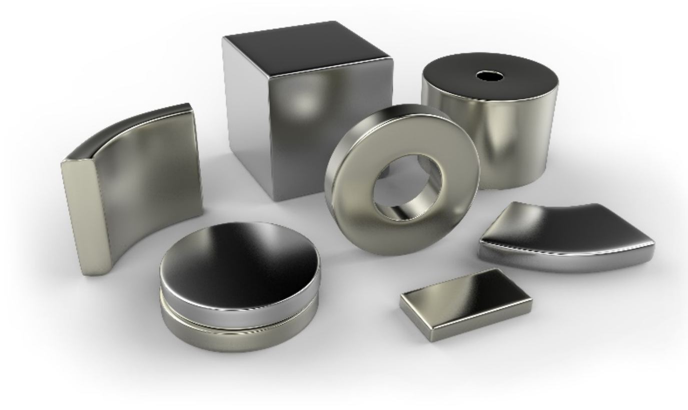
RFC Ambrian

The Alchemist



Issue 28:

Neodymium (Nd) & Praseodymium (Pr) Primer

The Alchemist examines the outlook of two rare earth elements with applications in modern energy technologies that are forecast to experience improved demand over the coming years

The Key Building Blocks for the Electric and Automotive Sectors

INTRODUCTION

Neodymium and Praseodymium, collectively known as NdPr, are metallic elements that belong to the lanthanide group of the periodic table (15 elements plus Scandium and Yttrium, which have similar properties).

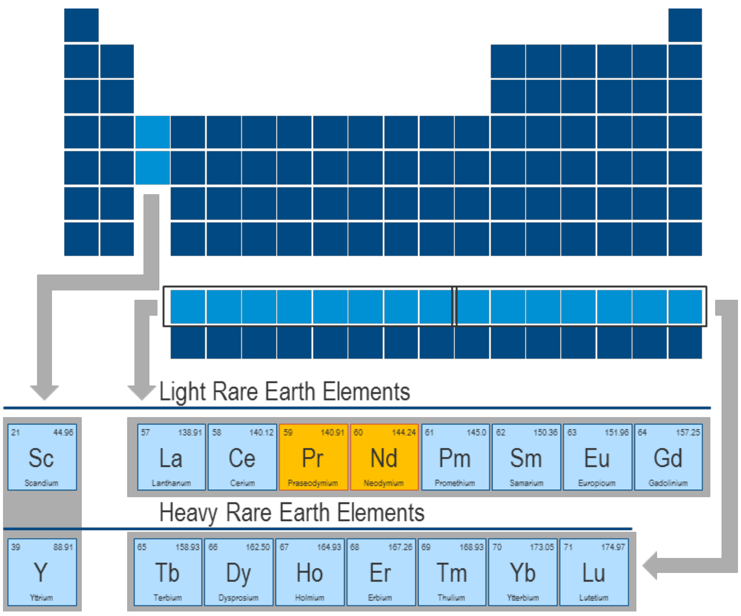
Long-term success for NdPr is linked to the heavyweight automotive and industrial power industries. NdPr has the potential to follow in the footsteps of Lithium in experiencing a long-term increase in demand alongside advancing energy technologies. While Lithium is used for energy storage, NdPr is used in both the generation of electricity and its subsequent conversion to mechanical energy for vehicle propulsion.

The lanthanide group was dubbed rare earth elements (REEs) for their relative scarcity in the earth's crust. It has since been found that REEs are not as rare as originally thought; Lanthanum, Cerium, Neodymium, Yttrium and Scandium are all more abundant in the earth's crust than Lead. However, deposits of mineable grades are difficult to find and, due to the chemical and atomic similarities between the elements in the group, their separation is complicated. REEs are sub-grouped into light (LREEs) and heavy (HREEs) groups based on their atomic weights.

REEs tend to be used as 'additives', sought for contributing specific properties to a product. They have a variety of uses, from alloying agents to catalysts to lubricants to electronics, and commonly feature as magnets in motors, headphones and speakers.

In 2015 global production of all 15 elements together is estimated to have been 124,000t. This is equivalent by weight to roughly 3% of global Lead production, 1% of Copper and 0.01% of Steel.

NdPr represent the most significant players in the lanthanide group by value. Global consumption of NdPr was 45,170t in 2015, making up roughly 36% of all global REE consumption by weight and 79% by value, up from 21% and 47% respectively in 2010. Current prices are ~US$50/kg for praseodymium oxide and ~US$40/kg for neodymium oxide. Demand for NdPr, which has become increasingly associated with energy generation and high-power motor technologies, is now projected to rise alongside the growing markets for electrical capture, storage and transportation.

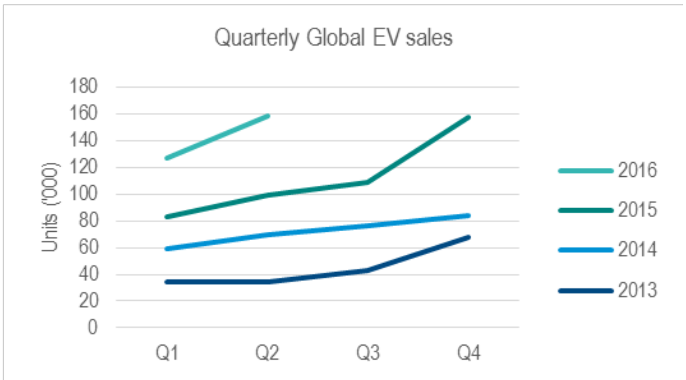


Lithium has recently seen massive growth for facilitating efficient energy storage solutions in these industries, and NdPr is essential for both the efficient generation of energy and the mechanical use of that energy. Thus, analysts expect that by 2020 NdPr demand will grow by as much as 43% to 64,600tpa.

APPLICATIONS

In 2015 some 95% of Neodymium and 85% of Praseodymium production was used to make permanent Neodymium-Iron-Boron (NdFeB) magnets. NdFeB magnets are produced commercially and have industry-dominating technical characteristics. They are used in hard disk drives, headphones, loudspeakers, MRIs and, most importantly, electric motors and generators. The properties of NdFeB magnets that differentiate them from competing technologies are magnetic flux density and coercivity. Magnetic flux density measures the degree of magnetisation, and coercivity is the ability of a material to withstand de-magnetisation. The product of magnetic flux density and coercivity is a magnet's maximum energy product. No other magnet — either produced commercially or created scientifically — matches NdFeB magnets by any of these metrics.

Forecast demand growth for NdPr is primarily driven by the proliferation of electric motors and generators used in motor vehicles and turbines. NdFeB magnets are used in high-torque, high-efficiency permanent magnet (PM) synchronous AC and DC electric motors. As with NdFeB magnets, PM motors are the premium product in the motor market and dominate competing electric motor configurations.

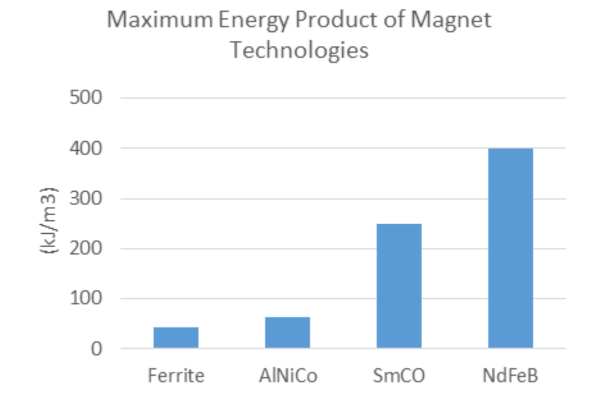


Source: Bloomberg New Energy Finance, 2016

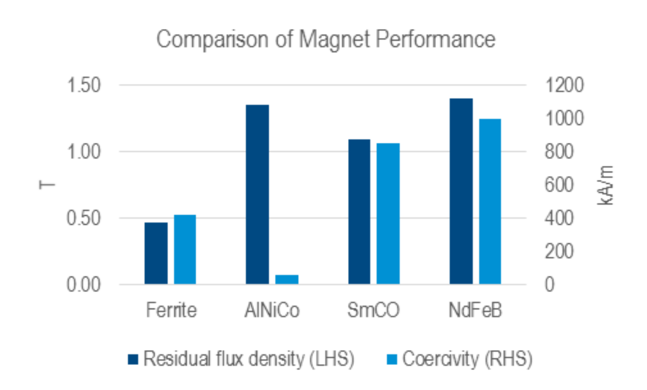
When judged against the closest competing technologies, these motors are considered unbeatable in delivering more torque and overall power by weight. They also suffer less electric and mechanical loss, and benefit from simple rotor/stator configurations.

This dominance of PM motors can be demonstrated through their nearly universal application by car manufacturers. The electric motors used in nearly all hybrid vehicles have used this configuration for years. Recent electric vehicles have also used PM motors; of the 370,000 hybrid and plug-in electric vehicles sold in the US YTD to September 2016, 89% (or 328,000 units) used PM motors.

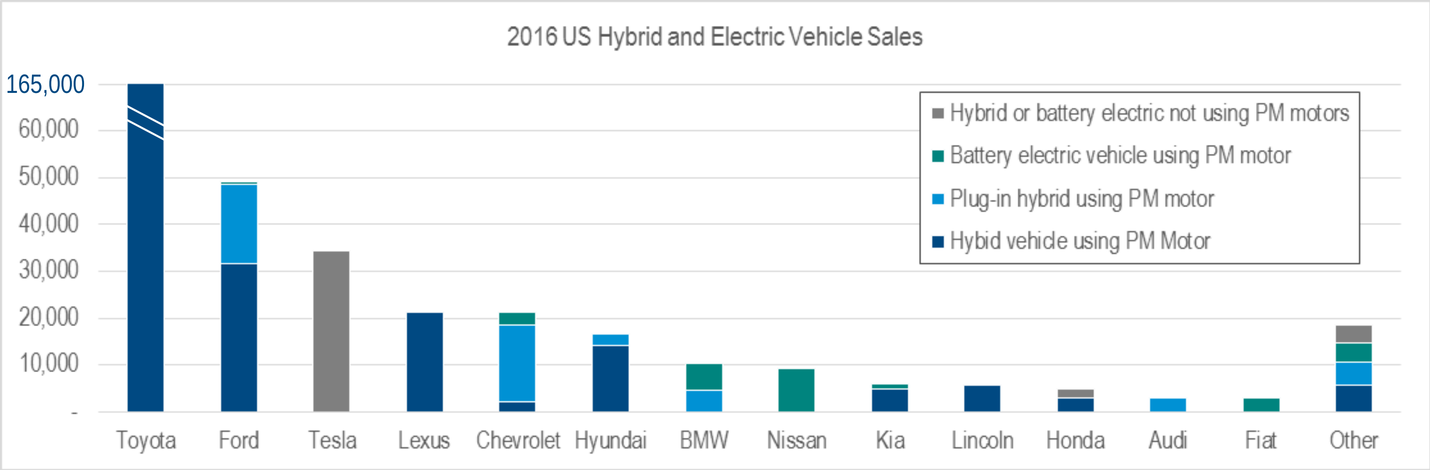
The use of NdFeB magnets in power generation has also allowed wind turbines to reduce costs and increase efficiencies, primarily by eliminating gearboxes. The majority of new wind turbines now use direct-drive PM generators that are more reliable and require less maintenance. In direct-drive PM motors, material demand is around 550kg of NdFeB magnets per MW.



Source: 2014, James D. Widmer et al.



Source: 2014, James D. Widmer et al.



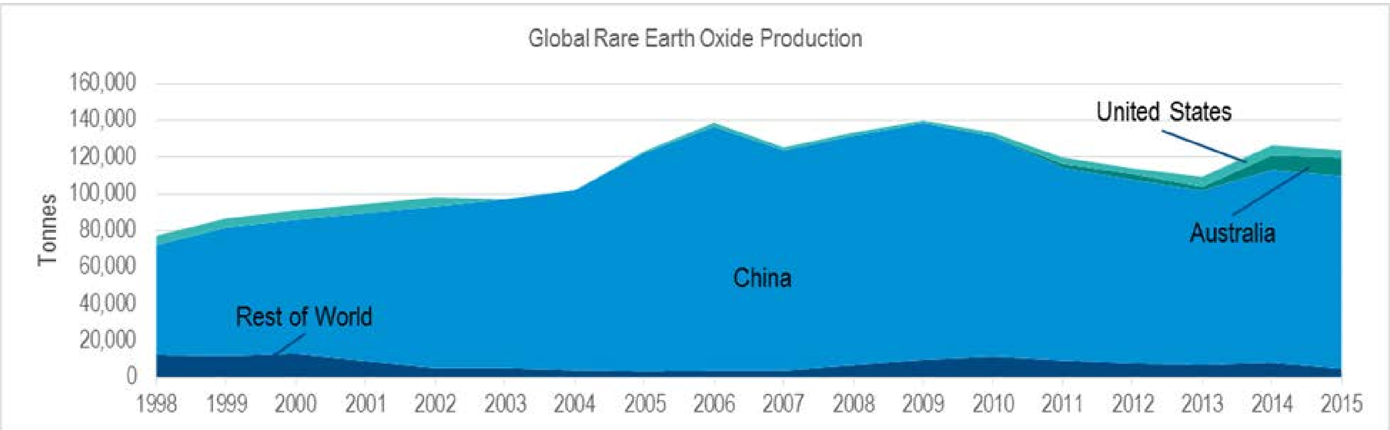
Source: HybridCars.com and Baum & Associates

SUPPLY

As a result of their chemical and atomic similarities, REEs typically occur together geologically, so grades and production are often quoted on a composite basis as total rare earth oxides (TREOs, or often just REOs). Normal mineralogy of mineable deposits occurs as bastnaesite, monzanite or low-grade ion adsorption clays, although a variety of other mineralogies also exist. Large, high-grade (and globally significant) operations, including the largest producer in the world, Bayan Obo, tend to contain bastnaesite as the main ore mineral. Ion adsorption clays are smaller but significantly more widespread, and are currently the world's primary source of HREEs. Mines targeting ion adsorption clays, largely located in China, have contributed to the 'dirty' reputation of REEs by applying processing methods that have caused environmental damage.

Despite having no production capacity whatsoever in 1985, by the early 1990s China had become the dominant global producer for the majority of REEs (including NdPr). Outside China, Australia is the second largest producer of REEs. The Lynas-owned Mt Weld mine is currently the only operating mine in Australia. It began production in 2007 and reached full-scale production in 2016. The US ranks third, producing roughly 1/25th of China's level. US production in 2015 was attributable to the Mountain Pass mine, which is now on care and maintenance. Together, these three countries produced 96% of the world's supply of REEs in 2015.

Part of the current supply surplus is as a result of REEs occurring at iron ore mines in China (Bayan Obo in particular), which produced roughly half of global production in 2015. Spurred by iron ore's bull run between 2009 and 2011, and only needing the addition of a processing circuit to the existing tailings/waste stream, REEs have been produced in large quantities as a convenient by-product with no regard for demand. However, the prolonged weakness of iron ore prices is now putting pressure on REE supply.



Source: USGS

Iron ore mines in China that have continued to operate despite negative margins are now being shut, and the flow of cheap lanthanide production has the potential to be reduced as a result. In June, top economic planners from China issued statements that the country would reduce steel production capacity by up to 150Mt within 3-5 years. Furthermore, the Chinese Government is targeting a reduction in illegal mining, which supplies REEs through the mining of ion adsorption deposits and is further damaging China's environment.

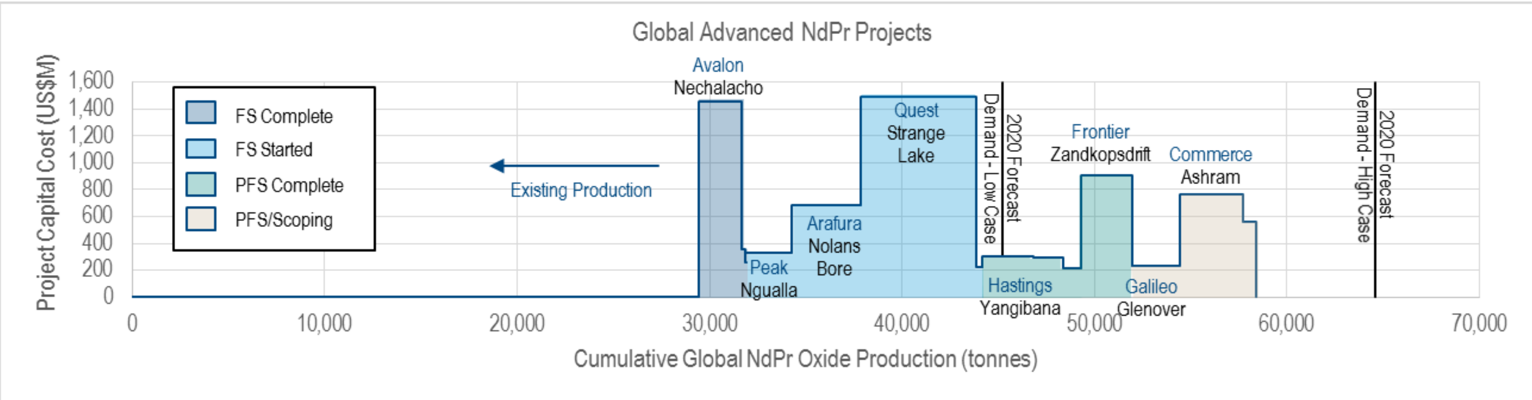
To accommodate demand growth, increases in global production of NdPr will need to total between 15,000t ('low case') and 35,000t ('high case') by 2020. China is expected to struggle to expand its capacity as a result of its efforts to tighten regulations on miners and through forced reductions in the mining sector. Therefore, a number of new projects will need to be brought online outside China to cover the shortfall. Fortunately, there is a pipeline of developed projects from which production could be provided.

NdPr INVESTMENT

REEs have historically been difficult for investors. The group saw dramatic price movements between 2008 and 2013; prices for oxide products increased more than 2,000% between June 2009 and June 2011. Soon thereafter, however, it turned out that a combination of China's loose regulatory environment and fortunate natural resource endowment had allowed it to flood the market with production. By 2013, prices had fallen by nearly 80%.

Improving demand, along with more rational supply, has brought NdPr back to the investment world as reasonable prospect. Manufacturers are placing a premium on certainty of supply and environmentally sound practices to accompany their products. An opportunity is arising for non-Chinese parties to capture a portion of the emerging market.

Long-term success for NdPr is linked to the future of electric industries; the heavyweight automotive and industrial power industries are set to provide a firm, broad range of downstream clients and off-takers. The NdPr industry has the potential to follow in the footsteps of Lithium in experiencing a long-term increase in demand. While Lithium enables energy storage, NdPr is used to generate and, subsequently, use stored electricity to propel vehicles.



Source: Company reports

Company	Project	Stage	Country	Capital Cost (US$m)	Product
Avalon Rare Metals Inc	Nachalaco	FS	Canada	1453	Intermediate Rare Earth Concentrate
Matamec Explorations Inc	Zeus	FS	Canada	357	Intermediate Rare Earth Concentrate
Northern Minerals Ltd	Browns Range	DFS	Australia	256	Intermediate Rare Earth Concentrate
Peak Resources Ltd	Ngualla	Feas Started	Tanzania	330	Fully Separated Rare Earth Oxides
Arafura Resources Ltd	Nolans Bore	Feas Started	Australia	680	Fully Separated Rare Earth Oxides
Quest Rare Minerals Ltd	Strange Lake	Feas Started	Canada	1493	Fully Separated Rare Earth Oxides
Ucore Rare Metals Inc	Bokan Mountain	Feas Started	US	221	Fully Separated Rare Earth Oxides
Hastings Technology Metals Ltd	Yangibana	PFS	Australia	306	Fully Separated Rare Earth Oxides
Rare Element Resources Ltd	Bear Lodge	PFS	US	290	Fully Separated Rare Earth Oxides
Mkango Resources Ltd	Songwe Hill	PFS	Malawi	216	Intermediate Rare Earth Concentrate
Frontier Rare Earths Ltd	Zandkopsdrift	PFS	South Africa	906	Fully Separated Rare Earth Oxides
Galileo Resources PLC	Glenover	PFS/Scoping	South Africa	233	Intermediate Rare Earth Concentrate
Commerce Resources Corp	Ashram	PFS/Scoping	Canada	763	Intermediate Rare Earth Concentrate
Pele Mountain Resources Inc	Eco Ridge	PFS/Scoping	Canada	563	Intermediate Rare Earth Concentrate

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