Rare Earth Elements: Market Issues and Outlook

Adamas Intelligence

Q2 2019

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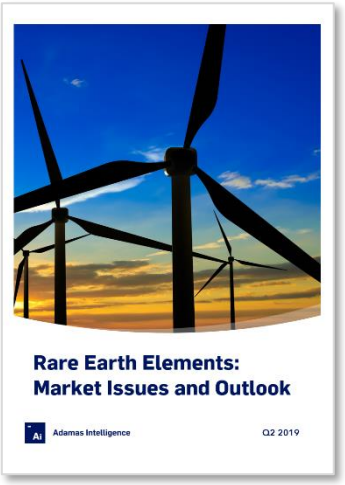

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Rare Earth Elements: Small Market, Big Necessity

Compared to similarly-abundant elements in nature, such as copper, lead, and tin, global annual production of rare earth elements is notably low. Nevertheless, rare earth elements have become critical enablers of technologies at the heart of clean energy initiatives worldwide, as well as ubiquitous gadgetry and electronics that have pervaded modern society.

Rare earth elements are used in small, but often necessary, amounts in hundreds of different technologies, materials, and chemicals worldwide in commercial, industrial, social, medical, and environmental applications.

Rare earth elements are the critical enablers of modern energy-efficient lamps, are at the heart of low-maintenance wind power generators and play a 'driving' role in the traction motors of nearly every electric vehicle produced to-date.

As a vital ingredient of the three aforementioned technologies, rare earth elements have become a cornerstone of global government macro-initiatives aimed at improving energy efficiency, increasing renewable power generation capacity and reducing greenhouse gas emissions.

Rare earth elements enable more efficient production of hydrocarbon distillates from crude oil and are used during the fuel cracking process to trap toxic metals and volatiles that would otherwise be emitted into the environment during refining and subsequent combustion of fuels.

Rare earth elements are used in the catalytic converters of gasoline-powered vehicles to convert harmful pollutants in the exhaust stream into less harmful varieties and are integral to fuel-borne catalyst systems used to manage the accumulation of exhaust particulate in diesel-powered vehicles' catalytic converters.

Rare earth elements are used in rechargeable batteries for everything from hybrid electric vehicles to rechargeable toothbrushes and are critical ingredients in high-strength magnets used in hard disk drives, optical disk drives, headphones, speakers, and electric vehicle traction motors, among hundreds of other applications.

Rare earth elements are used to produce camera lenses, container glass, paint thinner, water treatment agents, fertilizers and thermal barrier coatings that protect jet engines during operation.

Rare earth elements are used in medicine and defense applications, and in alloys, electronics, lighting, and display screens for applications in aerospace.

In just a period of decades, rare earth elements have seeped deeply into the fabric of modern technology and industry and have proven exceptionally challenging to duplicate or replace.

Figure 1: Rare earth elements include the lanthanide series plus scandium and yttrium

21 **Sc**	57 **La**	58 **Ce**	59 **Pr**	60 **Nd**	61 **Pm**	62 **Sm**	63 **Eu**	64 **Gd**	65 **Tb**	66 **Dy**	67 **Ho**	68 **Er**	69 **Tm**	70 **Yb**	71 **Lu**	39 **Y**

Source: Adamas Intelligence

Eight End-Use Categories

Rare earth elements are used in hundreds of unique end-uses and applications that collectively fall into one of eight end-use categories: 1.) Battery Alloys, 2.) Catalysts, 3.) Ceramics, Pigments and Glazes, 4.) Glass Polishing Powders and Additives, 5.) Metallurgy and Alloys, 6.) Permanent Magnets, 7.) Phosphors, and 8.) Other End-Uses and Applications (see Figure 2).

Figure 2: Rare earth applications and end-uses fall into one of eight end-use categories

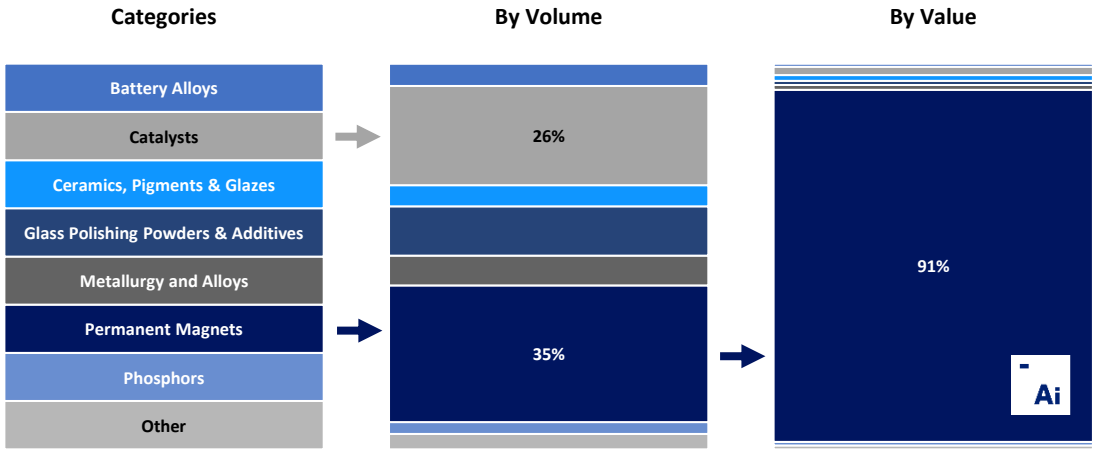
End-Use Category	Description
Battery Alloys	Rare earth elements are used to produce anode materials for nickel-metal hydride ("NiMH") batteries. NiMH batteries are used in hybrid electric vehicles, consumer electronics, cordless shavers, cordless powertools, baby monitors and other applications of rechargeable batteries.
Catalysts	Rare earth elements, such as cerium and lanthanum, are used in catalytic converters of gasoline- and diesel-powered vehicles, as well as fuel cracking catalysts and additives used by oil refiners to break down crude oil into lighter distillates, such as gasoline, diesel, kerosene and more.
Ceramics, Pigments and Glazes	Rare earth elements are used to produce decorative ceramics, functional ceramics, structural ceramics, bio ceramics and many other types of ceramics used in everything from jet engine coatings to ceramic cutting tools, dental crowns, ceramic capacitors, ceramic tiles, and more.
Glass Polishing Powders and Additives	Rare earth elements, such as cerium, are used to polish optical glass, hard disk drive platters, LCD display screens and gemstones, among a long list of applications. Cerium is also used as an additive in UV-filtering glass and container glass, whereas lanthanum, yttrium and gadolinium are used to produce high quality optical glass used in camera lenses, microscopes and telescopes.
Metallurgy and Alloys	Rare earth mischmetal (a mixture of light REE metals) is used during production of some types of steel, as well as ductile iron making. Rare earth elements are also used to produce a variety of different alloys, such as ferro-cerium, ferro-holmium, ferro-gadolinium, ferro-dysprosium and a growing list of others.
Permanent Magnets	Rare earth elements are used to produce high-strength permanent magnets that have enabled the production of ubiquitous gadgets and electronics, such as mobile phones and laptops, as well as power dense energy-efficient electric motors and generators used in electric vehicles, wind power generators, energy efficient appliances and hundreds of other applications.
Phosphors	Rare earth elements are used in phosphors for energy efficient lamps, display screens and avionics, and are added to fiat currency in some nations as an anti-counterfeit measure.
Other	Aside from the above described end uses and categories, rare earth elements are used in a long list of other end uses and applications, including many in defense, medicine, agriculture, high-tech and chemical industries.

Source: Adamas Intelligence

Global Rare Earth Consumption in 2018

By volume, permanent magnets and catalysts were collectively responsible for over 60% of global TREO consumption in 2018 (see Figure 3). However, by value, permanent magnets alone were responsible for over 90% of the total value of global TREO consumption last year (see Figure 3) and this share is poised to expand further as demand (and prices) for neodymium, praseodymium, dysprosium and terbium continue to rise strongly in the years ahead.

Figure 3: Permanent magnets and catalysts are the largest rare earth demand drivers

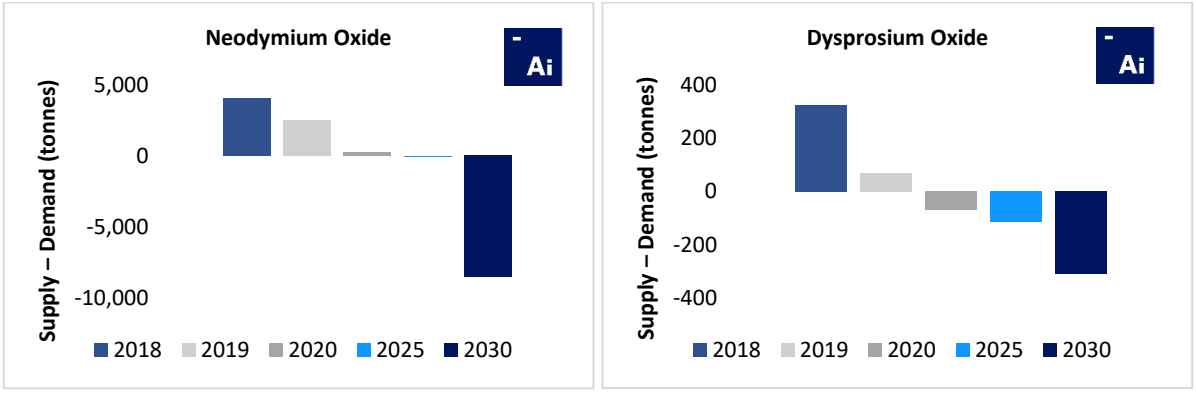


Source: Adamas Intelligence

Not only does demand for neodymium, praseodymium, dysprosium and terbium make up the lion's share of global value today, but in the years ahead demand for these four rare earth elements is expected to grow faster than demand for all other rare earth elements, challenging the ability of the supply-side to keep up.

As shown in Figure 4, Adamas Intelligence forecasts that global annual demand for neodymium oxide and dysprosium oxide (or oxide equivalents) will substantially exceed global annual production by 2030, leading to the depletion of historically accumulated inventories and, ultimately, shortages of these critical magnet materials if additional sources of supply are not developed.

Figure 4: The supply-side will struggle to keep up with rising demand for neodymium and dysprosium

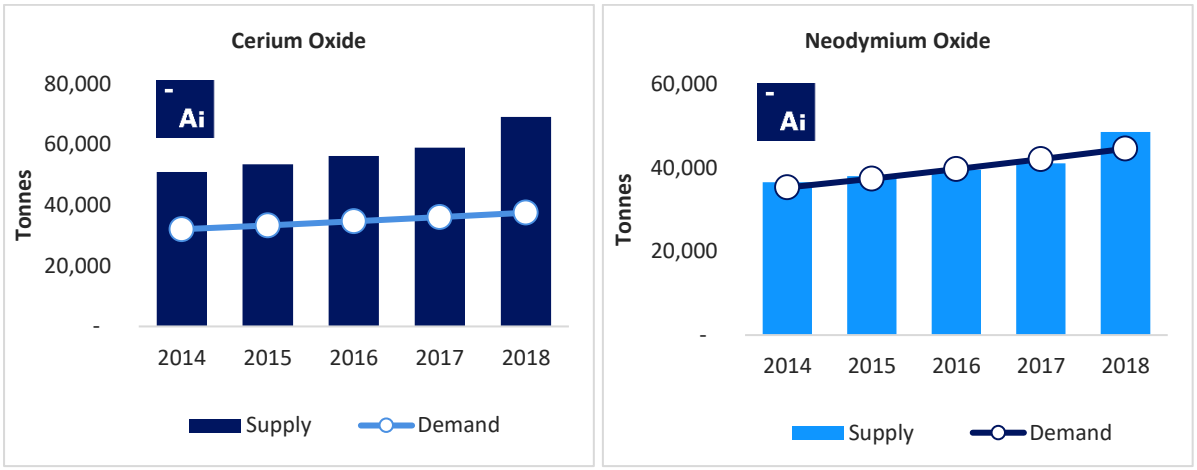


Source: Adamas Intelligence

Rare Earth Balance Problem

Over the past decade, rare earth producers globally have sacrificially overproduced certain low value rare earth elements, such as cerium (see Figure 5 – LHS), in order to keep up with rapidly growing demand for other high value rare earth elements, such as neodymium (see Figure 5 – RHS).

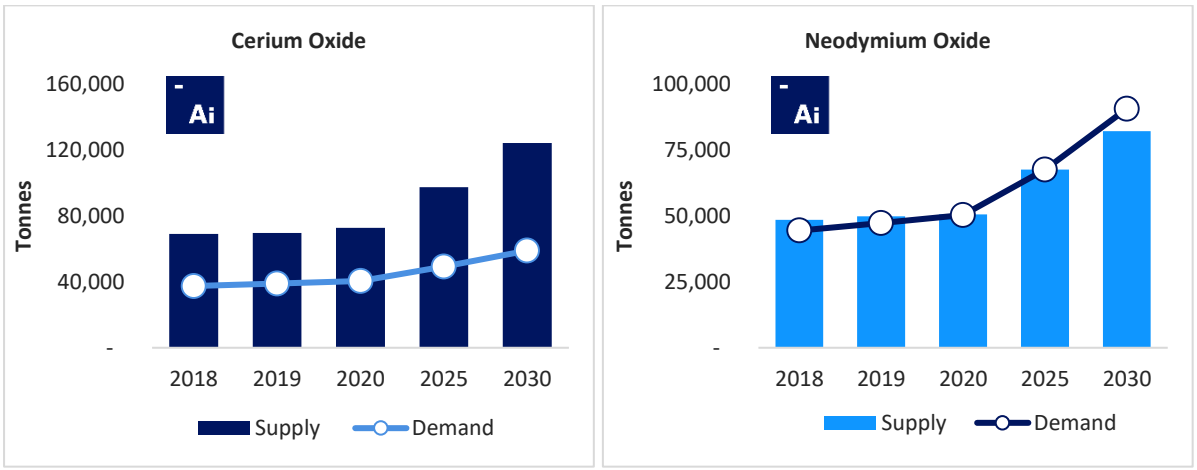
Figure 5: Sacrificial over-production of cerium to satisfy rapidly-growing demand for neodymium



Source: Adamas Intelligence

Looking ahead, Adamas Intelligence forecasts that ever-increasing demand for rare earth permanent magnets will drive global demand for neodymium oxide (or oxide equivalent) to unfathomable new heights (see Figure 6 – RHS), exacerbating the imbalance between production and demand of other rare earth elements, such as cerium oxide (see Figure 6 – LHS) if the industry continues on a path of business-as-usual.

Figure 6: Strong future demand growth for permanent magnets will exacerbate the balance problem



Source: Adamas Intelligence

Implications of the Balance Problem

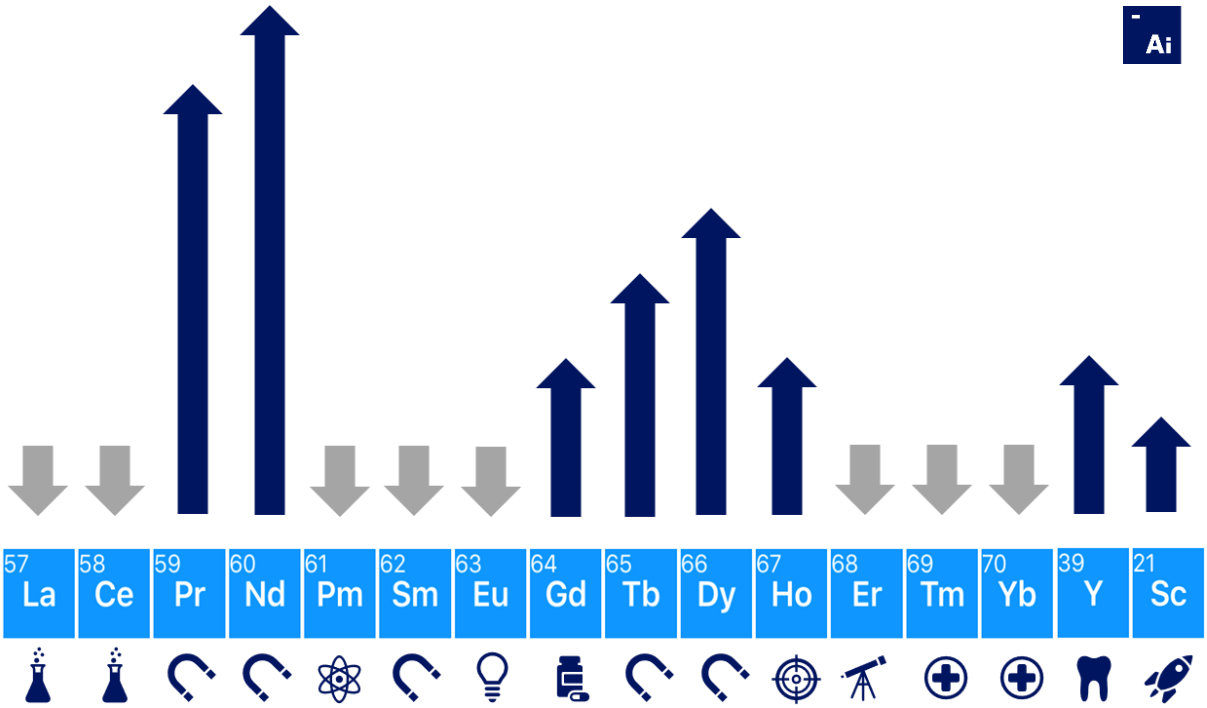
Unless new end-uses and applications are developed for cerium, lanthanum, and other sacrificially-overproduced rare earth elements in the near-term (see Figure 7 – light grey arrows), Adamas Intelligence forecasts that prices of high-demand elements, like neodymium, praseodymium, dysprosium and terbium will rise accordingly (see Figure 7 – dark blue arrows) to pay for losses that producers are incurring by necessarily over-producing the other unsaleable, surplus rare earths.

The industries that will feel these price increases the most in the coming decade are those reliant on use of high-strength rare earth permanent magnets, such as the automotive industry, the wind power sector, the consumer electronics industry, the defense industry, and many others.

Price increases of rare earth magnet input materials may upend the economics of using rare earths in some of the aforementioned sectors – pushing them to adopt alternatives to rare earth permanent magnets where possible.

However, for the most propitious of end-use sectors – such as electric vehicles, wind power and automated manufacturing – the economics of using rare earth elements are robust and these industries will continue to fuel strong rare earth demand growth into the foreseeable future.

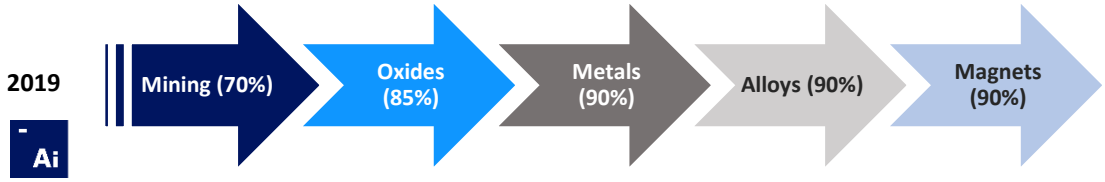
Figure 7: Prices of some rare earths will rise to compensate for losses incurred on other rare earths



China's Evolving Monopoly

In recent years, China's share of global rare earth mine production has fallen slightly as a handful of new rare earth mines have come on stream outside China. However, while the nation's share of mine production has fallen, China's share of downstream value-adding capacity to convert rare earth mine outputs in oxides, metals, alloys and magnets has continuously expanded, speaking to the nation's growing focus on dominating the downstream where profit margins are greater and activities are cleaner, environmentally-speaking.

Figure 8: China's evolving dominance of the global rare earth value chain

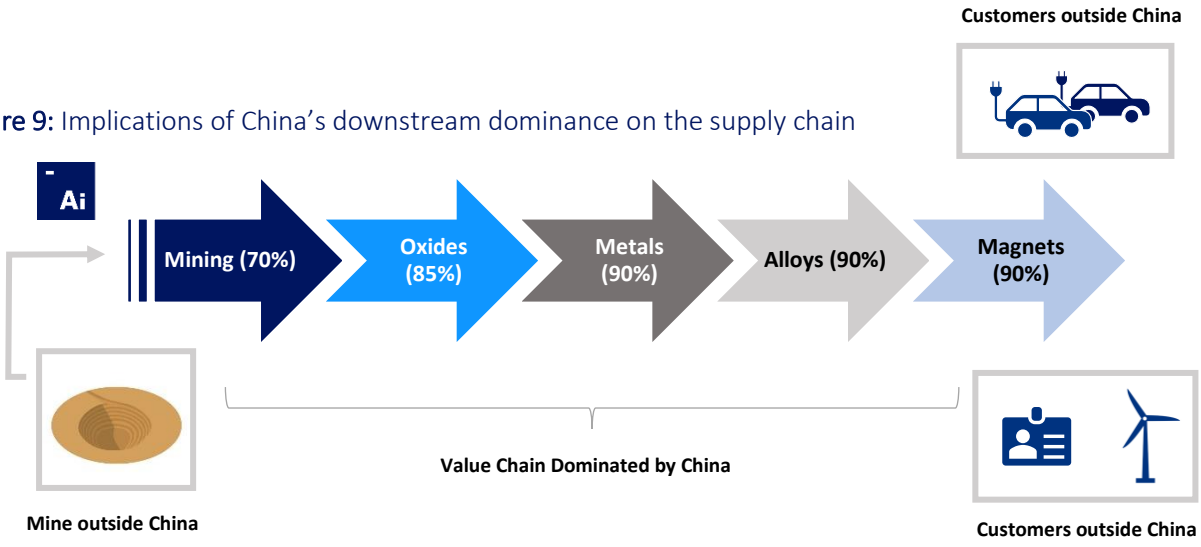


Source: Adamas Intelligence

Implications of this Evolving Monopoly

For a producer bringing online a new rare earth mine outside of China in the coming years – be it in Greenland, Canada, Australia or anywhere else – there is a high probability that your rare earth mine outputs are going to flow through China's value chain, leaving you as a producer, your investors and your customers subject to a higher degree of opacity and uncertainty than some may be comfortable with.

Figure 9: Implications of China's downstream dominance on the supply chain



Source: Adamas Intelligence

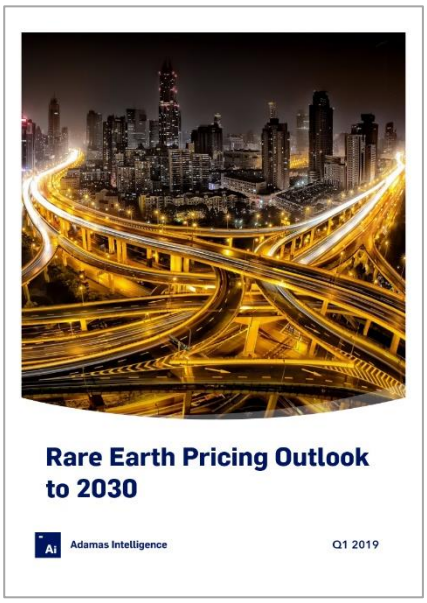
In conclusion, until the rest of the world starts investing in the critical downstream linkages that take rare earth mine outputs and upgrade them into market-desired materials, such as NdFeB magnets, **end-users outside of China will remain reliant on (and vulnerable to) China's monopoly into the foreseeable future** – irrespective of how many new mines are brought online elsewhere.

Additional Reading: Rare Earth Pricing Outlook

For more information on the outlook for rare earth supply, demand and prices in the years ahead, we recommend Adamas Intelligence's recent "Rare Earth Pricing Outlook to 2030" report.

Rare Earth Pricing Outlook to 2030

Published: April 2019



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We empower clients on six continents with the data-backed insight, analysis and foresight they need to capitalize on emerging trends and new business opportunities.

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