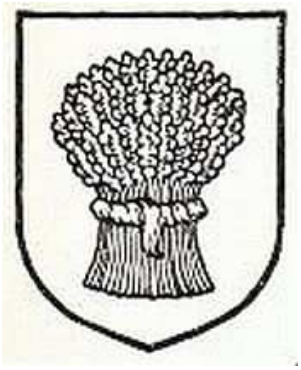
Wednesday, September 19, 2018



HALLGARTEN & COMPANY

Sector Review

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Dysprosium

The Dark Horse in the Rare Earth Stakes

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- + The EV revolution is giving impetus to higher projections of market needs for Dysprosium and other key REE magnet metals into the 2020s
- + Potential supply is constrained by tight financing having choked off development of new projects
- + The Rare Earth universe is stable without much prospect of new interlopers
- + New technologies could lower processing costs and simplify extraction from the broader suite of Lanthanides
- + The steep rise in Cobalt has choked off any tendency to use that metal as a substitute for key Rare earths, particularly Dysprosium
- ✘ Dysprosium price movements and stockpiled materials remain essentially at the discretion of the Chinese
- ✘ Excessive upward price move or supply problems could prompt revival of experiments at substitution
- ✘ Financing of projects remains very difficult and almost inevitably requires a committed offtaker

Dysprosium – The Dark Horse in the REE Stakes

We have often likened the REE space to a horse race. Usually the metaphor was regarding the companies in the field and attempting to predict which shall make it to the finish line and which shall end up getting sent, metaphorically-speaking, to the glue factory.

However, in another respect the Lanthanide Stakes has ended up being perceived as a two-horse race amongst the elements in the series with all the other runners, excepting Neodymium and Praseodymium being scratched before the starting gun. Of course this reflects yet again the short-termism of the analytical community who have trouble remembering the day before yesterday let alone the uses to which Lanthanides were put in the 1950s or, heaven forbid, the 1910s. Rare Earths were around before they arrived and will be here well after they are gone.

One of the horses that should not have been scratched from the race though is Dysprosium as it is still up and running and dare we say it, racing up on the outside and potentially giving those wagering on deposits slanted towards Dysprosium their moment of glory in the **Winner's Circle**.

These thoughts have been prompted by the publication of a report by Adamas Intelligence dedicated to Dysprosium alone and its outlook. This in itself is a rarity as the reports on the space have usually

covered the whole suite of Lanthanides. The report came out in the second quarter of this year and copies of it have been now filtering around the Rare Earth space like a *samizdat* novel by Solzhenitsyn back in the days of the USSR.

Who Uses It?

Dysprosium's name is derived, curiously, from a Greek term meaning "hard to get at". Dysprosium's hard texture and slow reaction in water distinguish it from some of the other Lanthanides. The main use, indeed the overwhelming application, for Dysprosium oxide consumption each year is for production of NdFeB permanent magnets. It is a potentially powerful para- or ferro-magnet within specified temperature ranges and can serve as an alloying substance added to permanent magnetic material in lieu of a certain amount of the Neodymium. In such an application, it boosts the performance of the alloy. From 2013 through 2017 Adamas Intelligence estimates that over 99% of global Dysprosium oxide (or oxide equivalent) went into the production of NdFeB magnets.

Where	RE Property	RE	Allows	Final Impact
Wind turbines	Permanent magnet generators	Nd Pr, Dy	No gear box (Cost) Better yield in light winds	Energy produced at lower cost
Cars	Permanent magnets motors	Nd Pr, Dy	Electricity savings	Saves energy
			Weight Reduction	
	Electricity storage	La, Ce	HEV Batteries	
	Catalytic reduction	Ce	Depollution systems	
Appliances	Permanent magnets motors	Nd, Pr, Dy	Electricity savings	Saves energy
Lighting	Efficiency (x3)	Eu, Tb, Ce, La, Y	Energy Savings	
Electronics	Smaller components	Dy, Nd	Improved functionality	Efficient operation

Source: Lynas Corp

Dysprosium is commonly added to NdFeB permanent magnet alloy for use in applications involving elevated temperatures (above 80 °C) and/or strong demagnetization fields.

With the addition of Dysprosium (and often Terbium) to NdFeB, the maximum operating temperature of

the material can be tripled (up to 240 °C), making NdFeB the ideal material for an ever-growing list of end-uses and applications.

From 2013 through 2017 Adamas Intelligence estimated that electric mobility and industrial applications were the greatest demand drivers of Dysprosium oxide (via use of Dy-containing NdFeB), followed by wind power, and vehicle accessory motors.The manufacture of control rods used in nuclear reactors also relies on Dysprosium, itself a potential by-product of nuclear fission. Dysprosium also plays an important role in compounds used to make laser components, in metal-based halide lamps, and as phosphor-activating agents.

Applications	Grade Suffix	Typical Dy Weight %
High Temperature Motors and Generators Hybrid & Electric Traction Drives	EH, AH	8.5 to 11.0
Commercial and Industrial Generators Wave Guides: TWT, Undulators, Wigglers	UH	6.5
Electric Bicycles Energy Storage Systems Magnetic Braking Magnetically Levitated transportation Motors, industrial, general auto, etc Pipe Inspection Systems Relays and Switches Reprographics Torque-coupled drives Wind Power Generators	SH	4.2
Gauges Hysteresis Clutch Magnetic Separation	H	2.8
Acoustic Transducers HDD, CD, DVD Magnetic Refrigeration MRI Sensors	M	1.4
Advertising Latches Toys	(no suffix)	<0.5

Source: Arnold Magnetics

The table above is quite interesting in showing the approximate Dysprosium content of Neo magnets in these applications (based on typical usages from 1985 to 2011). New or refined technologies are permitting reduced percentages.

Swapping Out – Swapping In

One of the on-going “myths” of the Dysprosium space is that of displacement by alternative materials.

These fears have been around for years and to some extend were mitigated by the extended period of low REE prices since 2011. However, beyond mere price considerations there is the issue of security of supply. That has scarcely been addressed yet, with the only Dysprosium-biased project reaching fruition being that of Northern Minerals.

Various companies had set themselves the task of minimizing Dysprosium in the hope of lowering dependence on, or at least percentages of, Dysprosium in magnets. One technique is the dysprosium (or HREE) diffusion method of Shin-Etsu, Hitachi, Vacuumschmelze and others. Another method is exemplified by Daido's use of melt-spun, nanostructured material – nano-structuring increases intrinsic coercivity without the use of Dysprosium. A third method is more finely milled and more uniformly fine powder alloy particles, which results in a 30% increase in Hcj (the thermal coefficient of coercive force) of the no-Dysprosium magnets as developed by the likes of Showa-Denko.

Despite the improvements, considerable Dysprosium is required for high temperature applications. HRE diffusion methods do nothing to mitigate loss of flux of the magnets which occurs with increasing temperature. A neo magnet capable of performing at 200°C because of HRE diffusion still loses 19.8% of Br (residual induction) and ~36% of the energy product between 20 and 200°C.

Improved materials are also being sought that minimize the use of Dysprosium while retaining high resistance to demagnetization. One method is to diffuse (by heating) Dysprosium into previously manufactured magnets having low base levels of dysprosium in order to put the additional Dysprosium into the microstructure where it will have the greatest effect on intrinsic coercivity (HcJ). This is being advertised by both Shin-Etsu and Hitachi and both companies have introduced new series of magnets with reduced Dysprosium content.

Numerous industrial and laboratory projects are underway attempting to discover new magnet materials that don't require Dysprosium and, perhaps, no Rare Earths at all. In a paper on the subject, Arnold Magnetics stated that, "At least a dozen projects have been funded but have not as yet (Sept 2015) resulted in commercially viable product. Most of the projects have now lost their funding with no commercialization".

Thinking outside the box, some researchers have tried to moderate the temperature of the application thus obviating the need for high coercivity. Additionally, designs using more readily available materials are also possible. Numerous motor manufacturers are engaged in improving designs utilizing La-Co-ferrite magnets, alternative motor structures (e.g. axial drives) and more sophisticated drive algorithms using electrically complex applied power. However, the mere mention of Cobalt in an alternative these days makes it less attractive.

Ironically, it was only a few years ago that Samarium Cobalt magnets, which represent an exceptionally good high temperature performance material, were seen as an alternative for those with Dysprosium. With the passing of time and the Cobalt price surge, those who thought of making this switch would be looking foolish as Cobalt looks harder to find, and more expensive, than the Rare Earth alternatives.

The Report

The key findings of the Adamas report were:

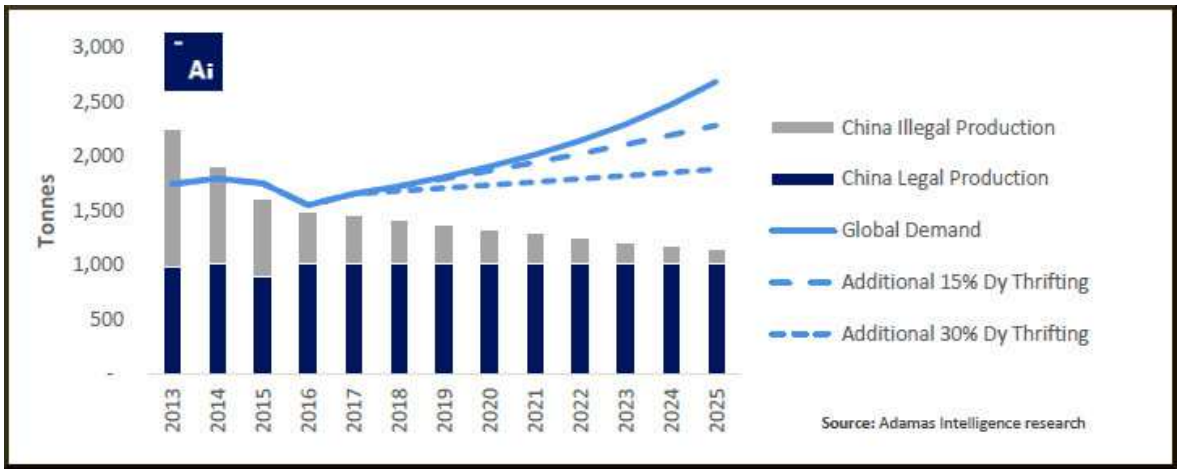
- An ongoing government-led crackdown on illegal rare earth mining in China has led to a 34% reduction in global dysprosium oxide production since 2013
- Looking ahead, Adamas Intelligence believes that China's production alone will be insufficient to support global demand growth
- In fact, by 2025 China's demand for dysprosium oxide for electric vehicle traction motors alone will amount to 70% of the nation's current legal production level, emphasizing the imminent need for new supplies
- Outside of China, there are a handful of advanced rare earth development projects with potential to add significant quantities of dysprosium oxide production annually by 2025
- If automakers, motor manufacturers, and other end-users of high-temperature NdFeB do not act today to secure long-term supplies, they will soon find themselves amidst a sellers' market scrambling for rare earth motor metals the same way many are scrambling today for battery metals

Let's look at these challenges.

The first two challenges are linked. They are to some degrees the cause and the effect. China has, surprisingly let its garden of Rare Earths go to wrack and ruin. The oft quoted comment of Deng Xiao Ping is that Rare Earths will be to China as oil is to Saudi Arabia. However, if Saudi Arabia let its domination slip away by underpricing its product and then letting its sources of production decay into environmental disasters or hastening their demise through high-grading or illegal mining then we might agree that they are alike. China has, like Saudi Arabia, from time to time sought to manipulate lower the price of Rare Earths (or oil) to maintain dominance. But while Saudi Arabia is in no danger of running out of product, China is in a danger zone with respect to Rare Earths.

That production has declined by the extent that Adamas claim is no surprise but that prices have not risen commensurately, or indeed exponentially, is probably a product of the Chinese suppression of prices (combined with a frittering away of stockpiles/reserves) to ensure that the wicked West don't get traction with projects destined to create REE independence from the Chinese mothership. In itself that is a reckless short-termist policy because the Chinese are transfer pricing scarce Rare Earths to the West in exchange for a transitory dominance. After all, ask yourself the question, who now knows or care that the English city of Manchester was once the dominant force in the global cotton trade? *Sic transit gloria mundi*.

The chart produced by Adamas (below) tells the story better than a thousand words could. As can be noted a market that was in surplus due to illegal mining is now just in deficit and the deficit is going widen either significantly or enormously depending on one's view on EV take-up and efforts by users to reduce the Dysprosium component in their product formulas.



Just as the Chinese surge in EV demand is seen as the great hope of the Lithium, Cobalt and Neodymium/Praseodymium producers, thus a problem is born for all those outside the attempts by the Chinese government to create a "Closed Circle of Prosperity" (read , circling of the wagons) with regards to resources needed to fuel this boom.

Obviously the Chinese will want *their* Dysprosium to go into *their* EVs before any other export markets are served. Adamas is arguing that the Chinese will essentially be using most of what they produce for themselves leaving other international auto manufacturers (and other Dysprosium applications) unserviced. Essentially non-Chinese sources will need to be the main ones for non-Chinese users of Dysprosium. The only serious new source of Dy is the Brown's Range project of the ASX-listed Northern Minerals.

Adamas Intelligence estimates that, from 2013 through 2017, the global consumption of Dysprosium oxide (or oxide equivalent) for BEV traction motors increased at a blistering CAGR of 54%, from 11 tonnes to 61 tonnes, while global consumption for PHEV traction motors increased at a CAGR of 31%, from 23 tonnes to 68 tonnes.

Collectively, BEV, PHEV and hybrid electric vehicle (HEV) traction motors were responsible for just 18% of total global Dysprosium oxide consumption in 2017 but, at the current rate electric vehicle sales are growing, are poised to become the dominant end-use of Dysprosium oxide by 2025. This is why we would posit that Dysprosium is the *dark horse* in the Lanthanide Stakes.

The next assertion of Adamas on the number of projects outside China as being a "handful" we would challenge. The term handful implies five and frankly we cannot name five projects that might be in production by 2020. The only two that seem destined to produce in the short-term are Rainbow Rare Earths and Northern Minerals. While we admire the determination of other survivors, imminent production is not likely. As for Rainbow we are rather bemused to be unable to find a resource statement for the Gakara deposit that might elucidate its Dysprosium content. The fact that Nd/Pr are

the only words on Rainbow's lips we can only presume they are Dy-light. Therefore as Agatha Christie would put it, "then there was one".

Finally we get to the fifth finding that the automobile sector will be scrambling. Well, it couldn't happen to a better collection of short-sighted managers in our opinion. Lazy, feckless and shiftless are words that come to mind. The mantra is that "Just-in-time will provide", as if "just in time" was some sort of divine providence. Instead it is (was?) a cargo cult that shall henceforth be failing to deliver. Adamas claim the buyers will be "scrambling". But scrambling where? If there is none available outside China and the Chinese won't let go of what they have they can scramble as much as they like and they will look like hamsters running futilely in their wheel in the cage. The time to back projects is now if the crunch is to be avoided.

Who Might Produce It

The brutal, and necessary, culling has left us with a small rump of REE developers that, by our calculations, number less than 15 companies. The group of survivors are geographically diverse and now tend to be classified by their stage of development rather than the old discriminators of light vs heavy or bastnesite vs monazite vs eudialyte vs Xenotime. Early stage no longer exists with virtually all players at least having a PEA, or better, a FS, to their name no matter how old, bloated or inaccurate it might be.

From this small universe we can glean which of the players have the strongest position in Dysprosium. This group, ranked by potential Dysprosium production, is shown in the table that follows.

Dyprosium Projects Comparatives

Project	Developer	Jurisdiction	Stage	Projected DyO tpa
Browns Range	Northern Minerals	Australia	Production	280
Kvanefjeld	Greenland Minerals and Energy Ltd.	Greenland	FS Complete	245
BioLantanidos	Mineria Activa	Chile	FS Complete	150
Kipawa	Matamex Explorations	Canada	FS Complete	145
Lofdal	Namibia Rare Earths	Namibia	PEA Complete	140
Dubbo	Alkane Resources	Australia	FS Complete	125
Ashram	Commerce Resources Corp.	Canada	PEA Complete	70

Northern Minerals as is well known is now in production and we would not be surprised to see the Chilean project of BioLantanidos also advance to production. The only other recent addition to the REE production universe is, or shortly will be) Rainbow Rare Earths. The two majors, Lynas and Molycorp were always skewed towards the lightest of the lights, Cerium and Lanthanum. Reports indicate Mountain Pass is now just a shipper of ore to China.

Alternative Technologies

We should also mention the potential of innovative technologies to transform the Rare Earth space. Most conventional processing techniques date back to their genesis in the 1950s or before. While there have been quantum leaps in the end uses of REE the actual application of new techniques has been slow to advance, partly happened by the lack to Western production to apply them to combined with the traditional conservatism of miners and the industry's consultants.

Geomega, the TSX-listed developer of the ISR technology in the REE space has recently announced that it achieved recoveries of Dysprosium per single run range between 60% and 85% and these keep improving as the testing of the technology continues. Dysprosium that is not recovered in the first separation run, is not lost but is recirculated back to the process. The image below is the Dysprosium Oxide at +99.5% produced by this technology.

Source: Geomega

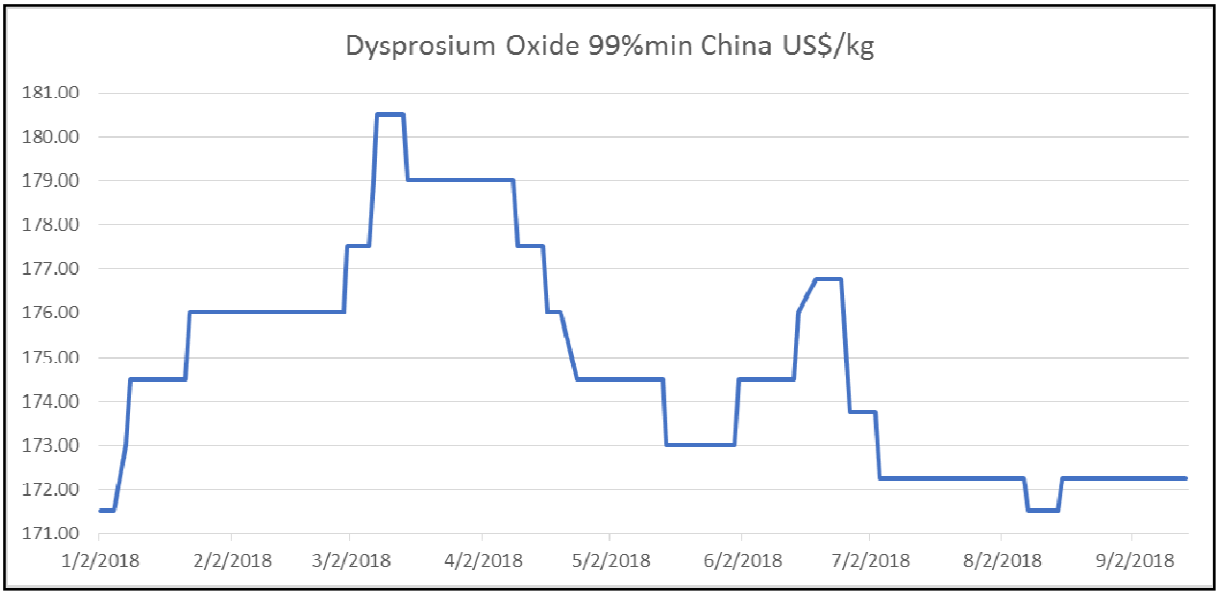
A key parameter to look at when comparing ISR versus solvent extraction (SX) is the separation factor (SF) between two separating elements, which quantifies readiness and efficiency of a single stage of separation. In the case of Nd and Dy, the SF in SX is reported between 22 and 42 while ISR technology shows a consistent SF of around 30. The higher the SF, the smaller the number of repetitions is required to attain a certain purity which makes the technology more cost-effective. Geomega has stated that work is ongoing to further increase the SF and that the current indications are positive.

Then we would also mention Ucore's MRT technology that we wrote about several years ago which

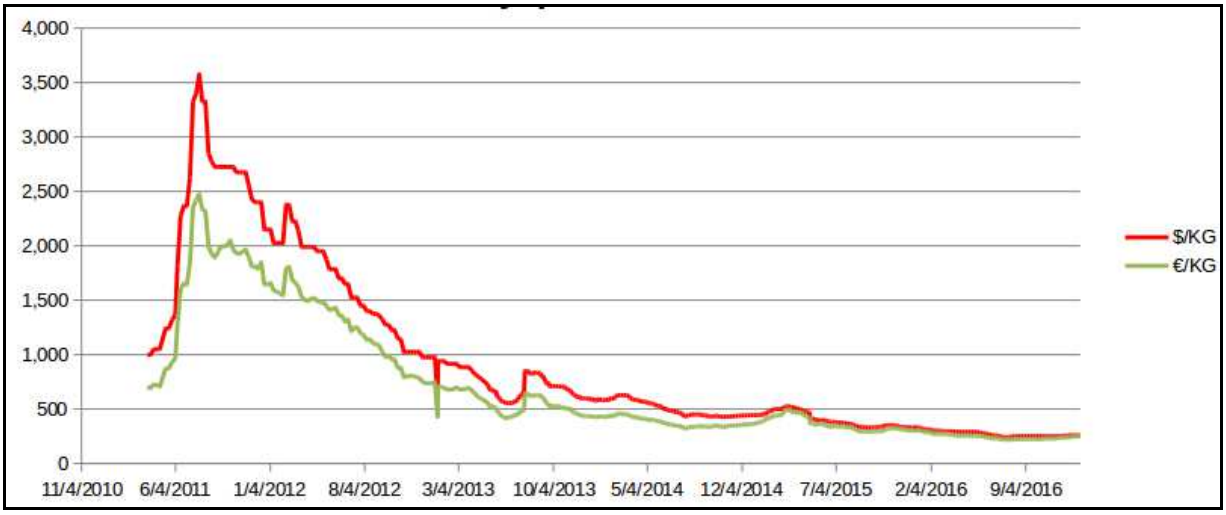
seems to be finding takers in other metal subspaces but has yet to achieve uptake in Rare Earths mainly because there are so few producers out there.

Prices

Dysprosium has not had such a great 2018 having gone up and then come down, pretty much back to where they started the year.



The longer term price is shown here, with the massive fall from 2011 levels. The sheer ridiculousness of prices at that time is poignant.



Risks

The potential risks are:

- That REE prices remain in the doldrums
- Ongoing tough financing conditions
- Significant substitution efforts if the metal went too steeply higher in price, or became too scarce
- Supply imbalance from too many players coming on-stream

REE prices are still captive to Chinese whims. There seems to be a perception that at least in the more strategic REEs (i.e. not Lanthanum and Cerium) that the Chinese would prefer to see higher prices but they do not want to trigger a rush of wannabes into the space that would threaten their dominance. The REE space has shrunk to a sufficiently small number of players that the Chinese can permit some price increases without triggering a rush of new entrants. The danger of prices going lower is negligible.

Financing will be available if prices start to rise. Already sentiment in the space has improved without prices having shown a meaningful improvement. This would be accentuated if the positive vibes start to expand.

Substitution of Dysprosium is a possible threat at much higher prices (or constrained supply) but this threat seems to have faded for the moment and as noted earlier some of the vaunted replacement technologies have not panned out as expected.

Too many players coming on-stream is unlikely at this stage with only Northern Minerals having been added to the ranks of producers since 2012. To bring one of the other contenders to production would require at least a two-year lead time, that is if the financing issue could be resolved.

Conclusion

The Rare Earth space since 2010 has been an example of Darwinian principles in action. A species burgeons and eats all the available food and then prompts a massive die-off that leaves a few survivors that are more cautious beasts and forage within the limits of the new environment in which they find themselves.

As if in a self-fulfilling prophecy the potential massive over-supply scenario evaporated as the universe of realistically developable projects shrank to almost nothing and the Big Beast of the space, Molycorp went spectacularly bust. The first Rare Earth boom (REE 1.0) had been coloured by a green energy tinge with wind turbines featuring prominently with background music on EVs. We would posit that the second go-around for Rare Earths will be driven principally by the crystallising EV surge. There is a direct correlation between Rare Earths and EV numbers due to the use of permanent magnets in various roles in the new vehicles. The high volume chatter about Lithium and Cobalt drowned out the admittedly feeble voice of Rare Earth developers but that does not remove the fact that Rare Earths will be needed in vastly greater quantities to feed this demand. If prices do not spike to crazy levels then substitution need not be a realistic threat.

The three magnet metals that will harvest this whirlwind will be Neodymium, Praseodymium and Dysprosium. It is not a guaranteed that these will be available in the quantities required because Mother China is not an inexhaustible supply of these metals. Moreover, just as it is corralling all the Lithium and Cobalt it can get its hands on then why would it continue to be as wasteful as it has been hitherto of its Rare Earth advantage? We sense this advantage as vulnerable to massive overexploitation over the last 30 years and the ONLY remedy is to cut back exports and start stockpiling material before the country becomes as vulnerable to outside forces in REEs as it is in Cobalt. This potentially sets the scene for a supply crunch outside China and no amount of WTO whining and appeals will stop the Chinese halting exports if it is deemed to be in the national interest.

Thus the Great Dysprosium Crisis of 2020 will come as a "surprise" to the powers that be. And yet the warning signs are there for everyone to see. The Adamas report is a red flag so large they could fly it in Tiananmen Square and yet when they will be searching for who to blame when no supply is available the cry will go up "how were we to know?". Ever was it thus is the corporate suites of the Western corporations who are supposedly the custodians of shareholder value. They were warned.

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