do so very efficiently.

For battery-powered electric vehicles (BEVs) where there is no other source of energy on-board but batteries, having a small, light and efficient motor on-board is a very good thing. It means that the (expensive) batteries, holding the only available energy to move that vehicle from Point A to Point B, are able to move the vehicle as far as possible. These types of motors, sometimes called permanent magnet motors (PMMs) are a really nice engineering solution, providing that (a) the rare earths needed stay at reasonable prices and (b) you can get the rare earth metals you need to make the magnets, at all.

The PMM is NOT an absolute requirement in a BEV or any electric vehicle. When Tesla started building its Model S sedan, the main motor driving those vehicles down the road was an induction motor that contained a lot of copper, aluminum and iron but no rare earths, in the form of magnets or otherwise. However, in a world where we want to build BEVs and where we want to use the on-board energy as efficiently as we can, PMMs using rare earth-based magnets are the best answer we have.

Those rare earths, however, are largely mined/processed in China. Even rare earth ore that is mined at the Mountain Pass Mine in California by MP Materials is currently shipped to China for downstream processing. While that is something that MP Materials is working to change (and I am confused as to why, but that's yet another report), it happens to be true for right now. I've tweaked my models for rare earth production to look only at the total of Nd and Pr being made and where it is being made, as of 2022.

The result is, I think, illuminating. About 88% of all the Nd oxide and Pr oxide made in the world in 2022 was processed in China, in spite of China only directly mining about 69% of this material. This is because, while China has downplayed domestic production of rare earths from some types of mines due to associated environmental impacts (production in south China from the so-called ionic clays), China dominates the global capacity for separating and purifying the individual rare earth oxides, converting those oxides to metals where required, producing good-quality magnet alloys (which is definitely not as simple as melting, mixing and pouring) and making good-quality magnets.

The rare earths are not really 'rare'. That term is a holdover from the days when it wasn't simple to take a bunch of elements with really interesting individual magnetic, optical and other properties but that do behave in similar chemical ways and separate them from one another. There are lots of rare earth deposits out there. The trick is whether or not western companies will develop better/faster/cheaper ways to do what Chinese companies currently do inexpensively and well, because I believe that if the western rare earth industry can't come up with better processing technology then the western industry will be a footnote, used to keep the Chinese industry honest.

Let's posit a simple theory: the Chinese rare earth industry is only really concerned with supplying Chinese industry. If there is material left over then it can and will be exported to overseas customers, but state-owned enterprises in China are focused on improving the Chinese economy, not on providing material to, for example, western car manufacturers. If producing more rare earth causes environmental damage, as it does, and if there is a growing shortage of young Chinese workers seeking their fame and fortune in rare earth production, as there probably is given what we know about Chinese demographics, then it doesn't seem certain that the Chinese industry will snap to attention if GM and Volkswagen start calling for twice the magnets. And if the trend is for some of that material mined outside China that has previously been processed in China to be withdrawn and processed elsewhere, whether that happens quickly and/or successfully or not, then the date when China is making just enough magnet material to keep their domestic industries happy is likely sooner than we think.

Add to the above the fact that Chinese new energy vehicle sales are growing strongly. The advantage to a centralized economic and planning framework is that initiatives such as the growth of the new energy vehicle industry can be mandated. Even if, as it seems right now, the initiative might be lacking in some planning details, such as where the electricity to charge all these new energy vehicles (NEVs) is supposed to come from (the well-publicized electricity shortages in China over the last two years suggests that switching all domestic transport to electricity is going to face challenges, but I digress). And for those that think a "communist' system of central planning means that the vehicles available to Chinese consumers are a drab and poorly-constructed lot, with Chinese consumers avoiding them like the plague, better think again. Chinese buyers of new energy vehicles have a much better and much wider selection of BEVs to choose from than consumers in the western world and they are actually buying them. A lot more NEVs means that much more Chinese demand for Chinese-made NdFeB magnets.

To put together a model that can predict if/when the Chinese industry is likely to stop exporting magnets to the auto industry outside China, we need a few things. First, we need some prediction regarding how the Chinese production and processing of rare earths will ramp through, say, the end of the decade. Second, we need some idea about how the sale of Chinese new energy vehicles will look over the same time frame. Finally, we need a better idea of how much magnet is really needed in the Chinese auto industry. So, let's try and put those elements together.

The most important aspect of our model, given we are looking at Chinese production and willingness to maintain exportation, is Chinese production along with non-Chinese rare earths that will continue to flow to China for processing.

Chinese rare earth production is essentially of two very different types. Traditional hard-rock mining, whether that production is direct extraction of rare earth minerals, happening at various mines in both the north and south of China, or by-product production from mine wastes, which is what happens at the world-famous Bayan Obo site, is straightforward. Ores are extracted, milled and rare earth-bearing minerals like bastnasite and monazite are concentrated and then leached. From that point a hydrometallurgical concentrate of rare earth elements can be separated and purified.

The extraction of rare earths from the southern so-called ionic clays is a different matter. The grade of the ionic clays is low, but the mining technology developed to exploit these deposits is a form of *in situ* recovery using a solvent such as ammonium nitrate in water or even a weak acid. A system of pipes is installed, usually on the soil surface, to allow the solvent to be pumped in. The solvent leaches through the soil and clay and carries off some of the loosely-bound rare earth. Horizontal collection channels are drilled into hills of this ionic clay, and the collected run-off is then allowed to settle and is chemically purified until the hydrometallurgical concentrate can be extracted.

Extraction of rare earths from conventional hard-rock mining is no more inherently polluting than any conventional mining operation in North America or elsewhere. As a consequence, the miners producing from this type of deposit have been allowed, by the Chinese Ministry of Industry and Information Technology, to write their own ticket, so to speak. It is sometimes misunderstood by westerners that the MIIT sets production quotas and does so in some academic way, but this is incorrect. The quotas are largely set by the state-owned producers, themselves, from their level of shipments and order book.

But harvesting from ionic clays inherently leaves a deposit that will continue to weep rare earths, in solution, for a long period of time. Whether this is significantly harmful is an open question, but there is sufficient environmental concern around this point that production quota increases from the southern ionic clay mines have been limited compared to allowed production quota increases from the northern conventional mines.

There is no data available from the MIIT or the major SOE producers to gauge future production expansion, so I will assume that production grows, annually, at a rate consistent with the growth of the last few years, for each of the northern- and southern-type mines. And I assume that no new technology intrudes that could change the *status quo*. For example, I've recently seen reports of a new technique for ionic clay harvesting involving the use of electric fields to improve the recovery and speed of *in situ* mining. If such a technology were proven to be commercially useful, extracting significantly more rare earth during the harvest period would, naturally, leave far less to leach into the environment following the active mining period. Perhaps this could encourage the Chinese MIIT to allow for larger and more rapid increases in southern ionic clay production quotas. For our purposes, however, let's assume such a change does not come to pass within this decade.

Exhibit 1 – Nd/Pr Oxide Production by Chinese Firms

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Total REO	140,000	168,000	210,000	241,500	289,800	362,250	439,866	534,668	650,508	792,104	965,237
North China	120,850	145,020	187,000	218,000	264,800	334,250	409,657	502,075	615,344	754,165	924,305
South China	19,150	22,980	23,000	23,500	25,000	28,000	30,209	32,593	35,164	37,939	40,932
Foreign Nd/Pr	17,321	17,585	13,941	16,703	20,311	23,099	25,476	27,266	27,733	29,570	29,807
Domestic Nd/Pr	30,142	36,171	44,824	51,347	61,399	76,528	92,667	112,358	136,396	165,753	201,622
Total Nd/Pr	47,463	53,756	58,765	68,050	81,709	99,627	118,143	139,624	164,129	195,323	231,429

Source: Stormcrow (2023)

It should be noted that Chinese rare earth production from the processing of Bayan Obo mine waste is, essentially, limited only by demand. According to the US Geological Survey, the Bayan Obo complex contains something like a reserve of 1,500 million tonnes of iron, at an average grade of about 35% iron, by weight. It also contains something like a reserve of 48-100 million tonnes of rare earth oxide at a grade of 4-6%, by weight (one source, in 2013, suggested grade is 4.1%, others suggest as high as 6.4%), contained in the minerals bastnasite and monazite. Assuming all this stuff is evenly mixed, and I grant that is a major assumption, the grade of REO is about $1/10^{th}$ the grade of iron. For every 10 tonnes of iron, Bayan Obo could produce at least a tonne of REO. Indeed, the same source article published in 2013 suggests that, at that time, for every 350 kg of iron, 60 kg of REOs are produced, which is a ratio that is a lot better than 10%.

Baosteel, the operator of the Bayan Obo mine, has previously noted that it has produced and could produce as much as 24 million tonnes of iron from the mine. This means that the mine could make 2.4-4.1 million tonnes of rare earth oxide per year, if there was demand for it. Remember, too, that a fair pile of rare earth-bearing tailings have already piled up at Bayan Obo (I've been there and seen them). Projections of roughly 900,000 tonnes of REO production from northern China in 2030 are, likely, not stretching reality, in any way, save that there actually needs to be enough demand to justify it.

Increasing Need

We do know that demand for rare earth magnets, due to new energy vehicle sales, is skyrocketing. Various predictions of demand for new energy vehicles in China have been made, but the Chinese Association of Automobile Manufacturers (CAAM) has a likely claim as being one of the more authoritative. And their projections result in impressive numbers. Assuming that the subsidies and the push to sell new energy vehicles remains strong in spite of electricity shortages, we believe sales in China could do the following:

Exhibit 2 – Projected Chinese Passenger Vehicle Sales (in millions)

Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Total (M)	25.3	26.3	26.5	27.0	27.6	28.1	28.7	29.3	29.8	30.4	31.0
NEV (M)	1.3	3.5	6.5	8.8	11.8	16.0	17.6	19.4	21.3	23.4	25.8

Source: Stormcrow, CAAM

Total light- and medium-duty vehicle sales in China are growing, but slowly. NEV penetration is growing dramatically, through a combination of the use of subsidies, both social and economic, as well as the simple fact that the least expensive vehicles to buy and to operate in China are NEVs. Reports have suggested that something like 85-90% of NEVs are equipped with a PMM. PMMs using NdFeB magnets allow for the simplest and cheapest construction and drivetrain configuration, providing that you can get the NdFeB permanent magnets that are required and providing that their price is acceptable.

The amount of magnet required scales with the power of the vehicle. Most modern vehicles, NEV or not, contain rare earth magnets already. These magnets are used in motors that do things as important as pumping gasoline into fuel injection systems or providing power to reduce steering effort but also less critical tasks such as moving the seats or changing the angle of door-mounted mirrors. Motors made with rare earths are small and very powerful, and this helps meet size and weight targets. But the main motor in a NEV, especially a BEV, swamps all the rest of rare earth demand for a vehicle, simply because the main motor is far more powerful.

Estimates for the amount of magnet in a vehicle range from 3 kg in a vehicle like a Tesla, where there is no other source of motive power, to less than 1 kg in a vehicle like a Toyota Prius, where there is a gasoline engine to work in conjunction with the electric drive and where maximum power is not a critical consideration. For the sake of making our demand forecast as robust as possible, let's assume every one of the NEVs to be sold in China is a firebreathing monster with 4 kg of magnet in it. And let's assume that all of them, 100%, use NdFeB magnets in their main motors.

The result, built on the table, above, is the resulting prediction for Nd/Pr oxide demand. Note that a current NdFeB magnet is really the material $Nd_2Fe_{14}B$. In rough terms, then, about 27% of the magnet, by mass, is actually a rare earth metal, like neodymium. And since the industry generally describes rare earth production in terms of oxides, I note that one kilogram of rare earth metal is produced from significantly more than one kilogram of rare earth oxide (Nd_2O_3 is about 84% rare earth metal, by mass, with the rest being oxygen). So, if I do the arithmetic, then the ridiculously inflated projection for how much neodymium and praseodymium are needed in the Chinese NEV industry is:

Exhibit 3 – A Ridiculously Inflated Chinese NEV Demand Analysis for Magnets

Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Total (M)	25.3	26.3	26.5	27.0	27.6	28.1	28.7	29.3	29.8	30.4	31.0
NEV (M)	1.3	3.5	6.5	8.8	11.8	16.0	17.6	19.4	21.3	23.4	25.8
Magnet (t)	5,080	14,080	26,000	35,100	47,385	63,970	70,367	77,403	85,144	93,658	103,024
Nd/Pr Oxide (t)	1,633	4,526	8,357	11,282	15,231	20,562	22,618	24,880	27,368	30,104	33,115

Source: Stormcrow (2023)

When Supply Easily Surpasses Demand, What Dreams Shall be Crushed?

So, just to make this point as obvious as possible, let's put our achievable levels of Chinese domestic Nd/Pr oxide production next to our completely ludicrous demand projections from the Chinese NEV industry:

Exhibit 4 – Achievable Production vs Ludicrously Inflated NEV Demand

Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Achievable Production (t)	47,463	53,756	58,765	68,050	81,709	99,627	118,143	139,624	164,129	195,323	231,429
Ludicrous NEV Demand (t)	1,633	4,526	8,357	11,282	15,231	20,562	22,618	24,880	27,368	30,104	33,115

Source: Stormcrow (2023)

At no point to 2030, when the volume of NEVs optimistically approaches total production of passenger vehicles in China, does the ridiculously inflated demand (remember, 4 kg of magnet per 100% of all NEVs versus the realistic 0.7-3 kg of magnet per 85-90% of all NEVs) level for Nd/Pr oxide outstrip available supply. We might add, at no point does the ridiculously inflated Chinese demand level for Nd/Pr oxide from the NEV industry for 2030 even outstrip *current* domestic Chinese production of Nd/Pr oxide.

Does anyone *seriously* believe that, with domestic GDP projections of only 5% recently being released by the Chinese government, Chinese authorities will willingly cut jobs in mining, processing and manufacturing to thumb their nose at the entire western world, which would then likely respond by significantly cutting our reliance on a lot more than just rare earths, and all this despite there being a surplus of rare earths to sell?

Seriously?

Conclusion – Not Gonna Happen

Many pundits and self-proclaimed experts have concluded that China can cripple the western world simply by suspending shipments of rare earths. Someday. Maybe soon. The basis for this conclusion appears to be that rare earths are somehow 'essential', the magic pixie dust that makes just about all technology in the west actually work.

This is, to put it mildly, organic fertilizer. Rare earths range, in their criticality, from very important (for materials like lutetium that forms the basis for some types of medical imaging devices or erbium that is used to make amplifiers for fiber optic communications networks) to important (for neodymium or praseodymium metal, used to make magnets) to available and convenient but entirely replaceable (for materials like cerium oxide, used as a polishing powder, or lanthanum metal, used as a catalyst). China produces all these materials, in quantity, from an industry involving large numbers of workers and companies. In many cases, China produces not only the raw material but also downstream products and the final assembly (for example, China mines the neodymium and dysprosium but also makes the rare earth metals, NdFeB magnet alloys, the magnets and, finally, the electric motors, themselves).

The goal of a trade war is to cause asymmetric damage; to hurt the side you impose sanctions or tariffs on more than you hurt yourself. China blocking the shipment of rare earths and all related downstream products would damage their own economy with an uncertain impact on western economies. The retaliation would likely harm the Chinese economy much more than the already considerable damage from the crippling of its rare earth industry. This is not smart politics or smart business, no matter who suggests it or how often.

What is more plausible would be a situation in which China kept such critical materials inside China for use by Chinese industry, if there were a pending shortage. With the rapid growth in new energy vehicle sales, it is conceivable that demand for NdFeB magnets might outstrip Chinese capacity to produce the required raw materials, leaving us in the west unable to utilize what is, today, China's excess supply. I believe I've shown that not only will potential future production of rare earths leave a large amount of excess production available for export but that even ridiculously overinflated demand figures for the Chinese NEV industry in 2030, with NEV production approaching all the vehicles sold in China, would still allow for some export from the quantity of neodymium and praseodymium produced in China *today*. It is extremely unlikely that we will see Chinese rare earth production enter into any sort of domestic shortfall, even assuming that new materials do not supplant the need for NdFeB magnets or that new technology allows for dramatic improvements in rare earth extraction in China.

'Rare earths are not rare' is an observation that I helped popularize. But common sense, at least when it comes to the situation around the supply of, and demand for, rare earths certainly does seem to be hard to find. Let's hope our political leaders are making decisions based on better analysis than what is supplied by many popular press writers and self-proclaimed industry 'experts'.

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