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# Rare Earths and China

## A Review of Changing Criticality in the New Economy

**John SEAMAN**

January 2019

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*This study has been carried out within the partnership between the French Institute of International Relations (Ifri) and Policy Center for the New South.*

ISBN: 978-2-36567-969-5
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**How to quote this document:**

John Seaman, “Rare Earths and China: A Review of Changing Criticality in the New Economy”, *Notes de l'Ifri*, Ifri, January 2019.

**Ifri**

27 rue de la Procession 75740 Paris Cedex 15 – FRANCE

Tel.: +33 (0)1 40 61 60 00 – Fax: +33 (0)1 40 61 60 60

Email: accueil@ifri.org

**Website:** Ifri.org

# Author

**John Seaman** is a Research Fellow in the Center for Asian Studies at Ifri, where he specializes in the geopolitics and political economy of energy and natural resources in Asia, with a focus on China and Japan. He also conducts research on Chinese foreign policy, the U.S. strategy and policy in East Asia, Europe-China relations, geopolitics in East Asia, and the political economy of critical raw materials (including rare earth elements).

Mr. Seaman joined Ifri in 2009 and holds a Master in International Affairs - International Security from Sciences Po, Paris, a Bachelor of Arts in International Economics from Seattle University, and studied as a NSEP David L. Boren Scholar at the Beijing Center for Chinese Studies (2002-2003). In the summer of 2011 and 2013 he was a visiting fellow with the Energy and Environment Program of the Canon Institute for Global Studies (CIGS) in Tokyo, Japan and is currently an International Research Fellow with CIGS.

His publications on rare earths include:

- "Rare Earths and Clean Energy: Analyzing China's Upper Hand", *Note de l'Ifri*, Ifri, September 2010;
- "Rare Earths: Future Elements of Conflict in Asia?" with Ming Hwa Ting, *Asian Studies Review*, Vol. 37, No. 2, 2013, pp. 234-252;
- and "Securing Energy and Mineral Resources for China: Debating the Role of Markets", *Note de l'Ifri*, Ifri, October 2015.

# Executive Summary

China's dominance in the production of rare earth elements symbolizes the competition for once obscure sets of mineral resources in our increasingly digital, low carbon world. For the last two decades China has produced between 80 and 95 percent of the world's rare earths – a group of 17 metals that have become key components of revolutionary technological progress in fields ranging from energy, to ICT, to medical devices, to defense. Despite their name, rare earths are not rare, and can be found across the globe. Environmental concerns, which spiked in the 1970s and 80s notably in the United States and Europe, liberalized global trade, and Chinese policies designed to harness the country's resource wealth are primarily responsible for the concentrated production of these metals.

From 2010, the world was made acutely aware of this distorted division of labor. Running counter to its commitments to global trade rules, China put in place stringent export control measures, including licenses, taxes and quotas, that would severely limit the supply of rare earths to industrial consumers abroad. In the same year, China was also widely accused of, though vehemently denied, placing a de-facto, two-month embargo on rare earth shipments to import-dependent Japan as a means of punishment for the detention of a Chinese fisherman in disputed waters in the East China Sea. The facts of these latter events can be disputed, and the gains that China may have achieved from such an embargo were marginal, but the damage was done. A combination of supply concerns and spiking prices – which for some rare earths rose by 500 percent or more in the year that followed – drove an investment boom in rare earth exploration that would include the jungles of Brazil, the depths of the Pacific Ocean and even the surface of the moon.

Some production outside of China, notably from the Mount Weld mine in Australia, has so far proven viable, but others, such as California's Mountain Pass mine, have faltered as market conditions have shifted. Following a dispute settlement process at the World Trade Organization, China returned to more or less normal trade practices in 2015 and still accounts for more than 80 percent of global rare earth production today – including nearly all of the world's output for some critical elements, such as dysprosium.

On the demand side, industrial consumers overseas went into high gear to find solutions. Many have been able to make efficiency gains, find substitute materials, or change technologies altogether that led to an estimated drop in nearly one third of global rare earth demand through 2016. But for others, for instance in the wind and automotive industries, solutions have proven more complicated and rare earths remain critical materials. Many project that demand for rare earths such as neodymium and dysprosium will rise significantly on the back of these dependent industries, but technological change and efficiency gains may yet hold further surprises. Herein, the risks are twofold. First is the continued dependence on China for rare earths that are still considered critical inputs by many industries of the future. Second is the risk that, in the frenzied search for solutions to supply constraints, industrial users may have to sacrifice competitiveness relative to other, particularly Chinese users which don't face the same material constraints.

For China, using its resource advantage as an economic "weapon" to fight its diplomatic battles is far from the primary goal. Indeed, China's approach to the rare earth industry has been largely driven by more domestic concerns. One is responding to the country's growing environmental crisis. In this effort, Beijing increasingly favors the more energy-efficient and low-carbon technologies such as wind energy and electric vehicles that often rely on rare earths. At the same time, it also looks to better manage the environmental disaster that rare earth production has brought to the country's mining regions. Another core driver is facilitating China's economic strategy to lead the industries of the future and increasingly master respective value chains – ensuring the country's long-term economic transformation and providing further legitimacy to the ruling Party. In this light, China's approach to rare earths has not only been to master resource production and ensure that Chinese industries have the resources they need, but also to increasingly dominate the downstream, value-added industries that depend on these critical metals. As such, China today is not only the world's primary producer of rare earth oxides, it is also their largest consumer and increasingly controls value chains for key dependent products such as rare earth magnets.

Still, China's resources are not infinite, and concerns over rising demand and increasingly limited reserves for some rare earths in China are pushing Chinese companies to seek out resource supplies from abroad. As such, a new wave of overseas Chinese investment may mean that the production (and pollution) that was once delocalized to China will increasingly be diverted to other areas of the globe, with China still looking to master the more valuable downstream industries.

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# Introduction

We have now entered the Rare Metal Age.[1] Science and human ingenuity have allowed the unlocking of various magnetic, luminescent, heat resistant and conductive properties of a diversity of metals such as lithium, cobalt, indium, gallium, neodymium and dysprosium that are now driving technological innovation. The digital revolution, the low-carbon energy transition, the development of ever-more complex weapons systems – these processes all increasingly rely on once-obscure raw materials. As our dependence on these increasingly sophisticated technologies grows, our reliance on the mineral resources that go into them also deepens. And while our consumption practices change with technology, many of the age-old geographical, and as such social, economic and geopolitical questions associated with natural resource exploitation remain: where are these resources situated, who holds the keys to producing them, are there risks of supply shortages, who suffers and who reaps the rewards? Some have even presaged that competition over these so-called "technology metals" will be the source of major power confrontation and the wars of the future, much as oil has done for the last century.[2] But need we be so apocalyptic?

Understanding the role that China plays in the field of technology metals, its ambitions and the drivers of its behavior, is crucial. To be sure, the geopolitics and economics of our rare metal age is not just a story about China – cobalt exploitation in the Congo (DRC) is a well-known story, Brazil is the world's dominant producer of niobium, the United States produces over 90 percent of the world's beryllium, and the list goes on. Nevertheless, China's rise is a central story of the 21st Century, and it plays an important role in driving demand, controlling production chains and shaping the market for many of these metals. As such, it has become a centerpiece and a symbol of the resource geopolitics at play. China today produces at least 80 percent of the world's rare earth elements,[3] antimony, bismuth, gallium, magnesium and tungsten, and more than 65 percent of natural graphite,

1. D. S. Abraham, *The Elements of Power: Gadgets, Guns, and the Struggle for a Sustainable Future in the Rare Metal Age*, New Haven: Yale University Press, 2015.
2. M. T. Klare, *The Race for What's Left: The Global Scramble for the World's Last Resources*, New York: Metropolitan Books, 2012.
3. For some rare earths, such as dysprosium, China remains the world's only producer today.

germanium and scandium.[4] At the same time, the needs of China's transforming economy and high tech ambitions also make it one of the largest markets for many of these resources – for example, China currently consumes over 80 percent of all rare earth oxides produced worldwide. Where China is not a major producer of the metals it needs, for instance in cobalt or lithium, it has proactively sought to secure these resources from suppliers abroad, shifting the market dynamics for these resources and the political, economic and even social dynamics in the regions where they are produced.

In particular, much of the concern and symbolism surrounding China has focused on its control over the market for rare earth elements – a group of 17 metals that include the 15 elements of the lanthanide family, plus yttrium and scandium, with a broad range of applications in modern society. These elements also have the misfortune of being considered rare, when in fact most are not.[5] Rare earths exploded onto the international political scene in 2010, when China produced roughly 95 percent of the world's rare earth oxides. In July of that year, Beijing put in place stringent export quotas, taxes and price control mechanisms that would effectively limit the supply of these important metals to the rest of the world. These measures had a clear economic and strategic impact for a broad range of industries from ICT to energy to defense. What's more, in September of 2010, China was accused of (though stringently denied) using its supply advantage as a weapon in a diplomatic standoff in the East China Sea with Japan – then the largest consumer of rare earths outside of China. While the facts around these latter events are still debatable, the message was clear: those who depended on China for rare earths and other raw materials were potentially vulnerable to strong-arming from Beijing. In the ensuing panic, consumers of rare earths frantically sought solutions and would-be suppliers began exploring some of the most far-flung corners of the globe – from the depths of the Pacific Ocean to the jungles of the Amazon, to war-torn Afghanistan – and even beyond, to distant asteroids and the surface of the moon.[6]

As the world worked itself into a frenzy over rare earths, much of the discussion around these resources became distorted or overblown. This paper is a contribution to efforts that seek to bring the conversation back

4. Mineral Commodity Summaries, United States Geological Survey (USGS), 2018, and Deloitte Sustainability, BGS, BRGM and TNO, Study on the review of the list of Critical Raw Materials, European Commission, June 2017, pp. 44-45, publications.europa.eu.

5. The first rare earths were discovered by Swedish miners the 1788 and owe their name to the perceived rarity of the mineral in which they were found at the time (gadolinite), rather than their geological occurrence, which has since proven to be less than rare. Indeed, some rare earth elements, such as cerium, are as abundant as copper.

6. J. M. Klinger, *Rare Earth Frontiers: From Terrestrial Subsoils to Lunar Landscapes*, Ithaca: Cornell University Press, 2017.

down to earth more than eight years later. It does so in two ways. First is to discuss the notion of criticality in relation to rare earths, how China remains the dominant producer today and how our dependence on these metals has changed – in some ways lessening, in other ways deepening. Second is to examine the drivers behind China's actions in the field to re-center the debate around the economic and environmental motivations behind these policy actions, downplaying the risks that Beijing will seek to use its rare earth advantage as a weapon for political gain, but nevertheless highlighting the advantages that China seeks to develop in the industries of the future.

# Critical and not-so-critical rare earths

Rare earth elements are often characterized as the “vitamins” of modern industry, in that their diverse properties have allowed us to boost performance in a wide range of technologies. While chemically these elements have been lumped into one group of 17 metals, they are often divided into groups of “light” and “heavy”, as defined by their atomic number. This distinction generally carries an indication of their geological occurrence, light being more abundant, heavy being less so (see the table below).

It also makes sense from an industrial standpoint to treat rare earths individually, as they each hold different properties that serve different functions. Rare earth-based permanent magnets, the most commonly used of which (NdFeB) rely on neodymium, praseodymium and dysprosium, are perhaps the most widely used application for rare earths today – being found in medical devices such as Magnetic Resonance Imaging (MRI) machines, hybrid and electric vehicles, wind turbines, hard disk drives, cell phones, and even the latest fighter jets, guided missiles and military hardware, among many other applications. Other elements, such as lanthanum and cerium, are used in ceramics and glass polishing, but most notably in applications such as fluid cracking catalysts for oil refining and catalytic converters that reduce emissions and make fuel consumption more efficient and less polluting. The luminescent properties of yet other rare earths, such as europium or yttrium, allow for more efficient lighting, such as Compact Florescent Light (CFL) bulbs, or in optics such as liquid crystal displays or laser guidance systems. Indeed, rare earths have found a broad number of uses in modern society.

While the rare earth market remains small – valued at USD 9 billion, with roughly 150,000 tons produced and traded annually (by comparison, 2.29 billion metric tons of Iron ore were produced globally in 2015) – they feed into industries worth up to USD 7 trillion.[7] This makes them important components of today’s global economy.

7. R. Ganguli and D. R. Cook, “Rare Earths: A Review of the Landscape”, MRS Energy & Sustainability, No. 5, 2018, E9, www.cambridge.org.

### Rare Earth Elements: Classification and Applications

| Rare Earth Elements | Classification | Abundance in earth's crust (parts per million) | Applications |
|---|---|---|---|
| Lanthanum (La) | Light | 5--39 | Battery alloys, metal alloys, auto catalysts, petroleum refining, polishing powders, glass additives, phosphors, ceramics, and optics |
| Cerium (Ce) | Light | 20--70 | Battery alloys, metal alloys, auto catalysts (emissions control), petroleum refining, polishing powders, glass additives, phosphors, and ceramics |
| Praseodymium (Pr) | Light | 3.5--9.2 | Battery alloys, metal alloys, auto catalysts, polishing powders, glass additives, and coloring ceramics |
| Neodymium (Nd) | Light | 12--41.5 | Permanent magnets, battery alloys, metal alloys, auto catalysts, glass additives, and ceramics |
| Promethium (Pr) | Light | N/A | Watches, pacemakers , and research |
| Samarium (Sm) | Light | 4.5--8 | Magnets, ceramics, and radiation treatment (cancer) |
| Europium (Eu) | Light | 0.14--2 | Phosphors |
| Gadolinium (Gd) | Light | 4--8 | Ceramics, nuclear energy, and medical (magnetic resonance imaging, X-rays) |
| Terbium (Tb) | Heavy | 0.65--2.5 | Fluorescent lamp phosphors, magnets especially for high temperatures, and defense |
| Dysprosium (Dy) | Heavy | 3--7.5 | Permanent magnets |
| Holmium (Ho) | Heavy | 0.7--1.7 | Permanent magnets, nuclear energy, and microwave equipment |
| Erbium (Er) | Heavy | 2.1--6.5 | Nuclear energy, fiber optic communications, and glass coloring |
| Thulium (Tm) | Heavy | 0.2--1 | X-rays (medical) and lasers |
| Ytterbium (Yb) | Heavy | 0.33--8 | Cancer treatment and stainless steel |
| Lutetium (Lu) | Heavy | 0.35--1.7 | Age determination, petroleum refining |
| Yttrium (Y) | | 24--70 | Battery alloys, phosphors, and ceramics |
| Scandium (Sc) | | 5--22 | High strength, low weight aluminum scandium alloys |

*Source: R. Ganguli and D. R. Cook, "Rare Earths: A Review of the Landscape", MRS Energy & Sustainability, No. 5, 2018, E9, www.cambridge.org.*

Not all rare earths are deemed "critical", as some have available substitutes or can simply be designed out of a product. Yet others have so far proven to be indispensable. Assessing to what degree rare earths are critical for various industries and the economies that rely on them has become somewhat of a cottage industry in the last eight years.[8] These assessments largely focus on two basic groups of risk factors as presented below – supply risks, and those related to the elasticity of demand.

It is also important not to overlook the environmental impact of rare earth production as a risk factor, both on the demand and the supply side. Indeed, extracting and refining rare earths is a highly toxic process with a direct impact on human health and the environment, and a major reason why production has become concentrated and is difficult to diversify. In particular, rare earth-bearing mineral deposits are very often associated with radioactive elements such as thorium or uranium. The extraction and refining process also regularly uses various forms of leaching and solvent extraction that employ highly toxic chemicals that seriously degrade soil and water quality if not properly treated.[9] As rare earths are key inputs in "clean" tech, it is important to also consider this dimension if we sincerely hope to achieve broader goals of sustainable development.

In any case, determining which rare earths are critical, for which applications and to what degree is a shifting process that depends on the point of view of the industry and the country in question, and can change over time as technology and markets change.

## Supply-side risk factors: China's monopoly on production largely remains

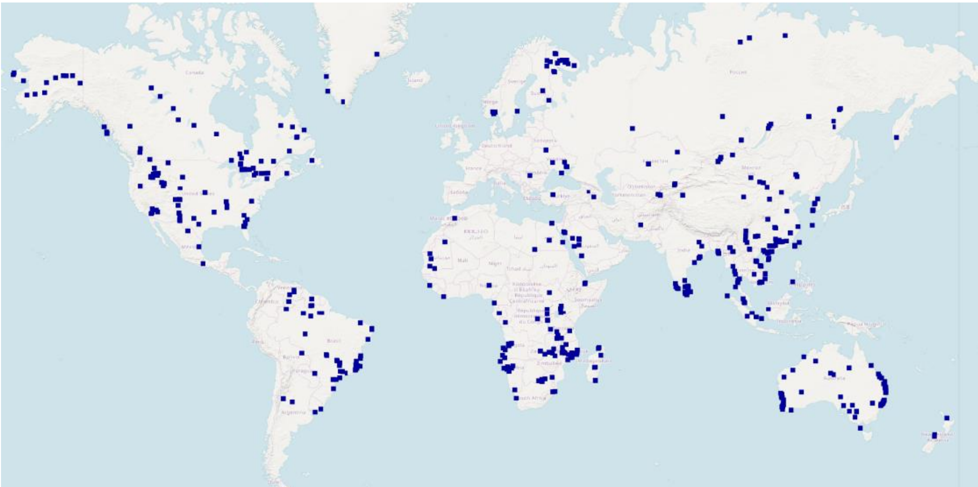
When assessing supply-side criticality, it should first be stressed that rare earths, despite their name, are not rare (nor are they earths). Some, such as cerium and lanthanum, are as geologically abundant as copper. Mineral deposits containing concentrations of rare earths can be found across the globe (see map below), and in more than sufficient quantities relative to demand. The key point here is that rare earths are not scarce – indeed, scarcity leads to a whole different set of implications about competition for

8. T. E. Graedel and B. K. Reck, "Six Years of Criticality Assessments: What Have We Learned So Far?", *Journal of Industrial Ecology,* Vol. 20, No. 4, 2016, pp. 692-699.

9. I. Borges de Lima and W. L. Filho (eds.), *Rare Earths Industry: Technological, Economic and Environmental Implications*, Amsterdam: Elsevier, 2016; H. Q. Liu, *Rare Earths : Shades of Grey – Can China Continue to Fuel Our Global Clean & Smart Future?*, China Water Risk, June 2016, www.chinawaterrisk.org.

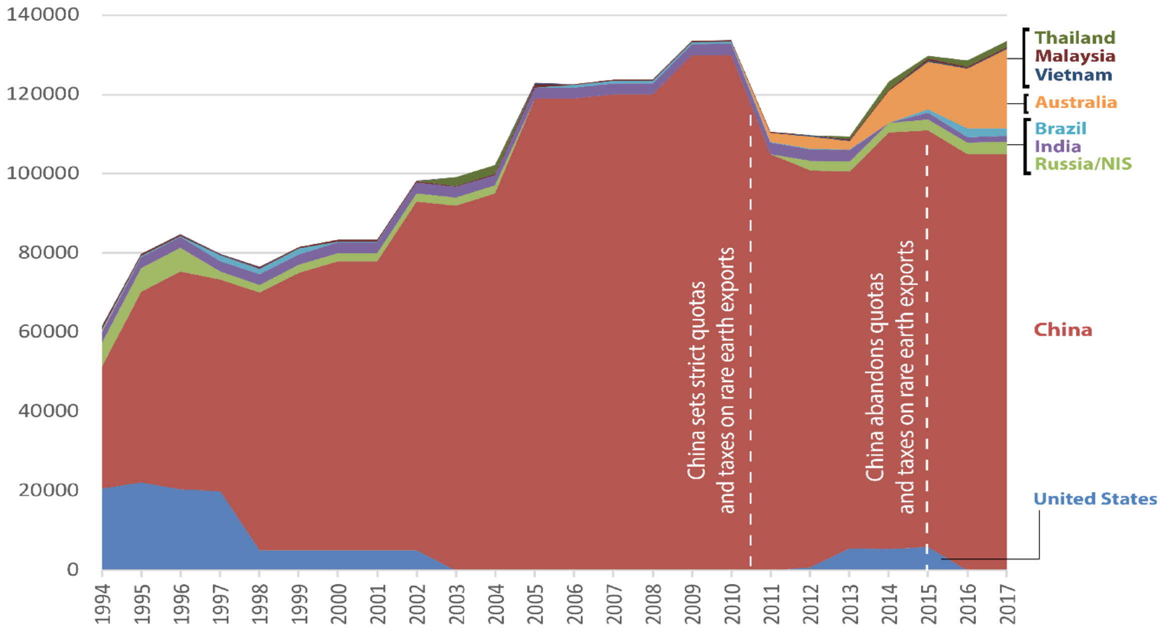
access that should not apply to rare earths from a geological and geographical perspective. Nevertheless, rare earths are often found in low-grade concentrations, and extracting them from the various minerals in which they are found and refining them to industrial-grade quality has proven highly difficult (and toxic). This is an important factor in the concentration of production.

**Known Mineral Deposits Containing Rare Earth Elements around the World**



*Source: United States Geological Survey (USGS), Rare Earth Deposits: Interactive Map, 2 March 2017, [mrdata.usgs.gov](mrdata.usgs.gov), accessed 27 November 2018.*

**Global Rare Earth Mine Production (tons)**




*Source: United States Geological Survey (USGS), Mineral Commodity Summaries, 1994-2018.*
*Note: Represents official production only and does not account for illicit production in China.*

## *Factors leading to China's control of the rare earth market*

While the United States was the world's dominant producer of rare earths through the 1980's, rare earth production has become highly concentrated in China since the mid-1990s. This has primarily come about for three reasons: Chinese policy initiatives and internal market conditions; policy changes in other producing regions; and the effects of globalization, with the relative liberalization of cross-border trade and investment.[10]

Over the last three decades, China has sought to take advantage of its rich deposits of rare earths to support technological innovation and economic development in a wide range of sectors, from space to defense to energy. Various forms of policy support, to include the low cost of land and energy and public programs for research and development in the rare earth sector, in addition to geological factors, traditionally lax environmental regulations and the low cost of labor, have historically allowed China to produce at low nominal cost.

At the same time, strong environmental protection movements in many producing countries beginning in the 1970s and 80s, notably the United States, put regulatory and pricing pressure on producers in these countries and provided incentive for companies in labor intensive, environmentally hazardous industries to seek alternative resource supplies and/or delocalize production.

The liberalization of global trade and investment, and China's liberalization in particular, further allowed global companies to set up in China, and Chinese companies to acquire technological knowhow in the rare earth sector from abroad. This latter point is important because it has not only led China to become the dominant upstream producer of rare earth oxides, but also to increasingly dominate the value chains of some rare earth applications such as NdFeB magnets. Examples in this field include the acquisition of magnet producer Magnequench from General Motors in the United States in the late 1990s, followed by the company's delocalization to China in the early 2000s,[11] and Japanese high-end magnet maker Hitachi Metals, which in 2015 established a joint venture with China's Zhong Ke San Huan, joining a long history dating back to the 1980s of Japanese industries

10. J. M. Klinger, "Rare Earth Elements: Development, Sustainability and Policy Issues", *The Extractive Industries and Society*, Vol. 5, 2018, pp. 1-7.

11. J. Seaman, "Rare Earths and Clean Energy: Analyzing China's Upper Hand", *Notes de l'Ifri*, Ifri, September 2010, pp. 22-23, www.ifri.org.

in rare earth-dependent sectors setting up production in China.[12] While many of the highest quality of rare earth magnets are still be produced in Japan or Europe, by 2013 China produced 90 percent of the world's magnet alloys and 75 percent of NdFeB magnets.[13]

## China tightens the screws on rare earth supplies

Until 2010, very little attention was paid to the concentration of rare earth production in China. Supply and trade in these raw materials were seen as stable, or the risks simply overlooked (as in fact, China's policies designed to exert greater control over the rare earth industry began to tighten from 2006 in particular). From July 2010, however, China set stringent quotas on rare earth exports – 30,000 tons for the year, as compared to the estimated 55,000 tons of non-Chinese demand – in addition to issuing export licenses and levying export taxes of between 10 and 25 percent.[14] When coupled with the alleged embargo on Japan from September to November 2010, supply risks became abundantly clear. A closer look at the drivers behind these policies is treated in more detail below, but the measures effectively shrunk the supply of rare earths on the global market overnight, putting pressure on rare earth consumers across the globe to either delocalize operations to China in order to secure access to raw materials, secure non-Chinese supplies, innovate, or perish.

## Consumers scrambles for rare earths

Consumers outside of China undertook various efforts at the sourcing level to deal with the new supply constraints. Some industries delocalized a portion of their production to China in order to secure access to raw materials.[15] Others took advantage of the sizeable black market for rare earths, which included combining rare earth oxides with other products such as steel or other metals, exporting them under a different name, and re-processing the material to extract the rare earths on the other side.[16] In order to avoid targeted sanctions from Chinese suppliers, some Japanese

12. N. A. Mancheri and T. Marukawa, "Rare Earth Elements: China and Japan in Industry, Trade and Value Chain", *ISS Contemporary China Research Series*, No. 17, Institute of Social Sciences, University of Tokyo, March 2016.

13. M. Humphries, "Rare Earth Elements in the Global Supply Chain", CRS Report for Congress, Congressional Research Service, 16 December 2013, p. 14.

14. N. A. Mancheri, "World Trade in Rare Earths, Chinese Export Restrictions, and Implications", *Resources Policy*, No. 46, 2015, pp. 262-271, www.researchgate.net.

15. Y. Inoue and J. Gordon, "Analysis: Japanese Rare Earth Consumers Set Up Shop in China", Reuters, 12 August 2011, www.reuters.com.

16. Author interviews with Japanese businesses in Tokyo, August 2011.

consumers also took to importing Chinese rare earth products via third countries, such as Vietnam.[17] Individual companies also took to building their own commercial stockpiles in order to weather the storm, some ranging from two to three months of supply, others allegedly up to two years.[18]

## Recycling: A necessary but limited solution

Recycling both at the industrial and the consumer level also gained notoriety as an alternative source of supply. At the industrial level, some magnet producers in Japan, for instance, were able to reprocess industrial waste and recover as much as 30 percent of the rare earths used in their initial production stages.[19] At the post-consumer level, recycling of electronic and urban waste has proven to be more complex due to problems associated with collection – related to low public awareness and inadequate collection programs – and the costs and technical difficulties of extracting the small quantities of rare earth material present in products such as mobile phones or personal computers. Recycling in some areas, such as florescent lighting, did nevertheless encounter initial success.[20] Still, recycling in Europe, for instance, still only accounts for a small fraction of supply (estimated at 6 or 7 percent today).[21]

The cost of recycling remains a significant constraint, but as products with higher rare earth and other technology metal content – such as hybrid and full-electric vehicles and wind turbines – eventually complete their life cycles and are decommissioned, and public policies such as the EU's Circular Economy Action Plan push for further recycling solutions, the supply of recyclable material will grow. This in turn should lead to greater economies of scale for recycling and put downward pressure on costs. Moreover, changes in the global trade of electronic waste may also put pressure on high-tech consumers in Europe, North America and Asia to emphasize recycling. Indeed, China, which is the world's largest importer of electronic waste, has announced a ban on all solid waste imports as of 31 December 2018.[22] Nevertheless, the technical hurdles for recycling remain significant

17. J. Seaman, "Rare Earths and the East China Sea: Why Hasn't China Embargoed Shipments to Japan?", *Ifri-CIGS Op-Ed Series*, Ifri, October 2012, www.ifri.org.
18. Author interviews with Japanese businesses in Tokyo, August 2011.
19. Author interviews with Japanese magnet makers in Tokyo, August 2011.
20. E. Machacek, J. L. Richter, K. Habib, and P. Klossek, "Recycling of Rare Earths from Florescent Lamps: Value Analysis of Closing-the-Loop under Demand and Supply Uncertainties", Resources, Conservation and Recycling, No. 104, pp. 76-93.
21. European Commission, "Report on Critical Raw Materials and the Circular Economy", Commission Staff Working Document, 16 January 2018, Part 1/3, p. 10, ec.europa.eu.
22. D. van der Kamp, "Will China's Waste Ban Force a Global Clean-Up?", East Asia Forum, 7 December 2018, www.eastasiaforum.org.

and, while necessary, recycling remains a solution for the long term. Some projections show that even by 2030 recycling will only be able to meet 10 percent of projected rare earth demand.[23]

## *Developing mines outside of China*

The most consequential responses to the rare earth supply crisis have so far been to seek out alternative production from potential mining operations overseas, and pressure China into reversing its export policies. With rare earth deposits scattered around the globe, one would expect that China's restrictive policy measures would result in an increase of production abroad, but this has proven more complicated in reality. Prices rose dramatically over the course of 2011 and 2012, in some cases by 500 percent or more, driven by market conditions, but also by rampant speculation.[24] High prices generated a deluge of capital investment in the rare earth mining sector, financing more than 200 projects outside of China. As a result of the ensuing exploration boom, between 2010 and 2015 the level of discernable non-Chinese rare earth mineral resources rose from 16.5 million to 87.3 million tons. Production at a number of sites was kick-started (or re-started), notably in Australia, Vietnam, Brazil and the United States, as illustrated in the graph above.[25]

Japan has proven to be a crucial player in this process. In the wake of China's export restrictions, the Japanese government modified public-sector investment rules to allow government agencies to become active stakeholders in mining operations overseas, in particular through the government's resources arm, JOGMEC.[26] In recent years, JOGMEC has teamed with Japanese private sector investors and trading houses to help secure rare earth materials from overseas, assisting with resource exploration and developing mining operations such as Australia's Mount Weld, which is currently the largest rare earth mining operation outside of China.

23. J. H. Rademaker, R. Kleijn, and Y. X. Yang, "Recycling as a Strategy against Rare Earth Element Criticality: A Systemic Evaluation of the Potential Yield of NdFeB Magnet Recycling", *Environmental Science and Technology*, Vol. 47, No. 14, 2013, pp. 10129-10136.

24. C. Cox and J. Kynicky, "The Rapid Evolution of Speculative Investment in the REE Market Before, During, and After the Rare Earth Crisis of 2010-2012", *The Extractive Industries and Society*, No. 5, 2018, pp. 8-17.

25. H. Paulick and E. Machacek, "The Global Rare Earth Element Exploration Boom: An Analysis of Resources Outside of China and Discussion of Development Perspectives", *Resources Policy*, No. 52, 2017, pp. 134-153.

26. Author's interviews with Japanese officials in Tokyo, August 2011 and July 2013.

**Evolution of Average Annual Prices
for Select Rare Earth Oxides (USD/kg)**

| | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|
| Ce | 40 | 30 | 30 | 30 | 100 | 28 | 8 | 5 | 2 |
| La | 30 | 30 | 38 | 38 | 100 | 58 | 20 | 5 | 3 |
| Nd | 45 | 42 | 63 | 63 | 270 | 124 | 72 | 65 | 47 |
| Pr | 60 | 38 | 60 | 60 | 225 | 118 | 85 | 99 | 67 |
| Y | 50 | 44 | 50 | 50 | 165 | 110 | 26 | 15 | 7 |
| Dy | 150 | 170 | 310 | 310 | 1600 | 1203 | 557 | 373 | 271 |
| Eu | 1000 | 1600 | 1400 | 1400 | 3300 | 2610 | 1102 | 771 | 269 |
| Tb | 800 | 900 | 1400 | 1400 | 2750 | 2035 | 925 | 657 | 547 |

*Source: H. Paulick and E. Machacek, "The Global Rare Earth Element Exploration Boom: An Analysis of Resources Outside of China and Discussion of Development Perspectives",* Resources Policy*, No. 52, 2017, pp. 134-153.*

## *Reversing China's export constraints: a double-edged sword*

In parallel, efforts were undertaken to reverse China's restrictive export policies. In 2012, the United States, the European Union, Japan and Canada filed a complaint with the World Trade Organization's Dispute Settlement Body (DSB), which ultimately ruled that China's export measures – quotas, export taxes and licensing – violated the terms of its accession agreement.[27] As a result, China scrapped its export restrictions in 2015. As the dust settled and prices came back to reality – aided by China's policy reversal, but also by adjustments on the demand side – only a handful of mining operations would prove viable. The total market capitalization of companies listed outside of China in the spring of 2011 was USD 19 billion. By 2015, the figure had fallen by 95 percent to just USD 1 billion.[28]

This reversal of fortunes is most notable in the case of the Mountain Pass mine in California, once the world's largest producers of rare earths, and the only historically active producer in the United States. The mine initially ceased production in 2002 due to unfavorable market conditions and an inability to secure financing for upgrades that were needed to comply with California's environmental regulations. As rare earth prices rose, the mine's new owners (Molycorp, which purchased the mine in 2010) were able to secure investment and re-start production in 2012. But this would only prove short lived. Hampered by high production costs and low market prices, Molycorp would declare bankruptcy and cease production yet again

27. "China – Measures Related to Exportation of Rare Earths, Tungsten and Molybdenum", DS431, World Trade Organization, 20 March 2015, www.wto.org, accessed 10 November 2018.
28. H. Paulick and E. Machacek, "The Global Rare Earth Element Exploration Boom", *op. cit.*, p. 143.

in 2015. Ultimately, China today still accounts for over 80 percent of total rare earth mine production, and nearly all production of certain heavy rare earths, such as dysprosium.

## Demand-side factors: between replaceable and irreplaceable rare earths

While efforts to diversify on the supply side have had mixed results, developments on the demand side also constitute an important factor in determining the criticality of rare earths. Today, nearly 60 percent of global rare earth demand is still accounted for by "mature" markets – catalysts, glass making and metallurgy – while the remaining 40 percent comes from newer, potentially high-growth markets that include ceramics, battery alloys and permanent magnets.

This second category of emerging technologies is where demand is mostly likely to grow in the future due to the potential for rare earths to enable the technologies that are driving the digital revolution and the low-carbon energy transition. Some project that on the back of NdFeB magnets, for instance, global demand for neodymium and dysprosium in particular could rise by as much as 2500 percent and 700 percent respectively by 2027.[29] Whether or not supply-side constraints will hamper the development of technology, or lead to an even greater comparative advantage for Chinese firms in these emerging technology fields will depend on the ability of industrial consumers not only to find alternative supplies, but to adjust their demand in ways that do not substantially hinder the competitiveness of their products.

### Estimated Global Rare Earth Consumption by Application and by Element (2015)

| | |
|---|---|
| Catalysts | 24% |
| Magnets | 23% |
| Polishing | 12% |
| Batteries | 8% |
| Metallurgy | 8% |
| Glass | 7% |

| | |
|---|---|
| Ce | 39.5% |
| La | 26.4% |
| Nd | 19.9% |
| Y | 7.1% |
| Pr | 4.1% |
| Gd | 1.1% |

29. E. Alonso, A. M. Sherman, T. J. Wallington, *et al.* "Evaluating Rare Earth Element Availability: A Case with Revolutionary Demand from Clean Energy", *Environmental Science & Technology*, Vol. 46, No. 6, pp. 3406-3414.

| | |
|---|---|
| **Ceramics** | 6% |
| **Phosphors** | 2% |
| **Others** | 10% |

| | |
|---|---|
| **Dy** | 0.7% |
| **Sm** | 0.3% |
| **Eu** | 0.2% |
| **Tb** | 0.2% |
| **Others** | 0.5% |

*Source: Roskill 2016,* via *K. M. Goodenough, F. Wall and D. Merriman, "The Rare Earth Elements: Demand, Global Resources, and Challenges for Resourcing Future Generations",* Natural Resources Research*, Vol. 27, No. 2, 2018, pp. 201-216.*

## Some successful demand-side adjustments…

In the wake of China's export restrictions in 2010, industrial consumers have indeed made significant efforts to adjust their resource requirements and reduce, or even eliminate altogether their dependence on rare earths. According to a report by Adamas Intelligence, global annual rare earth demand between 2011 and 2016 decreased by roughly 50,000 tons on supply concerns and technological change.[30] In the lighting industry, for instance, high prices were a major factor behind a significant shift from the use of rare earth-intensive CFL towards alternative LED systems. Similarly, the use of rare earth-dependent battery technologies – namely NiMH – has been dramatically scaled down in favor of lithium-ion battery technology. Many other examples also exist, for instance in the glass polishing and ceramics industries.[31]

Defense industry applications, which are varied and numerous and where market forces are less relevant, are often thought to be particularly vulnerable to supply disruptions. Still, their small market size and low volume of rare earth demand relative to civilian sectors has led many analysts to conclude that supply solutions can be found even in the extreme event of an embargo.[32]

## …but rare earths remain critical for many technologies

While there have been some notable successes, demand adjustments have elsewhere proven difficult. The use of neodymium and dysprosium in NdFeB

30. F. Els, "China to Become Net Importer of Some Rare Earths", Mining.com, 2 January 2017, www.mining.com.

31. R. Eggert, C. Wadia, C. Anderson, *et al.*, "Rare Earths: Market Disruption, Innovation and Global Supply Chain's", *Annual Review of Environment and Resources*, Vol. 41, November 2016, pp. 199-222.

32. E. Gholz, "Rare Earth Elements and National Security", *Energy Report*, Council on Foreign Relations, October 2014, www.cfr.org.

magnets is often considered the most problematic in that the degree of economic impact of supply disruptions is high, with the civilian industries most impacted being the wind power sector, the automotive sector, manufacturers of various appliances (air conditioners, washing machines, refrigerators, etc.) and ICT consumer electronics (smartphones, laptop computers and desktop PCs).

Since 2010, magnet manufacturers have been searching for ways to adjust the composition of rare earth magnets in order to reduce the quantities of rare earths needed. Much of this effort has focused on reducing or eliminating the need for dysprosium, for which China is still the world's only producer. In particular, dysprosium allows magnets to maintain their magnetic properties when operating at high heat. In the wind sector, NdFeB magnets have been privileged by a number of turbine manufacturers to enable "direct drive" systems that are lighter and require less maintenance, a feature that is particularly attractive for offshore usage. Whereas 23 percent of today's wind turbines use rare earth magnets, the figure is expected to grow to 72 percent by 2030.[33] But here, the need for heat resistance, and thus dysprosium, has been reduced. While demand for neodymium will likely remain high, projections show that by 2020 the use of dysprosium in magnets for the wind industry will shrink from 4.5 percent to 1 percent per magnet, likely leading to a relative decline of dysprosium use for the sector in the long term (see table below for an analysis of projected demand in the EU).[34] This efficiency gain has been much more problematic for hybrid and full-electric vehicles (HEVs and EVs), where dysprosium continues to be crucial for heat resistance in motors. On average, power trains of HEVs and EVs each use up to 2.5kg of rare earths (in addition to up to 100 applications in smaller electric motors used in windshield wipers, sound systems, air conditioning systems and automatic windows).[35] Still, some automotive companies have succeeded in marketing electric vehicles that rely on rare earth-free motor technologies, for instance Tesla, which uses an induction motor, and Renault, which employs a wound motor technology.

33. WindEurope, "Research and Innovation Needed to Provide Substitutes for Rare Materials Used in Turbines", *WindEurope News*, 15 November 2018, windeurope.org.
34. A. Monnet and A. A. Abderrahim, "Report on Major Trends Affecting Future Demand for Critical Raw Materials", SCRREEN, Deliverable 2.2, 22 May 2018, p. 20, scrreen.eu.
35. K. M. Goodenough, F. Wall, and D. Merriam, "The Rare Earth Elements: Demand, Global Resources and Challenges for Resourcing Future Generations", *Natural Resources Research*, April 2017.

**Demand Growth Potential for Critical Rare Earth Elements in the EU (tons by sector)**

| | Wind power | | Electric vehicles | | Domestic appliances | | ICT consumer electronics | |
|---|---|---|---|---|---|---|---|---|
| | 2015 | 2035 | 2015 | 2035 | 2015 | 2035 | 2015 | 2035 |
| **Nd** | 390 | 750 | 2 | 2200 | 1530 | 2370 | 90 | 120 |
| **Dy** | 80 | 60 | 1 | 700 | 130 | 190 | 9 | 12 |
| **Pr** | 130 | 250 | 1 | 700 | -- | -- | -- | -- |

*Source: A. Monnet and A. A. Abderrahim, "Report on Major Trends Affecting Future Demand for Critical Raw Materials", SCRREEN, Deliverable 2.2, 22 May 2018, scrreen.eu.*

## *Substitution and risks to competitiveness*

On the whole, finding adequate substitutes for rare earths has proven difficult. In the European Commission's "Substitution Index" of critical raw materials in 2017, for instance, heavy rare earths scored 0.96 on a scale of 0 to 1, with 1 being the least substitutable. Light rare earths scored an only slightly better 0.90.[36] What is interesting about this index is that it correlates economic importance to the technical and cost performance of the substitutes for individual applications of each material. This score underlines a commonly raised concern that, in their search for substitutes, industries may be sacrificing technical performance and/or cost competitiveness in an effort to avoid supply disruptions for critical raw materials.[37] If so, this would provide a clear advantage to those who are able to invest in R&D and innovation without having to consider the same constraints on raw material supplies. In the case of rare earths, this clearly means industries in China.

36. "Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the 2017 list of Critical Raw Materials for the EU", European Commission, 13 September 2017, eur-lex.europa.eu.
37. D. S. Abraham, *The Elements of Power: Gadgets, Guns and the Struggle for a Sustainable Future in the Rare Metal Age*, *op. cit*.

# China's rare earth strategy

China's actions in restricting rare earth trade have been the cause for much of the world's attention on the market since 2010. Over the course of 2018, this attention resurfaced in the context of the deepening US-China trade war. Ironically, on the one hand, the Trump Administration initially signaled that rare earth imports from China would fall into the basket of the more than USD 260 billion of taxable goods levied from September 2018, though a last-minute reversal ultimately kept them off the list.[38] On the other hand, voices in the US have warned that China holds a rare earth "trump card", and can win the trade war with the US in "just one move".[39] Against this discussion, it is important to take a step back and discuss some of China's actions in the rare earth sector over the last decade and why it has (or hasn't) taken them. This will help us to better understand where China's policies are likely to go in the future. Understanding China's actions should first start with the most extreme scenario – that China would use its resource advantage as a means of obtaining diplomatic or economic gains by levying an embargo.

## The rare earth "weapon" that wasn't?

The importance of rare earths for modern economies and the concentration of their production in China would seemingly give Beijing an ideal means of exerting pressure by cutting off exports of critical raw materials in order to obtain diplomatic gains – or so-called "economic statecraft".[40] Indeed, there are multiple examples of China using pointed economic pressure to modify the positions and behavior of states on issues of great importance to Beijing: with South Korea in the case of Seoul's acceptance of the THAAD missile defense system; with the Philippines in the case of Manila's stance on territorial sovereignty in the South China Sea; or with Norway in the case of Oslo's refusal to denounce the awarding of the Nobel Peace Prize to Liu Xiaobo, to name a few. At face value, rare earths would appear to be the

38. This change was led mostly by concerns from the fuel and refining industry, which accounts for over half of US rare earth demand. See H. Sanderson, "US Spares Rare Earths in China Trade War", *Financial Times*, 18 September 2018, www.ft.com.

39. J. Spross, "How China Can Win a Trade War in just 1 Move", *The Week*, 6 April 2018, www.theweek.com. See also A. Stevenson, "How Rare Earths (What?) Could Be Crucial in a U.S.-China Trade War", *New York Times*, 11 July 2018, www.nytimes.com.

40. S. Kalantzakos, *China and the Geopolitics of Rare Earths*, New York: Oxford University Press, 2018, pp. 22-47.

perfect weapon with which China could fight many of its geopolitical battles, particularly with more economically advanced states. Indeed, this is believed to have happened with Japan more than eight years ago.

In September 2010, a Chinese fisherman was detained by the Japanese Coast Guard after ramming two patrol boats in disputed (though Japanese administered) waters around the Senkaku/Diaoyu islands in the East China Sea. Reports quickly began to surface that shipments of rare earths (in addition to a host of other products) were being held up at Chinese ports, effectively constituting an embargo on the export of critical resources to an import-dependent Japan.[41] But a closer examination of these events, aided by analysis and field work done by Johnston[42] and Klinger[43], paints a much more nuanced picture on the role of policy makers in Beijing and serves to downplay the risks and potency of China's rare earth "weapon" and the willingness to brandish it in the future.

## *A locally-driven embargo*

There is no question that rare earth shipments to Japan were disrupted, and indeed, all of the thirty-one companies handling rare earths in Japan reported either a stoppage or disruption.[44] At the same time, Japanese import data show that during the time of the conflagration (September to October, or in some reports November), Japanese ports continued to receive shipments of rare earths and that the trade disruptions that did occur were haphazard.[45] Some contextual elements are necessary to keep in mind, here. On the one hand, it should not be forgotten that less than three months earlier, in July 2010, China had put in place export quotas that would severely limit the global supply of rare earths, dramatically raising prices and giving incentive for exporters to delay sales and shipments in order to profit from rapidly rising prices. On the other hand, it should also be underlined that illicit production and the black market play a strong role in China's rare earth industry, accounting historically for as much as one third or more of production.[46] Profit-seekers on the black market would certainly have an incentive to ignore a covert directive from Beijing in order to cash

41. K. Bradsher, "Amid Tension, China Blocks Vital Exports to Japan", *New York Times*, 22 September 2010, www.nytimes.com.
42. A. I. Johnston, "How New and Assertive Is China's New Assertiveness?", *International Security*, Vol. 37, No. 4, Spring 2013, pp. 7-48.
43. J. M. Klinger, *Rare Earth Frontiers: From Terrestrial Subsoils to Lunar Landscapes*, Ithaca: Cornell University Press, 2017, pp. 139-143.
44. Agence-France Presse, "Japan's Rare Earth Minerals May Run Out by March: Govt", 21 October 2010, phys.org.
45. A. I. Johnston, "How New and Assertive Is China's New Assertiveness?", *op. cit.*, 2013.
46. D. J. Packey and D. Kingsnorth, "The Impact of Unregulated Ionic Clay Rare Earth Mining in China", *Resources Policy*, No. 48, 2016, pp. 112-116.

in on high-priced sales to Japan. But this last point also underlines a broader notion that rare earths were (or would have been) a poor choice of "weapon" in that the central government ultimately had little effective control over the market actors.

Rather than a centrally-directed initiative, evidence suggests that it was military and local government officials and port workers that were responsible for halting rare earth shipments in order to punish Japan, and that it did not constitute a national trend, nor was it a policy choice on the part of Beijing.[47] Indeed, Chinese central government officials, from customs authorities to the Ministry of Commerce to the Prime Minister, stringently denied that an embargo had been put in place,[48] and their efforts to demarche local government and port authorities to resume shipments infer that these were the actions of overzealous local actors.

## An ineffective "weapon"

It is still possible that Beijing, despite its public declarations and its lack of effective control, did intend to specifically disrupt rare earth flows to Japan, either as a form of bargaining chip, or to demonstrate to an enflamed domestic audience that it was taking action (all while walking a fine line not to break certain diplomatic taboos by openly declaring sanctions). If bargaining was the goal, Beijing ultimately made poor use of its advantage. Broadly speaking, the role rare earths played in the diplomatic crisis served to highlight fears about the consequences of China's rise more generally, and on the need to counter China's influence in the rare earth sector in particular. On the specific question of the East China Sea, Beijing ultimately secured only the release of a detained fisherman – who was released in late September, while the alleged embargo lasted for another month or more – with Tokyo maintaining full administrative control over the Senkaku/Diaoyu Islands and their surrounding waters, making no concessions on this point. It is also telling that in subsequent tensions with Japan over these islands, for instance in 2012 following the sale of some of the islands by their private owner to the Japanese government, provoking what is arguably a much deeper diplomatic crisis, rare earth exports to Japan were unaffected. Behind this fact is an explanation which suggests that, even if China decided to disrupt rare earth trade in a diplomatic stand-off, its integration in global value chains was such that supply disruptions of rare earths ultimately had a negative impact on Chinese industries that were (and

47. J. M. Klinger, 3Rare Earth Frontiers: From Terrestrial Subsoils to Lunar Landscapes3, *op. cit.*, 2017.
48. "Ensuring Sustainability of Rare Earth", *China Daily*, 7 October 2010, www.chinadaily.com.cn.

are) still reliant on parts and components shipped back to China from rare earth consumers in other countries, such as Japan.[49]

## Economic development and environmental protection: the drivers of China's policy action

Rather than considering its dominant position in rare earths as a weapon with which to fight its geopolitical battles, the real value of China's resource endowment is the role it plays in the country's economic development. Indeed, since the 1980s the primary goal of developing the rare earth sector in China has been to facilitate innovation and the growth of high tech industries at home – for use both in the real economy and in the country's military modernization.[50] These goals are all the more central to China's economic strategy today, as Beijing seeks to respond to the increasing necessity to restructure the national economy from one based on low-wage manufacturing and heavy industry towards higher value-added production.

### *Rare earths and China's economic strategy*

Since 2010, at the same time as more stringent export policies were put in place, the State Council has repeatedly placed an emphasis on developing so-called "strategic emerging industries", which include aerospace, high-speed rail, high-end manufacturing equipment, electric power equipment, and new-energy vehicles, many of which rely on rare earth components. Notably, the list also includes "new materials", which explicitly include rare earth-based materials themselves. In 2015, the State Council drafted its "Made in China 2025" blueprint that is considered a guide for developing these industries in the years to come, turning China into a global leader of the industries of the future. In particular, this blueprint emphasizes nationalizing much of the value chain for new strategic industries – setting goals for Chinese production to account for up to 70 percent or 80 percent of the value of the domestic market for products such as new energy vehicles, new and renewable energy equipment and high-tech medical devices.[51] In this respect, the export quotas, taxes and other price-distorting measures put in place until 2015 gave Chinese firms an added advantage of stable rare

49. K. Bradsher, "China Resumes Rare Earth Shipments to Japan", *New York Times*, 19 November 2010, www.nytimes.com.

50. C. Hurst, "China's Rare Earth Elements Industry: What Can the West Learn", Institute for the Analysis of Global Security (IAGS), March 2010.

51. J. Wübbeke, M. Meissner, M. J. Zenglein, J. Ives and B. Conrad, "Made in China 2025: The Making of a High-Tech Superpower and Consequences for Industrial Countries", MERICS Papers on China, 8 December 2016, www.merics.org.

earth supplies at comparatively lower prices than consumers abroad, and even enticed some value-added production and technology transfer in downstream industries overseas to China.

## Overcoming sectoral constraints

Still, despite this broad economic strategy, aligning China's resource advantage in rare earths with its wider development goals has not been so simple. Indeed, China's rare earth industry has been hampered by a number of challenges, including inefficient production, low prices, rapid mineral depletion rates (particularly in heavy rare earth producing regions), catastrophic pollution and weak regulatory control. As opposed to major strategic industries such as oil and gas, the rare earth industry in China has been historically scattered. Before 2010, for instance, there were as many as 170 officially registered rare earth refiners and more than 130 NdFeB magnet producers.[52] As mentioned above, illicit mining has also been a rampant problem, with between 25,000-50,000 tons of rare earth oxides illegally produced in China, some 60 percent being in the "heavy" rare earths.[53]

Many of the policies that China has put in place in the rare earth field over the last decade have sought to prepare the industry to meet the needs the economy's new strategic direction. These include strengthening regulatory power of central government authorities, allocating production licenses and quotas, issuing export licenses, creating resource stockpiles to manage supplies and pricing, and enacting a broad-based consolidation of the industry.[54] By encouraging mergers, phasing out small-scale mines and cracking down on illegal mining, China has sought to reduce the number of separation enterprises to just 20, and consolidate resource extraction into the hands of six state-owned enterprises, namely Northern Rare Earth (Group) Hi-Tech (including Baotou), Aluminum Corporation of China (Chinalco), China Minmetals Corporation, Xiamen Tungsten, Ganzhou Rare Earth Group, and Guangdong Rare Earth Industry. So while meaningful export restrictions and price distortions have been erased since 2015, the risks of a return to a less stable supply situation remains a source of great concern for consumers outside of China, as Beijing now seems keen on exerting a greater amount of control over the industry with a view to achieving its broader industrial goals.

52. Jost Wübbeke, "Rare Earth Elements in China: Policies and Narratives of Reinventing an Industry", *Resources Policy*, No. 38, 2013, pp. 384-394.

53. R. Ganguli and D. R. Cook, "Rare Earths: A Review of the Landscape", *op. cit.*

54. L. Shen, N. Wu, S. Zhong and L. Gao, "Overview of China's Rare Earth Industry Restructuring and Regulation Reforms", *Journal of Resources and Ecology*, Vol. 8, No. 3, May 2017, pp. 213-222.

### *Responding to China's growing environmental crisis*

In this process, ensuring that China has enough resources to meet its growing demands is one important aspect, but responding to the country's growing environmental crisis is certainly another. On the one hand, China will increasingly rely on rare earths as it favors technologies in sectors such as renewable energy and electric vehicles that respond to worsening air pollution and climate change. But the devastating pollution caused by the production of rare earths itself has become a crisis that the country can no longer ignore.[55] For instance, estimates by the Chinese Society of Rare Earths indicate that producing one ton of rare earths in Baotou, Inner Mongolia also produces 75,000 liters of acidic wastewater and one ton of radioactive residue.[56] Rare earth production has laid waste to the mining regions of Jiangxi, Guangdong, Fujian, Sichuan and Inner Mongolia, giving rise to toxic water systems, barren farm land and a growing number of cancer villages.[57]

As public pressure mounts and China increasingly places "green development" at the heart of its national strategy, responding to this growing crisis has become an indicator of legitimacy. As a result, Beijing has revamped environmental standards, strengthened the regulatory authority of the Ministry of Environmental Protection (which was reorganized under the banner of the Ministry of Environment and Ecology in 2018), and stepped up enforcement – to include cracking down on illegal mining. Industry consolidation and price support measures are also designed to facilitate the adoption of improved production methods and the respect for higher environmental standards.

## From exporter to importer: Towards a shift in China's role in the rare earth market

China's high and rising demand for rare earths may soon bring about a major change in its role as a global supplier of rare earths. In 2012, China's State Council noted in its White Paper on the rare earth sector that the reserves-to-production ratio of country's ion-absorption clays in Jiangxi Province, which are the world's major producer of heavy rare

55. G. Pitron, *La guerre des métaux rares : La face cache de la transition énergétique et numérique*, Paris: Les Liens qui Libèrent, 2018.
56. D. S. Abraham, *The Elements of Power: Gadgets, Guns, and the Struggle for a Sustainable Future in the Rare Metal Age*, *op. cit.* p. 176.
57. H. Liu, Rare Earths: Shades of Grey – Can China Continue to Fuel Our Global Clean & Smart Future?, China Water Risk, June 2016, www.chinawaterrisk.org.

earths, notably dysprosium, have fallen dramatically in the last two decades from 50 years to just 15.[58] Indeed, Chinese demand could reach up to 190,000 tons as early as 2020, compared to 105,000 tons of official production in 2017.[59] This stark conclusion, coupled with growing environmental concerns and more stringent regulations at home, is pushing some Chinese firms to seek out rare earth supplies from mines overseas, in line with guidance from Ministry of Industry and Information Technology's 13th five-year plan (2016-2020) for the sector.[60] Such a change constitutes a major evolution in the rare earth market, where China now appears increasingly set to become a net importer of rare earths in the years to come. In a way, China will also be repeating the practice of exporting pollution, in much the same way that other post-industrial societies have done in the decades before.

One firm in particular, Shenghe Resources, is increasingly active in developing overseas rare earth mine production. Based in Chengdu and listed on the Shanghai stock exchange, with a market capitalization of over USD 2 billion at the end of 2018, Shenghe is a vertically integrated rare earth company that is involved in the mining and processing of rare earths and the manufacture of rare earth alloys and other products for industrial consumers in China and around the world.[61] Shenghe's largest investor, holding over 14 percent of shares, is the Chengdu Institute of Multipurpose Utilization of Mineral Resources (IMUMR), which is owned by the Ministry of Land and Resources (a ministry that was reorganized and strengthened under the name of the Ministry of Natural Resources in early 2018). The Chairman of Shenghe Resources is also director of IMUMR.[62]

Shenghe began its foray into mines outside of China in September 2013 by signing a Memorandum of Understanding with Australia's Arafura to develop the company's Nolans Project.[63] In 2015, it signed an off-take agreement with Tatalus Rare Earth for 30 percent of production (estimated at 3,000 tons) from the company's development in

58. *Situation and Policies of China's Rare Earth Industry*, Information Office of the State Council, PRC, June 2012.

59. L. Shen, N. Wu, S. Zhong, and L. Gao, "Overview on China's Rare Earth Industry Restructuring and Regulation Reforms", *op. cit.*, 2017, p. 215.

60. "Notice of the Ministry of Industry and Information Technology on Printing and Distributing the Rare Earth Industry Development Plan (2016-2020)", Ministry of Industry and Information Technology, People's Repubic of China, No. 319, October 2016, www.miit.gov.cn.

61. J. Lifton, "Lifton Comments on 'Significant Signing' of Tatlus Rare Earths Off-Take Agreement with Shenghe Resources", InvestorIntel.com, 9 February 2015, investorintel.com.

62. M. Martin, "China in Greenland: Mines, Science and Nods to Independence", *China Brief*, Vol. 18, No. 4, The Jamestown Foundation, 12 March 2018, jamestown.org.

63. "Arafura Resources", *International Resource Journal*, 2017, www.internationalresourcejournal.com, accessed 10 December 2018.

Madagascar, though the project has encountered resistance due to environmental concerns.[64] In 2016, Shenghe acquired a 12 percent stake in Greenland Minerals and Energy (GME), the owner of Greenland's Kvanefjeld project, which has a rich deposit of heavy rare earths and uranium. In addition to providing technical expertise, Shenghe has entered into a supply agreement that includes all of the Kvanefjeld mine's 32,000 tons of annual production[65] – though a mining license for the project has yet to be handed down. More recently, and as a sign of the changing times, in 2017 Shenghe Resources also became a non-voting minority shareholder in a consortium (MP Mine Operations) that acquired the Mountain Pass mine in California from a bankrupt Molycorp.[66]

To date, none of the ventures above have entered into the production stage, but Shenghe's activism is clearly a sign of the changing times. This is not the first wave of Chinese investment in overseas rare earth mining, but for political reasons and national security concerns raised in host countries, much of the previous activity largely failed to result even in agreements, much less production. In 2005, China's state-owned oil and gas giant CNOOC nearly acquired the Mountain Pass mine in California through a bid for the mine's then-owner, UNOCAL – a move that was blocked by US authorities for reasons that seemingly had little to do with rare earths. UNOCAL was eventually sold to Chevron, which in 2007 was again solicited by Chinese buyers for the sale of Mountain Pass, which instead went to Molycorp.[67] In 2009, China Non-Ferrous Metal Mining (Group) Co. also made an unsuccessful bid for a 51.6 percent stake in the Lynas Corporation, which owns the Mount Weld mine in Australia and is today the largest rare earth-producing mine outside of China, having started operations in 2012. The deal was ultimately blocked by Australian authorities on supply concerns.[68] One acquisition that did go through was the purchase of a roughly 25 percent stake in Arafura from the East China Mineral Exploration and Development Bureau (ECE), which later resulted in the connection between Arafura and Shenghe Resources.

While Chinese interest in developing rare earth mines outside of China is therefore nothing new, what is striking about the current wave

64. E. Carver, "Another Blow to Troubled Madagascar Rare Earth Mine", Mongabay, 22 November 2017, news.mongabay.com.

65. H. Black, "Shenghe Poised for 100% of Kvanefjeld Uptake", Miningnews.net, 21 August 2018, www.miningnews.net.

66. A. Topf, "Mountain Pass Sells for $20.5 Million", mining.com, 16 June 2017, www.mining.com.

67. K. Bradsher, "China Tightens Grip on Rare Minerals", *New York Times*, 31 August 2009, www.nytimes.com.

68. "Australia Blocked China Investment on Supply Concerns", *Sydney Morning Herald*, 15 February 2011, www.smh.com.au.

is that it has been particularly successful in concluding deals despite of the heightened concerns about Chinese control of rare earth production since 2010.

# Conclusion and recommendations

China's primary objective in exploiting its resource advantage in the rare earth field has not been to fight political and diplomatic battles, but to service its economic strategy for carving out a competitive advantage and leading the high-tech industries of the future. While since 2015 China has returned to normal exporting practices in this field, its actions between 2010 and until then clearly gave its industries a leg up in raw material prices and sourcing. In the frenzy to find alternatives, some important substitutions and efficiency gains have been made, but in this process there is also the risk that industries outside of China will be made to sacrifice competitiveness out of concern for raw material constraints that their Chinese counterparts do not have to consider.

## *Make rare earth production more sustainable*

While some production outside of China has so far been successful, China remains the world's dominant producer of rare earths. Nevertheless, the crisis period did generate important investments into exploration and development that will be critical for generating non-Chinese production in the future – and China seems increasingly keen to facilitate this process.

Given the harsh environmental impact of rare earth mining, however, the development of rare earth projects should be undertaken with extreme caution. There is indeed risk that, just as pollution from rare earth production was effectively outsourced to China in the past, the emergence of mining operations elsewhere in the world risks shifting the environmental burden once again. In the wake of China's export restrictions, numerous exploration efforts have been undertaken to exploit previously undeveloped deposits in environmentally sensitive areas such as Madagascar, Greenland or the floor of the Pacific Ocean.

If the rare earth saga of the last eight years has shown anything, it is that the future of both the supply and demand remain uncertain, with the market remaining relatively small and volatile, despite the critical importance of these raw materials for many emerging industries. In addition to the environmental risks, countries and investors that are drawn to exploiting rare earth deposits should be aware of this volatility, which can change radically with technology or on the whims of Chinese policymakers.

In the search for new sources of rare earths, we should also not overlook areas where they have been extracted but never used. Indeed, one important feature of rare earths is that they regularly appear in conjunction with other minerals, such as iron ore or uranium, and can often be found in tailing of previous mining operations. Usable concentrations of rare earths have also been found in post-mining waste such as coal ash, bauxite residue (so-called "red mud"), and phosphate from fertilizer production.[69] Some rare earth extraction projects could therefore be coupled with efforts to revitalize and clean up old mines, rather than create new ones.

## *Reduce consumption, improve efficiency and recycle more*

Facilitating recycling, rationalizing demand and improving the efficiency of resource use should also remain central to any long-term strategy.[70] While technical and cost hurdles remain and rare earths do not present the scarcity challenges of other, truly rare metals, the future of our planet nevertheless depends on our ability to make responsible consumption choices, use resources more efficiently and re-use what we have already dug from the ground.

In this respect, incentivizing measures could be taken to encourage industrial designers to account for the ease of post-consumer recycling of rare earths and other technology metals in their product designs. Likewise, industrial consumers should consider their resource needs against a backdrop of supply chain risks and environmental impact, seeking optimal solutions to reduce resource use while maintaining competitiveness. Perhaps the development of clear standards for the rare earth industry can help mitigate some of the risks. Furthermore, consumers in tech-oriented societies should be made increasingly aware of what it takes to produce the products of today's digital and energy revolutions, and be called upon to consider their consumption habits accordingly.

69. J. Yang, *et. al.*, "Production Techniques of CRM from Primary", SCRREEN, Deliverable 4.1, pp. 193-197, http://scrreen.eu/results/, and R. Ganguli and D. R. Cook, "Rare Earths: A Review of the Landscape", *op. cit.*, 2018, www.cambridge.org.

70. R. Danino-Perraud, "Face au défi des métaux critiques, une approche stratégique du recyclage s'impose", *Édito Énergie*, Ifri, December 2018, www.ifri.org.

## Improve global trade rules for resources

Meanwhile, improvements also need to be made in the global trading system for mineral resources, and minor metals in particular. The liberal global trading system has allowed for rare earth production to become concentrated in China, but China's commitment to this system has also allowed trade to continue, despite notable obstructions. Indeed, the dispute settlement mechanism within the WTO system, while slow to respond to market distortions created by China, nevertheless settled the dispute in a peaceful manner. Economic development is a central goal of China's policies in the rare earth sector as in other raw material sectors. It has become clear that China's economic development is also dependent on a functioning international trade architecture, and remaining plugged into global trade is an overarching priority for Beijing that outweighs the gains it perceives from export restrictions in the rare earth sector, as in others.

Yet many underlying issues remain unresolved within current global trading system, from the disproportionate division of environmental burdens (particularly in a context where China will begin importing rare earths) to the unfair advantages provided by the Chinese state to many industrial actors. This is also coupled with, and on the latter point has even motivated, the increasing pressure that the Trump Administration in Washington is placing on the WTO system, to the point of holding it hostage. As we re-imagine the global trading system, we should not forget the benefits it has brought in resolving issues such as the rare earth crisis, but also not overlook the distortions it has created – seeking sources of inspiration from the work of groups such as the Extractive Industries Transparency Initiative (EITI).

## Think in terms of value chains, not just raw materials

Finally, China's advantage in the rare earth field lies not only in its resource endowment, but in the fact that it consumes some 80 percent of the rare earths mined in the world today and has increasingly cornered the market for many rare earth-derived products, in particular rare earth magnets. This also means that much of the raw minerals extracted from new mining operations outside of China in the future are quite likely to be shipped back to China for processing, as demonstrated by the activism of Chinese companies such as Shenghe Resources. This will ultimately maintain China's dominant position not only in rare earth mine production, but also in the global market for downstream rare earth products as well.

In this light, public policies and corporate strategies that seek to respond to raw material dependencies must also account for supply chain diversification further downstream, taking an integral look at the evolution of value chain vulnerabilities in areas such as magnets that extend beyond the simple access to raw materials.

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