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レアアース元素

産業、貿易、バリューチェーンにおける中国と日本

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Rare Earth Elements China and Japan in Industry, Trade and Value Chain

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Nabeel A. Mancheri
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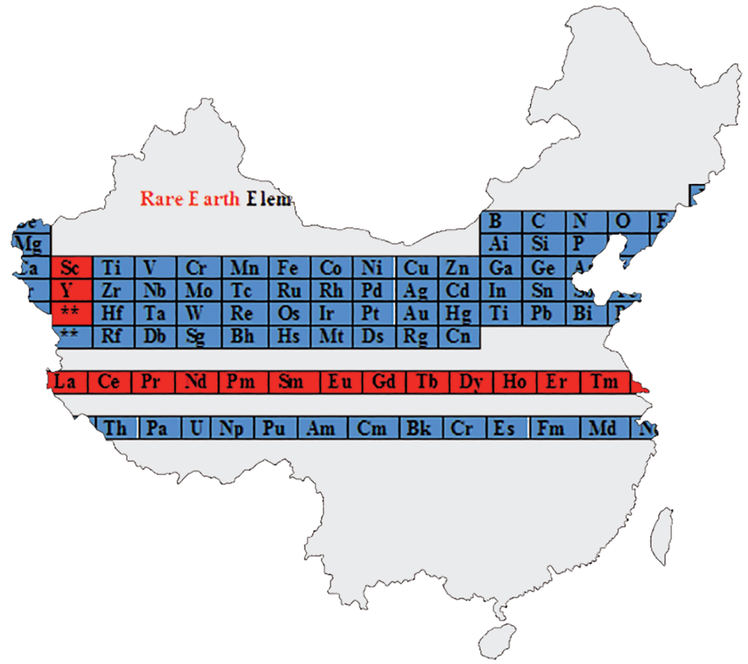
Tomoo Marukawa



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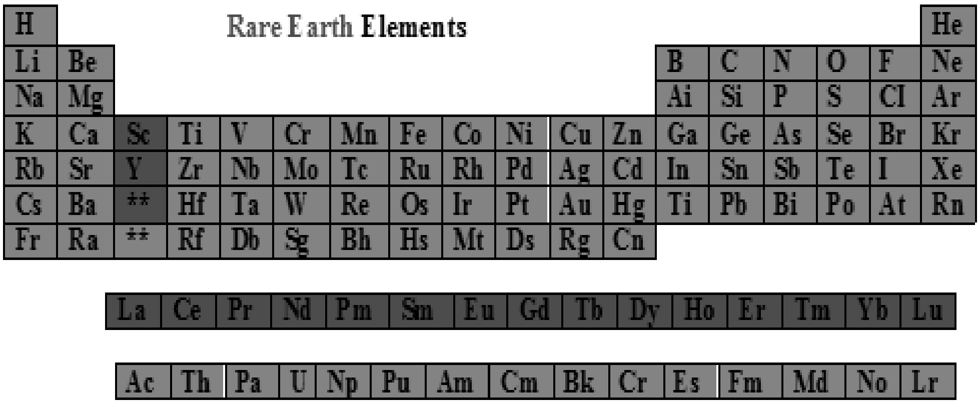

March, 2016

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Preface

The concentration of rare earth elements (REEs) production in China raises the vital issue of supply susceptibility. Rare earths are critical components of many high technology goods such as mobile telephones, computers, televisions, energy efficient lights, wind energy turbines and solar panels. Rare earth elements are important ingredients in lasers, superconducting magnets and batteries for hybrid automobiles. Rare earths play a significant role in strategic, civil and military applications. These elements and their related industries represent the latest manifestation of China climbing and dominating the supply chain. Such shifts have implications particularly in the wake of 2010 skirmishes over the Senkaku islands dispute, followed by limits on rare earth exports from China to Japan.

Since then, the Japanese companies along with the active support of Japanese government have been trying to diversify their supply chain away from China. However, these policies have not been completely successful so far. The companies who ventured into non-Chinese territories looking for rare earths are actually riding against the market fundamentals and some of them have abandoned their plans. Trying with alternate supply, there are also new initiatives to recycle the RE minerals in Japan and other R&D initiatives on replacing the RE minerals with non-critical minerals in major industrial applications.

Currently, several critical areas of the Japanese economy, including clean energy technology, national defense and high-tech manufacturing, are at risk largely because of two reasons. One, Japan’s dependence on critical minerals such as rare earths are not mined, processed and traded in healthy and robust markets. As a result, Japan has become dependent on unreliable trading partners such as China. Rare earths are indispensable for the manufacturing of automobiles and electronic products, etc. Therefore, it is extremely important to ensure stable supplies of such metals from the standpoint of maintaining and strengthening the competitiveness of Japan’s manufacturing industry. In the meantime, the environment surrounding the supply of such metals remains unstable and there are concerns about possible supply and price shocks.

In this comprehensive study we explore all relevant aspects of the industry from mining to the final product, roles of China and Japan in the supply-demand equation and price mechanism at large and its implications for Japanese manufacturing industry. The study also briefly examines the history of rare earth elements and China's current monopoly over the industry, including possible repercussions and strategic implications of limited supply from China. The study provides insights into how widely traded these minerals are and China's positions in the supply side and Japan's role as the largest consumer outside China. The study investigates who are the major customers of Chinese rare earth and analyses the various trade restrictions imposed by China. The study presents instructive and appropriate data for considering how the decrease of China's REE exports, new technology, and price uncertainties will affect the trajectory of REEs industry.

The study also evaluates the major developments in rare earth using industries in Japan, their supply chain dependence on Chinese companies and Japan's efforts to build alternate supply chains in recent years. The study traces the value chain link between major rare earth companies in China and Japan specializing in separation, oxide, alloys, metallurgy, permanent magnets etc.

The book has eleven chapters including introduction and conclusion. The chapters in the book deal with various issues such as evolution of global rare earth industry, reserves, production and supply, international trade in rare earth elements and Chinese export restrictions, supply chain dynamics of Japan's rare earth industry, demand, industrial applications and value chain links, competition with China and value chain uncertainties, REE pricing and price movements, the current situation in the international market and China's endeavor to control the rare earths industry. Nabeel Mancheri authored all parts of the book except for 7.1, 7.2, and 10 and Tomoo Marukawa authored sections 7.1, 7.1, and Chapter 10.

1 Introduction

The concentration of rare earth elements (REEs) production in China raises the vital issue of supply susceptibility. Rare earths are critical components of many high technology goods such as mobile telephones, computers, televisions, energy efficient lights, wind energy turbines and solar panels. Rare earth elements are important ingredients in lasers, superconducting magnets and batteries for hybrid automobiles. Rare earths play a significant role in strategic, civil and military applications. These elements and their related industries represent the latest manifestation of China climbing and dominating the supply chain. Such shifts have implications particularly in the wake of 2010 skirmishes over the Senkaku islands dispute, followed by limits on rare earth exports from China to Japan. Rare earth elements are a collection of seventeen chemical elements in the periodic table, namely scandium, yttrium, and the fifteen lanthanides. Scandium and yttrium are considered rare earth elements since they tend to occur in the same ore deposits as the lanthanides and exhibit similar chemical properties.

The study explores the roles of China and Japan in the supply-demand equation and price mechanism at large and its implications for Japanese manufacturing industry. It also briefly examines the history of rare earth elements and China's current monopoly over the industry, including possible repercussions and strategic implications of limited supply from China. The study provides insights into how widely traded these minerals are and China's positions in the supply side and Japan's role as the largest consumer outside China. The study investigates who are the major customers of Chinese rare earth and analyses the various trade restrictions imposed by China. The study presents instructive and appropriate data for considering how the decrease of China's REE exports, new technology, and price uncertainties will affect the trajectory of REEs industry.

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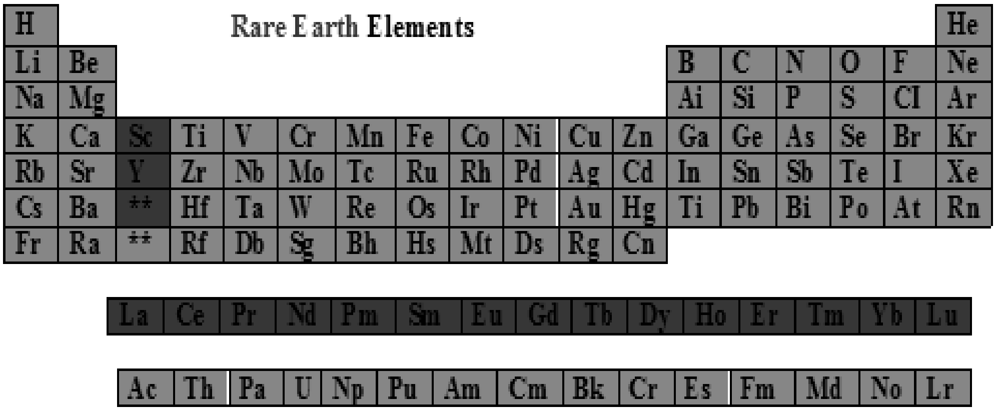
Table 1.1: What are the Rare Earth Elements?



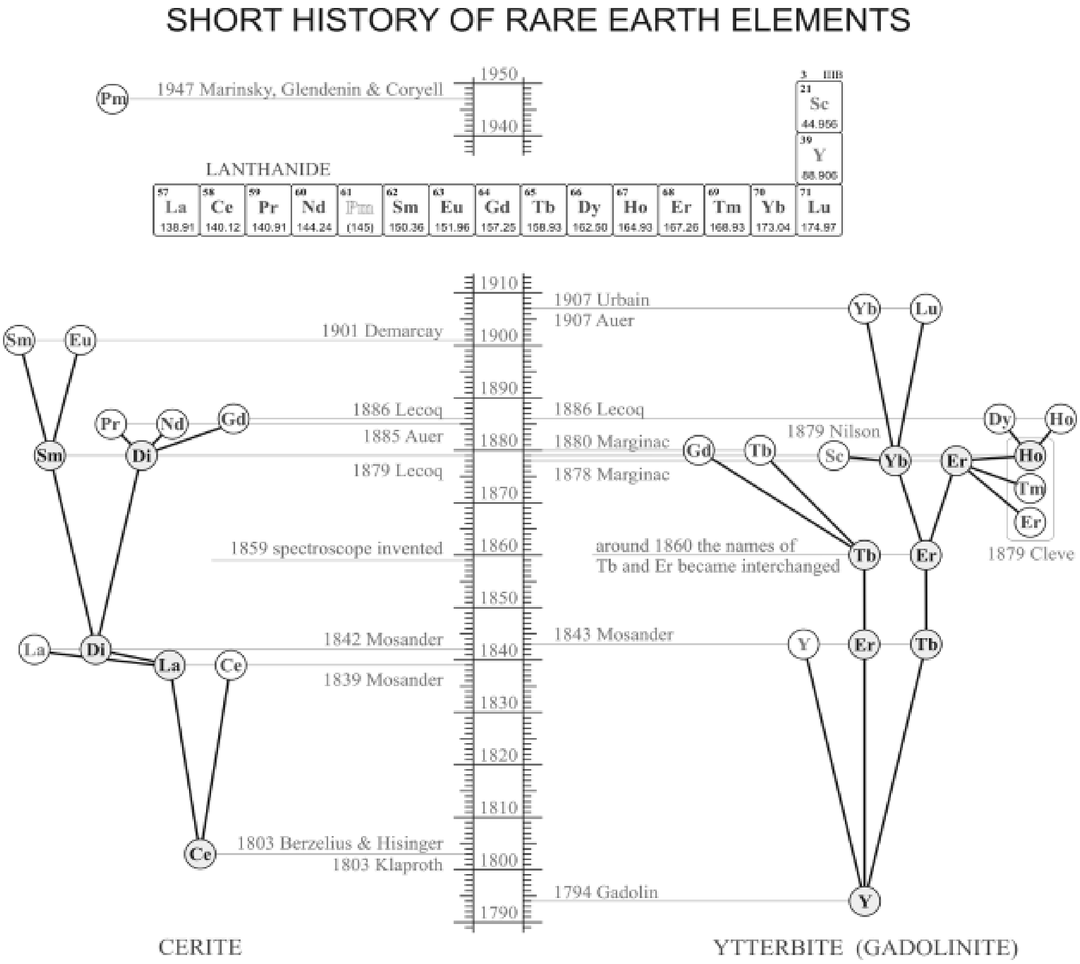
Rare earth elements are increasingly perceived to be of strategic importance not only because of their use in critical defence equipment but also because of their use in major electronic consumer products as well as in products for creating a greener planet. REEs have experienced fast growth in advanced technology sectors including luminescent (phosphors), magnetic, catalytic and hydrogen storage technologies. The demand by clean energy technology sectors is largely a result of the ramp-up of clean energy technology manufacturing and use by the United States, the Organization for Economic Co-operation and Development (OECD) nations and China. Magnets dominates REE usage by weight, with catalysts claiming the second-highest usage, and metal alloys accounting for the third highest (Kingsnorth, 2015).

There have been a number of policy reports and journal articles published recently on these minerals as there was heightened interest, particularly after the 2010 incident of Chinese export restrictions to Japan over the Diaoyu/Senkaku islands dispute. These articles have dealt with a wide range of aspects concerning rare earths from assessing criticality of individual minerals to forecasting future demands (Hedrick, 2010; Hurst, 2010; Hoenderdaal et al, 2013; Mancheri, 2013; Wübbeke, 2013; Mancheri, 2015; Sprecher et al, 2015; Kleijn, 2012). Most studies that try to evaluate a country's capabilities in science and technology focus on some easily measurable macro performance indicators. These include funding for science and technology, patents, publications, citations of papers and other related indices. A few studies from entities like the Rand Corporation extend this to try and assess a country's ability to assimilate knowledge and use it for the production of new products and services that could either transform existing industries or create new industries (Silberglitt et al, 2006). China has also been studied using such frameworks.

More recently China has established a dominant position in the global rare earths industry. It effectively controls the entire global supply chain in rare earths (RE). This control extends all the way from mining to the production of key intermediate products such as magnets. Many of these intermediate products are critical inputs for high growth industries such as hybrid cars, wind turbines and lighting. These are also the industries in which China is trying to build scale for future dominance.

1.1 Evolution of Global Rare Earth Industry

Rare earths were first discovered in 1787 at a place called Ytterby near Stockholm in Sweden. Since their physical and chemical properties were very similar they were difficult to separate. Because of this, in the early years after their discovery rare earths remained largely in laboratories. It took a little more than ninety years from their discovery before they were used in commercial products. In 1884 rare earths were first used commercially to make the incandescent mantles for the gas lighting industry. The second commercial use of rare earths took place in 1903 when mischmetal—an alloy of unseparated rare earth metals— was used to make the flints that go into lighters. In 1911 rare earths were added to glass to provide color to the glass (Hurst, 2010; Habashi, 2012)



Source: E. Generalic, http://www.periodni.com/rare_earth_elements.html

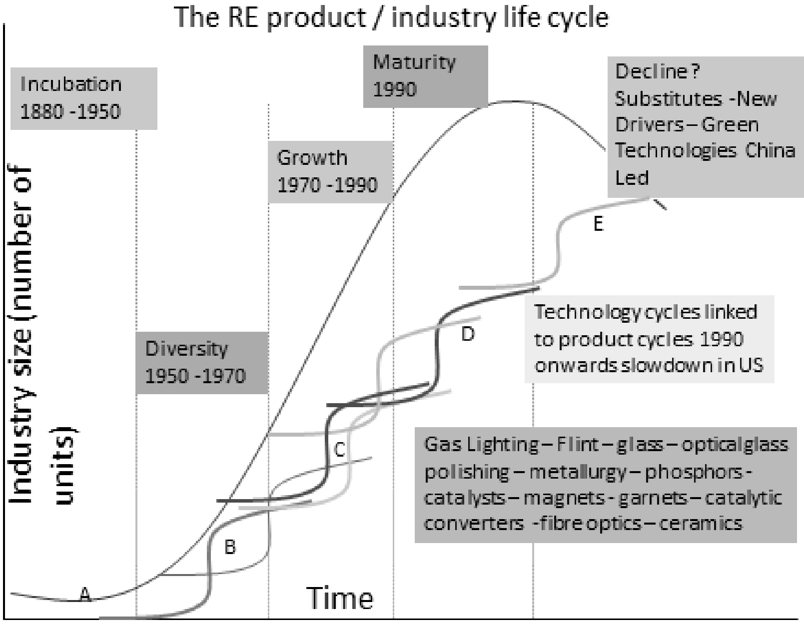
Major discoveries in the understanding of the atom took place in the early part of the 20th century. The ordered placing of the electrons in various orbits around the central nucleus as the atomic number increases and their role in determining the physical and chemical properties of the various elements became a major area of study. This knowledge was incorporated into the periodic table of elements in the early years of the 20th century. The special position of the rare earth elements in the periodic table opened up the world of rare earths to new investigations and new applications (Walters and Lusty, 2011). In 1934 Kodak used such knowledge for making glass doped with rare earth elements to increase the refractive index for glass. This reduced the curvature required for making various optical elements like lenses and also created some additional demand for rare earths.

The Second World War led to the creation of the Manhattan project by the US for making the atomic bomb. The project led to new methods for the separation of various isotopes and closely related elements. The ion exchange process became a major method of separation of closely related elements and was used to separate the various RE elements. Commercial quantities of RE became available both to industry as well as to the research community.

In 1948 mischmetal was added to improve the properties of nodular cast iron. The Mountain Pass Mine in California was discovered in 1949. In the early 1950s cerium oxide became a preferred material for polishing glass. Lanthanum hexaboride discovered in 1951 became the cathode material for ion thrusters used in space by the Soviet Union. The solvent extraction process became commercial in 1953. This reduced the cost of material extraction even more and also made RE available in larger quantities for commercial use.

Figure 1.1 provides an overview of the evolution of the global RE industry that links the various technology breakthroughs for product development to the growth of the industry via the products that they are used in.

Figure 1.1: The Rare Earth Product / Industry Life Cycle



Source: Chandrashekar, 2013

The 1960s saw the movement of RE from niche applications in selected markets into more mainstream commercial products and industries.[1] In 1964 the addition of lanthanum and cerium to zeolite catalysts used for cracking petroleum crude into various lighter fractions became a major user of RE. The addition of RE to these catalysts raise the temperature and significantly increase the yield of the desired products. RE additions to catalysts continue to be an important market especially in the US. In 2007 China exploited this vulnerability by cutting off RE supplies to a leading US manufacturer of catalysts – WR Grace (Garber, 2009).

1965 saw the emergence of another consumer product that went on to become a major market. Large quantities of europium that were available from the operation of the Mountain Pass Mine in the US were used in the phosphors for the screens of the cathode ray color television sets that were becoming widespread in the US market. Phosphors have continued to be an important market for RE especially in various consumer

[1] In terms of the life cycle model this marks the shift from the incubation phase of the industry into its diversity phase.

electronic products. Their use in the emerging energy efficient lighting industry that includes both compact fluorescent lamp (CFL) and light-emitting diode (LED) lighting will continue to be important for some time to come.

Another major application of RE that developed during 1964 to 1970 was the development and commercialization of neodymium-doped yttrium aluminum garnet (NdYAG) lasers. They were originally used for range finding applications in the defense sector but have now moved into surgery as well as general manufacturing applications.

The period 1970 to 1975 also saw two major developments of significance to the automobile industry. The discovery of the hydrogen absorbing properties of lanthanum nickel alloys led to the patenting of the lanthanum nickel hydride battery in 1975. Catalytic converters using RE coatings for controlling pollutants in the exhaust gases of cars also became a major commercial product with the advent of tighter pollution laws in the US and went on to become a global requirement.

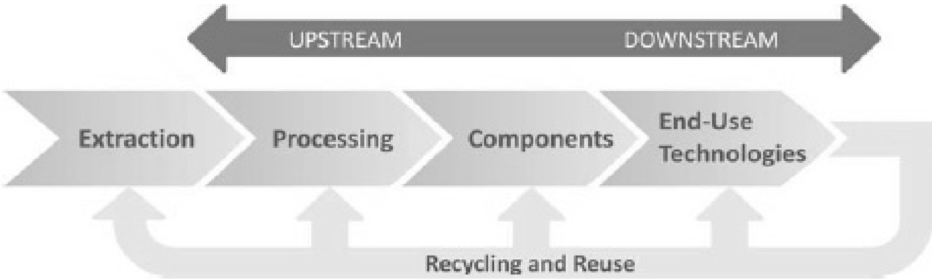
The 1970s also saw the development of semiconductor LED products for lighting and other applications. The addition of RE phosphors to these as well as compact CFLs would become important much later when some of the technical bottlenecks related to commercial use of LED had been resolved. From about 2005 onwards as LED and CFL products enter mainstream markets and hence the RE requirements though small are likely to increase.

In the 1980s the pace of new discoveries and applications seem to be slowing down. However the early years of this decade saw a shortage of cobalt supplies arising from the pursuit of cold war strategies by the two superpowers. This affected the production of samarium cobalt magnets. This shortage directly led to the discovery of the neodymium iron boron (NdFeB) magnets by General Motors in the US and Hitachi in Japan. These entered commercial use in 1986. Today these permanent magnets have become an industry with both strategic and commercial importance. Along with RE based batteries their use in the electric motors of hybrid and electric cars provide a potential growth market for RE as countries move towards a more environment friendly green future.

This account of the evolution of the RE industry makes it clear that though the origins of the industry were in 18th and 19th century Europe most of the significant developments in technology and in products took place in the US. The RE industry really took off in the 1960s and 1970s when a number of breakthrough technologies were developed and commercialized in the US. In the early part of the 1980s the US was the undoubted leader of the RE industry with a dominant position in the entire value chain from mine to product. It also had significant research capabilities both in its government sponsored laboratories as well as in industry. However by the turn of the century this situation had fundamentally changed. Entire value chains for RE had moved away from the US and other western countries to China which now controls the global supply of RE materials and key intermediates.

Despite their name, rare earth elements (with the exception of the highly unstable promethium) are relatively plentiful in the earth's crust, with cerium being the 25th most abundant element at 68 parts per million (similar to copper). However, because of their geochemical properties, rare earth elements are not often found in concentrated and economically exploitable forms or ores. It was the very scarcity of these minerals (previously called "earths") that led to the term "rare earth". The first such mineral discovered was gadolinite, a compound of cerium, yttrium, iron, silicon and other elements. Cerium, for example, ranks number 26 in abundance among the elements and is five times as common as lead. And even the scarcest of rare earths, thulium, is more abundant than gold or platinum. Because the elements share similar chemical properties, most REEs deposits contain a large number of all 17 elements in varying albeit small concentrations. In addition, rare earths are often of low quality, which has made the material uneconomical to mine, and also because the elements are usually found within a cocktail of rare earths that need to be separated in laborious process.

Figure 1.2: Basic materials supply chain



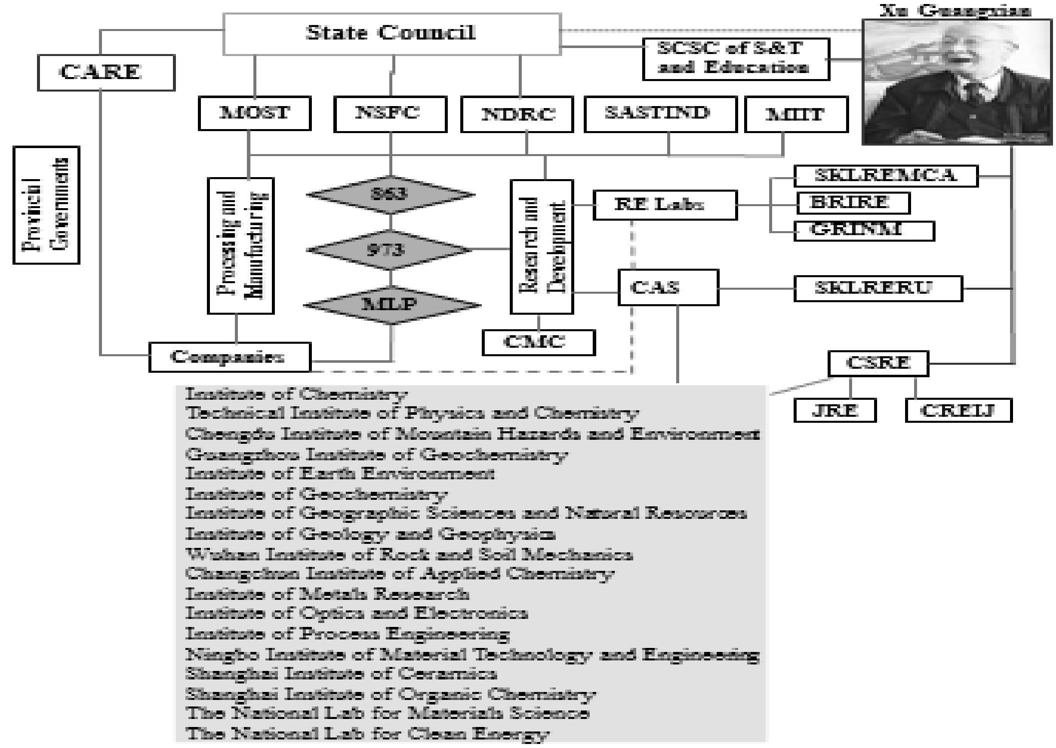
Elemental materials are extracted from the earth via mining (Figure 1.2). Next, they are processed via separation and refining to obtain the desired composition or purity. Materials may be extracted either as major products, where ore is directly processed to extract the key materials or they may be co-products or byproducts of other mining operations. The co-production and by-production processes create complex relationships between the availability and extraction costs of different materials, which may cause supply curves and market prices to vary in ways not captured by simple supply and demand relationships (DoE, US, 2010). Processed materials are used to manufacture component parts that are ultimately assembled into end-use technologies. The generic supply chain also shows the potential for recycling and reusing materials from finished applications, though materials can be reclaimed at any stage of the supply chain and reused either upstream or downstream (DoE, US, 2010).

Rare earths are critical components of many high technology goods such as hybrid vehicles, mobile telephones, computers, televisions and energy efficient lights. Although rare earths have relatively a high unit value, the impact of their cost has little, if any, impact on the selling price of the final item because they are present in minute concentrations. RE elements are also considered as strategically important because of its uses in defense and essential components to products with high growth potential-electronics and technology industries, energy efficiency and greenhouse gas reduction.

Rare earth elements are important ingredients in lasers, superconducting magnets, batteries for hybrid automobiles; Makers of hybrid cars use these elements in their lanthanum nickel magnets to give them greater rechargeable capabilities. Portable X-ray units can function much more effectively with thulium. Erbium-doped fiber optic cables can amplify the speed of communication. Night vision goggles and rangefinder equipment use rubidium to increase accuracy and visibility. Radar uses the samarium cobalt magnet to withstand stresses as it has the highest temperature rating of any rare earth magnet.

There has been a modest growth in demand recently. However, the demand is expected to increase further by a modest CAGR of 6-9%, over the next five years, marking a recovery as alternative supplies to China come on-line (Kingsnorth, 2015). While REEs have been produced for almost a century, the companies supplying them have changed. In the mid-twentieth century, almost all rare earth mining was done at Mountain Pass, California. Today, more than 97 percent of mining and refinement is done in China. The shift occurred mainly due to the elaborative separation and refining processes, which is labor intensive, and raises safety and environmental concerns. Not only do the Chinese mine most of rare earths today, they possess 36 percent of world reserves (Hedrick, 2010:129).

Figure 1.3: Organization and Management of Rare Earth Industry



Acronyms used in the figure

BRIRE	*Baotou Research Institute of Rare Earths (1963)*
CARE	*Chinese Rare Earth Association (2012)*
CAS	*Chinese Academy of Science*
CMC	*Central Military Commission*
CSRE	*Chinese Society of Rare Earth*
CREIJ	*China Rare Earth Information Journal*
GRINM	*The General Research Institute for Nonferrous Metals (1952)*
JRE	*Journal of Rare Earth*
KLRECP	*CAS Key Laboratory of Rare Earth Chemistry and Physics*
MEP	*The Ministry of Environmental Protection*
MIIT	*Ministry of Industry and Information Technology*
MLP	*Medium to Long-term Plan for the Development of Science and Technology*
MLR	*Ministry of Land and Resources*
MOFCOM	*Ministry of Commerce*
MOST	*Ministry of S&T*
NDRC	*National Development and Reform Commission*
NSFC	*The Nature Science Foundation of China (1986)*
SASTIND	*State Administration for Science, Technology, and Industry for National Defense*
SCSC	*State Council Steering Committee of S&T and Education*
SKLREMCA	*The State Key Laboratory of Rare Earth Materials Chemistry and Applications*
SKLRERU	*The State Key Laboratory of Rare Earth Resource Utilization (1987)*

There are a number of interconnected agencies within the Chinese government system for the management and development of rare earth resources (Figure 1.3). Most of these state institutes are integrated vertically and linked to the highest decision making apparatus of state council either directly or indirectly. The information is freely flown up and down on any policy issues. Also there are specific institutes that coordinate policies among different ministries and agencies and regulate the industry. China has been continuously investing in the development of rare earth industry aiming to become an industrial leader in the rare earth based industries. The Ministry of Science and Technology (MOST) takes the lead in drawing up S&T development plans and policies and guaranteeing the implementation. MOST is responsible for drafting the National Basic Research Program, the National High-tech R&D Program and the S&T Enabling Program. MOST also outlines the technologies it hopes to pursue in the short term through the megaprojects. The megaprojects incentivize industry R&D labs, universities and research institutes to work together, augmenting each other's strengths and pooling their resources on technological challenges.

Since 1980s all the major science and technology programs of the government had a vital component related to material developments particularly on rare earth materials. China's efforts draw significantly on the resources and planning role of the state, whose national science programs have long made targeted investments in research and development (R&D) efforts in areas deemed critical to China's economic and military needs. China's industrial bureaucracies have also supported high technology industries through subsidies for industry, procurement policies; financial support for enterprises' international expansion, and large-scale investments.

China's dominance in the RE supply chain is directly related to Beijing's consistent and long term planning, which dates back to as early as the 1950s. However, the Chinese RE industry greatly advanced when Xu Guangxian (also known as "The father of Chinese rare earths chemistry") developed the Theory of Countercurrent Extraction—which is applicable for the separation of a mixture with more than ten components such as rare earths—in the 1970s. Since then, China's rare earths oxides (REO) output has increased rapidly from slightly over 1,000 tons in 1978 to 11,860 tons in 1986, when a production spike at the giant Bayan Obo mine first propelled China past the United States as the world's leading producer of REO. Meanwhile, Beijing has continuously invested heavily in technological innovations through key national R&D programs, such as the 863 and 973 projects, in order to gain a decisive advantage in the rare earth supply chain including mining, separation, refining, forming and manufacturing (Hurst, 2010:6).

According to China's Ministry of Science and Technology, the objective of these program was to "advance in key technological fields that concern the national economy and national security; and to achieve 'leapfrog' development in key high-tech fields and take strategic positions in order to provide high-tech support to fulfill strategic objectives in China's modernization process". In 1992 the late Chinese patriarch Deng Xiaoping famously stated, "the Middle East has oil, and China has rare earths", since then, China has not only remained the world's largest REO producer, but has also successfully moved its manufacturers up the supply chain (Hurst, 2010). Since 1990, domestic consumption of REO for high value-added product manufacturing in China has increased at 13 percent annually, reaching more than 90,000 tons in 2015 (Kingsnorth, 2015).

China has also set up national level institutions over the years to support science and technology in targeted areas and these institutes work in hand with all related ministries as a coordinating mechanism. The top most among them is the 'State Council Steering Committee (SCSC) of S&T and Education' established directly under the State Council. China attempts to achieve national S&T policy coordination through this high-level leading group comprised of the leaders of the major science agencies, including the Director of the National Development and Reform Commission (NDRC), the Ministers of Science and Technology, Education, Finance, and Agriculture, the Presidents of the Academies of Science and Engineering, the Director of State Administration for Science, Technology, and Industry for National Defense (SASTIND), and the President of the National Natural Science Foundation of China (NSFC)[2] (Micah et al, 2011). The State Science and Technology Steering Group, founded in 1998, serves as an inter-ministry coordination institution. It is chaired by the Premier of the State Council and co-chaired

[2] NSFC is an organization directly affiliated to the State Council for the management of the National Natural Science Fund. NSFC supports basic research and some of applied research, identifies and fosters talented researchers in the realm of science and technology. NSFC undertakes other tasks entrusted by the State Council and the State Leading Group for Science and Technology and Education.

by a State Councilor, with senior department and agency officials as its members. This steering group is the principal means for the Premier to coordinate science and technology policy across the State Council. The SCSC of S&T and Education, the NSFC, MOST, SASTIND, NDRC all have been actively involved in implementing the major national science and technology projects such as “863”, “973” and the 2006 National Medium to Long-term Plan for the Development of Science and Technology (2005-2020).

State-run labs in China have consistently been involved in research and development of REEs for over fifty years. There are two state key laboratories in China, both established by Xu Guanxian. The State Key Laboratory of Rare Earth Materials Chemistry and Applications and the State Key Laboratory of Rare Earth Resource Utilization established in August 1987. The State Key Laboratory of Rare Earth Resource Utilization was known as the Open Laboratory of Rare Earth Chemistry and Physics affiliated with the Changchun Institute of Applied Chemistry, under the Chinese Academy of Sciences and is located in Changchun. There are currently 40 faculty members in the lab, including two CAS academicians and 20 professors. The lab primarily focuses on rare earth solid state chemistry and physics, bioinorganic chemistry and the chemical biology of rare earth and related elements and rare earth separation chemistry (CIAC, 2012).

The State Key Laboratory of Rare Earth Materials Chemistry and Applications is affiliated with Peking University. The laboratory made significant progress in the 1980s in the separation of rare earth elements. Professor Xu Guangxian is the honorary chairman of the Academic Committee. There are 31 research staffs in the Lab, including three CAS members, 14 full professors, 3 distinguished research fellows, 11 associate professors, 2 senior engineers and 1 lecturer. The Lab has so far undertaken a variety of national key projects of basic research on rare earth science, including “973” Project, “863” Program, NSFC Fund for Innovative Research Group and many projects from the National Science Foundation of China. During the last five years, the Lab has published over 500 SCI research papers and had acquired more than 45 applied and licensed patents for exploration and application of rare earth resources. The lab deals with key issues in rare earth science, including the fundamental research of rare earth material chemistry, the exploration of novel rare earth functional materials as well as the correlative theoretical methods and materials design (Peking University, 2012).

Additional labs concentrating on rare earth elements include the Baotou Research Institute of Rare Earths, established in 1963, the largest rare earth research institution in the world. It focuses on the comprehensive exploitation and utilization of rare earth elements, the research of rare earth metallurgy, environmental protection, new rare earth functional materials and rare earth applications in traditional industry (BRIRE, 2014). The General Research Institute for Nonferrous Metals (GRINM) established in 1952 is the largest research and development institution in the field of nonferrous metals in China. Heralding the R&D of rare earth metallurgy and materials and hosting National Engineering Research Center for Rare Earth Materials, GRINM has made great contributions to national rare earth industry (GRINM, 2014). The institute is also part of the large conglomerate involved in rare earth mining, separation and manufacturing intermediate products.

While each of the four laboratories and institutes mentioned above complement each other, they each have different keystone research efforts. The State Key Laboratory of Rare Earth Resource Utilization focuses on applied research. The State Key Laboratory of Rare Earth Materials Chemistry and Applications focuses on basic research. Baotou Research Institute of Rare Earths and GRINM both focus on industrial applied research of rare earth elements. In addition to having state run laboratories dedicated to researching and developing rare earth elements, China also has two publications dedicated to the topic. They are the Journal of Rare Earth and the China Rare Earth Information (CREI) journal, published by the Chinese Society of Rare Earths. These are the only two publications globally, that focus almost exclusively on rare earth elements and they are both Chinese run. This long term outlook and investment has yielded significant results for China's rare earth industry.

The Chinese Society of Rare Earths (CSRE), founded in 1980, is a scientific and technological researchers' organization. There are more than 100,000 registered experts in CSRE, which is the biggest academic community on rare earth in the world. Besides serving for the government and researchers on science and technology of rare earths, CSRE provide a stage for rare earth scientists to exchange their research ideas, propose the scientific and technical plans on fundamental and applied fields on rare earths, as well as rare earth R&D plans for industry. CSRE is therefore, the most important social force in developing the rare earth science and technology in China. It organizes the International Conference on Rare Earth Development and Application once every four years, and Annual Meeting once every two years periodically. There are 15 subcommittees in CSRE, which cover almost every R&D field on rare earth.

The Chinese Academy of Sciences (CAS) established in 1949 operates 100 research institutes with over 50,000 researchers. The eighteen CAS labs showed in Figure 1.3 have involved in certain level of research on rare earth materials. Founded in 1955, the Academic Divisions of the Chinese Academy of Sciences (CASAD) is China's highest advisory body in science and technology. Many scientist and technologists from these institutes are members of the Chinese Society of Rare Earths.

System integration is one of the most challenging and difficult tasks in the development of complex high technology systems. The Chinese have managed to couple the domain knowledge organizations with high quality system integration skills. They do this through various organizational processes that cut across the structure of the traditional academies. Over all the Chinese science and technology system works on a model of top-down, state directed science and technology programs to spur developments in strategically important areas. Nationally directed strategic approaches still stand front and center on the agenda of the most influential members of China's science and technology (S&T) establishment, including government planners, prominent university scientists, and principal industrial cadres (Feigenbaum, 1999).

1.2 Scope and Significance of the Study

The two major drivers of demand for mineral commodities are the rate of overall economic growth and the state of development for principal material applications. The most rapid growth in rare earths has been the demand from new materials, that include magnets, phosphors, catalysts and batteries, which now account for over 60 percent of the global demand (Kingsnorth, 2015). This demand will continue to be fueled by heavy investments in clean energy. High-technology and environmental applications of the rare earth elements have grown dramatically over the past four decades. Many of these applications are highly specific and substitutes for REEs are inferior or unknown. REEs have acquired a level of technological significance, much greater than expected from their relative obscurity in a couple of decades back. These uses range from mundane, (lighter flints, glass polishing) to high-tech (phosphors, lasers, magnets, batteries, magnetic refrigeration), to futuristic (high-temperature superconductivity, safe storage, and transport of hydrogen for a post-hydrocarbon economy). The rare earth elements are essential for a diverse and expanding array of high-technology applications (Quantum Rare Earth Development Corp. 2011).

Risk in mineral resource procurement has been increasing due to excessive oligopolies and an increase in resource nationalism. The international market related to rare earth minerals, which are essential for future manufacturing industries has become so volatile and uncertain. The stable procurement of mineral resources required for production activities has become an important issue for management at resource using companies in developed countries, particularly for Japanese companies. Japan is totally dependent on imports for mineral resources, despite the fact that manufacturing is the backbone of Japanese economy. Therefore the issue of stable supply with its significant influence on the country's industrial competitiveness makes it important to the Japanese government.

The over dependence on China for these minerals is a major issue in Japan and perceived as a great risk particularly after the Senkaku-Diaoyu incident in 2010. Since then, the Japanese companies along with the active support of Japanese government have been trying to diversify their supply chain away from China. However, these policies have not been completely successful so far. The companies who ventured into non-Chinese territories looking for rare earths are actually riding against the market fundamentals and some of them have abandoned their plans. Trying with alternate supply, there are also new initiatives to recycle the RE minerals in Japan and other R&D initiatives on replacing the RE minerals with non-critical minerals in major industrial applications.

As the competition over resources and market increase particularly from the countries like China, it has become harder for Japanese companies to secure resources and market. Japan is the major consumer of resources including rare earths. Therefore, in negotiations at the resource development stage, Japanese companies could negotiate more efficiently than companies from other countries by promising to buy a large amount of resources over the long term. These days, however, China has become a major new consumer of resources displacing Japan and Japan's competitive superiority. Resource supply risks will continue to be a major issue for Japanese companies in the future as a result of international developments and changes in the supply and demand balance.

Growing number of applications for rare earths, coupled with the burgeoning demand for clean energy, and the latest consumer technologies have raised the importance of rare earths. In 2010 and 2011 when the Chinse export restrictions became more apparent, many of the world's experts predicted a supply deficit of REO in future, as demand expected to exceed the industry's ability to produce, as commercial stocks are depleted. However that situation has changed completely now. While new or reopened mines outside China are expected to increase global production, resulting in an overall surplus, shortfalls are expected in certain elements, particularly in neodymium and europium, and the heavy rare earths such as terbium, dysprosium and yttrium. Analysts predict, demand for rare earths is likely to increase between 7 to 8 percent each year, due to growing demand for elements like neodymium, which is used in making hybrid electric vehicles and generators for wind turbines (Kingsnorth 2014).

Japan has expressed a sense of urgency to secure new non-Chinese supplies of REEs since the September 2010 maritime incident with China and the claim of a Chinese supply embargo of REEs and other materials. Japan's primary end use application of REEs include polishing (12%), metal alloys (22%), magnets (30%), and catalysts (10%), glass (6%), ceramics (10%), much different than that of the United States and other major consumers. Japan used to import almost 100 percent of REEs from China. However in recent years, the dependency has come down to 50-60 percent. Close to forty percent of China's REE exports go to Japan and about 20 % to the United States. Japan-based firms and the Japanese government are making a number of joint venture agreements and potential partnerships around the world to secure supplies of REEs, particularly at the raw material stage in an effort to diversify the supply.

Significance of the Study

Currently, several critical areas of the Japanese economy, including clean energy technology, national defense and high-tech manufacturing, are at risk largely because of two reasons. One, Japan's dependence on critical minerals such as rare earths are not mined, processed and traded in healthy and robust markets. As a result, Japan has become dependent on unreliable trading partners such as China. Rare earths are indispensable for the manufacturing of automobiles and electronic products, etc. Therefore, it is extremely important to ensure stable supplies of such metals from the standpoint of maintaining and strengthening the competitiveness of Japan's manufacturing industry. In the meantime, the environment surrounding the supply of such metals remains unstable and there are concerns about possible supply and price shocks.

A nonfuel mineral can be important at a scale larger than a product as well as at the product level. A mineral might be important to the commercial success of a company and the company's profitability (importance at a company level). A mineral might be important in military equipment and national defense. Production of a mineral or products that use the mineral as an input might be an important source of employment or income for a local community, a state, or the national economy (importance at a community, state, or national level). In all of these cases, the greater the cost or impact of a restriction in supply, which depends importantly on the substitutability of the mineral in question, the more important is the mineral (NAP, 2008).

Under such a scenario, this study examines the roles of China and Japan in rare earth industry, its significance to the Japanese economy and Japan's dependence on China. The study focuses in particular on the role of key materials in emerging technologies. Deployment of these technologies is expected to grow substantially in the years ahead and many of these technologies—including wind turbines, electric vehicles, solar cells and energy-efficient lighting—depend on components often manufactured with these materials. Recognizing that restriction in an individual mineral's supply will not have the same macroeconomic impact on the nation as in the case of restriction in the supply of, for example, oil, the study evaluates each of these identified minerals on the basis of whether or not a particular industry sector, or the manufacture of one or more fairly ubiquitous consumer products would be adversely affected, if a restriction on the supply of that mineral occur. To do so the study uses a supply chain matrix to evaluate the movement of each mineral to all possible intermediate and final products and analyses the micro level links in a complex value chain that span between China and Japan. More precisely, the study also evaluates the major developments in rare earth using industries in Japan, their supply chain dependence on Chinese companies and Japan's efforts to build alternate supply chains in recent years. The study also traces the value chain link between major rare earth companies in China and Japan specializing in separation, oxide, alloys, metallurgy etc.

The issues go much deeper than the availability of RE raw materials outside China. Of the developed countries, Japan is the only one that retains significant downstream supply chain capabilities to make the RE intermediate products that go into wind turbines, CFLs, hybrid and all electric vehicles. In the EU and the US these capabilities were largely relinquished years ago. The study also tries to identify this whole supply chain infrastructure in Japan and its criticality to Japanese economy and long term sustainability in competition with China.

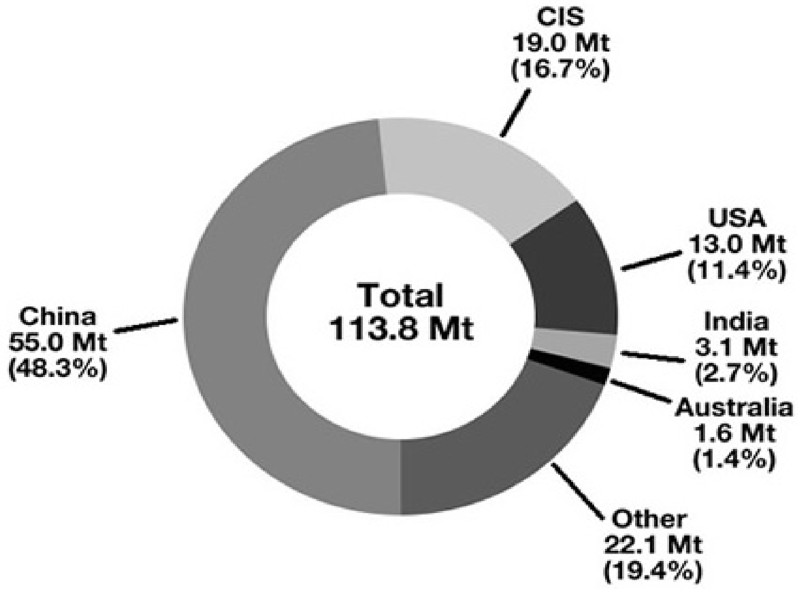
While these materials are generally used in low volumes relative to other resources, the anticipated deployment of clean energy technologies are expected to substantially increase the worldwide demand for these minerals. The importance of green energy in Japan has increased many folds particularly after Fukushima accident. Investments in green technology will continue to increase to ensure the energy without the risk to the environment. It would be relevant to study how much of these minerals are important to Japanese green technology companies and how do these green energy sources rely on rare earth minerals. In many cases, it is possible that these minerals could become hard to find. What result will that have on these energy sources? Or, how consumers and sectors of the Japanese economy could be significantly affected if the supply of any of these minerals is curtailed?

2 Reserves, Production and Supply

2.1 Rare Earth Elements – Reserves

Reserves are the resources that could be economically extracted or produced at the time of determination. However, the term reserves need not signify that extraction facilities are in place and operative or economically viable to extract (King, 2011). Globally, the four principal high-yield REE-bearing minerals are bastnäsite, monazite, xenotime and ion absorption clays. A mineral deposit that does not fall in any of these four categories typically requires more metallurgical testing to establish the mineralogy and processing steps (Bulatovic, 2010). The rare earth content of each deposit is essential to estimating the deposit's profitability. It determines how the ore will be processed and how complicated it will be to separate the rare earth elements from each other. Most rare earth elements throughout the world are found in deposits of the minerals bastnaesite and monazite. Bastnaesite deposits in the United States and China account for the largest concentrations of REEs, while monazite deposits in Australia, South Africa, China, Brazil, Malaysia, and India account for the second largest concentrations of REEs. Bastnaesite occurs as a primary mineral, while monazite is found in primary deposits of other ores and typically recovered as a byproduct. Over 90% of the world's economically recoverable rare earth elements are found in primary mineral deposits, i.e. in bastnaesite ores (Humphries, 2010).

Figure 2.1: REE world reserves



Source: United States Geological Survey Mineral and Commodity Summaries, 2011

According to the US Geological survey, total known reserves of REEs world wide amounted roughly 113 million metric tons, which would last 800 years, provided the production remained unchanged at the current level of approximately 124 thousand tons compared with its peak of 137 thousand tons in 2006. Rare earth output has thus come down some 9 percent. There are three primary criteria, among others, that determine the economic feasibility of a potential rare earth mine: tonnage, grade and the cost of refining the rare earth mineral. A mine may be economically viable (and therefore attractive to investors) if a low-grade (<5%) ore occurred with large tonnage and familiar mineralogy or if high-grade ore occurred with familiar mineralogy. Heavy rare earths (atomic numbers 65–71), such as terbium and dysprosium, along with yttrium (atomic number 39), are somewhat more scarce and often concentrated in ionic adsorption clay and xenotime, commonly found in southeastern China (Hedrick, 1997:471).

China supplies approximately 95 percent of global demand and consumes more than 60 percent of the global supply, but its reserves of rare earths are finite. The Chinese government has indicated that if the exploitation of these resources is not controlled, they could be exhausted in 20-30 years. These valuable resource endowments are not evenly distributed in China and about 83% of the resources are located in Bayan Obo (Baotou, Inner Mongolia), 8% in Shandong province, 3% in Sichuan province (light rare earth deposits of La, Ce, Pr, Nd Sm, Eu), 3 percent of the deposits located in Jiangxi province are middle and heavy rare earth deposits (Middle: Gd, Tb, Dy, Ho, Heavy: Er, Tm, Yb, Lu, Sc, Y). In comparison, while most of the global supply of heavy REs (e.g. yttrium) originates in the "ion adsorption clay" ores of Southern China, the proven reserves of heavy REs in the 7 Southern Chinese provinces are 1.5 million metric ton (Huatai United Securities, 2010). Since heavy REs are considered more strategically valuable, significant efforts have been made by Beijing in recent years to crack down rampant illegal mining in Southern China.

Table 2.1: Examples of The Rare Earth Oxide Reserves at Individual Potential Mines- 2010 estimates (in million metric tons)

Country	Mine Name	Resources (MMT)	Grade (%TREO)	TREO (MMT)
China	Bayan Obo	1460	3.9	56.9
USA	Mountain Pass	20	9.2	1.8
USA	Bear Lodge	9	4.1	0.4
Greenland	Kvanefjeld	215	1	2.2
Canada	Nechalacho	65	2.1	1.4
Australia	Mount Weld	12	9.7	1.2
Australia	Nolans	30	2.8	0.8
Vietnam	Dong Pao	11	6.9	0.8
Canada	Hoidas Lake	1.5	2.6	0.0

Source: Hocquard, 2010

Reserves of medium and heavy rare earths may only last 15 to 20 years at the current rate of production, which could lead to China being forced to imports supplies. Medium and heavy rare earth, also known as ion-adsorbed-type rare earth, is more valuable than the lighter variety. It is used in advanced areas such as missiles. China's verified reserves of ion-adsorbed-type rare earth stood at 8 million tons, while reserves of light rare earth totaled 50 to 60 million, according to data from the Ministry of Land and Resources.

China's rare earth resources are widely distributed throughout the country. The scattered distribution makes it difficult to carry out efficient oversight of the industry. The 2009-2015 Plan aimed to create 'large rare earth districts' to simplify management of China's rare earth resources. The new plan will divide China's industry into three large districts: south, north, and west. The southern district would comprise of Jiangxi, Guangdong, Fujian, Hunan, and Guangxi; the northern district would be centered on Inner Mongolia and Shandong and the western district would consolidate mines located in Sichuan (Hurst, 2010). China is also reported to have around 84 deposits /mines of rare earths, spread over 18 provinces. The consolidation process has almost completed now.

In this respect, consolidation process started in 2014 allowed six large state-run groups led by China Minmetals, Chinalco, Baotou Steel, Xiamen Tungsten, Ganzhou Rare Earths and Guangdong Guangsheng Rare Earths to bring all rare earth mining and separation companies under their control. The government supported them with legislation and financing to complete the integration process by the end of 2015 and these large firms are licensed to take over small operations and illegal mines. As a policy support, over 90 percent of production quotas are now allocated to these groups. The consolidation of the industry dramatically affected China's ability to control the flow of rare earths. During this consolidation process there may be unexpected supply shortages because of shutdowns or increased availability of products due to new efficiencies. The details of the number of mines operating in various provinces are indicated in Table 2.2.

Table 2.2: Rare earth deposits/mines in China

Province	**No. of Mines**	**Province**	**No. of Mines**
Fujian	3	Jiangxi	8
Gansu	1	Jilin	1
Guangdong	17	Liaoning	2
Guangxi	7	Shandong	2
Guizhou	3	Shanxi	1

Hainan	6	Sichuan	4
Hebei	3	Xinjiang	1
Hubei	3	Yunan	3
Hunan	12	Not Known	**2**
Inner Mongolia	5	**Total**	**84**

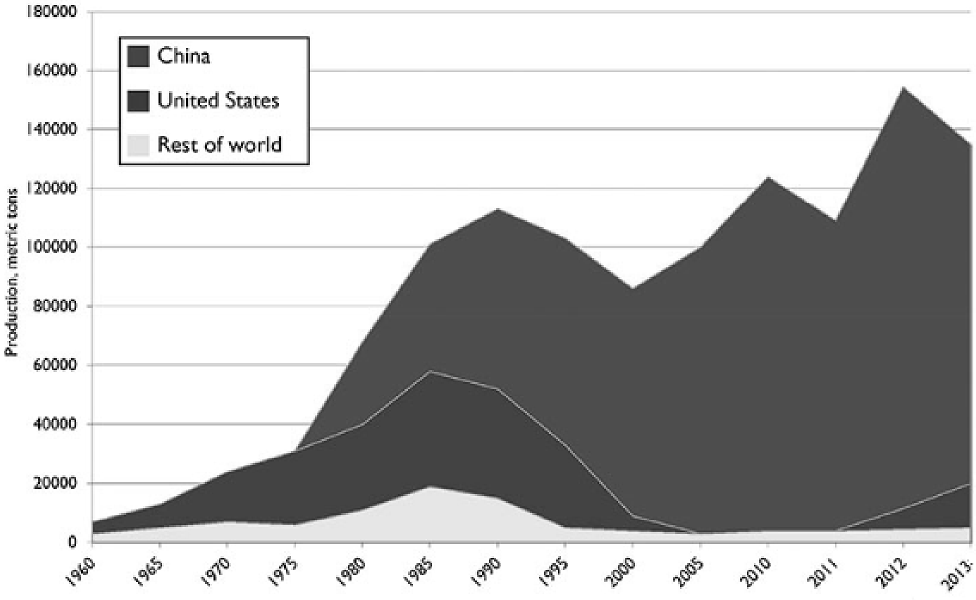
Source: Orris and Grauch (2002)

Interestingly, the data suggests that China has controlled output successfully since 2006 introducing production as well as export quotas as it sought to consolidate the domestic industry into a handful of players. China has long lagged behind the U.S. technologically. However, as of the early 1990s, China’s vast rare earth resources have propelled the country into the number one position in the industry. Additionally, China has set out on an expansive effort to increase its overall technological innovation, effort which includes the use of rare earth elements. China’s academic focus on rare earth elements could one day give the country a decisive advantage over technological innovation.

2.2 Production of Rare Earth Elements

In fact, there are very few companies outside China producing rare earths and rare earth based products. Inner Mongolia Baotou Steel Rare Earth Hi-Tech Co. is China’s single largest producer. China rare earth extraction know how is currently unparalleled, the necessary production capacities, infrastructure and distribution channels all exist and, on top of that, the country benefits from fairly lax environment and work place safety regulations and low labour costs. China, which once focused on exporting rare earths in their raw forms, has shifted its end goal from production to innovation. In the 1970s, China was just exporting rare earth mineral concentrates. By the 1990s, it began producing magnets, phosphors and polishing powders. Now, it is making finished products like electric motors, batteries, LCDs, mobile phones and so on (Kingsnorth, 2014).

Figure 2.2: Chinese rare earth industry in the international context

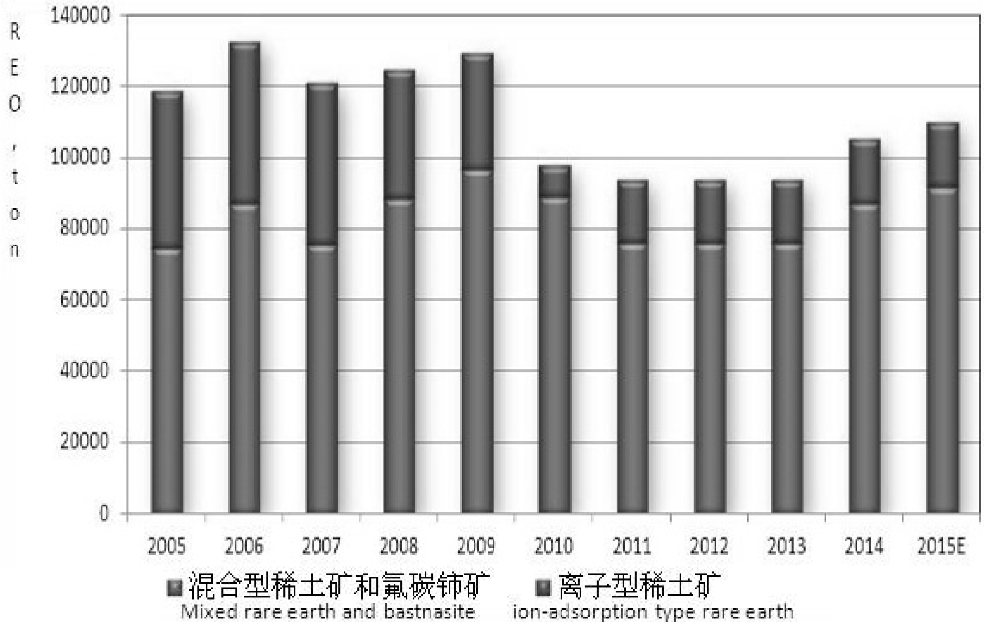


Source: Klinger, 2013

The significant cost advantage for Chinese producers, which has crushed almost all overseas competitors, is not only driven by low labor costs, but also unintentionally reinforced by Beijing's policy failures in regulating the resource extraction sector as a whole, and the RE industry in particular. To keep pace with its booming economy, Beijing promulgated the so-called "Let Water Flow Rapidly" (*You Shui Kuai Liu*) policy in 1981 to stimulate a rapid spike in resource demand without appropriate considerations of environmental protection, safety and sector consolidation. The lack of entrance standards and patent enforcement led to a proliferation of small scale and technologically backward mines and separation plants.

There are many dimensions in the forms of impact that the rare earth industry creates. These different dimensions directly or indirectly take a toll on the environment. The first factor is that the rare earth minerals are a non-renewable resource. Hence the over exploitation not only creates environmental degradation but also leads to over supply breaking the equilibrium in the demand-supply curve. In this context illegal mining and trading plays an important role. China as mentioned earlier had no interest in regulating the industry in blind pursuit of industrialization, which had in fact helped to flourish the illegal mining.

Figure 2.3: The mandatory plan of China for production of rare earth minerals during 2005 -2014



Media reports have often pegged China's rare earth cost advantage on poor environmental standards, which is a problem in the chaotic mining operations in Southern China (Tu, 2010). However, China's largest source of rare earths does not even come from a rare earth mine. Rather, it comes out of the tailings (or waste material) from the giant Baotou iron ore mine in the province of Inner Mongolia in Northern China. A cheap processing method is used to convert them into high-purity products. As production from these sources continued to ramp up in the 1990s, there was massive overcapacity built in China, and prices collapsed. The Chinese government introduced the first export quotas in 1999. In less than one decade, the market experienced a complete shift in leadership. Whereas prior to 1990 major production was in the United States and other countries. China is now facing the possibility that reserves of medium and heavy rare earths might run dry within 15 to 20 years if the current rate of production is maintained.

Table 2.3: Chinese production of rare earth minerals 2004-14

Year	Bayan Obo Bastnaesite	Sichuan Bastnaesite	Ion Adsorption clays	Monazite	Total
2004	42-48,000	20-24,000	28-32,000	-	9-100,000
2006	45-55,000	22-26,000	40-50,000	8-12,000	125-140,000
2008	60-70,000	10-15,000	45-55,000	8-12,000	125-140,000
2010	55-65,000	10-15,000	35-45,000	4-8,000	110-130,000
2014	80-100,000	20-40,000	40-50,000	8-12,000	160-170,000

Note: Illegal or uncontrolled mining and processing is not included. It has amounted to 20,000t-40,000t REO per annum over the last 3-5 years

Source: Kingsnorth, 2014, 2015, Baogang Rare Earth Hi-Tech, Sichuan RE Association, GRIREM, 2014

Table 2.3 reveals that the production in Bayan Obo remains the largest REE industry in China contributing almost half of the total production. The production has been constant between the periods 2006 and 2008 ranging between 125- 140 thousand tons. China has greatly reduced the production of REE to 110-130 thousand tons by the end of 2010 and also restricted the exports through various quota systems which are discussed in detail in Chapter four. In recent years, Chinese government has been controlling mineral output by setting legal exploitation limits and cracking down on illegal mines. Still, an average 200,000 tons of minerals are in the market on an annual basis. The government maintained the mandatory plans for rare earth output in 2015 same as 2014, which was equal to 87,100 tons of light rare earths and 18,000 tons of heavy rare earths. Like many other industries, China is facing a huge overcapacity problem in rare earth industry as it was one of the least regulated industries by any standards including environment. It is estimated that the annual capacity of rare earth separation nationwide is more than 450,000 tons and the actual output is between 200 to 300 thousand tons, where the actual demand on a global scale is about 120-150 thousand tons per annum (Chen, 2015). This unbalanced supply-demand relationship is the major reason for the lower prices and this in fact cause other projects outside China financially unviable and uncompetitive.

2.3 Supply of Rare Earth Elements

The supply of a material is a function of resources, reserves and production. “Resources” include identified and undiscovered resources. Production generally occurs in countries with large resources and reserves, but exceptions exist. In some cases, small reserve holders may also produce the material, while countries with no reserves could be a major refinery producer of imported primary or raw material.

Table 2.4: Chinese REE supply compared to other countries in 2010 and 2014

<table>
<tr><th>Chinese Supply Sources</th><th>QTY 2010</th><th>QTY 2014.est</th><th>Non Chinese Supply</th><th>QTY 2010</th><th>QTY 2014.est</th></tr>
<tr><td rowspan="2">Baotou
• By-product of iron ore mine
• Moving to higher grade iron, with lower impurities and rare earths
• Tailing facilities near capacity</td><td rowspan="2">55000t</td><td rowspan="2">60000t</td><td>India
• Subsidiary of Indian Atomic Energy Agency
• Toyota Tsusho</td><td>3000t</td><td rowspan="2">12000t</td></tr>
<tr><td>Russia & CIS
• Limited expansion capacity
• By-product of Mg production</td><td>4000t</td></tr>
<tr><td>Sichuan
• Target to increase value added
• Capacity expected to increase</td><td>10000t</td><td>20000t</td><td>Australia,
Mount Weld</td><td></td><td>22000t</td></tr>
<tr><td>Ionic clay regions
• Reportedly 14 yrs of resources
• Large amount of illegal mining
• Government action taking effect</td><td>35000t</td><td>30000t</td><td>USA-Mountain pass
• Reprocessing stockpiles</td><td>3000t</td><td>20000t</td></tr>
<tr><td>Recycling</td><td>3300t</td><td>4000t</td><td>Recycling
• Magnet swarf
• Batteries-future potential</td><td>1500t</td><td>1800t</td></tr>
<tr><td>Total</td><td>103300t</td><td>114000t</td><td>Total</td><td>11500t</td><td>55800t</td></tr>
</table>

There was still more than enough supply reaching other markets and there was no real talk of a problem in the sector until the past few years, when growing global demand for rare earths highlighted the fact that China had put everyone else out of business. Comments from Chinese government officials started to suggest that they view the industry as more strategic than ever before, and were securing more supply for domestic use. They started taking measures to consolidate domestic supply and reduce smuggling. The growing economy of China is creating a worldwide risk to supply and China's growing consumption limits its exports of rare earths. China insists that it requires restricting the supply to meet the demands of its clean energy and high-tech sectors.

Most of the rare earth enterprises in China are located around the large rare earth mines, such as Baotou city, Sichuan province and Ganzhou city. There are about 24 enterprises for rare earth concentrate production, and 100 rare earth enterprises for smelting separation production in China. Baotou is the largest supplier of rare earth products and an average 55,000 tons of rare earth product reach market every year from Baotou.

Table 2.4 reveals a number of developments in production and supply of rare earths between 2010 and 2014 and shows that a 10 percent increase in production at Baotou plant during this period. The supply from ionic clay regions have been reduced to 17,900 tons in 2015 by the mining quota system of the government (Seah, 2015). Chinese supply restrictions had prompted the major rare earth using countries to look for alternative sources and by 2015 a number countries are in a position to supply some amount of rare earth as the data shows that the Mount Weld mine in Australia and Mountain Pass in California have been ramping up the production along with increased supplies from Russia, CIS countries and India.

Table 2.4 also shows that the supply from recycling in China increased marginally from 3300t in 2010 to 4000t in 2014 and from 1500t to 1800t globally. The reuse and recycling capacity of rare earths is currently limited as recovery of manufacturing waste and measurable recovery from aftermarket products are yet to develop. Also recycling them is often difficult and expensive, because they are often mixed with other materials when products are made. And there is little economic incentive to recycle, since rare earth elements are available raw on the world market at comparatively low prices. However, improved designs for recycling coupled with larger streams of materials could eventually allow for the economical recycling and reuse of magnetic materials

Table 2.5: Rare earths types and contents of major contributing source minerals (Percentage of total rare earth oxides)

		LIGHT				MEDIUM			HEAVY								
TYPE	**Location (s)**	**La**	**Ce**	**Pr**	**Nd**	**Sm**	**Eu**	**Gd**	**Tb**	**Dy**	**Ho**	**Er**	**Tm**	**Yb**	**Lu**	**Y**
Currently Active:																	
Bastnaesite	Bayan Obo Inner Mongolia	23	50	6.2	18.5	0.8	0.2	0.7	0.1	0.1	0	0	0	0	0	0
Xenomite	Lahat, perak, Malaysia	1.2	3.1	0.5	1.6	1.1	0	3.5	0.9	8.3	2.0	6.4	1.1	6.8	1	61
Rare earth laterite	Xunwu, Jianxi China	43.4	2.4	9.0	31.7	3.9	0.5	3.0	0	0	0	0	0	0.3	0.1	8
Ion adsorption clays	Longnan, Jianxi, China	1.8	0.4	0.7	3.0	2.8	0.1	6.9	1.3	6.7	1.6	4.9	0.7	2.5	0.4	65
Loparite	Lovozerskaya, Russia	28	57.5	3.8	8.8	0	0.1	0	0.1	0.1	0	0	0	0	0	0
Various	India	23	46	5	20	4	0	0	0	0	0	0	0	0	0	0

Source: U.S Department of Energy (2010)

Table 2.5 shows that most of the oxides are produced at different mine sites in China. The industry in Malaysia is largely dependent on the ores from Australia. Most analysts believe that China will eventually change its policy to restrict the export of rare earths individually. Because China has an abundance of light rare earths available through the Bayan Obo project in Inner Mongolia. Even with new mines coming online within the next five years, analysts are forecasting a shortage of heavy rare earths terbium and dysprosium and a very tight supply of light rare earths neodymium and praseodymium. Of note is that nearly all rare earth deposits contain the radioactive material thorium and the cost of treating and storing thorium is an important factor in evaluating the economics of a mine. This may be particularly true to the rare earth production in India where the deposits of thorium is very high in beach sand minerals. In general, each rare earth ore body is unique and requires a site-specific processing system. As a result, production costs vary from deposit to deposit based on ore content and mineralogy.

The development of increased stockpiling of REE in China has gained momentum in recent years with assertion of government authority over mining regions. The Chinese stockpiling, under the direction of the Ministry of Land and Resources, began with a pilot project in early 2010 in China's primary mining region of Baotou in Inner Mongolia. At least 10 storage facilities are being built and managed by the world's largest producer of rare-earth metals; government-controlled Baotou Steel Rare-Earth (Group) Hi-Tech Co. Chinese state media reports say stockpiles may eventually top 100,000 metric tons (Areddy, 2011). The move to build reserves will have many repercussions on supply as well as price in future. In response to Chinese restrictions on supply the high-tech-focused nations of U.S, the European Union, Japan and South Korea, all of which are dependent on China for rare earth supplies, have highlighted stockpiling strategies.

There are few basic features of Chinese supply that we can derive from the above analysis. The facts include, China still hold more than 25 million tons of rare earth oxide reserves, excessive secondary processing capacity and easy availability of cheap processing chemicals, and heavy investment in research and technology. Moreover, the supply of Chinese heavy rare earth is finite with 15- 20 years of mine life. After China gained decisive advantage in the RE supply chain, Beijing's restrictions on REO production and exports in recent years have been primarily motivated by the strong political desire for resource conservation.

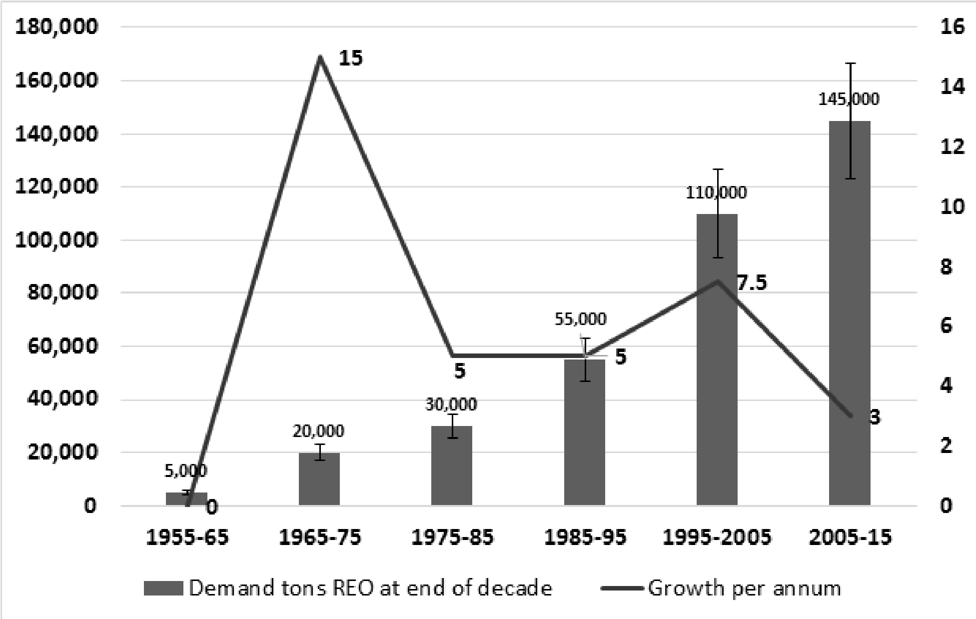
3 Demand and Global Consumption of Rare Earth Elements

The two major drivers of demand for mineral commodities are the rate of overall economic growth, and the state of development for principal material applications (e.g., clean energy technologies). Demand for key materials in clean energy technologies compete for available supply with demand for the same materials in other applications.[3] With 1.3 billion people and the fastest growing economy in the world, China is faced with the challenging task of ensuring adequate natural resources to sustain its economic growth. As China also faces an overcapacity problem and not capable of using all materials domestically at present, out of a production level of perhaps 100,000 tons of total rare earth oxides in past years, 30 to 40 percent of that material has ended up being purchased by end-users in first-world nations.

World demand for rare earth elements are estimated at 140,000 tons per year, with global production around 124,000 tons annually. The difference is covered by above-ground stocks or inventories. The market has shifted in such way in last five years and many predictions and forecasts have been proved wrong. It was predicted that by 2015, global demand for rare earth elements may exceed 200,000 tons per year, but this has not been realized. It was also predicted during the crisis period of 2011 and 2012 that there would be a huge gap between supply and demand and capacity shortfall of 40,000 tons per year may occur. This prediction of potential shortfall had raised concerns in the major rare earth consuming countries including Japan as new mining projects could easily take up to 10 years for development. In the long run, however, the United States Geological Survey (USGS) expects that reserves and undiscovered resources are large enough to meet the global demand. This expected growth, coupled with the export cuts from China has prompted in starting at least four dozen rare earth mining projects around the world.

[3] Generally and with respect to the key materials, demand for end-use items for building use (e.g., phosphors for lighting) or construction tend to be more cyclical, whereas those that enter big-ticket consumer items such as cars tend to be more volatile and sensitive to short-term economic movements. Uses that enter portable devices and personal consumer goods (e.g., batteries for portable electronics) tend to experience more stable demand. Regional factors are important also: China's and India's rapid economic growth have had and will continue to have a huge impact on global demand for mineral commodities (Eggert, 2010).

Figure 3.1: Rare earths demand over the past 5 decades

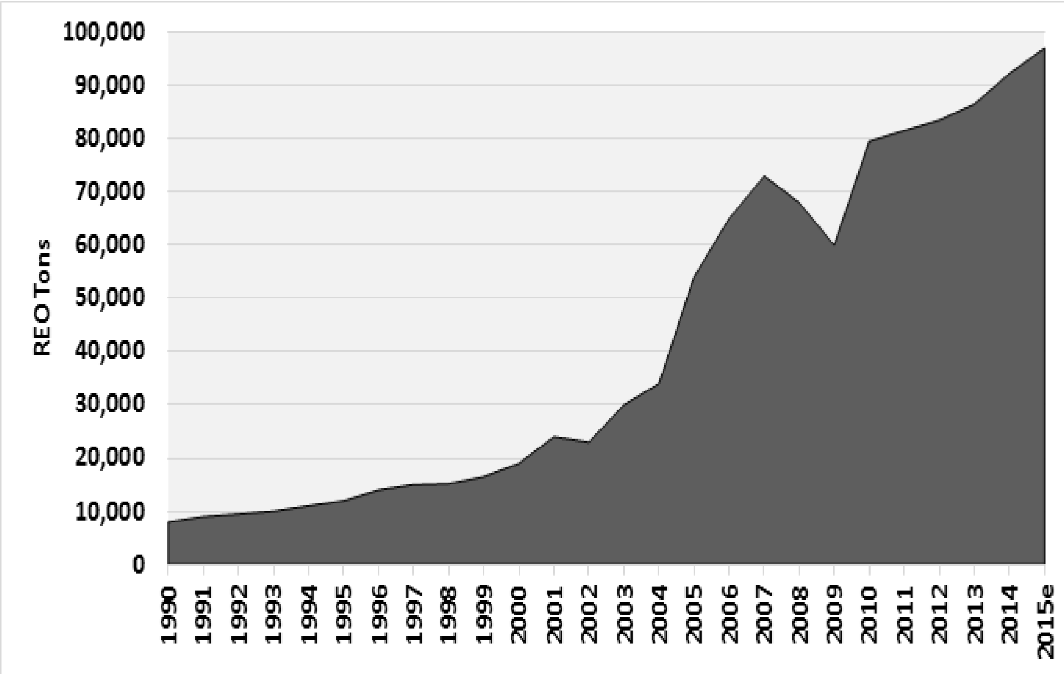


Source: Based on Kingsnorth, 2015

Just as worldwide demand for REO is growing, so is China's own demand. However, the global demand outside China has been moderate in the present decade compared to the previous one. Data from the Chinese Society of Rare Earths (CSRE) shows that China's consumption has grown rapidly since 2004 reaching over 70,000 tons in 2008. Growth in demand from China will continue to outpace the demand from the rest of the world. Chinese demand has reached around 97,000 tons in 2015 and rest of the world demand is around 49,000 tons. It can be concluded that rare earth materials has become a major growth point of China's stride towards industrialization (Chen Zhanheng, 2010). China, Japan and the United States are the largest consumers of rare earth metals. With the growing demand for 'green' products, the demand for rare earth metals is only expected to increase. The annual growth in demand is expected to hover around 7-8 percent. China had strategized an industrial policy wherein it not only mines and produces these elements but also to manufacture the finished goods. So, not only does the country produce 97% of the world's REEs but also uses approximately 70% of that material to build products domestically. Thus, China came to dominate the entire industry.

The most rapid growth in China has been in demand from new materials, that include magnets, phosphors, catalysts and batteries, which now account for over 60% of the country's demand. This demand as no doubt been and will continue to be fueled by heavy investments in clean energy.

Figure 3.2: Chinese consumption of rare earths from 1990 to 2015



Source: Chen Zhanheng, 2010, Kingsnorth , 2015

Figure 3.2 shows the Chinese consumption of rare earths from 1990 to 2015. It can be noticed that the consumption of rare earths in China increased rapidly since 2004. During the last 25 years, China's annual consumption increased from 8,000 tons in 1990 to 97,000 tons in 2015, growing by 10.4 percent per annum. The main reason for this tremendous growth is that ever increasing production of manufacturing items in China such as wind turbines, solar panels and electronic commodities. During the global financial crisis, there was a slight decline in Chinese consumption which declined from 73,000 tons in 2007 to 60,000 tons in 2009.

High-technology and environmental applications of the rare earth elements have grown dramatically in diversity and importance over the past four decades. Many of these applications are highly specific and substitutes for REEs are inferior or unknown. REEs have acquired a level of technological significance much greater than expected from their relative obscurity. These uses range from mundane (lighter flints, glass polishing) to high-tech (phosphors, lasers, magnets, batteries, magnetic refrigeration) to futuristic (high-temperature superconductivity, safe storage and transport of hydrogen for a post-hydrocarbon economy).The rare earth elements are essential for a diverse and expanding array of high-technology applications as explained in Table 3.1

Table 3.1: Major applications and final products rare earth elements

Rare Earths	Products	Industrial applications
Nd, Pr, Sm, Tb, Dy	Magnets	Demand for large magnets for permanent magnet motors in HEVs, EVs, and Maglev trains, Wind turbines, also increased demand for HDDs and ODDs, mobile phones, MP3 players, cameras, VCMs
La, Ce, Pr, Nd	Battery alloy	Rising demand for HEVs
Eu, Y, Tb, La, Dy, Ce, Pr, Gd	Phosphors	Increased use of energy efficient florescent lights, also growing demand for LCDs, PDPs
La, Ce, Pr, Nd	Fluid cracking Catalysts	Increased use of catalysts in processing heavy crude and tar sands
Ce, La, Nd	Auto catalysts	Tighter NOx and SOx standards – offset to some extent by increased use of zirconia in the wash coat
Ce, La, Nd	Polishing powders	Increased demand for mechano- chemical polishing of electronic components, and some types of LCD screens
La,Ce, Pr, Nd, Y	Ceramics	Growth in use of multi-layer ceramic capacitors, use of PSZ in advanced applications

Notes: HEV = Hybrid Electric Vehicle, EV = Electric Vehicle
HDD = Hard Disc Drive, ODD = Optical Disc Drive
VCM = Voice Coil Motor, LCD = Liquid Crystal Display, CRT = Cathode Ray Tube
PSZ = Partially Stabilized Zirconia

Table 3.1 depicts the REE products and their applications. Dysprosium and terbium are alloyed into rare earths magnets to make them capable of operating at elevated temperatures. At current alloying levels, dysprosium and terbium make up about

5% of the metal used in these magnets. The majority of applications depend on the rare earth magnets. China exported 3 billion worth of rare earth magnets and 374 million worth of other rare earth products in 2014. The rare earths market represented approximately USD 4-5 billion in 2014. Over the past decade, market growth has been in the range of 8-11% per year, with the exception of the correction in 2001/02 due to the fall in technology markets and the global economic crisis. While the global financial and economic crisis in 2009 reduced consumption of REE, the industry growth returned to 7-8 % in recent years (Kingsnorth, 2014).

Table 3.2: Forecast of global rare earths demand in intermediate product category by 2017

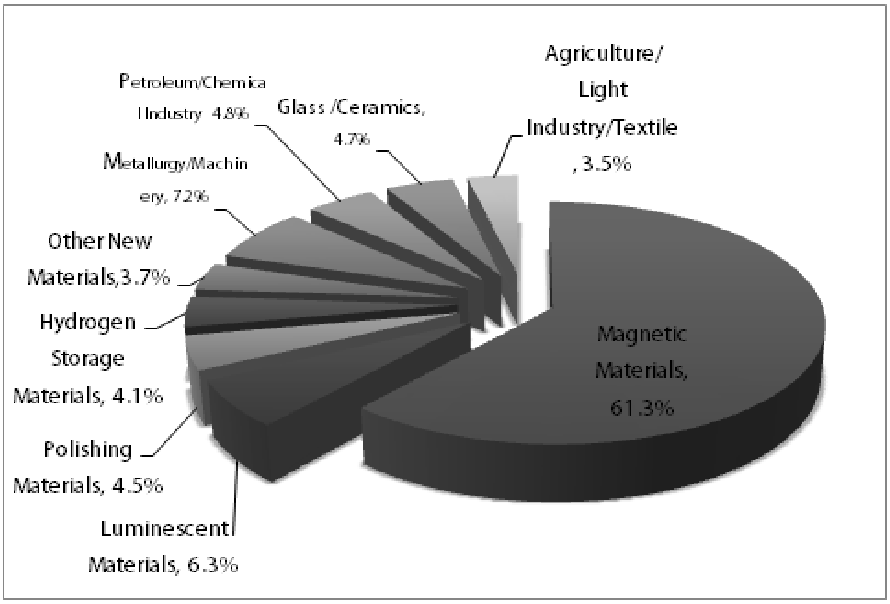
Application	**China**	**Japan & NE Asia**	**USA**	**Others**	**Total**	**Market Share %**
Catalysts	10,000	2,000	13,000	2,000	27,000	18%
Glass	6,500	1,000	1,000	1,000	9,500	6%
Polishing	12,500	1,750	3,000	1,000	18,250	12%
Metal Alloys	20,500	5,500	2,000	1,250	29,250	19%
Magnets	29,500	6,000	3,500	1,500	41,500	27%
Phosphors	5,500	500	500	500	7,000	5%
Ceramics	3,250	2,500	1,750	500	8,000	5%
Other	5,000	2,000	4,000	1,000	12,000	8%
Total	92,750	21,250	28,750	8,750	152,500	100%
Market Share	61%	14%	19%	6%	100%	--

Source: Kingsnorth, 2014

Table 3.2 forecasts a number features of rare earth demand in 2017. The Chinese demand constitutes about 61 percent of global demand followed by Japan and North East Asian countries and USA. The demands for magnets, metal alloys and catalysts will be higher compared to other applications as these are used in industrial applications of hybrid vehicles, electronic vehicles, hard disc drives, optical disc drives, voice coil motors, liquid crystal displays, cathode ray tubes, petroleum refining industries and wind turbines. The demand from magnet sector is equal to 27 percent followed by 20 percent demand from catalysts and about 18 percent demand for metal alloys. Magnets phosphors and metal alloys are the largest end uses of rare earths by value.

In China and globally, REEs have experienced fast growth in advanced technology sectors including luminescent (phosphors), magnetic, catalytic and hydrogen storage technologies. The demand by clean energy technology sectors is largely a result of the ramp-up of clean energy technology manufacturing and use by the United States, other Organization for Economic Co-operation and Development (OECD) nations and China. Magnets dominated REE usage by weight in 2014, with catalysts claiming the second-highest usage and metal alloys accounting for the third highest (Kingsnorth, 2015). REE consumption has grown most rapidly in China. China's REO demand exceeded half of global demand for the first time in 2005 and more than tripled in absolute terms between 2000 and 2015.

Figure 3.3: China: consumption structure of rare earths in 2015



Source: Report Linker, 2012

In China, rare earths were mainly consumed in traditional areas of metallurgy, machinery, petroleum industry, chemical industry, light industry and textile industry.

There were dramatic changes in the consumption structure as the consumption of rare earths in new materials increased very fast since 2004. In 1988, the consumption of rare earths in new materials was only 1 percent, but in 2007, it was about 53 percent. In 2008, it was claimed that about 60% of rare earths were consumed in new materials and related industries. In recent years, driven by downstream demand, the new material field has witnessed rising consumption of rare earths. The demand for rare earth from new materials account for 79.8% of the total, of which, magnetic materials show the largest of 61.3% in 2015. China's consumption of rare earth elements is also expected to increase dramatically as more and more foreign companies move their production sites to China to take advantage of the lower cost of rare earths and therefore reduce their overall production costs. This is part of China's larger strategy to maintain a tight hold on the industry.

In 2009, China produced about 7,200 tons of rare earth fluorescent powder, ranking top in the world and the trend has continued since then. The three-band fluorescent lamp industry consumed about 75% of rare earth luminescent materials. The three-band fluorescent lamp with the advantages of energy saving and long lifespan will gradually replace the incandescent lamps. In 2009, China produced over 3 billion three-band fluorescent lamps. If 80% of the incandescent lamps are replaced, 3 billion three-band fluorescent lamps will be needed every year. Hence, the annual demand for fluorescent powder is about 10,000 tons. It was estimated that in 2015, the total demand for three-band fluorescent powder will be about 60,000 tons.

In 2008, the consumption of rare earth polishing powder in the world was 20,000 tons, including 8,000 tons for LCDs. In recent years, with the booming of the LCD industry, high-performance polishing powder has achieved fast development. It was forecasted that China's annual production capacity of rare earth polishing powder will reach 20,000 tons by 2013. In 2009, the rare earth consumption by China's petrochemical catalytic cracking sector was about 7,500 tons. It is estimated that China's crude oil processing volume will maintain over 500 million tons in 2015-2020. The rare earth for FCC catalysts will exceed 10,000 tons. Besides, with the considerable growth of the demand for rare earth catalytic materials in the fields of fuel cell, water pollution control, air purification, etc., China's total demand for rare earth catalytic materials will exceed 17,000 tons between 2015 and 2020 (China Research and Intelligence, 2010).

Because of their ability to readily give up and accept electrons, the rare earth elements have become uniquely indispensable in many electronic, optical, magnetic, and catalytic applications. From iPads to catalytic converters, from wind power generators to computer disc drives, and hybrid electric vehicles, rare earth applications are ubiquitous and critical for the overall economic wellbeing of any country. China is most interested in supplying its domestic needs first. Because, there's such a wide range of products that use rare earth elements, its domestic REE-product industry is growing rapidly. China is doing everything it can to bring new investment into the country, and to develop new industries to use this material. For example, it will sell REEs to local industries at a much cheaper price than it sells the same material to sources outside of China. In that sense, it's trying to do everything it can to increase the country's internal need.

Table 3.3: Global rare earths demand in tons 2010 & 2014

Application	Demand Tons 2010	Volume (%)	Value (%)	Demand tons 2014	Growth rate p.a. (%)	Value (%)
Magnets	35000	26%	38%	55100	12%	42%
Battery Alloys	18600	14%	10%	32500	15%	13%
Metallurgy ex battery	11700	9%	7%	12700	2%	5%
Auto Catalysts	9000	7%	5%	12200	8%	4%
Fluid cracking Catalysts	21300	16%	11%	24900	4%	9%
Polishing	19100	14%	10%	28000	10%	10%
Glass	7800	6%	4%	7800	0%	3%
Phosphors	7900	6%	10%	10800	8%	10%
Others	5700	4%	5%	6100	6%	5%
Total	136 100	100%	US$7.8 bln	190100	9%	11.2 b

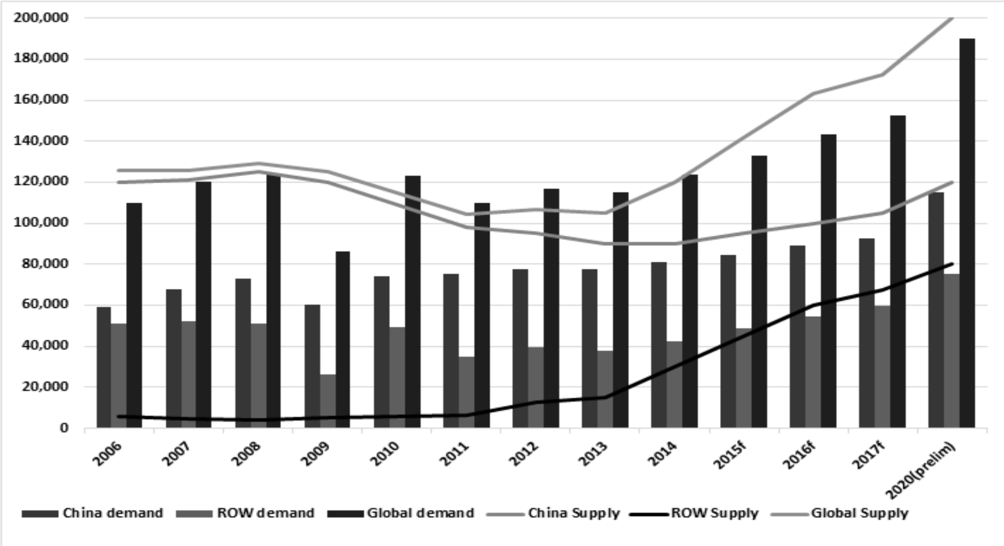
Source: Lynas Corp, 2010

The data released by Lynas Corp in 2010 showed that the largest growth rate will be in demand for magnets and battery alloys which would be 12 percent and 15 percent respectively by 2014 (Table 3.3). The report predicted that total demand for the group of elements, used in products such as industrial magnets, flat-screen TVs, and military weapons systems is likely to grow to 190,100 metric tons in 2014, from 136,100 tons in 2010. For example, permanent magnet demand was expected to grow by 10%-16% per year through 2014. Demand for rare earths in auto catalysts and petroleum cracking catalysts was expected to increase between 6% and 8% each year over the same period. Demand increases were also expected for rare earths in flat panel displays, hybrid vehicle engines, and defense and medical applications. The global demand in value terms expected to grow from USD7.8 billion in 2010 to 11.2 billion in 2014.

3.1 Global Demand-Supply Interface by 2020

The growing number of applications for rare earths, coupled with the burgeoning demand for clean energy and the latest consumer technologies has increased the importance of rare earths. Many of the world's experts forecasted a supply deficit of REO by 2014 as demand over time is expected to exceed the industry's ability to produce and as commercial stocks are depleted. However, that concern is over now as China removed its export quotas and many new projects opened up in many parts of the world. New or reopened mines outside China are expected to increase global production, resulting in an overall surplus in the international market in next five years. However, shortfalls are expected in certain elements, particularly in neodymium and europium, and the heavy rare earths like terbium, dysprosium, and yttrium. The increased focus on recycling of heavy elements in many advanced countries including Japan and China may solve this problem. Demand for rare earth metals is likely to increase between 8-10 percent each year, analysts say, thanks to growing demand for elements like neodymium, which is used in making hybrid electric vehicles and generators for wind turbines.

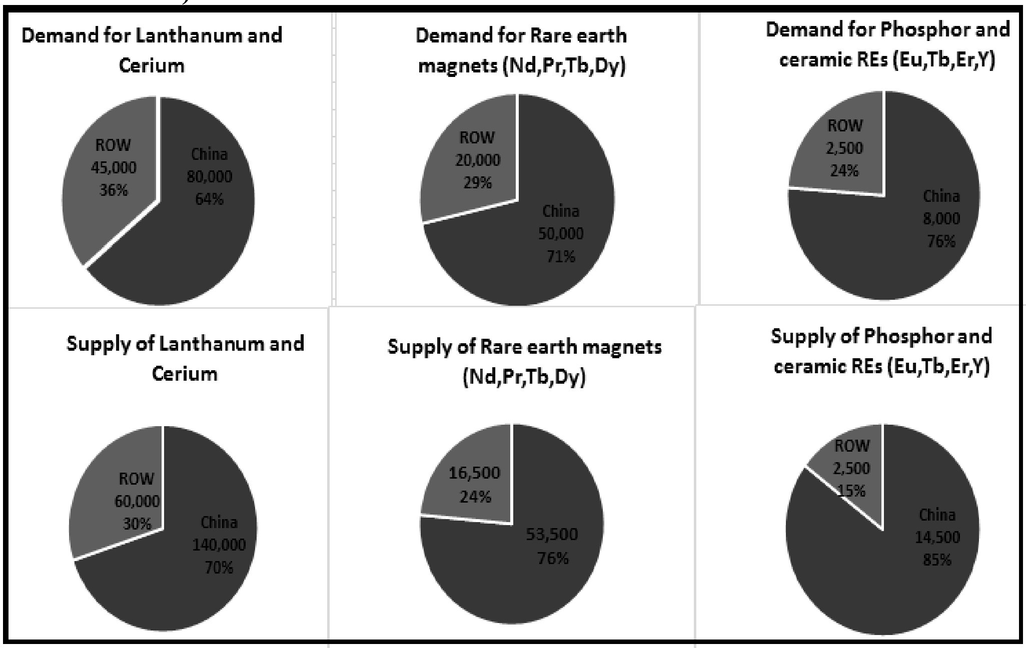
Figure 3.4: World supply/demand balance for rare earths, 2006-2020 (t REO)



Source: Based on Kingsnorth (2014)

World demand for rare earth elements in 2014 are estimated at 123,500 tons with global production around 120,000 tons annually (Figure 3.4). The marginal deficit is covered by above-ground stocks or inventories. World demand is projected to rise to 152,500 tons annually by 2017, while it is likely that new mine output will alleviate the shortage in supply and in 2017 there would be a surplus of 20,000 tons of REEs in the market. By 2020, global demand for rare earth elements may exceed 190,000 tons per year. China's output may reach 120,000 tons per year in 2020 (up from the legally produced 100,000 tons in 2015). An additional surplus in output of 15,500 tons is expected for the year 2020. New production from the rest of the world (ROW) could meet increased demand during this five year period, but will the "balance" be right? This brings spotlight on sustainability of rare earth production in other countries to get to full-scale rare earth production and to deploy a complete mining-to-magnets manufacturing supply chain as soon as possible outside China.

Figure 3.5: Forecast supply and demand for selected rare earths for 2020 (tons per annum of REO)



Source: Based on Kingsnorth (2015)

Figure 3.5 shows that in 2020, the global demand for lanthanum and cerium, the most used but less critical RE elements will be around 125,000 tons much less than the global supply of 180,000 tons. The demand for more critical rare earths like neodymium, praseodymium, terbium and dysprosium will be in near short of supply, particularly the heavy rare earths like terbium, dysprosium and yttrium. Their proportion to the total demand is comparatively less, although their importance to some of the applications are very important. Since supply of these elements is going to be so tight, the prices for Tb, Dy and Y will remain strong. Neodymium iron boron permanent magnet is the leading product among rare earth magnetic materials. With the development of new application areas, it is forecasted that the global neodymium iron boron industry will maintain the growth rate of 15% in the coming five years, whereas Chinese neodymium iron boron industry will maintain the growth rate of 20% and the global demand for neodymium will outstrip the global supply with a thousand tons marginal difference in 2020.

The rare earth content of NdFeB magnets varies by manufacturer and application. An electric vehicle may use up to a kilogram (kg) of Nd, while each wind turbine may contain several kilograms. Rare earth permanent magnets may also incorporate praseodymium (Pr), which can be substituted for or combined with Nd. Dysprosium (Dy) or terbium (Tb) may also be added to the inter metallic alloy to increase the temperature at which the magnet can operate before losing its magnetic. The cumulative demand for Nd and other REEs in these clean energy technologies is a function of both the material content per individual product and the total number of products sold. Therefore, aggressive technology penetration rates envisioned under many worldwide clean energy strategies could significantly increase global demand for Nd, Pr, Dy and Tb (London, 2010).

Chinese economy will continue to grow close to double digit rates for the foreseeable future and disposable income for automobiles, personal electronics, etc. will drive significant internal RE demand. The automobile industry in China has also begun to develop a large and reputable electrical vehicle sector, supported by both the private and public sector. China is already the largest auto market and had the plan to produce 500,000 electric vehicles by 2014. There are already at least one million low-speed EVs in use in China and companies in the industry expect sales to increase by at least 50 percent and top 600,000 units in 2015, and to reach at least one million units by 2020. In fact, some industry observers believe that the one million mark could be achieved within a year or two, and that as many as three million low-speed EVs will be sold in 2020, generating revenue of RMB 100 billion ($16.1 billion) (Perkowski, 2015). So to meet this increasing demand for REEs, China has employed a number of controls to date such as, production limits, export quotas, export tariffs, stockpiling, closing of separation plants and even literally blowing up illegal mines.

4 International Trade in Rare Earth Elements and Chinese Export Restrictions

The concentration of rare earth elements (REE) production in China and Chinese export restrictions have raised concerns in industrialised countries about the criticality of these materials. In spite of the Chinese monopoly, there was still enough supply reaching other markets until the past couple of years. The growing economy of China is creating a worldwide risk to supply, as China's growing consumption limits its exports, making rare earths more critical. Export restrictions on metals and mineral products have been broadly applied by many countries with a view to securing domestic supply and for addressing the problem of resource depletion. Export restrictions are designed to meet diverse policy objectives that range from environmental protection and increasing fiscal revenue to development of processing sectors. Restrictions to trade include taxes and other legislation, such as tariff and non-tariff trade barriers such as quotas.

There is no single General Agreement on Tariffs and Trade (GATT) /WTO article dealing exclusively with export restrictions. Still, Article XI of the GATT 1994 is the key provision regarding export restrictions. It prohibits the use of quantitative restrictions regarding both imports and exports. Export duties are in principle not subject to Article XI and thus not prohibited under this article, while quantitative restrictions are. Regarding quantitative restrictions which are generally prohibited, the issue is whether these measures can be exceptionally allowed under Article XI: 2 (a) (critical shortage of foodstuffs), Article XX (General Exceptions) and Article XXI (Security Exceptions). Article XI: 2(a) allows each member to apply export restrictions "temporarily" to prevent or relieve "critical" shortage of foodstuffs or other products essential to the exporting country. Article XX allows exceptional quantitative restrictions for policy objectives such as conservation of exhaustible natural resources, and ensuring essential materials for domestic processing industry under "certain qualifications" (OECD, 2010).

Prior to the global financial crisis of 2008, export restrictions had been used by many countries to achieve diverse policy objectives. Piermartini (2004) noted that approximately one-third of WTO members imposed export taxes. Economic analysis provides several motivations for using these instruments: (i) export taxes can raise the world price of exported products and therefore improve terms of trade; (ii) export taxes can reduce the domestic price of the taxed commodity and thus benefit final consumers of this commodity; this element is especially important when food security is at stake; (iii) export taxes can reduce the domestic price of the taxed commodity and benefit consumers of this commodity as inputs;(iv) export taxes increase public revenue which is beneficial in a country where fiscal receipts on domestic base are limited (Bouet and David, 2010). This study finds that all these reasons barring the fourth one may have prompted China to impose restrictions on export of rare earth minerals, though China claims environmental degradation as the main reason.

Recently, a number of scientific articles and policy reports both from governmental and private organizations have been published on these minerals particularly after the 2010 incident of Chinese export restrictions to Japan over a territorial dispute. These articles and reports have dealt with a wide range of aspects concerning rare earths from assessing criticality of individual minerals to the possible effects of future scarcity (Hedrick, 2010, Hurst, 2010, Hoenderdaal et al. 2013, Wübbeke, 2013). Most of these reports introduce a framework for measuring the criticality of raw materials. Key factors considered are their economic importance, their substitutability, the diversity of supply, the size of known resources and reserves and the potential for recycling (Kleijn, 2012). Assuming these minerals are critical based on the previous studies, this section of the present study evaluates China's monopoly over the industry and provides insights on how widely traded these minerals and China's positions in the international trade both in terms volume and value. The chapter investigates the various trade restrictions imposed by China and its implications including the availability of the materials to the developed countries. Some of the individual rare earths minerals are more critical from demand and supply side. Though China has been restricting more the export of heavy rare earths, the study doesn't attempt to evaluate the criticality of individual elements and doesn't differentiate among them rather has taken as a total, largely because of the non-availability of data on individual rare earths.

Metals and minerals account for a relatively small share of world industrial output, but their supply is essential for a large value adding activities in any economy. The demand for raw materials has been accentuating as greater number of countries move up in the developmental stage. The greater demand from outside usually prompts the resource endowed countries to impose restrictions on minerals that are considered critical. There have been several such restrictions imposed by various countries. Researchers have already conducted studies with different background using different techniques on these trade restrictions. Restrictions to trade include quotas, taxes and other legislation such as tariff and non-tariff trade barriers. For example, Gordon et al., (2010) provides an economic context of export restrictions with particular focus on the metal and mineral sector. There could be various policy objectives in imposing these restrictions and many argue that Chinese export taxes on these minerals are imposed for maintaining mineral security to domestic industries. Kim (2010) examines the use of export restrictions on raw materials and analyses the policy objectives of export restrictions and their effectiveness to achieve their stated goal. This study found that, by affecting the price and quantity of trade, export restrictions produce trade distorting effects in the same way as import restrictions and may result in efficiency losses.

Export restrictions of one country may induce other exporting countries to take similar measures. Once an export restriction is applied, it is likely that importing countries will shift their source of imports to other countries. The other exporting countries may then be forced to apply similar measures in order to meet domestic demand by limiting their exports (Dollive, 2008). Some studies such as Fabiosa et al. (2003) and Fabiosa and Beghin (2002) examine the effect of the removal of all border taxes, including export taxes, domestic subsidies and other distortions to world commodity markets. Bouet and David (2010) provide a theoretical background to the use of export taxes for maintaining food security. Their analysis emphasises the negative impact of such measures on the welfare of trade partners and the effects of non-cooperative trade policies. Tarr (2010) analyses export restraints by Russia on natural gas and timber which share the dual effect of decreasing domestic prices while increasing export prices. The analysis focuses on development perspective of export restrictions that the restrictions are applied to improve the exporter's terms of trade. Our study does not find that China had the intention of improving its terms trade by applying export taxes and duties on rare earths. This may be true in case of trade in hydrocarbons as both exporters and importers impose several taxes and duties for increasing the government revenue or improving the terms of trade.

China claims that its export restrictions are imposed to protect the environment and to conserve its rapidly depleting resource base. However, a study by Korinek and Kim (2010) found that the export restrictions put in place did not fulfill their objective of environmental protection and the presence of export restrictions in one country put pressure on other exporters to apply restrictions suggesting the potential for competitive policy practices in restricting exports. Another important question raised in literature is that whether weak environmental laws attract foreign firms into mining. This may be true for domestic firms as weak environmental regulation may prompt private companies to mining business and this has happened in Chinese rare earth mining business for long time. But, Tole and Koop (2010) found that stringent environmental regulations have no effect in forming investment location decisions by mining firms. Regardless of any short-term cost savings from lower environmental standards, most multinational mining firms now view their presence in environmentally 'dirty' parts of the world as potentially damaging of their corporate reputation, even though they may adopt international best practice standards. In China's case, though the environmental regulations were weak, but for international firms, the regulatory framework for the minerals sector was complex. The framework manifests itself both in terms of a complex approval process and inconsistent regulations and policy between central, provincial and local levels of government (Penney et al, 2007).

4.1 Case against China in WTO on REE export restrictions

In June 2009, the issue of dwindling supply of rare earth minerals and Chinese export restrictions came to the fore when the US and the European Union (EU) (later joined by Mexico, India, Brazil, Japan and Korea as third parties) lodged a complaint against China to the WTO, claiming that export restraints (including quotas and export taxes) imposed by China on a number of raw materials violate WTO rules. Although, it is well-known that WTO rules aim to reduce protectionism on the import side, the rules concerning export restrictions are less known and vague. Again on March 2012, the US, the EU and Japan filed a coordinated complaints against China to the WTO over China's export controls on rare earth and non-rare earth metals such as tungsten and molybdenum. They were also challenging aspects of the allocation and administration of export quotas, export licenses and minimum export prices, and the alleged non-publication of certain measures. They further contend that the Chinese measures are aimed to satisfy domestic demand and to control the international price of minerals which violates WTO law (Mancheri, 2012a).

China's defense hinged on two important provisions of the GATT: one supports use of trade restrictions when exhaustible natural resources are involved, and the other allows temporary use of export prohibitions or restrictions to prevent or relieve critical shortages of foodstuffs or other products essential to the exporting countries. While the former set of provisions have been used in several WTO disputes involving the use of environmental measures, the latter provisions had not been used in any of the GATT or WTO disputes till date (Bridges Weekly, 2011).

China had argued in its defense that its export restriction policy was justified under WTO law, more precisely the general exception clause of Article XX of the GATT, for reasons of natural resource conservation and on environmental ground. The most common justification for restricting exports of raw materials is the need to conserve natural resources. GATT Article XX (g) recognizes this by allowing trade-restricting measures for the purpose of conserving exhaustible natural resources only if such measures are made effective in conjunction with restraints on domestic production or consumption (Price and Nance, 2010). Finally in August 2014, the Appellate Body of WTO ruled that China's export duties, quotas, and administration of rare earths, tungsten and molybdenum products violate various provisions of the GATT and the Accession Protocol that China promised to implement when it joined WTO in 2001. Ruling in favour of US, the EU and Japan, WTO asked China to remove its export tariffs and quotas within a reasonable amount of time or face punitive retaliatory tariff measures, saying that China can't justify export restrictions on environmental ground of a mineral that it continues to extract for domestic use.

4.2 International Trade in Rare Earth Elements and China's role

China was a small player in REEs prior to the 1990s and was an exporter of low-value rare earth concentrates during this period, but it became the world's leading producer and exporter of REEs in 2000. China has a monopoly over the resources, as no other country can match Chinese capabilities and resources in this sector (Hedrick, 1997; Humphries, 2012), and the country's imposition of export restrictions on REEs hinges on the domestic requirements for its clean energy and high-tech sectors. The government wants rare-earths companies to add value by making more technologically advanced products rather than by exporting the raw material. Although there are many restrictions on mineral exports, there are no restrictions on exports of finished products (Seaman, 2010).

Figure 4.1: Gross volume and value of REE trade from 1990 to 2014

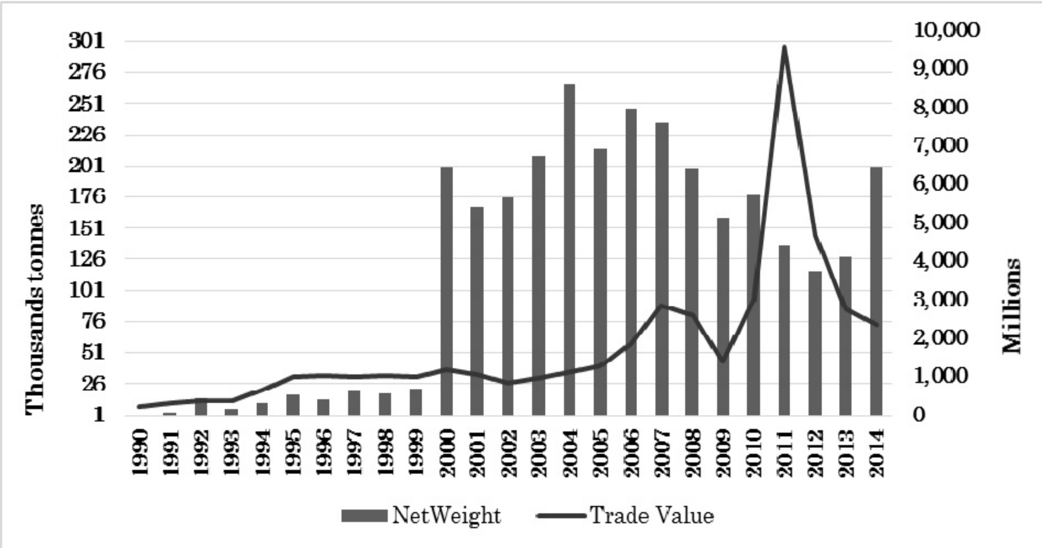


Figure 4.1 shows the gross volume and value of world trade in REEs from 1990 to 2014. The data is extracted from the UNCOMTRADE database and comprises two commodity groups classified as rare-earth metals, scandium and yttrium (HS-280530), and compounds of yttrium or of scandium (inorganic or organic) or mixtures of these metals (HS-2846).

Figure 4.1 shows that the gross volume of global trade in REEs grew from a mere 930 metric tons in 1990 to a peak of 267,000 metric tons in 2004. Global trade is calculated as the sum of imports plus exports of REEs of all reporting countries, including China. Since then, the global trade in these minerals has dropped considerably, hitting 199,000 metric tons in 2014. Furthermore, the gross trade volume increased until

2006 and then gradually declined until 2012. A number of reasons can be attributed to this decline in trade. However, the sudden fall between 2007 and 2009 is traced to the lack of demand from developed countries during the global financial crisis that severely affected major REE-consuming countries, such as the United States, Japan, and European countries.

Figure 4.1 also shows the growth in the gross value of the REE trade from 1990 to 2014. Trade in terms of total value also grew, reaching a maximum in 2011 of USD 9.5 billion from just USD 203 million in 1990. From 1998 to 2005, the annual average gross value of exports was about USD 420 million, and the annual average gross volume of exports was about 46,946.63 metric tons. The average price was about USD 8.98 per kilogram during this time, whereas it was approximately USD 13 per kilogram in 2007. The average export price exuberantly increased to USD 70 per kilogram in 2011 after Chinese export restrictions became apparent when China halted its shipment of REEs to Japan over territorial disputes. However, the data show that average prices across the elements have normalized since 2012, returning to 2010 levels.

While REEs have been produced for almost a century, the countries supplying them have changed. In the mid-twentieth century, almost all rare earth mining was done at Mountain Pass, California and in 1990 there were just eight countries who reported export of these minerals either in concentrate form or the refined form. Today, more than 90 percent of mining and refinement is done in China. In fact, there are very few companies outside China that produce rare earths. Inner Mongolia Baotou Steel Rare Earth Hi-Tech Co is China’s single largest producer. China, which once focused on exporting rare earths in their raw forms, has used forward integration to its benefit. In the 1970s, China was just exporting rare earth mineral concentrates. By the end of 1990s, it began producing magnets, phosphors and polishing powders. Now, it is making finished products like electric motors, batteries, LCDs (Mancheri, 2012b)

Rare earth prices had remained static for decades due to plentiful supplies, lulling the high-tech industry into a false sense of security. Low prices for rare earth elements from China, contributed to cuts in the production at the Mountain Pass mine in the US, one of the main source of supply for many years, before it closed in 2002 (Hurst, 2010). However, the situation changed drastically after Beijing cut export quotas for almost 70 percent in 2010, causing a sudden surge in prices as the prices for some of the rare earths gone up as much as 850 percent. Until then there were less interests in the REEs as no company was capable of competing with China's price. When prices began to climb because of strong demand as well as tightening supply from China, dozens of new mining projects have been operationalized in various countries.

UNCOMTRADE database shows that in 2013, a total of 56 countries reported exports of either of rare-earth metals, scandium and yttrium or compounds, inorganic or organic, of rate-earth metals, of yttrium or of scandium or of mixtures of these metals. The total exports of 62,000 tons of rare earths valued USD 1.263 billion in 2013. However, a total of 108 countries reported the imports of rare-earths in above mentioned category valuing a total of USD 1.492 billion for 65,000 tons in the same year. The details of the top 10 exporting countries by volume and value in million USD for the year 2013 are shown in Table 4.1.

Table 4.1: Top ten exporters of rare earths by volume and value in 2013 (Million USD)

Reporter	Net Weight (tons)	% of world export by Qty	Reporter	Value USD million	% world export by value
China	22493.30	26.43	China	576.165	31.32
Austria	7267.90	8.54	Japan	188.464	10.24
USA	7116.20	8.36	Austria	85.024	4.62
Japan	5952.82	6.99	USA	75.693	4.11
Russia	5314.13	6.24	France	50.557	2.74
Estonia	3559.43	4.18	Estonia	47.035	2.55
Netherlands	2944.74	3.46	Germany	46.072	2.5
France	1892.42	2.22	Italy	33.434	1.81
Korea	1298.02	1.52	Norway	24.087	1.3
Kazakhstan	956.78	1.12	Russia	18.850	1.02

Source: Author's calculations on the basis of UNCOMTRADE database 2014

China, exported about 22,000 tons of REEs with a share of more than 26 percent in 2013, followed by Austria, which exported about 7,000 tons with a share of 8.54 percent and USA exported around 7116 tons. Japan and Russia were in the fourth and fifth position respectively in terms of export volumes. Analysis of exports in terms of value shows that China accounted for more than 31 percent of rare earths exports followed by Japan with a share of 10.24 percent. US and Germany used to be the leading exporters of the refined rare earths until 2010 have now cut short their exports probably because of the fear of international supply crunch and increasing domestic demands. Japan had an export share of 23 percent and Germany had a share of around five percent of exports in 2008. China, in fact continues to be the dominant exporter of rare earths both in terms of volume and by value and an effective monopolistic supplier of rare earths.

The details of the top 10 importing countries by quantity and value in 2013 are depicted in Table 4.2. In 2013, Japan was the top importer of rare earths, in terms of quantity as well as value with US and Germany occupying second and third positions in terms of quantity, while USA and China occupy second and third positions in terms of value of imports. This is the first time that China being listed as a major importer of these minerals as it has started to import concentrates to refine domestically, particularly sourcing the oxides from companies like Molycorp of USA. Japan accounted for 22.38 percent of the world's rare earth imports by quantity, which was equal to 14693 tons in volume. Japan's imports of rare earth constitute mostly the refined and high rare earth products increasing its share to 30.94 percent in value terms.

Table 4.2: Top ten importers of rare earths by quantity and value in 2013

Reporter	NetWeight (Tons)	% Imports Qty	Reporter	Value USD Million	% Imports by Value
Japan	14693.59	22.38	Japan	461.758	30.94
USA	14320.08	21.81	USA	292.278	19.58
Germany	6973.54	10.62	China	158.321	10.60
Estonia	4794.55	7.30	Germany	114.376	7.66
China	3668.85	5.58	France	65.615	4.39
Austria	3203.90	4.88	Korea	52.841	3.54
Korea	2226.31	3.39	Austria	47.286	3.16
Kazakhstan	1760.82	2.68	UK	40.429	2.70
France	1733.93	2.64	Malaysia	29.255	1.96
UK	1414.91	2.15	Italy	28.520	1.91

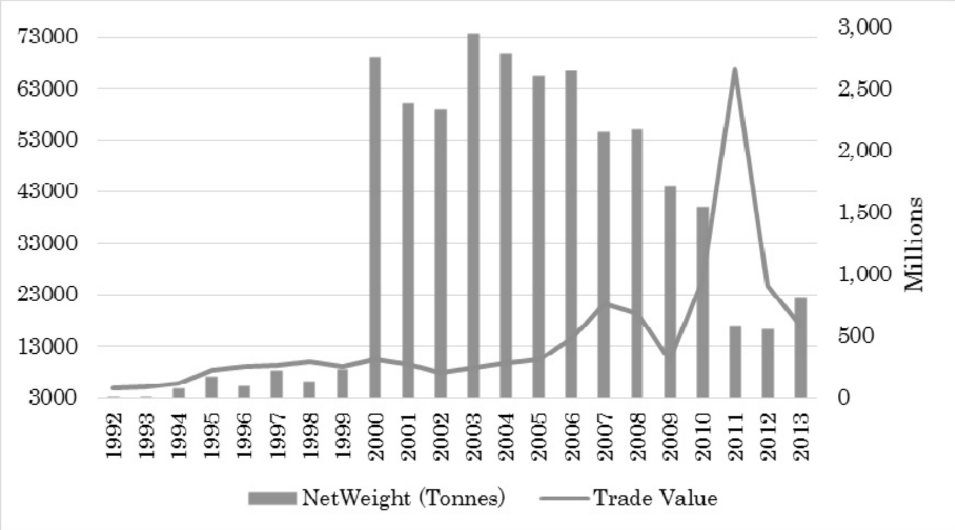
Source: Author's calculations on the basis of UNCOMTRADE database 2014

According to the UNCOMTRADE database, the difference in quantity of total rare earths exports and imports account for almost three thousand tons. This difference is quite large and cannot be explained away as statistical error. One possible reason could be the rare earths are smuggled from countries like China and India. Illicit exports are typically in the form of REEs mixed with iron ore, exported as steel composites or as mineral sands. The process is reversed in the receiving country, which recovers the REEs (British Geological Survey, 2010). In case, the smuggled REEs are accounted for at the receiving country either deliberately or inadvertently, then some portion of this discrepancy could be partially explained. The differences in rankings of the trading countries in terms of value and quantity can be attributed to the fact that rare earths as a group constitute 17 different elements and largely classified as light, medium and heavy. While the supply of light and medium elements are not so critical as compared to heavy rare earths and this reflects in the price volatility as the heavy elements are highly priced and volatile. Some countries may be importing large quantities of light elements with low prices while others may be importing only the more critical heavy elements.

4.21 China's Exports of REEs from 1992 to 2013

With 1.3 billion people and being the fastest growing economy in the world, China is faced with the challenging task of ensuring enough supply of natural resources to sustain economic growth. The increasing consumption by China in recent years has overtaken the world consumption of REEs, impacting the availability of these minerals to outside world.

Figure 4.2: China's Exports of REEs from 1992 to 2013



In 2013, China exported a total of 22,493 tons of rare earths to 43 countries. In quantity wise, a considerable increase from 2011 and 2012 exports. In 1992, the total exports of rare earth from China valued just 74.67 million, in simple calculation, about USD 25 per kilogram, but in 2012, China's total exports of rare earth valued USD 908 million with an average export price of USD 55.88 per kilogram, more than doubling the export price. The price was peaked in 2011 and the issue was contentiously discussed internationally about Chinese export restrictions and supply risks. In 2011, China exported around 16,860 tons of rare earths, a sharp decline from the 2003 quantity of 73,522 tons. The data shows that starting from 2008, the export from China has been declining gradually along with pushing the average price upward reaching its peak of USD 158.21 per kilogram in 2011. It was reported at that time that the average price of some heavy rare earths went up to 800 percent. The price level has moderated since then, reaching almost the level of 2010.

Just as worldwide demand for REE is growing, so is China's own demand. From 1990 to 2014, China's annual consumption has increased from 10,000 tons to 73,000. The main reason for this tremendous growth is because of the ever-increasing domestic production of manufacturing items such as wind turbines, solar panels, and electronic commodities. Growth in demand from China continues to outpace the rest of the world thereby impacting world supply. By the year 2017, it is estimated that the global demand of rare earths is expected to reach 145,000 tons; China's domestic demand will be 86,500 tons accounting for 59 percent of the total global consumption. It can be concluded that rare earth materials has become a major growth point of China's industrialisation (Kingsnorth, 2014).

Table 4.3: China's top 10 customers by quantity and value in 2012 and 2013

Partner	NetWeight (tons)	% Share	Partner	Trade Value million USD	% Share
Japan	6606.52	40.61	Japan	380.731	41.88
USA	3460.72	21.27	USA	145.329	15.98
France	2641.64	16.24	France	126.929	13.96
Hong Kong	559.39	3.43	Hong Kong	84.581	9.30
Italy	464.30	2.85	Germany	27.701	3.04
Viet Nam	419.78	2.58	Netherlands	25.265	2.77
Netherlands	350.53	2.15	Korea	23.738	2.61
Germany	239.86	1.47	Viet Nam	22.515	2.47
Korea	225.72	1.38	Italy	15.353	1.68
Brazil	221.30	1.36	UK	7.732	0.85
Total	16265.43	100	Total	908.972	100
China's top 10 customers by quantity and value in 2013					
Partner	NetWeight (Tons)	% Share	Partner	Trade Value million USD	% Share
USA	8057.54	35.82	Japan	190.962	33.14
Japan	7565.12	33.63	Hong Kong	125.711	21.81
Italy	1598.97	7.10	USA	115.152	19.98
Viet Nam	1217.41	5.41	Netherlands	22.731	3.94
Netherlands	879.50	3.91	Germany	22.283	3.86
France	853.80	3.79	Italy	19.661	3.41
Germany	505.55	2.24	France	19.106	3.31
Hong Kong	446.63	1.98	Korea	17.882	3.10
UK	291.80	1.29	Viet Nam	16.583	2.87
Korea	269.67	1.19	UK	6.075	1.05
Total	22493.30		Total	576.165	

Source: Author's calculations on the basis of UNCOMTRADE database 2014

China, Japan, and the US are the largest consumers of rare earth metals. The quantity and the percentage share of the top 10 customers of China are indicated in Table 4.3. Japan is the largest importer of Chinese rare earths and way ahead of all other importers. In 2012, Japan imported around 6,606 tons of rare earths, accounting almost 40 percent of the total Chinese exports. Around 20 percent of the Chinese exports were destined to western developed countries led by Netherlands, Germany, US, UK, Belgium, Russia etc. With the growing demand for 'green' products, the demand for rare earth metals is only expected to increase. REEs are also needed for China's expansion of its own military needs (aircraft carriers, nuclear-powered submarines, and ballistic missiles). Home-grown production needs will further cut exports. Not surprisingly, the Chinese export restrictions of REEs have raised real concerns outside China regarding the future availability.

4.3 Rare Earth Export Restrictions of China

Several objectives motivate implementing export restrictions on raw materials. In some cases, this can be understood as a response to market imperfections. Many export restrictions are put into place for environmental reasons or to preserve natural resources. In other cases, export restrictions are imposed in order to encourage supply of raw materials to domestic producers of downstream semi-processed goods. On September 23, 2010, exports of REEs from China to Japan apparently stopped due to a dispute over maritime boundaries, raising concerns about the impact of China's strategic hold on these precious metals.

Since 2007, China has announced a number of changes affecting the rare earths sector. These changes included a reduction in the total amount of rare earths that may be exported from China besides other measures (Hatch, 2010). According to the Chinese Government document '2009-15 Rare Earth Industry Development Plan', in the next six years, no new rare earth mining permit will be approved and the separation of newly formed rare earth smelting companies will be strictly reviewed (Tu, 2010).

4.31 Chinese Rare Earth Export Quotas

Export quotas fix a limit on the volume of exports of a given material. China, for example, imposes export quotas on a number of raw materials, including coke, fluorspar, magnesium carbonate, molybdenum, silicon carbide, tin, and tungsten. These quotas may be supplemented by an export quota bidding system. Under this system, qualified companies are allowed to bid for the right to export a given quantity of a material subject to an export quota.

In recent years, the Chinese Government has cut down the volume of export enterprises, export quotas and annual exploitation volume of rare earth ores. China's Ministry of Commerce (MOFCOM) allots these quotas to companies. This was an alarming indication to Japan and Western countries as the export quota declined almost 50 percent from between 2008 and 2014 (Table 4.4). Although China's export curbs have created opportunities to open mines or revive dormant production in Canada, Australia and the US, none of these projects could emerge as an alternative to Chinese supply. There has been much speculation about China's future policy on rare earths. However, it is quite clear that China has been systematically and methodically been reducing quotas (Kara et al, 2010). However, in January 2015, in response to unfavorable WTO ruling, the country has abolished the quota system and a more stringent licensing system for exporters is being implemented.

Table 4.4: Chinese export quota and demand from rest of the world (ROW)
2005–2010 (Tons REO)

Year	Domestic Companies	Foreign Companies	Total	Change	ROW Demand
2005	48,048t	17,657	65,609	-	46,000t
2006	45,752t	16,069	61,821	-6%	50,000t
2007	43574t	16,069	59,643	-4%	50,000t
2008	40,987t	15,834	56,939	-5.50%	50,000t
2009	33,300t	16845	50,145	-12%	25,000t
2010	22,512	7,746	30,258	-39.6%	48,000t
2011	22,983	7,263	30,246	-0.04	35,000
2012	22,406	8,590	30,996	2.47	39,500
2013	22,299	8,700	30,999	0.0096	37,500
2014	22,792	7,819	30,611	-1.25	44000

Source: Chinese Ministry of Commerce and Kingsnorth (2014) http://wms.mofcom.gov.cn/article/zcfb/d/p/201312/20131200424659.shtml

The Chinese Government had policy of allocating quotas near the end of the year, followed by a smaller supplemental allocation in the summer. The latest allocation of quota before the system abandoned in January 2014, the Chinese Government had allowed 29 rare earth producers and distributors to export a total 30,611 tons in 2014, a 1.25 percent reduction compared to the previous year. During quota regime, China didn't distinguish between the individual rare earth oxides, but divided the total tonnage of exports as light rare earth and medium-and-heavy rare earth. This has led to Chinese companies exporting as much as possible of the high value heavy rare earths like dysprosium, instead of low-value light rare earths like cerium. According to the revised 2009-15 Development Plan of the Rare Earth Industry, prepared by the Ministry of Industry and Information Technology (MIIT), the annual REO export from China will be restricted below 35,000 tons between 2009 and 2015. In addition, China will only produce 130-150 kilo tons of REO, annually (Tu, 2010). If the aforementioned targets be strictly enforced, then the existing stockpiles outside China are expected to be exhausted over time, which will further strengthen China's competitiveness. The recent actions such as consolidating the whole industry by the central and provincial governments in China suggest that they view the industry as more strategic than ever before and intent to divert more supply for domestic use in high end products.

4.32 Export Taxes on Rare Earth Exports from China

Export taxes are not prohibited by the WTO. About one third of WTO members impose export duties. In contrast, on the basis of the recognition that export taxes distort trade, many regional trade agreements have prohibited them. Countries that use export taxes commonly impose higher rates on exports of raw materials than on exports of processed goods. They frequently justify such differential export taxes as a means to diversify exports and to develop a domestic processing industry. Export taxes are sometimes used with other mechanisms, such as indirect taxes, import tariffs (on both the product itself and on inputs), and exchange rate policy, to promote the development of a domestic processing industry; such a strategy is often called import substitution industrialization (Tarp et al, 2002).

In China, the same minerals/products that were subject to quotas were subject to an export tax suggesting that the Chinese Government used both instruments in tandem to restrict exports rather than employing the tax as a revenue raising device (Gordon et al, 2010). Export taxes were applied to many of the rare earth metals originating from China as high as 25 percent.

Table 4.5: Chinese Export taxes on Rare Earths

Rare Earth Materials	Export tariff (2014)
Cerium, Dysprosium oxide, Dysprosium, Dysprosium chloride, Dysprosium carbonate, Other dysprosium compounds, Europium oxide, Lanthanum chloride, Other lanthanum compounds, Neodymium, Other neodymium compounds, Terbium oxide, Terbium, Terbium chloride, Terbium carbonate, Other neodymium compounds, Yttrium oxide, Other unmixed rare earth metals, scandium and yttrium, Praseodymium, Praseodymium oxide, Other praseodymium compounds, Mixed rare earth metals, Scandium and yttrium compound	25.00%
Cerium oxide, Cerium hydroxide, Cerium carbonate, cerium compounds, Dysprosium tetrafluoride, Lanthanum oxide, Lanthanum carbonate, Lanthanum tetrafluoride, Neodymium oxide, Neodymium chloride, Neodymium tetrafluoride, Neodymium carbonate, Terbium tetrafluoride, Other rare earth oxides (except red powder for lamps), Praseodymium chloride, Praseodymium tetrafluoride, Praseodymium carbonate, Mixed rare earth chloride, Unmixed rare earth chloride, Mixed rare earth carbonate, Unmixed rare earth carbonate, Rare earth metal ores, Yttrium chloride, Yttrium tetrafluoride, Yttrium carbonate, Other rare earth tetrafluoride	15.00%
Ferro rare earth alloys	20.00%
Other rare metal ores and concentrates	10.00%

Source: Metal Pages, 2014
http://www.metal-pages.com/resources/chinese-export-tariffs/

China had imposed a 15-25 percent tax on rare earth exports and 41 rare earth products have been listed in the category of prohibited trade. Rare earth exporters, including foreign companies are facing stricter supervision on their qualification. On individual rare earth elements, there is a 15 percent temporary export tax on neodymium used in batteries for hybrid cars including Toyota Motor Corp.'s Prius. Lanthanum, another element also used in hybrids and cerium used for polishing semiconductors, were not taxed till 2010, but taxed at 25 percent since 2011. China's export tax for dysprosium, a critical and heavy element is kept at 25 percent along with terbium. However, starting in May 2015, the Chinese government removed export tariffs on REEs and introduced a new resource tax calculated based on price rather than on production volume. The more critical heavy rare earth concentrates are taxed at a blanket 27 percent across all regions, and light rare earth concentrates are taxed at 11.5 percent in Inner Mongolia, 9.5 percent in Sichuan province, and 7.5 percent in Shandong province (Argus, 2015).

In 2007, China withdrew the refund of VAT (16 percent) on exports of unimproved rare earths, while the refund on higher value-added exports, such as magnets and phosphors remains in place. The effect of this decision, combined with the export tax is that non-Chinese rare earth processors, such as cerium polishing powder producers and rare earth magnet producers pay more for rare earth raw materials (plus transport and storage costs), than their Chinese counterparts.

China has begun to implement strict regulations to control the rare earth industry. For example, the Ministry of Land and Resources (MLR) implemented a regulation starting from 2009, which would protect and make rational use of China's superior natural resources, in particular tungsten, antimony and rare earth ores. According to the regulation, the MLR is suspending any applications nationwide for survey or mining licenses for rare earth ores. The goal for controlling the rare earth industry in China is to prevent over-exploitation and blind competition, and to advance the effective protection and scientific rational use of these superior mineral resources (Mancheri et al, 2013).

The increased regulation of REEs in China has gained momentum in recent years. Under the direction of the Ministry of Land and Resources (MLR), at least 10 storage facilities are being built as a strategy and managed by the world's largest producer of rare-earth metals; government-controlled Baotou Steel Rare-Earth (Group) Hi-Tech Co. Chinese state media reports say stockpiles may eventually top 100,000 metric tons (Areddy, 2011). The move to build reserves comes as China's supply of rare earth metals to the rest of the world is already shrinking. In response to Chinese restrictions on supply, the high-tech-focused nations—the United States, the European Union, Japan and South Korea—all of which are dependent on China for rare-earth supplies have highlighted stockpiling strategies.

Businesses and policy makers alike are concerned by the increasingly restrictive and unpredictable environment of international trade in industrial raw materials. Multilateral forums governing the use of export restrictions are weak. This creates uncertainty for industries that depend on supply of these materials and raises the risk for investment in both mining and processing facilities worldwide.

There is no evidence that shows that the export restrictions implemented by China had the desired effect on production. In order to fulfill the stated policy objectives of environmental stability and preservation of natural resources, the export restrictions would have resulted in a decrease in the production of rare earth elements in China. This has not been the case as the production has risen continually over the years. This is the reason why China lost the case in WTO.

However, WTO ruling against China will not have considerable impacts on the market, which is already imperfect in case of rare earths. This could be considered as a political win against an assertive and rising economic player. Even though China applied a number of restrictions on export of REEs, there were enough supply to meet international demand and several times even the allocated quotas were not fully exported due to lack of demand from abroad. As a result the prices for most of the rare earth minerals have almost declined to the level of pre-bubble time of 2011.

China has started complying with the WTO ruling and has partially removed its export restrictions such as quotas, fearing substantial repercussions. Foreseeing an unfavorable ruling, the country had already initiated a number of steps to control its resources, such as a major drive to consolidate the industry into a few big conglomerates. Over the last few years, almost 300 REE-producing firms were either ordered to suspend production or had their production licenses revoked. As part of consolidation, six major state-owned enterprises (SOEs) were ordered to complete integration by the end of 2015, merging all legitimate mining, smelting, separation, and utilization companies into six large national rare-earth conglomerates based on their geographic locations (See Chapter 10 for details of the integration plan).

The consolidation of industry along with the curtailing of illegal mining would enable China to effectively control its supply and set the prices to an extent. As an industry that China has developed strategically since the early 1990s, China wants (and has achieved) domestic control of the entire supply chain, from mining to end products. Under the current situation, any high-end REE products must originate or pass through China's vast value chain. Even US defense industries are dependent on China for some advanced materials and components, including magnets used in F-35 fighter jets. Many US chemical, steel, and non-ferrous metal industries and their downstream clients rely heavily on imports from China, as several of the raw materials can only be sourced there.

China is assiduously building up dominant positions in entire supply chains of REEs. The country incentivizes companies to produce more technologically advanced products rather than exporting raw materials, and it continues to strengthen its capabilities in refining metals, alloys, components, and material science research facilities. Over the last decade, China has encouraged nearly every major multinational using REEs to move their manufacturing facilities to China or to establish subsidiaries in the country. From being a laggard and a follower, China has successfully overtaken more advanced countries in the REE industry and has gained control over the whole value chain.

China should implement better environmental and labor standards and measures targeting illegal mining and smuggling to naturally increase the prices for domestic resources. Increasing the domestic price may compensate the loss-making SOEs and would reduce the huge imbalance between domestic and international prices for REEs. In the longer term, this would also help China cut its overcapacity, improve the environment, and better price for what it produce.

5 Supply Chain Dynamics of Japan's Rare Earth Industry

Risk in mineral resource procurement has been increasing due to excessive oligopolies and an increase in resource nationalism. The international market related to rare earth minerals, which are essential for future manufacturing industries has become so volatile and uncertain. The stable procurement of mineral resources required for production activities has become an important issue for management at Japanese resource using companies. Japan is totally dependent on imports for mineral resources, despite the fact that manufacturing is the backbone of Japanese economy. Therefore the issue of stable supply is also important for the Japanese government, with its significant influence on the country's industrial competitiveness.

The overdependence on China for these minerals is a major issue in Japan and perceived as a great risk particularly after the Senkaku-Diaoyu incident in 2010. Since then, the Japanese companies along with the active support of Japanese government have been trying to diversify their supply chain away from China. However, these policies have not been successful all the time. The companies who ventured into non-Chinese territories looking for rare earths are actually riding against the market fundamentals and some of them have abandoned their plans. Trying with alternate supply, there are also new initiatives to recycle the RE minerals in Japan and other R&D initiatives on replacing the RE minerals with non-critical minerals in major industrial applications.

As the competition over resources and market increase particularly from the countries like China, it has become harder for Japanese companies to secure resources and market. Japan is the major consumer of resources including rare earths. Therefore, in negotiations at the resource development stage, Japanese companies could negotiate more efficiently than companies from other countries by promising to buy a large amount of resources over the long term and some of Japanese companies have used this strategy in developing new mines. These days, however, China has become a major new consumer of resources displacing Japan and Japan's competitive superiority. Resource supply risks will continue to be a major issue for Japanese companies in the future as a result of international developments and changes in the supply and demand balance.

5.1 Japan's Import of REs from China and the World

Japan has expressed a sense of urgency to secure new non-Chinese supplies of REEs since the September 2010 maritime incident with China and the claim of a Chinese supply embargo of REEs and other materials. Japan used import almost 100 percent of its REE requirements from China. Close to forty percent of China's REE exports go to Japan and about 20% to the United States. In order to diversify the supply, Japan-based firms and the Japanese government are making a number of joint venture agreements and potential partnerships around the world to secure supplies of REEs, particularly at the raw material stage.

Figure 5.1: Japan's import of REs from China and the World (Quantity 1990-2014)

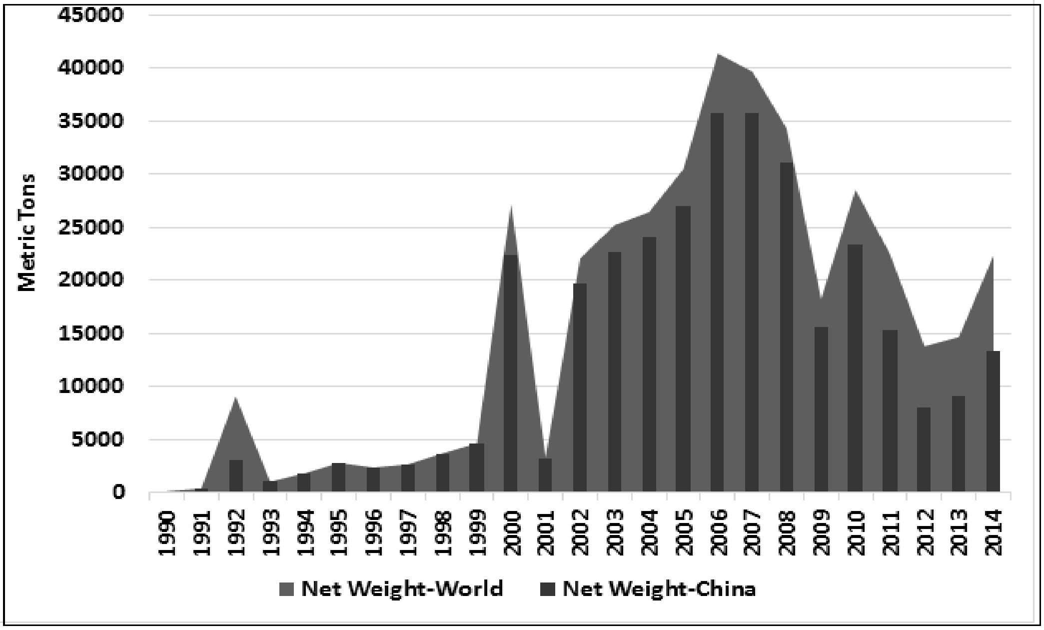
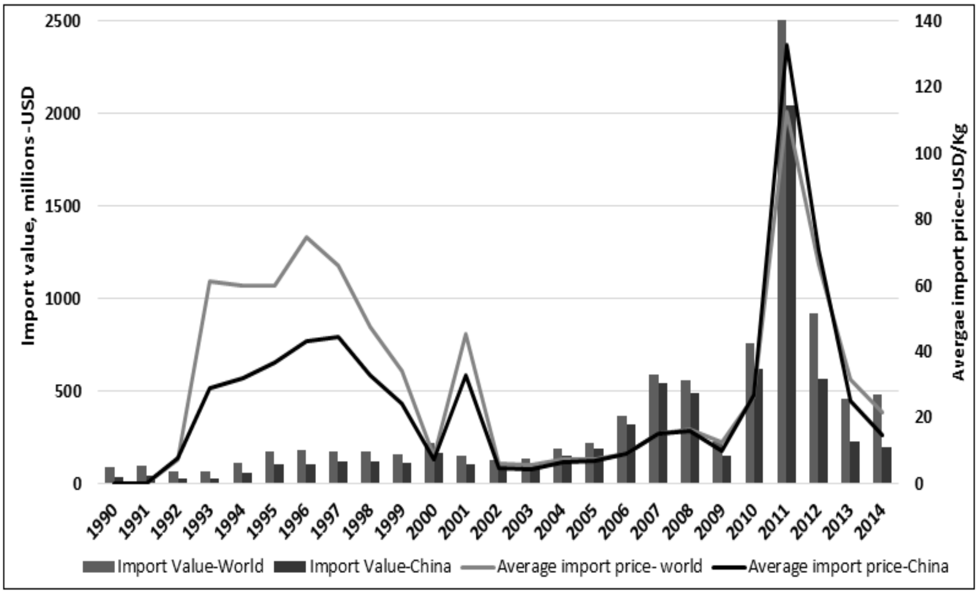


Figure 5.1 shows Japan's import of rare earths such as rare-earth metals, scandium and yttrium and compounds, inorganic or organic of rate-earth metals, of yttrium or of scandium or of mixtures of these metals from the world and China. The figure shows that in 1990 Japan imported a total of 1,799 tons of rare earths out of which 1,285 tons were imported from China. The import from China as well as other countries peaked to its highest level in 2006, reaching 41,408 tons and import from China was

35,749 tons. Since then the import volume has declined considerably. The declining trend started during the global financial crisis, reached its lowest level in 2012 with a total import of 13,829 tons, of which, 8,013 tons were imported from China. However, last two years (2013-2014) have seen a considerable increase in Japanese imports of REs with a sharp increase in 2014 accounting 22,307 tons of total imports with a China's share of more than 50 percent.

Currently, several critical areas of the Japanese economy, including clean energy technologies, national defense and high-tech manufacturing, are at risk largely because of two reasons. One, Japan's dependence on critical minerals such as rare earths are not mined, processed and traded in healthy and robust markets. As a result, Japan has become dependent on unreliable trading partners such as China. Rare earths are indispensable for the manufacturing of automobiles and electronic products, the sectors which are most important to Japanese economy. Therefore, it has become extremely important to ensure stable supplies of such metals from the standpoint of maintaining and strengthening the competitiveness of Japan's manufacturing industry. In the meantime, the environment surrounding the supply of such metals remains unstable and there are concerns about possible supply and price shocks. The following figure gives an idea about Japan's import of rare earths in value terms and it shows a great volatility in the market.

Figure 5.2: Japan's Import of REs from China and the World (Value 1990-2014)



Source: Author's calculations based on the UNCOMTRADE database 2015

Figure 5.2 shows that Japan's import of rare earths from China and the world in value terms along with average import price per kilogram. Japan had imported a total of USD 89 million worth of RE commodities in 1990 and import from China valued about 34 million at that time, around 45 percent of total imports. The import value increased to 170 million by 1995 along with 102 million worth of import from China in same year. As in the case of import volume, the import value also surged to 592 million in 2007 and the import from China valued 543 million. Japan's imports of rare earths in value terms almost remained stable until 2010 in contrast to the total imports in terms of volume, which has grown outstandingly over the years as shown in Figure 5.1. By 2010, it was clear that Chinse export restrictions had a direct impact on the market and the September 2010 incident related to territorial disputes at East China Sea and China's apparent halting of rare earth exports to Japan triggered a price surge for rare earths both in China and in the international market. Though Japan had cut short its import of rare earths both from China and rest of the world, the import bill amounted to USD 2.5 billion and more than 2 billion was paid to imports from China in 2011. In 2014, Japan increased its imports of REs, which was equal to USD 484 million in total and imports from China valued 196 million, which was about 40 percent of its total imports.

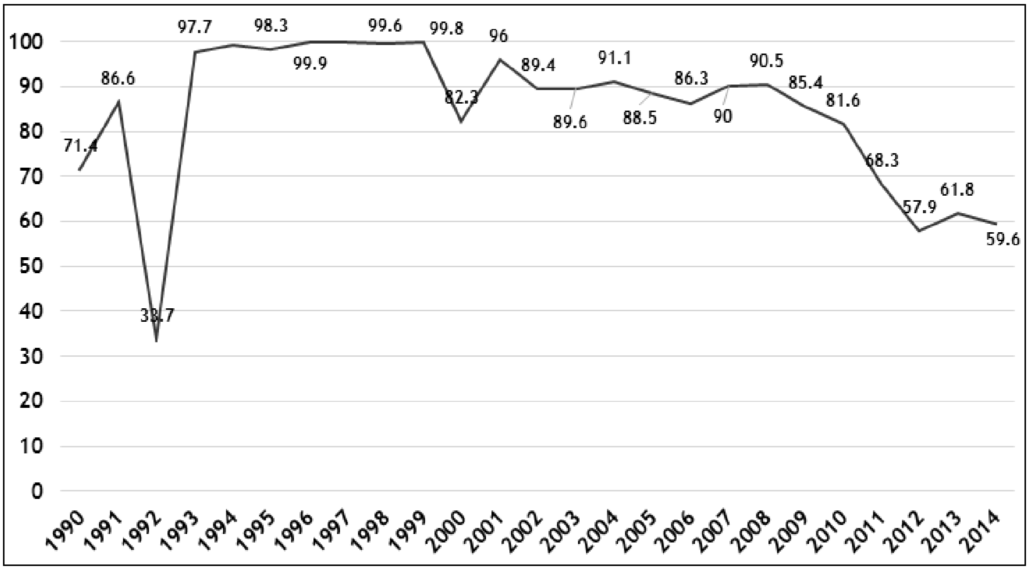
Figure 5.2 also shows the average import price per kilogram Japan paid for its imports of rare earths from China and rest of the world from 1990 to 2014. This also reflects the global developments in rare earth industry. The average prices were almost equal for rare earths import from China as well as other countries in 1990 and 1991. However, between 1992 and 1997, there has been a huge gap between the price in China and global price. The price started to decline sharply from 1997 when China ramped up its production of rare earths in 1990s and flooded the market. The sharp decline in prices and Chinese supply pressured Molycorp mine in Mountain Pass, California, the only producer at that time in North America, to close the operation in 1998. The price remained almost static until 2007 and China's price was comparatively lower than international market price during these periods. In 1993, Japan's average import price for rare earths from countries other than China was above 61 US dollar per kilogram, while average price for Chinese rare earths was about 28.84 US dollar. The price has been increasing till 1997 internationally as well as for China's REs and Japan's average import price reached 65 dollar per kilogram and average price for import from China was 44 dollar per kilogram.

Since then the price has continued to decline, reaching its lowest level in 2003 when Japan's average import price was just 4.48 dollar per kilogram for the import of rare earths from China. Price remained almost static in this range with marginal increases until 2010 when the price surged to 26 dollar per kilogram for imports from China as well as rest of the world. The industry reached its peak in 2011 and 2012 and Japan's average import price reached 132.82 per kilogram and 112.58 per kilogram from China and rest of the world respectively. However, the price fell again considerably in post 2013 and in 2014 the average import price was 21.74 dollar per kilogram and import from China valued 14.79 dollar per kilogram. There is a considerable gap between the international price and China price, a situation of late 1990s where cheap resources from China had forced out others from the market including operations at Mountain Pass. Echoing the past developments in the industry, in August 2015, Molycorp announced that it is suspending the production of rare earths again unable to compete with China's price as the company never recovered from its financial turmoil.

5.2 Japan's Rare Earths Dependence on China

While these materials are generally used in low volumes relative to other resources, the anticipated deployment of clean energy technologies are expected to substantially increase the worldwide demand for these minerals. The importance of green energy in Japan has increased many folds particularly after Fukushima incident. Investments in green technology will continue to increase to ensure the energy without the risk to the environment. It would be relevant to study how much of these minerals are important to Japanese green technology companies and how do these green energy sources rely on rare earth minerals. What result will that have on these energy sources? What sectors of the Japanese economy could be significantly affected if the supply of any of these minerals is curtailed?

Figure 5.3: Japan's RE dependence on China (in percent)



Source: Author's calculations based on the UNCOMTRADE database 2015

The overdependence on China for rare earth minerals is a major issue in Japan and perceived as a great risk particularly after the Senkaku-Diaoyu incident of 2010. Figure 5.3 shows that Japan used to depend on China for almost 100 percent in the second half of 1990s and the trend continued around 90 percent till the global financial crisis. Japan has been trying to reduce its dependence on China since 2008 as the Chinese export restrictions and quota system became strong. In 2008, 90 percent of Japan's total RE imports were from China and by 2011 at the height of the RE crisis, dependency declined to 57.9 percent and it has remained around 60 percent since then.

Even prior to the informal embargo of rare earth exports to Japan in 2010, Chinese experts and nationalists who are aware of the importance of REEs were anguishing over loss of China's national wealth at low rates to its rival countries such as Japan and Western countries. Xu Guangxian, China's "Father of Rare Earths," has been vocal to build up strategic reserves of rare earths in China. On November 2nd, 2009, in an interview to *China Economy Times*, Xu, complained publicly that Japan and South Korea have built up stockpiles, which are enough for 20 years of consumption by taking advantage of low market prices of Chinese oversupply. He was pushing the government on policy issues and suggesting the major rare earth producers such as Baotou, Minmetals, and Jiangxi Copper to formulate stockpiling strategies. He also criticized the government's inability to prevent smuggling of Chinese natural resources to Japan, claiming that Japan gets approximately 20 per cent of its rare earths from China's black market (Rare Element Resources Ltd, 2009). The REE embargo episode in 2010 had sent clear indication to the leaders around the world about China's real intentions and that a more powerful China might use its economic leverage or similar forms as a weapon. Given the critical reliance on rare earths for different military applications from missile to radars to satellites and promising new technologies, the exclusive reliance on China as a sole source of supply is a great risk. However, unlike in this case, Chinese capacity and willingness to use its economic strength to leverage political disputes may lead to countermeasures by other countries, which may not be in China's long-term strategic interests.

5.3 Japan's Efforts to Diversify Supply Away from China

As in the case of global RE Industry, between 2010 and 2012, there was great panic in the industry in Japan too and uncertainty about future supply. The shock appeared from two angles, one from the reduced Chinese supply and another one from the dramatic increase in prices. For example, in 2009 Japan had paid an import bill of just USD 154 million for 15,000 tons of rare earths from China, but in 2011 for the same quantity of 15, 000 tons, the import bill was above USD 2.04 billion. In an effort to diversify the supply, broad collaborative actions have been initiated between Japanese government agencies and private companies with financial helps from the government. The high-tech industry in Japan relies on these metals and also, in turn, exports these high-tech products to the United States and throughout the world. Without raw materials, a lot of Japanese industries, from multinationals to tiny factories, will be forced to suspend activity. Since Japan is prominent in the production of certain high-tech products, a disruption of RE supply to Japan would not only upsets the country, but would disrupt the entire market (Yu, 2012). Therefore, Japan has responded swiftly to address potential shortages. For example with the help of Japan Oil, Gas and Metals National Corporation (JOGMEC), Toyota Tsusho and others are investigating potential sites around the world to secure supply of rare earths outside China.

In order to secure a stable supply, even before the 2010 crisis Japanese government had initiated a number of policies. In 2005, a "Resources Strategy Committee" was founded on behalf of the Japanese Agency for Natural Resources and Energy. In 2006, the Agency published a report on "Strategies for Securing a Stable Supply on Non-Ferrous Metal Resources" (Kawamoto, 2008). The report had emphasized four points such as encouraging exploration and development; encouraging recycling; encouraging development of substitute materials; stockpiling that is already performed. To secure a stable supply the following actions were considered: Adopting a diplomatic approach with countries rich in raw materials by supporting their exploration and development of resources; Recycling of raw materials through the whole production chain; Developing of recycling technologies and mainly for problematic materials that difficult to be recycled; Developing of substitutes for materials that are critical for the supply chain; Gathering of information—geopolitical and resource data (Vateva, 2012). There were also scientific projects such as "Elements Strategy Project" by the Ministry of Education, Culture, Sports, Science and Technology and "Development Project on Rare Metals Substitution" to promote the development of high efficient substances and materials without the use of rare metals and hazardous elements, which can be used as substitutes to these elements (Kawamoto 2008).

The Japanese government has also stepped in by creating a US$1.25 billion integrated policy to try to mitigate any future disruptions. Out of this fund, US$490 million was allocated toward improving the production of REEs through technological innovation and US$370 million was allocated towards supporting Japan's foreign rare earth mining ventures. Japan is also planning to spend money on research and development to come up with alternatives and other projects (Hurst, 2011).

Table 5.1: Japan's import of rare earth products in 2007

Partners	Net Weight (in Kg)	Partners	Value in USD
World	39,724,019	World	$592,597,621
China	35,784,167 (90%)	China	$543,404,618 (92%)
Estonia	1,445,752	France	$17,745,849
France	1,245,364	Norway	$12,705,260
India	540,671	Estonia	$5,468,364
Kazakhstan	245,400	USA	$4,600,357
USA	101,918	Rep. of Korea	$1,856,547
Rep. of Korea	99745	Germany	$1,556,946
Russia	44,610	Russia	$1,139,712
Austria	5,274	Kazakhstan	$889,745
Germany	4,243	India	$822,345
Norway	3,086	Austria	$794,711
Mongolia	1,000	Denmark	$332,392
Italy	750	Italy	$116,611
Denmark	400	U.K	$34,185
Kyrgyzstan	382	Kyrgyzstan	$17,654
U.K	35	Mongolia	$7,359

Source: UNCOMTRADE database 2015

Table 5.1 shows Japan's import of rare earths from China as well as other countries in 2007. The table shows that Japan's dependence on China and rest of the world for rare earths before the current turmoil. Japan had imported a total 39,000 metric tons of rare earths in 2007, and out of this, 35,000 tons were imported from China, more than 90 percent of its total imports. Remaining 4,000 tons (10 percent of the total) were imported from 16 countries including Estonia and France. In value terms, the total import was equal to USD 592 million and import from China was equal to USD 543 million, more than 92 percent of total rare earth imports. So the following section explains whether Japan's efforts to diversify the supply away from China were successful and if so how much. After the 2011 crisis dozens of rare earths projects have been propped up all over the world. Japanese companies with active support of the government have been part of some of these projects.

Figure 5.4: New REE mining projects around the world

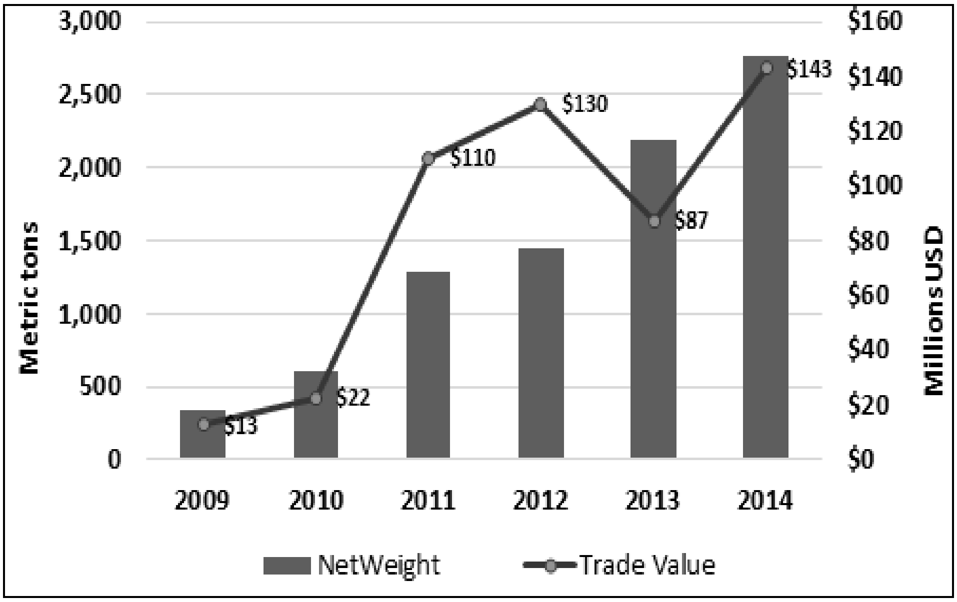
There are commercially viable rare earth mineral (REM) deposits in many countries as shown in Figure 5.4. Japanese companies have developed ties with REM reserve holders such as Vietnam, Kazakhstan, Australia, Brazil and India. These countries can supply Japan with alternative sources so that the Japanese are not reliant solely upon China. But these efforts to diversify supply have not been successful all the time. The problems in developing alternate supply are discussed in detail in chapter 8 of this book.

5.31 Japan's imports of rare earth from Vietnam

Japan has realized the overdependence on China for rare earths even before the 2010-11 crisis and way back in 2008 Toyota Tsusho and Sojitz Corporations had established a joint venture with Coal and Mineral Industries Group (Vinacomin), a Vietnamese state-run company. Vietnam holds one of the largest REM reserves in the world. Many of the Vietnamese reserves are untapped and are located in the northwestern part of the country, such as in the Province of Lai Chau. In exchange for financial and technical support, Japan acquired the right to mine REEs at the Dong Pao mine in Lai Chau province, Vietnam. This venture is followed by preparations for a refinery plant focusing on the production of cerium, lanthanum and neodymium.

Also Sumitomo Corporation, Japan's third largest trading company, launched a feasibility study on a mine in Yen Bai, located in the northern province of Vietnam during the crisis. They were expected to start exporting rare earths to Japan as early as 2013.

Figure 5.5: Japan's import of rare earths from Vietnam



Source: Compiled from Ministry of Finance, Japan, Trade statistics database, 2015 http://www.customs.go.jp/toukei/srch/indexe.htm

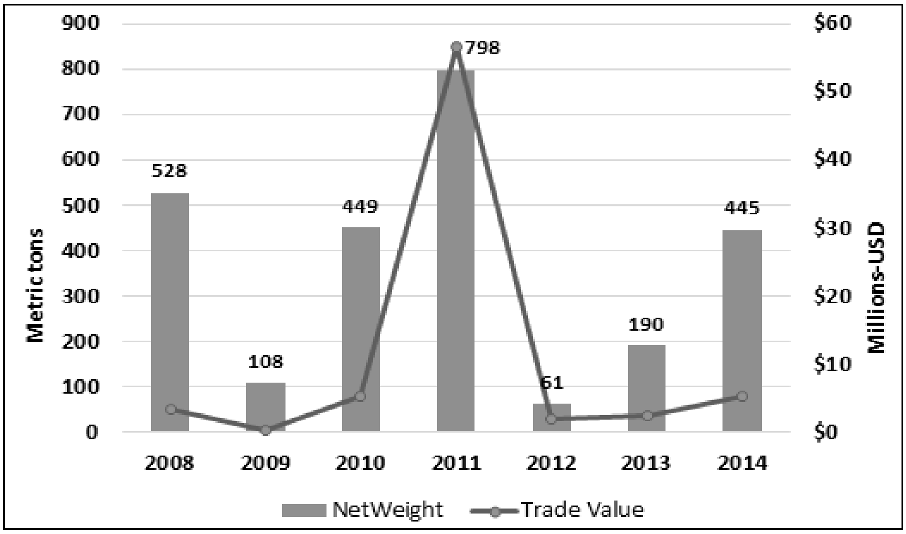
Through these projects, Japan has ensured a stable annual supply of REM from Vietnam. Starting with a 334 metric tons of import in 2009, the volume has continuously increased, reaching 2758 tons in 2014, which was equal to USD 143 million. In 2012, Japan and Vietnam launched a joint rare earth research and technology transfer center in Hanoi to carry out research on the production of the materials utilized in the technology industry. Japan funds the equipment for the center and Vietnam pays the construction costs. There are Japanese scientists who stay in the center and collaborate with

Vietnamese researchers from the Institute for Technology of Radioactive and Rare Elements (Fuyuno 2012).

5.32 Japan's imports of rare earth from Kazakhstan

While Kazakhstan is a new player in the REM industry, Japanese companies are helping the country to become a significant competitor to the Chinese rare earth supply. Sumitomo is working with Kazakhstan's state nuclear company to produce light rare earths and dysprosium (1,500 tons a year). Sumitomo had opened a plant in a joint venture with Kazakhstan's National Atomic Company, also known as Kazatomprom. The two invested a total of about $30 million to create Summit Atom Rare Earth Company in 2009 with the Kazakhstan side controlling 51% stakes. They were expecting the production output could reach 6,000 metric tons by 2017. The plant extract the deposits through refining soil left in an old uranium mine. Production includes "high content of dysprosium and neodymium" –two of the 17 types of rare earth minerals.

Figure 5.6: Japan's import of rare earths from Kazakhstan



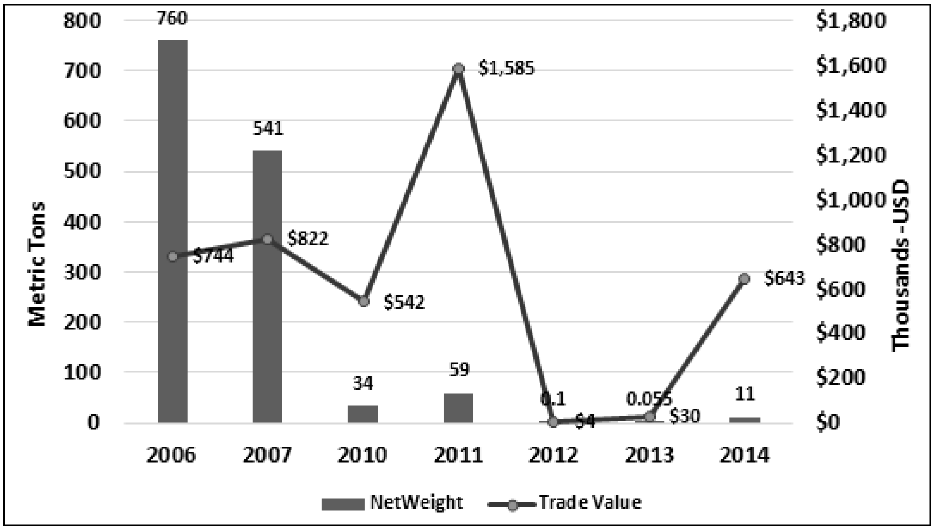
Source: Compiled from Ministry of Finance, Japan, Trade statistics database, 2015
http://www.customs.go.jp/toukei/srch/indexe.htm

In 2012, the Japanese and Kazakh governments also had signed an agreement to jointly develop REM critical to electronic applications, weaving a path for partnership between Japanese and Kazakh companies. In this joint development, a REM plant being built in Stepnogorsk—located in northern Kazakhstan—to produce dysprosium, which is crucial to the production of the motors of electric and hybrid vehicles. The agreement ensures that Japan will receive 55 tons of dysprosium per year from the plant. This number makes up around 10% of the Japanese annual demand for dysprosium and is expected to increase yearly. However, the data shows that the targeted production level are not achieved yet as the maximum volume of import was 798 tons in 2011 and in 2014, the import was just 445 tons valuing around 5 million USD. The joint venture Company had also signed sales contracts with Sumitomo Corp and two other companies, Japan's Shin-Etsu Chemical Co and French chemicals group Rhodia.

5.33 Japan's imports of rare earth from India

India has been producing marginal quantity of light rare earths for many decades and it holds a considerable quantity of rare earths in monazite bearing beach sand minerals. It is estimated that India currently holds about 3 percent of global rare earth reserves. India stopped producing rare earths in 2004, because of lack of competitiveness. In 2009, the Indian government invested around 32 million dollars in a 5,000 metric tons capacity plant built in Indian state of Orissa (Mukherjee 2010). In October 29, 2011, Asahi Shimbun reported that the Foreign Minister of Japan and the Indian Minister of External Affairs agreed for a joint development of a rare earth project on backdrop of a negotiation for nuclear energy treaty (Matsumura, 2011). Indian Rare Earths, an Indian government entity, and Toyota Tsusho had signed a contract in 2009, for supplying raw materials. But it was later dissolved by India, which wanted to price the materials at above-market value in light of China's export restrictions. However, the deal went through later and a cooperative agreement has been signed between India Rare Earths Ltd (IREL) and Toyota Tsusho in 2012.

Figure 5.7: Japan's import of rare earths from India



Source: Compiled from Ministry of Finance, Japan, Trade statistics database, 2015 http://www.customs.go.jp/toukei/srch/indexe.htm

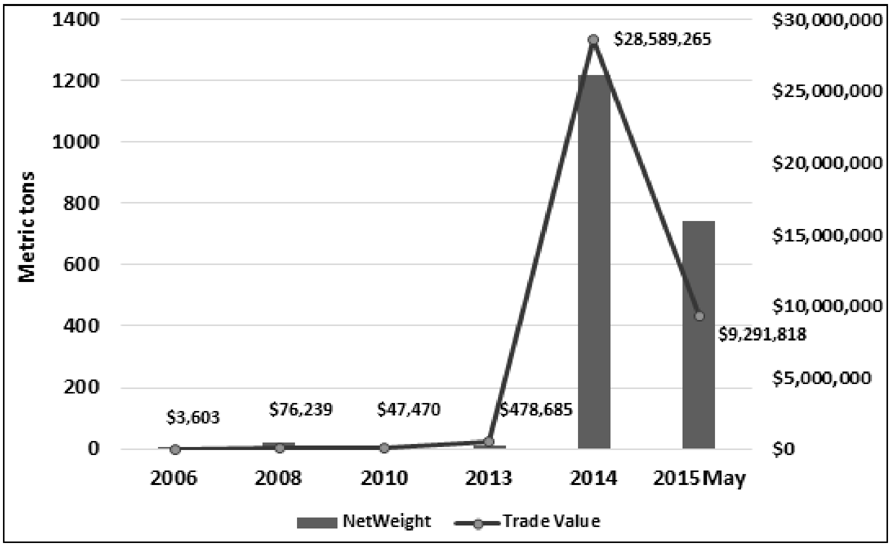
Toyota Tsusho established a subsidiary called Toyotsu Rare Earths India Pvt Ltd in Indian state of Andhra Pradesh and started operations in October 2013. The company process ores supplied by IREL from its plant, Odisha Sand Complex. A number of issues have affected the complete operationalization of the plant. Pricing of rare earth ores remains a sticky point between India and Japan as the price of the REs has come down substantially. Figure 5.7 also shows that a considerable quantity of RE import from India in 2006 and 2007, even before the current negotiations started. During this time it was reported that some private companies were involved in beach sand mining and smuggling in the form of concentrates. Illegal export of REE bearing monazite ore to countries like Japan and China has also been reported in press (Das, 2012).

5.34 Lynas production in Malaysia

The REO reserves in Malaysia is estimated to be around 30,000 tons, they consist largely of light rare earths in monazite concentrates and xenotime that contains more of the heavy rare earth elements like yttrium. Both these minerals contain some radioactive elements. The rare earth minerals currently mined in Malaysia are mainly byproducts from tin production. There used to be two processing plants in Malaysia: Asian Rare Earth (ARE) and MAREC. ARE was established by a joint venture between Mitsubishi Chemical Industries and BEH Minerals. The rare earth containing minerals were processed into a concentrate of about 50%, which was then shipped to Japan for further purification. MAREC produced yttrium oxide from xenotime. However, both these plants were shut down because of problems with the radioactive waste from the production. The clean-up is still ongoing.

In a bigger move in 2010, JOGMEC and a Japanese trading company Sojitz invested $250 million in Lynas rare earth project at Mount Weld, Western Australia in exchange for an agreement allowing Sojitz to purchase 8,500 metric tons per year of rare earths processed in Malaysia by Lynas for the next ten years. The separation plant of Lynas has been technically and financially supported by Solvay, JOGMEC and Sojitz. Japanese manufacturers used to import the products of Nd and/or Pr oxide from Lynas through Vietnamese rare earths smelters, and now they are also directly importing from Malaysia. Lynas has been mining in Australia for more than two years, although it did not complete construction and permitting for its new processing plant in Malaysia until April 2013.

Figure 5.7: Japan's import of rare earths from Malaysia



Source: Compiled from Ministry of Finance, Japan, Trade statistics database, 2015
http://www.customs.go.jp/toukei/srch/indexe.htm

Before operationalization of Lynas' plant in Malaysia, Japan didn't have a considerable amount of imports from the country. Japan had imported around 9 tons in 2013 as the processing started only in October 2013 and the quantity increased to 1200 tons in 2014, which was valued USD 28.58 million. Import shows an increasing trend and Japan has imported 744 tons of rare earths from Malaysia by May 2015, which was equal to USD 9.29 million. Lynas now has the capacity to produce 11,000 metric tons of rare earth oxides annually and will soon complete construction to double that capacity, although it is methodically working out the kinks in its process and waiting for higher market prices before actually expanding production of oxides to that level.

It is estimated that the Indian deal would provide 15 percent of Japan's needs and if Lynas is able to ramp up production as agreed, Japan could be sourcing more than 60 percent of its expected rare earths import from outside China by 2018

5.35 Other initiatives to diversify the supply

Toyota Tsusho is participating in the Kipawa mineral deposit project in Canada to quickly secure supply of medium and heavy rare earths. The property is owned by a junior mining exploration company named Matamec Explorations Inc based in Quebec. The two companies have signed a sale and purchase agreement (SPA) and a joint venture agreement (JVA) in connection with the Kipawa HREE deposit. Through this transaction, the two corporations intend to continue their fruitful collaboration and complete a feasibility study on the Kipawa deposit.

Under the SPA, Toyota Tsusho acquired from Matamec an undivided interest of 49 percent in the Kipawa deposit for a total consideration not exceeding $16,000,816 CAD which will be used to fund the expenses related to the feasibility study. Matamec was the first rare earth exploration company to sign a JVA with a reputable and experienced end-user company with a substantive international rare earth network. They had planned to start production in 2014 or 2015 (Matamec, 2013).

Toyota Tsusho is also establishing technology for recovering rare earths from tin slag (medium and heavy rare earths) and has completed the construction of a pilot plant on the island of Bangka in Indonesia, which is one of the world's leading tin producers and the company plan to develop processes and build a commercial plant.

In December 2010, Japanese firms Sumitomo and Mitsubishi had signed agreements with Molycorp, which owns the Mountain Pass Mine in California to import rare earths.

5.36 The deals that were withdrawn due to unfavorable market conditions

In September, 2012, Nippon Light Metal had entered into a MOU with the Jamaican Bauxite Institute (JBI) for establishment of a pilot project and to determine the feasibility of a commercial project. The objective was to extract some 1,500 metric tons of rare earths per annum from the bauxite tailings. A state-of-the-art pilot plant, totally financed by a US$5-million investment by the Japanese company Nippon Light Metals, was completed in 2014 to explore the profitable extraction of rare earth minerals from the bauxite waste.

However, due to unfavorable market conditions, both parties have agreed to suspend the process. In October 2014, a Termination Agreement was signed by both parties to formally mark the conclusion of the pilot project and facilitate the transfer of the plant's full ownership to the Jamaica Bauxite Institute (JBI). Over the next two years, the JBI will continue to receive technical expertise in bauxite red mud mineral extraction from Nippon Light. A collaboration agreement has also been formalized to accommodate a two-year research and development program, and a patent application agreement that will protect the JBI's and Nippon Light's interests in the project. JBI, on behalf of the Jamaican Government owns 50 per cent, while Nippon Light Metals owns the other 50 per cent of patent rights of the new technologies. In addition, the pilot facility will be used to conduct a wide range of related experiments (Brooks, 2015).

In another deal to diversify the RE supply, in 2013, Brazilian firm CBMM, the world's biggest niobium producer has signed a cooperation agreement with Japan Oil, Gas and Metals National Corporation (JOGMEC) and compatriots Sojitz Corporation and Mitsubishi Materials Corporation. The details have been not publically available about the deal.

Neo Material Technologies signed a development agreement with Brazil based mining firm Mineracao Taboca in April 2009 to develop Pitinga mine and later Mitsubishi signed a MOU with Neo to fund up to $2.5 million. In return Mitsubishi is to have the right to purchase no less than 20 percent of the annual output of separated REE. However, due to unfavorable market conditions both these Brazilian projects have been suspended or temporarily on hold.

Table 5.2: Japan's import of rare earths and RE based products in 2014

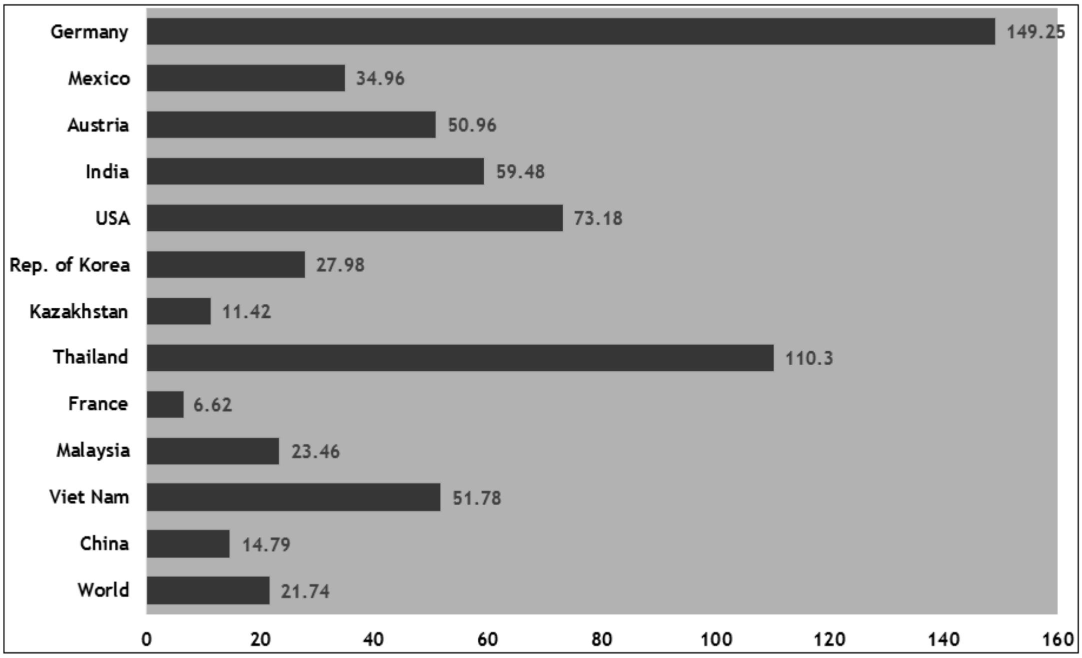
Partners	Net Weight (in Kg)	Partners	Value USD
World	22,307,537	World	484,998,350
China	13,302,599 (59%)	China	196,865,076 (40.5%)
France	3,351,718	Viet Nam	142,829,019
Viet Nam	2,758,025	Italy	52,787,733
Malaysia	1,218,150	Malaysia	28,589,265
Estonia	880,298	France	22,202,851
Kazakhstan	445,320	Thailand	12,279,404
Thailand	111,325	Philippines	8,725,465
Italy	84,808	Kazakhstan	5,088,616
Rep. of Korea	56,131	Estonia	4,696,842
Lao.	52,538	Norway	3,938,896
USA	14,139	Netherlands	1,762,746
Austria	12,436	Rep. of Korea	1,570,631
India	10,806	USA	1,034,731
Philippines	4,012	India	642,806
Germany	2,331	Austria	633,749
Norway	1,224	Lao	556,548
Netherlands	211	Germany	347,907
Kyrgyzstan	76	United Kingdom	74,999
Hong Kong	20	Russia	31,964
U.K	10	Hong Kong SAR	25,195
Mexico	4	Slovenia	19,040
Slovenia	3	Belgium	18,766
Belgium	3	Mexico	4,160
Russia	2	Kyrgyzstan	2,657

Source: UNCOMTRADE database 2015

Table 5.2 shows that the Japan's efforts to diversify supply away China have been successful to a certain extent. The table reveals that the dependence on China for rare earths was 59 percent of Japan's total RE imports in 2014 and in value terms it was 40.5 percent. For example in 2007, Japan had imported above 90 percent of its RE requirement from China both in quantity and value terms and just 10 percent of the total RE imports came from other countries. However, in 2014, 23 countries contributed to more than 40 percent of Japan's total RE imports and close to 60 percent in value terms.

There could be a number of reasons for the differences in percentage between quantity and value of imports from China as shown in Table 5.2 Japan either imported less valued light REs from China and high priced heavy ones from other countries (less likely) or China's price is still low compared to other countries for the same products. If so, it will have many implications, particularly in developing alternative supply sources.

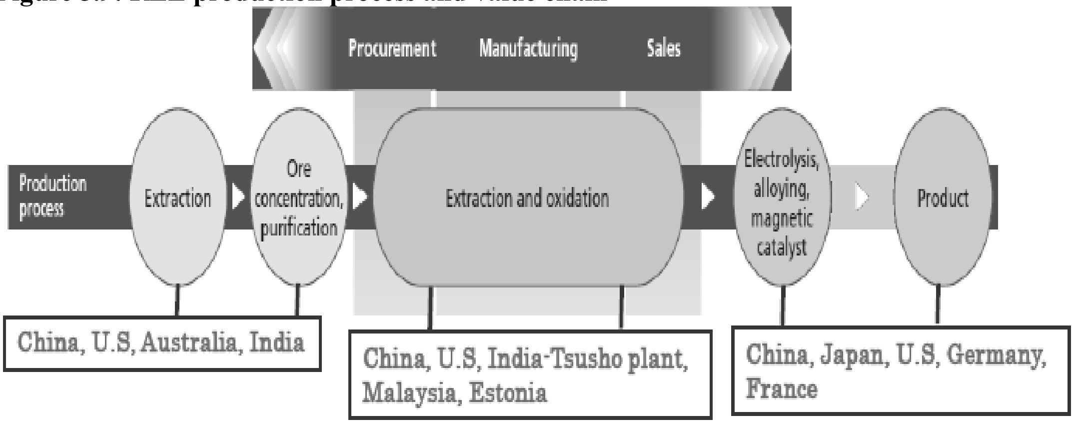
Figure 5.8: Average import price for Japan in 2014 (USD Per Kilogram)



Source: Author's calculations based on the UNCOMTRADE database 2015

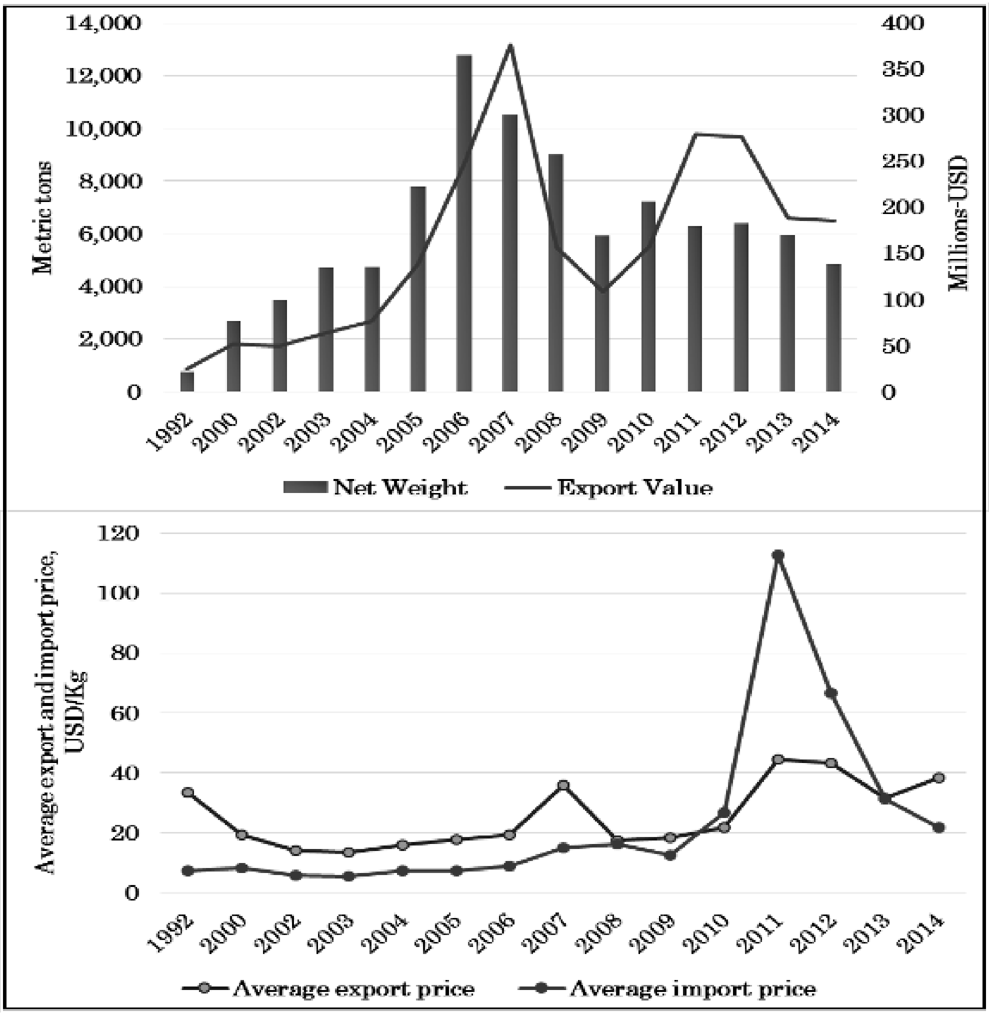
Figure 5.8 reveals Japan's average import price per kilogram of REs and it shows that the import from China is much cheaper compared to other trade partners. In 2014, the average price was around 14.79 USD per kilogram for imports from China. Japan had paid much higher price even to the new suppliers like India and Vietnam in 2014. However, the data shows the average price for imports from Kazakhstan and France was lower than the Chinese price in 2014. Probably Japan might have imported the high priced rare earth metals or alloys rather than oxides from countries like Germany, Austria, United States, and Thailand and this might explain the huge price differences among various trade partners of Japan. The considerable price differences between China and others also make the Japanese companies in disadvantageous position in the value chain if they source these materials outside China.

Figure 5.9: REE production process and value chain



Japan also has some industries processing rare earths domestically but not its own mines. For this reason, it is looking for partnerships with countries rich in rare earths and investing in mining operations in these countries to secure its own supply. The online Chinese newswire (China.org.cn) published an article in August 17, 2011 stating that "Japanese manufacturers have also started to relocate their operations to China in an effort to resolve their lack of rare earth materials" (Yan, 2011). But China will allow this relocation only if there is technology exchange from the side of Japan for raw materials, and if there is only production of low-end technologies there will be no deal. The Japanese Ministry of Trade, Economy and Industry is already giving subsidies at around 15.2 billion yen to its national companies such as Toshiba Corp. and Hitachi Metals Ltd. to work on projects for the minimization and recycling of rare earths. The aim is to reduce rare earth imports from 30,000 metric tons to 20,000 metric tons (Nakamichi, 2011).

Figure 5.10: Japan's export of rare earth elements (oxide, metal and alloys)



Source: Author's calculations based on the UNCOMTRADE database 2015

Japan is not only the importer of REs but also an exporter of value added rare earth products and this aspect will be elaborated in following chapters. Some of the Japanese companies like Shin-Etsu, Santoku, and Toyota Tsusho are active in upstream industries such as electrolysis, alloying and magnetic manufacturing fields. The export of these value added RE products from Japan has grown substantially in last two decades both in quantity and value terms. As Figure 5.10 shows, the quantity of Japanese exports of purified rare earths has increased from 745 metric tons in 1992 to its peak of 12,778 tons in 2006, then gradually declined to 4,831 tons in 2014. Previously, we have found a similar trend in Japan's import of these minerals. The figure also shows an increasing value of exports till 2007 and drastic decline during the global financial crisis followed by an increase in prices until 2011 and a declining trend later, which is highly reflective of the global trend in rare earth industry we discussed in previous chapters.

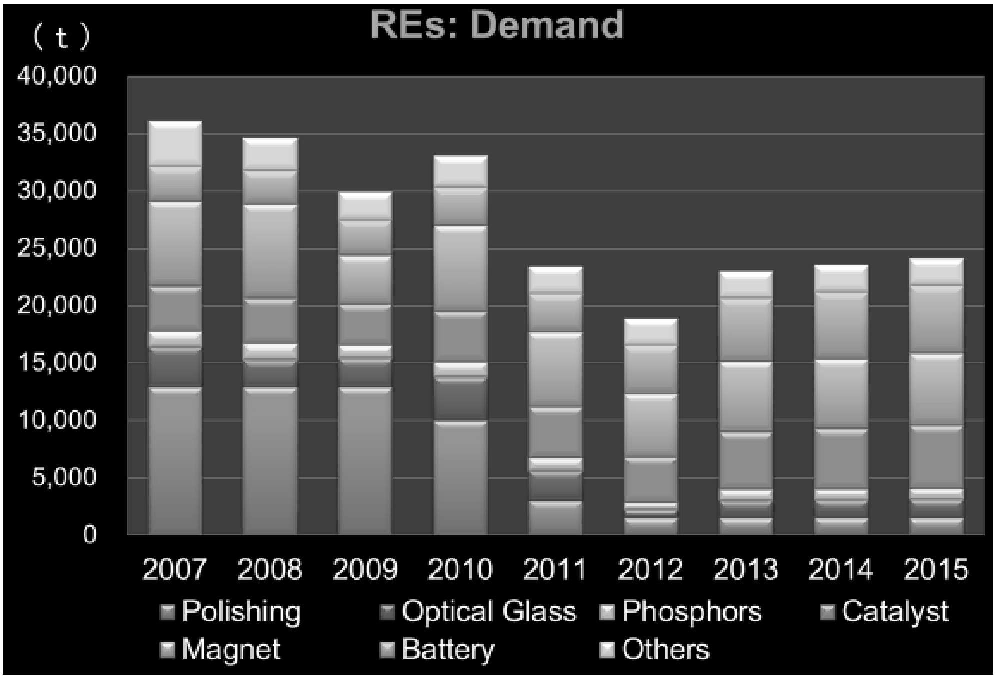
The bottom part of Figure 5.10 shows the average export and import price of rare earths for Japan. The difference in value shows the value addition done in Japan of imported elements. There are considerable margins between the import and export values except for the years 2010 to 2013. This was the period of great turmoil in global rare earth market as import prices have skyrocketed for all importing countries during this period as a result of Chinese restrictive policies.

The issues go much deeper than strictly the availability of RE raw materials outside of China. Of the developed countries, Japan is the only one that retains significant downstream supply chain capabilities to make the RE products that go into wind turbines, CFLs, Hybrid and all electric vehicles. In the EU and the US these capabilities were largely relinquished years ago. The study also tries to identify this whole supply chain infrastructure in Japan in following chapters and its criticality to Japanese economy and long term sustainability in competition with China.

6 Demand, Industrial Applications and Value Chain Links

The rare earth elements as a group have magnetic, chemical and spectroscopic properties that have led to their application in wide range of end-uses. These metals are utilized in a broad range of manufacturing areas that include materials, machineries and electronics. These are the raw materials for high value added products. Although often needed only in small quantities, these metals are increasingly essential to the development of technologically sophisticated products. They play a critical role in the development of innovative 'environmental technologies' to boost energy efficiency and reduce greenhouse gas emissions. Demand for rare earths, often referred to as "industrial vitamins," will only increase. Several clean energy technologies, including wind turbines, electric vehicles, photovoltaic cells and fluorescent lighting, use materials at risk of supply disruptions in the short term. Those risks will generally decrease in the medium and long term.

Figure 6.1: Rare earth demand by application in Japan



Source: Nakamura (2015)

It is estimated that Japan's primary end use application of REEs include polishing (8%), metal alloys (22%), magnets (30%), and catalysts (20%), glass (6%) and ceramics (10%).

Though materials in various forms may constitute a small fraction of a country's GDP they are critical links in a complex web of interdependent industries and value adding activities. Materials are primary drivers for various value chains – many of which are interconnected either from the supply or technology side or from the demand or market side. All these applications mentioned above are rare earth based intermediate products and used as input in various value adding activities and become part of various end products such as electronic commodities, wind turbines, efficient lights etc.

For example if we consider 'permanent magnets', one the most critical elements in many commodities, it is indispensable and add value in many final products such as telecommunication, defense, electric bicycle, aerospace, power generators including wind turbine, automotive, medical, consumer electronics, data processing etc. The major rare earth elements that go into these magnets are neodymium, praseodymium, dysprosium and samarium. Over the last fifty years or so, permanent magnets have evolved through four generations of technologies. Aluminium-nickel-Cobalt (AlNiCo) magnets have been replaced by hard ferrites. These in turn have been replaced by superior samarium cobalt (SmCo) rare earth magnets in many high end applications. In response to the perceived shortfall of Cobalt, companies in the US and Japan like GM and Hitachi developed another Rare Earth based permanent magnet, i.e. the neodymium-iron-boron (NdFeB) Magnets. These two companies used to hold global patent for producing these magnets. However, by acquiring Magnequench, the sub division of GM and acquiring licenses from Hitachi to produce these magnets domestically, China has over taken both US and Japan as the leading producer and exporter of these magnets (Chandrashekar, 2013).

A number of Japanese companies who use rare earths as input have moved some of their manufacturing facilities to China, sharing their technologies with Chinese joint venture partners. Risking their business, but they were ready to do so in return for a secure supply of rare earths. Today, permanent magnets dominate rare earth technology because of their ability to provide greater magnet power in vastly smaller sizes. Currently the two primary rare earth magnets are the samarium cobalt (SmCo) magnet and the neodymium-iron-boron (NdFeB) magnet.

6.1 Value Chain Links and Joint Venture Partnerships between Japan and China in Rare Earth Industry

As explained in the previous chapter Japan not only depend on China for its rare earth requirements, but also there exist extensive value chain links and joint venture partnerships between Chinese and Japanese companies. This value chain relations have been built over the years and exist from primary levels to intermediate levels to end products. The data represented in Figures 6.2, 6.7, 6.8, 6.9 and 6.11 is largely drawn from a study commissioned by JOGMEC with some modifications and updates in the analysis (Shimizu et al, 2012).

Figure 6.2: Value chain links between China and Japan in rare earth magnet sector

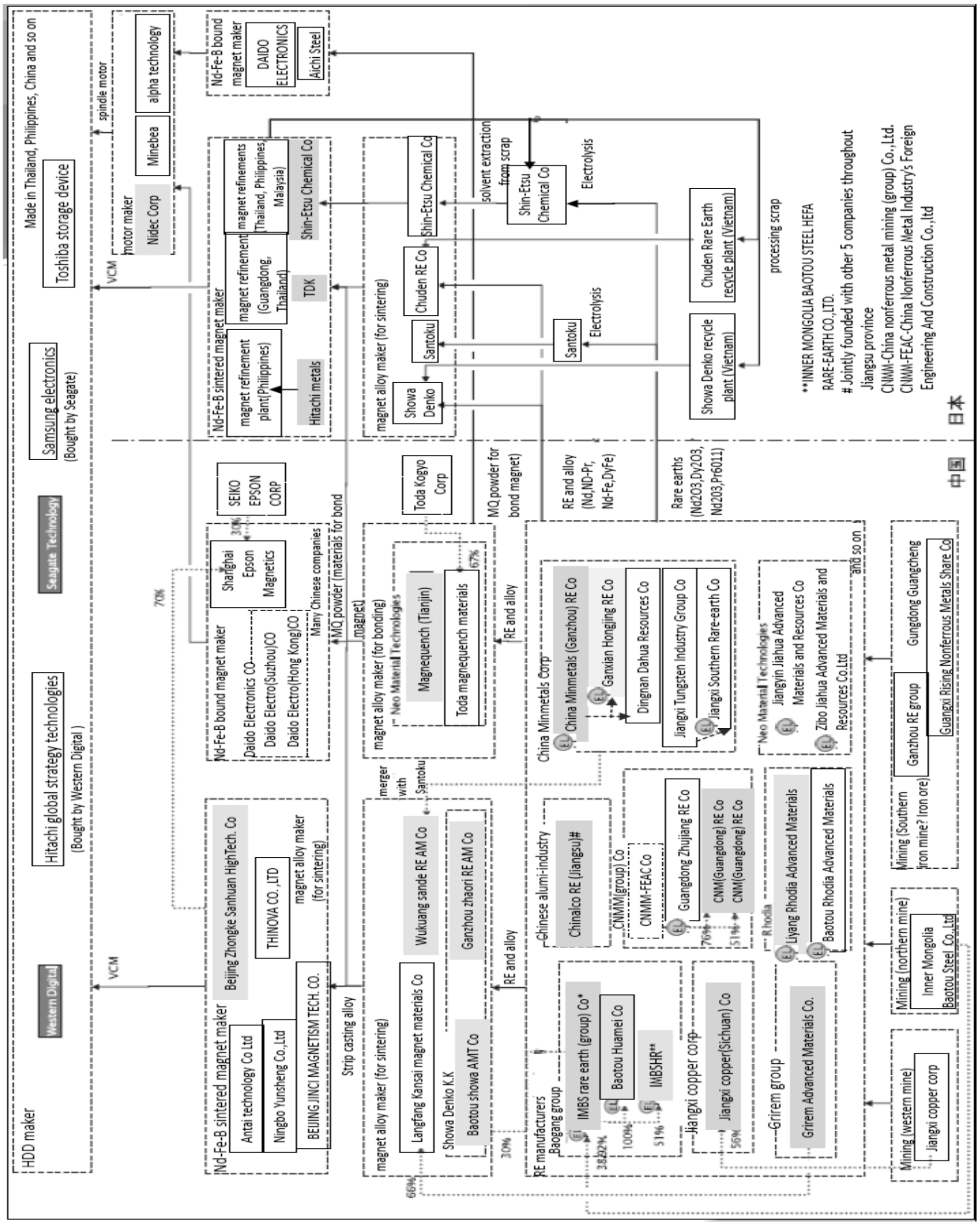


Figure 6.2 shows the industrial value chain in both China and Japan in permanent magnet industry and in hard disk drive (HDD) industry. One of the leading applications of NdFeB permanent magnets are in hard disk drives. Left side of the figure represents

China and right side represents Japan. Black lines in the figure show the transaction relationship and red broken lines show the relationship of investment. The more powerful company in the market is indicated by a deeper color. (EL) means the company has the export license from the Chinese government.

The figure shows the Chinese rare earth industry before the current consolidation process started in 2013 as currently China is in the final stage of a consolidation process of merging all rare earth mining and processing companies under the control of six large state-run groups led by China Minmetals, Chinalco, Baotou Steel, Xiamen Tungsten, Ganzhou Rare Earths and Guangdong Guangsheng Rare Earths. The Chinese government supported them with legislation and financing to complete the integration process by the end of 2015 and these large firms are licensed to take over small operations and illegal mines. As a policy support, over 90 percent of production quotas are now allocated to these groups. The figure shows all these six major state owned companies and their subsidiary companies dominating in the mining and processing sector and even before the current consolidation started. In the mining sector Jiangxi Copper Corp dominates the western region of China, Baotou Steel Company is in control of the northern region that includes Inner Mongolia and mining in the southern region is dominated by Ganzhou Rare Earth Group, Guangdong Guangsheng Rare Earths and Guanxi Rising Nonferrous Metals Share Company. In the processing industries at intermediate levels, subsidiaries of these companies dominate the value chain along with China Minmetals, Chinalco etc. For example, Baotou Steel controls 39 percent share of Inner Mongolia Baotou Steel Rare Earth (Group) Hi-tech Co. Ltd, and under them there are a number of fully or partially owned companies involved in processing and making RE based intermediate products such as oxides, metals and alloys.

Also the foreign companies such as Rhodia, now owned by Belgian conglomerate Solvay and Neo Material owned by Molycorp of USA operate in China at intermediate products level with export licenses from Chinese government. The figure shows rare earth value chain starting from mining to the final product HDD. There are at least five stages in the value chain before the rare earths reaches the final product stage in this case. Japanese companies have extensive business networks in their value chain with Chinse companies in all stages at intermediate product level. Some of them have also joint venture partnerships and license agreements with Chinese companies. Currently, the global NdFeB permanent magnet industry is divided into two, based on their production process and technology, which is sintered magnets and bounded magnets and sintered magnet industry has a market share close to 90 percent. Both these sectors, companies from Japan and China are interlinked.

Global permanent magnet industry has a long history of technological developments and competition. Their ability to provide high magnetic fields for low weight is critical for converting electrical energy into mechanical movements in applications where weight is a premium.

Over the last fifty years or so, permanent magnets have evolved through four generations of technologies. Aluminium-nickel-cobalt (AlNiCo) magnets have been replaced by hard ferrites. These in turn have been replaced by superior samarium cobalt (SmCo) rare earth magnets in many high end applications. In response to the perceived shortfall of cobalt during cold war period where Soviet Union used to be the largest supplier of cobalt, companies in the US and Japan developed another rare-earth-based permanent magnet, which is the neodymium-iron-boron (Nd-Fe-B) magnet. Magnequench, a fully owned subsidiary of General Motors Corporation (GM) in United States and Sumitomo Special Metals Japan discovered a new permanent magnet material composed of neodymium, iron and boron. For the same product, the technology has been quite different, while GM's process was called bonded and Sumitomo's process was known as sintered magnets. Now both these technologies dominate the market. This seems to be currently the dominant technology route for making permanent magnets especially for many high end products. Other materials including the heavier rare earths as well as nanotechnology based RE materials are under active investigation. Following the Chinese embargo, other architectures for critical motors that may not need a permanent magnet are also being researched.

Now in the sintered magnet market Japanese and Chinese companies dominate the market and in fact China has replaced Japan as the largest permanent magnet maker and exporter. Until 2014, only Japanese companies had the patent to make the sintered magnets and major producers such as Hitachi, TDK and Shin-Etsu have licensing and joint venture partnership with Chinse companies and they also have magnet refinement plants in Philippines, Thailand and Malaysia and through these joint ventures and taking license from Japanese companies, China has been producing these magnets for many years. Japan remains realistic about its relationship with Chinse rare earth producers, despite its efforts to diversify its supply sources, and investment have continued to flow to China. Japan's Hitachi Metals and Chinse rare earth permanent magnet maker Zhong Ke San Huan (ZKSH) had set up a joint venture company in June 2015 to produce high performance neodymium-iron-boron (NdFeB) magnets. According to Hitachi, the construction of the integrated NdFeB magnet production facility was planned to start by December 2015. The plant is located in Jiangsu province and the joint venture will carry out raw material procurement, manufacturing and sales.

Japanese companies are also active in the bond magnet sector. For example Toda Kogyo Corp has 67 percent stake in a joint venture it formed with Neo Materials in China and Seiko Epson Corp has a 30 percent stake in Shanghai Epson Magnetic Company, which produces bonded magnets. Daido also has two subsidiaries in China in this segment. In Japan, Daido Electronics and Aichi Steel are the major producers of bonded magnets.

6.2 Case Study: Chinese Strategy of Technology Acquisition Abroad: The Case of Magnequench

Who is responsible for making important technology decisions in China? How have Chinese technology leaders thought about the relationship between technology and national power during the past twenty years. Chinese S&T policies represent perhaps the most explicit connection between national security and economic development issues in China's policymaking process. In addition, they constitute a critical link between purely domestic economic policy agendas and the international strategic concerns so central to Chinese decision makers. Nationally directed strategic approaches dominate on the agenda of the most influential members of China's science and technology (S&T) establishment, including government planners, prominent university scientists, and principal industrial cadres (Feigenbaum, 1999).

While relatively small thus far, China's technology-intensive acquisition abroad has received substantial media attention. These include Lenovo's purchase of IBM's personal computer unit in 2005 and Geely Auto's purchase of Volvo Cars from the Ford Motor Company in 2010. To put technology acquisition in perspective, 80 percent of the value of China's outbound M&A from 2003 to 2009 was in energy or financial-related acquisitions, with seven percent in technology, media and telecommunications (TMT) companies, six percent in industrials, and one percent on pharmaceuticals, medical and biotech firms (Deloitte, 2009).

One prominent case among them was the acquisition of Magnequench by Chinese state owned companies. Magnequench had a unique expertise in the manufacture of high-powered neodymium magnets, which it invented in the 1980s for its parent company, General Motors. These magnets are needed for making an array of sophisticated products, from smartphones to smart bombs, as well as wind turbines and other green technologies. Some critical military applications for the NdFeB magnets include lasers as rangefinders, target designators, and target interrogators; and communication systems such as traveling wave tubes (TWT) and klystrons, which are used in satellite communications, troposcatter communications, pulsed or continuous wave radar amplifiers, and communication links.

Before analyzing the connection between the state strategies and harnessing technology issues in China's policymaking process and the critical link between purely domestic economic policy agenda and the international strategic concerns, it is interesting to trace the history of Magnequench, which is depicted in the following table.

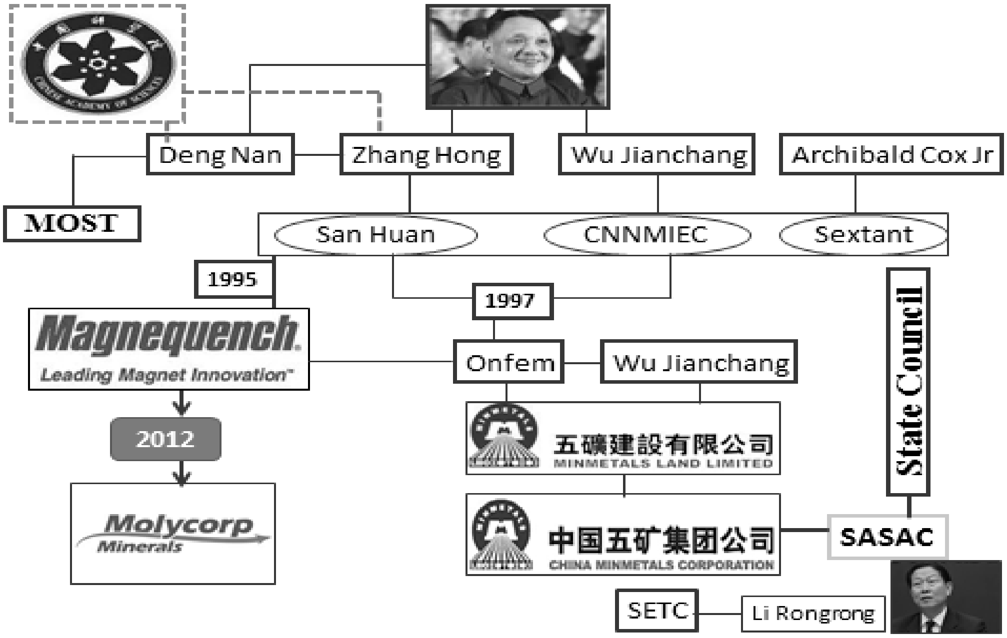
Table 6.1: History of Magnequench

1982	General Motors Corporation (GM) and Sumitomo Special Metals discover a new permanent magnet material composed of neodymium, iron and boron
1886	By creating the Magnequench division, GM commercializes its 1982 invention of Neodymium powder and related process. In the same year, Magnequench builds a 175 000sqft neo powder and neo magnet facility in Anderson, Indiana
1995	China National Non Ferrous Metal Import& Export Corp.(CNIEC), San Huan and Sextant MQI Holdings acquire Magnequench on 30th September
1998	Magnequench acquires a China based alloy producer and begins building a 145,000sq.ft new powder production facility in Tianjin, China
1999	Magnequench opens a technology center in North Carolina
2000	Neo powder production commences at the Tianjin plant and Magnequench acquires two magnet manufactures

2001	Magnequench ceases powder production in Indiana in December and consolidates all production at Tianjin, China facility
2002	Indiana plant is closed
2004	Two magnet manufacturers are divested, and Magnequench expands its operations in Singapore, including the movement of technology centre from North Carolina, as well as the addition of sales and marketing resources and the relocation of its administrative and finance functions
2005	Magnequench merges with AMR Technologies, inc of Toronto, Canada. Neo Materials Technologies, Inc. is established.
2006	43,000sq.ft Korat, Thailand manufacturing facility is equipped with two Magnequench jet casters
2007	Production begins with Korat, Thailand manufacturing facility. Magnequench and Hitachi agree to exclusive licensing agreement for US patent 5,645,65
2012	Molycorp buys Neo Material for C$1.3 billion

Magnequench began its corporate life back in 1986 as a subsidiary of General Motors. Using Pentagon grants, GM had developed a new kind of permanent magnet material in the early 1980s. It began manufacturing the magnets in 1987 at the Magnequench factory in Anderson, Indiana. And in a well-coordinated move Chinese SOEs acquired Magnequench in 1995 that caused many ripples in US at that time. Using the Magnequench acquisition by Chinese companies as a case study, we try to analyze here the Chinese national system capability which is reinforced with a fairly closely knit informal network of people that span the political, military, technology and academic domains. We map some of these inter-linkages between various organizations and individuals who were in the helm of affairs during the whole acquisition period.

Figure 6.3: Inter-linkages between various organizations and individuals involved in the acquisition and Chinese decision making process



When General Motors was restructuring in the early 1990s, the company began to divest itself of subsidiaries that were not in its core competence and Magnequench, a subsidiary of GM was put up for sale with the $70 million asking price. An investment consortium called Sextant Group headed by Archibald Cox Jr. (son of the illustrious Watergate prosecutor) with two Chinese state-owned metals firms, San Huan New Material and China National Nonferrous Metals Import and Export Company (CNNMIEC) bought the company.

In the deal, the two Chinese firms took at least 62 percent majority shares of Magnequench. The chairman of San Huan, Mr. Zhang Hong (who later became the head of the Research and Development Bureau of the Chinese Academy of Sciences), son-in-law of former Chinese "paramount leader" Deng Xiaoping, took over as chairman of Magnequench and Cox as chief executive officer (CEO). Hong Zhang is married to Deng Nan, the daughter Deng Xiaoping. He had served as Chairman of San Huan since 1985. He served as Chairman of Magnequench International, Inc. since 1995. He was the

Chairman of the Board and Director of Neo Material Technologies Inc since 1995. Zhang's wife Deng Nan was the Vice-Minister at State Science and Technology Commission during this period. Before her career, holding positions in the political department of the State Science and Technology Commission, she worked at Chinese Academy of Science. She is currently Vice Chairman and First Secretary of the China Association for Science and Technology and she was a member of the 17th CPC Central Committee. No doubt, Mr. Zhang's desire to acquire Magnequench was supported by his wife and his father-in-law's "Super 863 Program" to develop and acquire cutting-edge technologies for military applications, including exotic materials (Hurst, 2010).

The other Chinese investor in Magnequench at that time was China National Non-ferrous Metals Import and Export Corp (CNNMIEC), which was run by yet another Deng Xiaoping son-in-law Wu Jianchang. He was secretary of the Party Committee in the National Association of the Iron and Steel Industry and was Independent Non-Executive Director in Jiangxi Copper Company Limited since June 6, 2008. He was Deputy General Manager and General Manager in China National Nonferrous Metals Industry Corporation. Jiangxi Copper Company is a subsidiary of China Minmetals Corporation. In 1997, the Magnequench shares held by the two Chinese firms were transferred to Onfem Holdings, a Chinese state-owned holding company based in Hong Kong and Mr. Wu Jianchang was heading the company at that time. Onfem was under the control of China Minmetals Corporation, one of the largest state-owned conglomerates that operate globally with core businesses in ferrous metals, non-ferrous metals, real estate, finance and logistics.

Since the Chinese SOEs were involved in the acquisition drive, the then regulatory authority of state owned enterprises (SOEs) in China, the State Economic and Trade Commission (SETC) headed by Li Rongrong, a powerful member of the CPC could have involved as well in the process. Li was a member of 16th Central Committee of the Communist Party of China, and is a member of 17th Central Committee of CPC. Forbes magazine listed him in the 61th position as World's Most Powerful People in 2009.

SETC was a special commission of the People's Republic of China, directly under the State Council (now it is known as SASAC) and is mandated to oversee the overall enterprises work of the country's state-owned enterprises. We could not trace how Cox got involved in these business and what was his relationship with the Chinese princelings. It was revealed that Cox and Sextant were acting as a front for Chinese companies.

The purchase was reviewed by the U.S. government and finally went through after China agreed to keep Magnequench in the United States for at least five years. Shortly after the Chinese took over, Magnequench's neodymium-iron-boron magnet production line was duplicated in China at a facility built by the PRC Company. The day after China's deal to keep Magnaquench in the United States expired in 2002, the entire operation, along with all the equipment, disappeared and the company moved to China. According to report published by the Heritage Foundation on May 2, 2008 (No. 1913), there were reports that the Chinese government pressured GM into selling Magnequench to Chinese entities as a condition for approving GM's bid to open an automotive production line in Shanghai.

By 2005, Magnequench remained a proprietor of several important rare-earths magnet patents and production processes. In less than one decade, the permanent magnet market experienced a complete shift in leadership. Magnequench merged with a Canadian rare-earths firm, AMR in 2005, and Archibald Cox was listed as the largest shareholder on the board of directors, apparently on behalf of an unnamed "initial holder". AMR is now known as Neo Materials Technologies with two divisions called Magnequench and Performance Materials. Neo and its Magnequench affiliate report that 85 percent of their manufacturing facilities are in China (the other 15 percent is in Thailand); that 95 percent of their personnel are located in China; and that all of their China manufacturing facilities are in the form of "joint ventures" with Chinese state-owned enterprises. Neo's value chain links are depicted in Figure 6.2.

The 2012 Conundrum of Magenquench

In March 2012, Molycorp Inc, a U.S based company and owner of the largest rare-earth deposit outside of China acquired Neo Material Technologies Inc. (NEM) for about $1.3 billion. NEM is the owner of Magnequench. Analysts related to the industry believed that the deal is another rare earth game changer that would give Molycorp access to Neo's rare earth processing capabilities and patents. Molycorp claimed this transaction will create a global, vertically integrated rare earth technology leader. The benefits accrued to Molycorp by this deal was

- It gave Molycorp greater exposure to the world's largest consumer of rare earths- China.
- It leveraged Neo Material's existing infrastructure and allowed Molycorp to increase its overall production in United States.
- It expanded Molycorp's production capabilities to include Neo Material's Magnequench patented neodymium-iron-boron magnets.

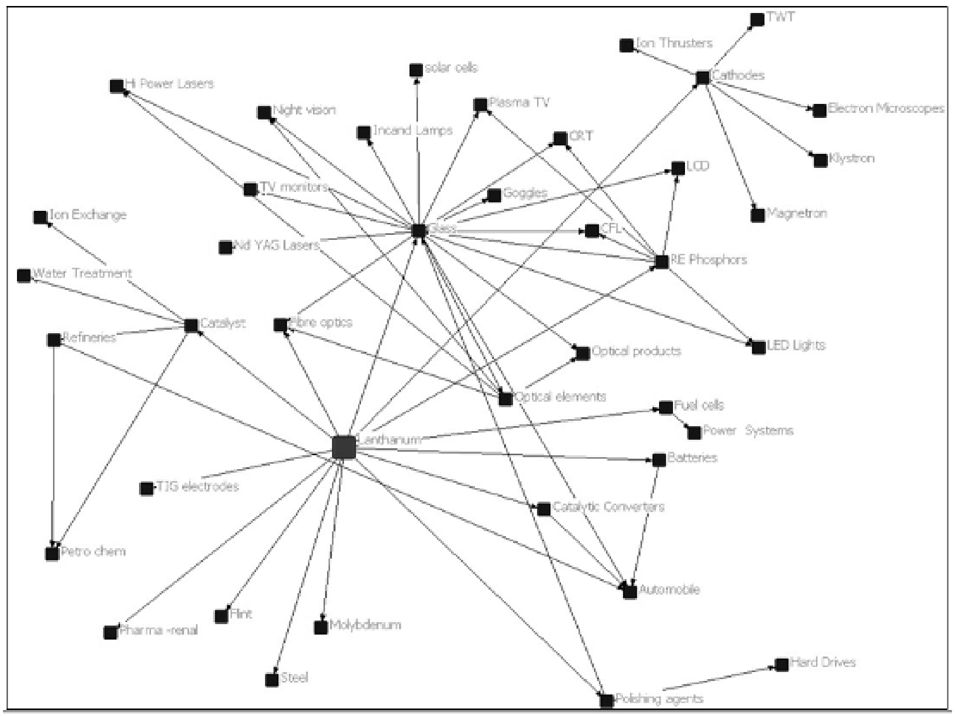
But there was also another side to this deal. Molycorp started to ship all its rare earth elements mined in U.S to factories based in China. The Chinese companies who had already moved up their technology chain became the greatest beneficiaries of this deal. What China could not achieve through its bid for UNOCAL in 2005 to acquire Molycorp and its assets, is achieved now with a zero cost and least political ramifications. The deal is a reminder of how much technological rare-earth capability resides in China. The U.S. is completely dependent on China for rare-earth-magnet materials, and the export of U.S. rare earth assets to China only intensified y this deal.

The major rare earth elements that go into these magnets are neodymium, praseodymium, dysprosium and samarium. As explained before over the last fifty years or so, permanent magnets have evolved through four generations of technologies. Aluminium-nickel-cobalt (AlNiCo) magnets have been replaced by hard ferrites. These in turn have been replaced by superior samarium cobalt (SmCo) rare earth magnets in many high end applications. In response to the perceived shortfall of cobalt, companies in the US and Japan like GM and Hitachi developed another rare earth based permanent magnet the neodymium-iron-boron (Nd-Fe-B) Magnet. These two companies used to hold global patent for producing these magnets. However, by acquiring Magnequench and acquiring licenses from Hitachi to produce these magnets domestically, China has overtaken both US and Japan as the leading producer and exporter of these magnets.

6.3 Structure of Rare Earth Industry in Smoke Exhaustion and Catalyst sector and Value Chain Links between China and Japan

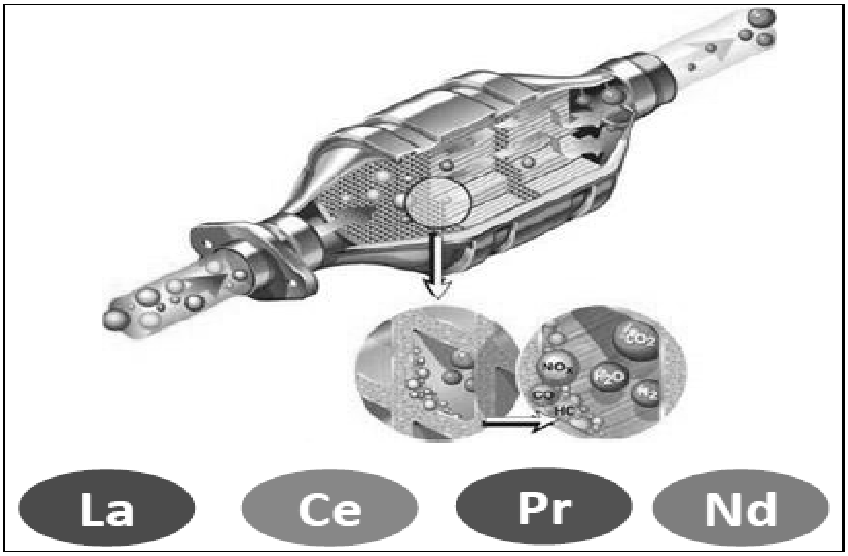
Catalysts represent a large market for rare earths. A catalyst is a substance used in very small quantities to increase the rate of a desirable chemical reaction without itself being changed chemically. It is employed to increase overall efficiency, quality and other favorable attributes. A variety of rare earth elements are utilized in catalysis applications. Reflecting key end-use applications, mixed lanthanide, cerium, and fluorides are widely used. Rare earths play a large role in providing bonding and other catalytic properties desired for effective catalysis in automotive and processing applications. Catalysis is pervasive in modern industrial and other economic activity (ACC, 2014). Lanthanum one of the rare earth element is largely used in this sector. Lanthanum is not considered as critical as there are plenty of reserves outside China and there are technologies available to replace the element in certain applications. However, the elements has wider applications in many sectors and contributes to many value added industries as shown in Figure 6.4

Figure 6.4: Application of Lanthanum in various sectors



The major applications are in petroleum refining as fluid cracking catalysts and in vehicles as catalytic converts. Small amount of lanthanum is also used in batteries and fuel cells and also used as polishing agents. The global market for lanthanum has been experiencing noticeable growth with lanthanum being the most widely used rare earth metal after cerium in various automotive and aerospace applications. The demand for lanthanum is also expected to increase as new demand arises from various industries such as hybrid electric vehicles and consumer electronics. Numerous factors such as the growth of the electronics, electric vehicle and the automotive industry are expected to drive the demand for lanthanum over the next few years. Growing market share of rare earth metal catalysts has also contributed to the growth of the market.

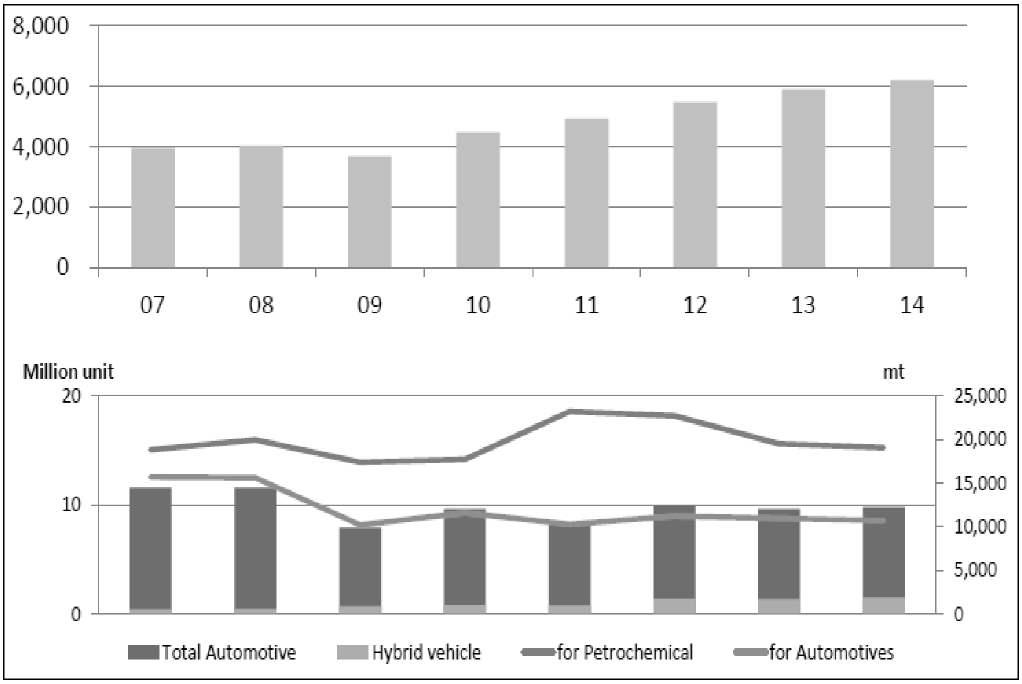
Figure 6.5: Automotive catalytic converter



RE catalysts are very important in the petroleum refining industry and as an automotive catalytic convertor. Lanthanum is the main rare earth element used as catalysts. Almost 20 percent of Japan's rare earth imports are utilized in catalysts industry. Petroleum refining catalysts comprise the catalysts used for naphtha reforming, FCC (fluid catalytic cracking) and hydrogenation of intermediate fraction such as naphtha, kerosene, and light oil. The production, delivery, and export and import of FCC catalyst have been increasing. Since the market needs shifted from heavy to light types, catalysts suitable for heavy-type petroleum FCC were newly developed.

The export of auto exhaust catalyst from Japan has continued to grow in volume over the last decade. However, the export in terms of value has decreased over the years largely due to market entry of China as well as inflow of low priced REE imports in 1990s and 2000s. The export of auto exhaust catalysts in value in the total shipments of catalysts decreased almost 40.7 percent from early 1990s to late 1990s (Iida, 1997).

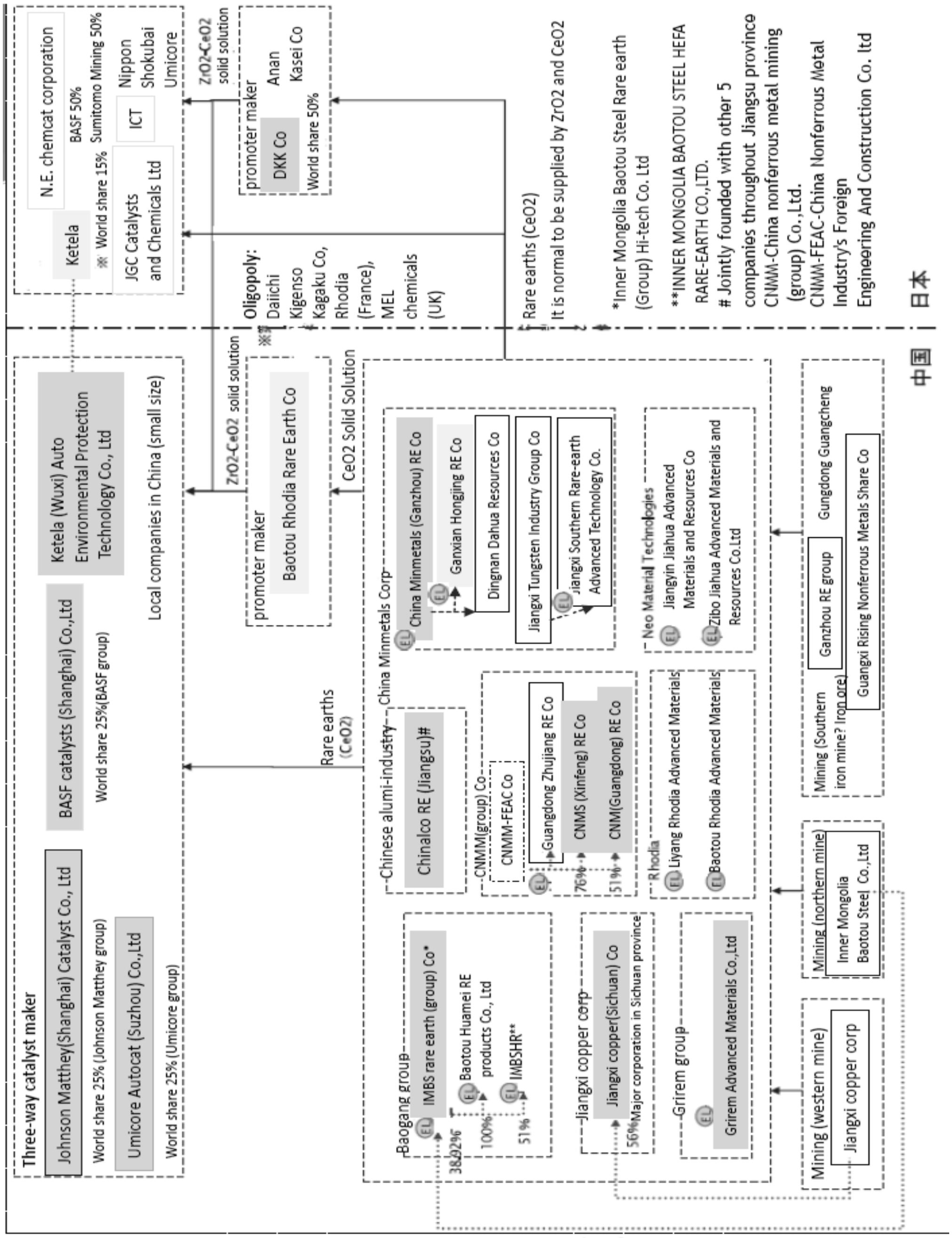
Figure 6.6: Rare earth consumption by catalysts industry in Japan



Source: Nakamura (2015)

The production volume in Japan across all catalysts sectors such as petroleum refining, petrochemical polymerization oil & fats processing production, pharmaceuticals & food and automotive exhaust has increased over the years, particularly during the last 10 years. The production volume was equal to 105,660 tons in 2009, which marginally declined to 96,331 tons in 2014. The export of these products has also changed at varying rate over the years as the export volume marginally increased from 49,206 tons in 2009 to 54,630 in 2014 (CMAJ, 2015). The overall demand for rare earths in catalysts sector in Japan has increased about 58 percent between 2007 and 2014 (Nakamura, 2015).

Figure 6.7: Value Chain Links between Japan and China in Catalysts Sector



Catalyst sector is one of the major users of rare earths in Japan and demand has slightly increased from 2011 onwards. The major RE elements used in catalyst sector are cerium, lanthanum and neodymium and the combined annual demand for these elements to use in catalysts sector in Japan has been around three to four thousand tons per annum. The demand has increased to 6,000 tons in 2014 and is expected to increase to around 7,000 tons in 2015. Japanese consumption data reveals that between 2007 and 2014, there is a 57 percent increase in rare earth demand in catalysts sector (Figure 6.6). Figure 6.7 shows the structure of smoke exhaustion and catalyst sector in Japan and China. Unlike in the magnet sector a number of multinational companies are dominated in final product level and the sector is actually an oligopoly market. Japanese companies are dominant along with few multinational companies like BASF and Johnson Matthey.

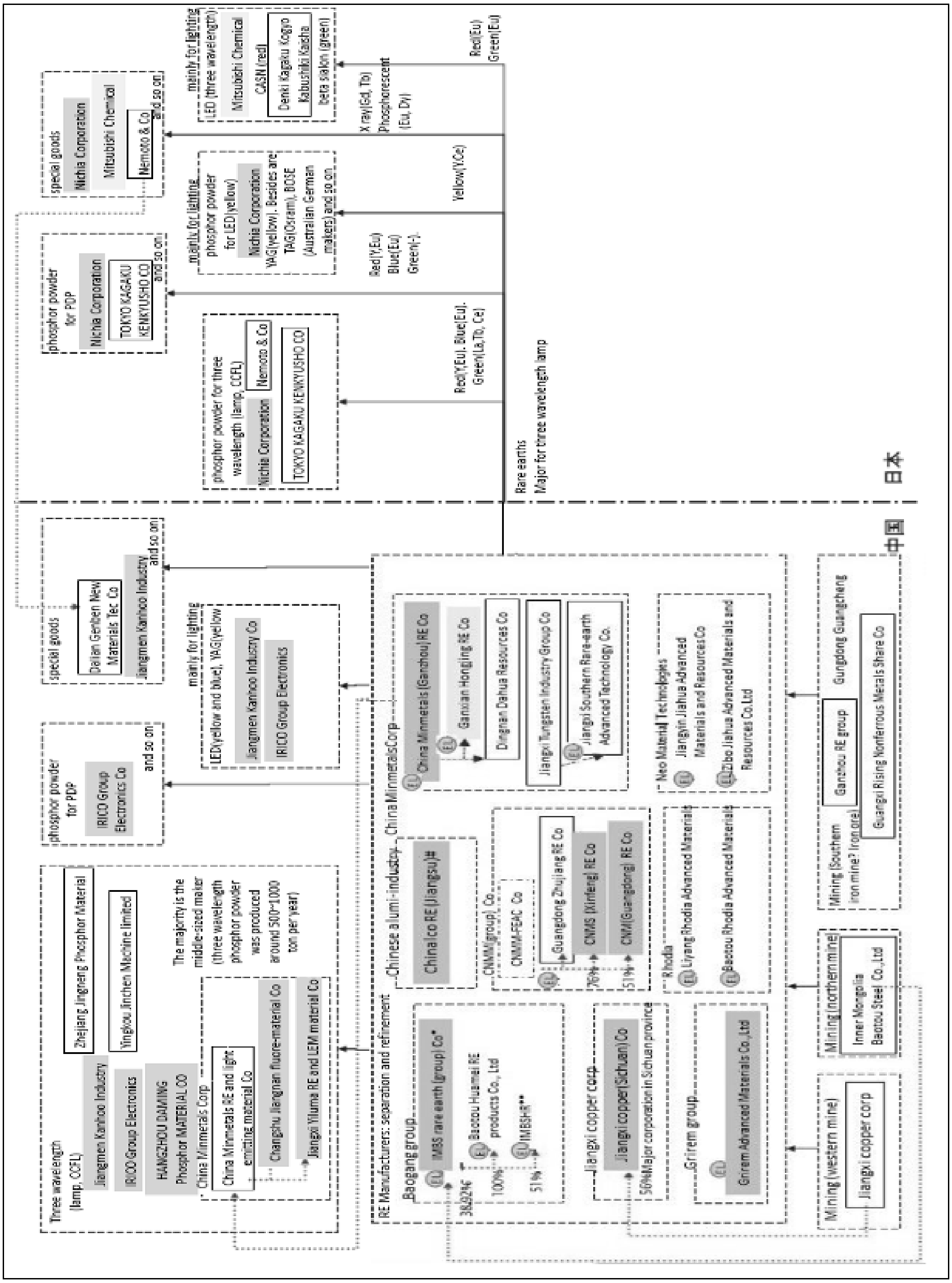
BASF, Johnson Matthey and Umicore, all three have a global market share of 25 percent each dominating 75 percent of global catalysts sector and Japanese company Ketela has about 15 percent of market share in this sector. All four companies have manufacturing plants in China and dominate Chinese domestic market as well as cater to global customers. In Japan, the catalysts sector is dominated by Ketela, NE Chemcat Corporation, a joint venture company of BASF and Sumitomo Mining each holding 50 percent stakes and ICT, a company formed by Nippon Shokubai and Umicore. Three companies such as Daiichi Kigenso Kagaku (DKK) of Japan, Rhodia of France and MEL Chemicals of UK have oligopoly power in RE based promoter segment, which is a major intermediate product for catalysts industry and DKK has about 50 percent of global market share in this segment and dominate in Japanese market along with Anan Kasei Company. However, the market shares of these multinational companies are challenged by emerging companies from China and Middle East. As for China and its impact on the Japanese chemical industry, the numbers speak for themselves. In 2005, global chemical shipments from China surpassed those of Japan, and the margin of China increases every year. While Japan recognizes the threat of growing competition from China, Japanese chemical companies also recognize the market opportunities available in such a large and rapidly growing economy of China as there already exists an integrated value chain between them as explained in Figure 6.7.

6.4 Structure of Rare Earth Industry in Phosphor Powder Sector and Value Chain Links between Japan and China

Phosphors are optical transducers providing luminescence. Rare earths are extensively used as dopant ions as well as part of many of the host compounds. Their role is as sensitizers. For example, the most important use of europium compound is associated with phosphors for color TV screens and for computer monitors. Other applications include compact and other energy-efficient fluorescent lighting and other lighting as well as medical imaging. In addition to europium, a wide variety of rare earths are used in phosphor applications, including cerium compounds, lanthanum, didymium oxide, praseodymium, and samarium oxide. Rare earth phosphors have been widely used to enhance the performance of medical X-ray imaging products since the early 1970s. The phosphor accepts the X-ray and efficiently converts the photon to the visible range, which is then used to expose the film. Activators include terbium, thulium and europium in various hosts, including a gadolinium oxy-sulfide (ACC, 2014).

Phosphor demand in Japan used to be around 1,000 to 2,000 tons per annum. Since the electronics and lighting industry has shifted to LED based applications, demand has been declined drastically in this sector globally and particular in Japan. The demand has decreased to around 57 percent between 2007 and 2014. The LED industry uses a wide and growing range of phosphor materials to convert the light emission from LED chips into a different wavelength spectrum. LED makers rely on their supply of phosphor materials as a crucial aspect of the production process. The most common use is the combination of a blue LED chip with one or more phosphors to create a white LED. Many of the phosphors used in LEDs contain rare-earth elements, but much less volume compare to applications in LCDs or CFLs.

Figure 6.8: Structure of rare earth based phosphor industry in China and Japan and value chain links



In phosphor sector most of Japanese companies use rare earth oxide processed by established Chinese companies. The main applications of phosphor in Japan are in three wave length (lamp and CCFL), phosphor powder for plasma display panel (PDP), LED and special goods. Phosphor powder for three wave length (lamp and CCFL) are used by Nichia Corporation, Nemoto & Company, Tokyo Kagaku Kenkyusho and they largely use yttrium and europium for red color, europium for blue and lanthanum, terbium and cerium for green in this application. Phosphor powder for PDP are used by companies such as Nichia and Tokyo Kagaku Kenkyusho and main users in LED applications are Nichia Corporation, Osram, Bose, Mitsubishi Chemical and Denki Kagaku Kogyo Kabushiki Kaisha. In special goods applications, the main manufactures are Nichia, Mitsubishi and Nemoto and Nemoto has a manufacturing plant in Dalian in China for producing phosphor based special goods.

6.5 Structure of Rare Earth Industry in Optical Glass Sector and Value Chain Links between Japan and China

Rare earth elements are widely used in glass manufacturing, primarily in five areas: decolorizers, color tint, refractive index enhancers, color filters, and radiation and UV protection. Cerium oxide is the most commonly used rare earth with lanthanum, neodymium, praseodymium, and erbium compounds. Color tinting is achieved in glass by adding various metal oxides that selectively absorb light in the visible range. Glasses colored by rare earths have high powers of light transmission. Neodymium oxide, which is used in artistic and technical glass, engenders a violet color that can be shifted to pink by the addition of selenium. Praseodymium oxide, which imparts a green color, is also used for artistic and technical glasses as well as welder's goggles. Erbium oxide gives a pink color to some photochromic and crystal glasses. A cerium oxide–titanium oxide colorant is also used with manganese to impart a yellowish-pink shade to ophthalmic glass. Europium, holmium, samarium and ytterbium compounds can also be used as colorizers.

Color filtration is important for glass used in safety goggles and glass containers. Neodymium oxide is added to glass to suppress the yellow light transmission. Goggles made with this additive are used by lamp workers, welders and glass blowers for protection. Finally, radiation and UV protection is possible by the addition of cerium compounds. Ultraviolet or higher-energy radiation, such as X-rays, gamma-rays and cathode rays, can cause glass to darken over time and long-term exposure to sunlight can oxidize metal ions to new states that impart color and darken the glass.

Rare earth demand for glass sector was around 2,000 to 3,000 tons per annum in Japan and since 2010 the demand has been in decline. There was a 71 percent decline in demand for REs by glass sector in Japan between 2007 and 2014 (Nakamura, 2015). The reason for decline in demand in glass sector is elaborated in the following paragraphs.

Figure 6.9: Structure of rare earth industry in optical glass sector and value chain links between China and Japan

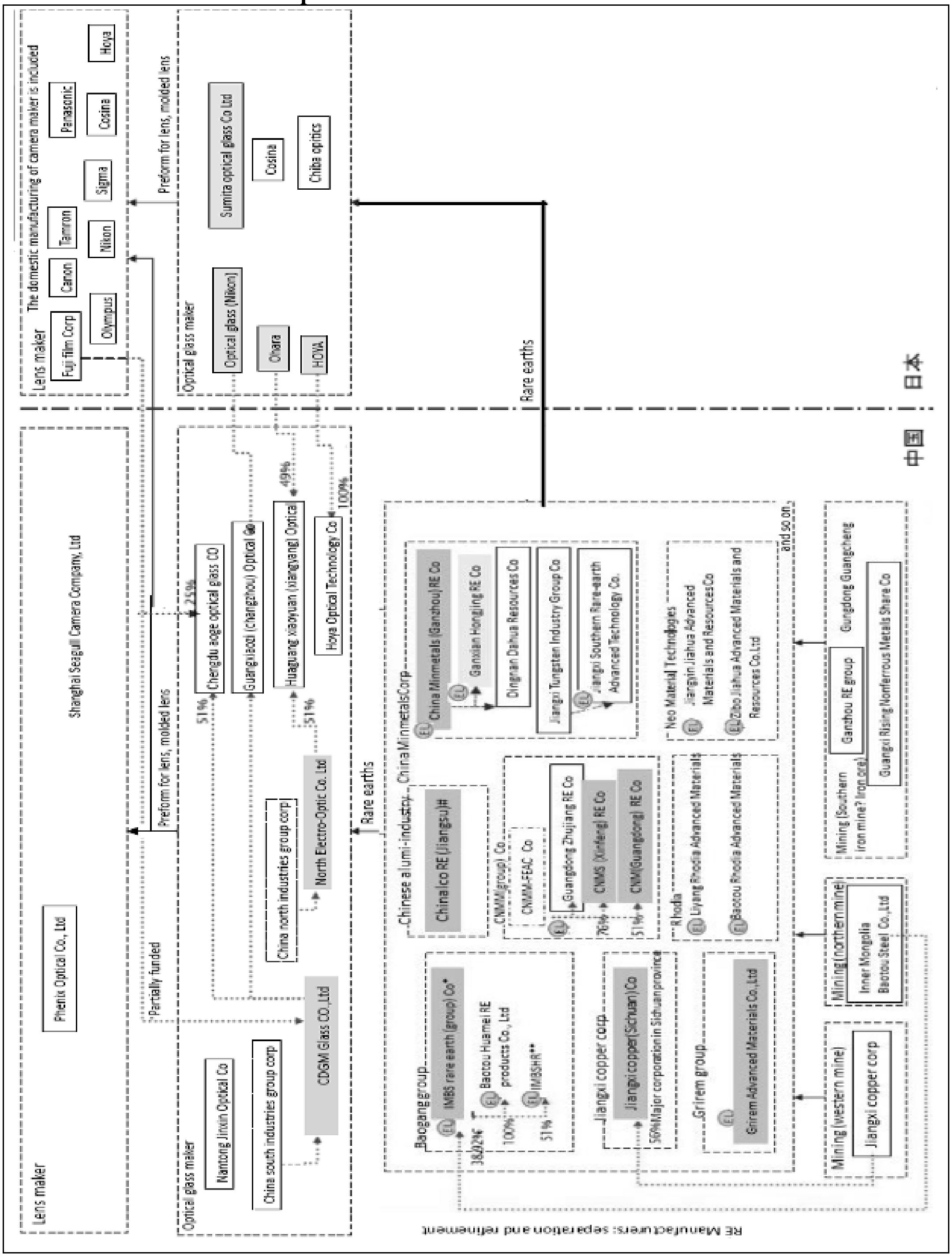


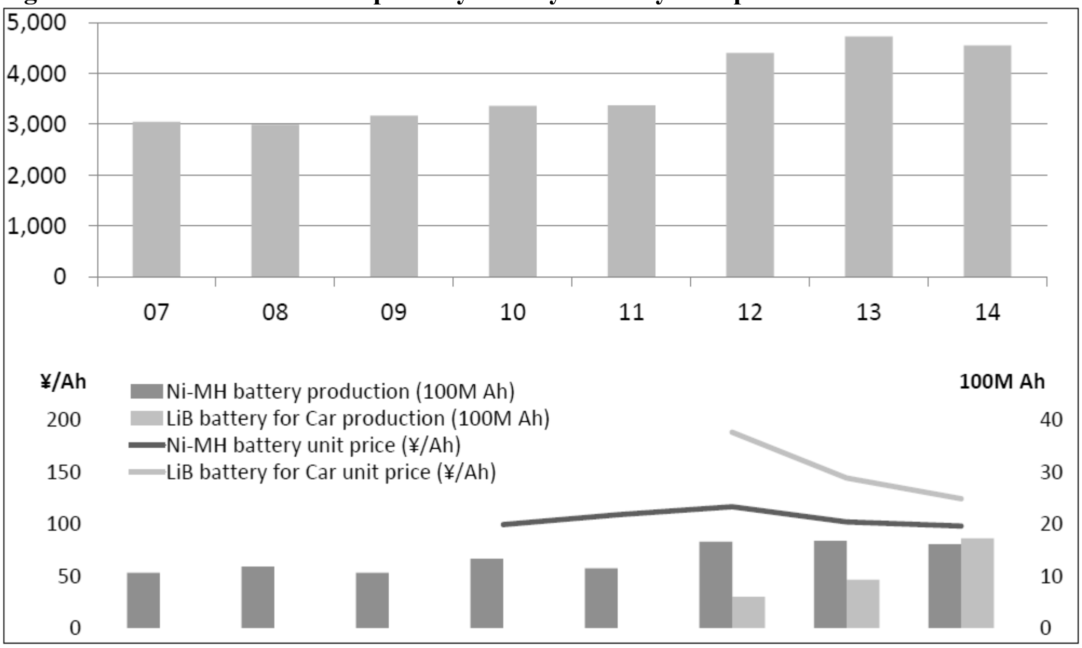
Figure 6.9 shows the value chain of rare earth based optical glass industry in China and Japan and the final product of lens, which is used in cameras, mobile phones and in defense applications. In the optical glass and lens sector, Japanese companies dominate the global market and in optical glass sector, the major manufacturers are Nikon, Ohara, Hoya, Sumita optical glass company, Cosina and Chiba Optics. All these companies get the RE elements from China for their manufacturing plants in Japan and most of them have joint ventures or fully owned subsidiaries in China in the optical glass sector. For example, Nikon Optical Glass has stakes in Guanxiaozi (Changzhou) Optical Company limited in China. Ohara has 49 percent stakes in Huaguang Xiaoyuan Optical Company and 51 percent stakes is held by North Electro Optic Company Limited which is based in Xian. North Electro-Optic Co., Ltd. is principally engaged in the manufacture and distribution of optoelectronic materials and components, as well as photovoltaic solar business. The Company operates its businesses primarily through optoelectronic defense business, the manufacture of optoelectronic materials and components, as well as photovoltaic solar business. The Company primarily provides defense products, solar cells and optical glass. Its defense products include precision-guided weapon systems, precision-guided seeker series, as well as ground display and control information equipment series. Through its subsidiaries, the Company is also involved in the manufacture and distribution of optoelectronic defense products, solar cells and glass substrates.

Hoya has fully owned subsidiaries in China called Hoya Optical Technology Company based in Suzhou in Jiangsu province and Weihai in Shandong province. Most of the camera makers also produce their own lens in final product category as shown in the figure and they buy preform for lens or molded lens from optical glass makers from Japan and China. Some of them also have stakes in optical glass manufacturing companies in China. For example, Fuji Film Corp has a 25 percent stake Chengdu Aoge Optical Glass Company and have partial stakes in CDGM Glass Company Limited, one of the major companies in optical glass sector in China. Moreover, most of the Japanese camera makers have their manufacturing plants in China. This may explain why the demand for REs in glass industry is declining in Japan along with many of them have moved their production facilities to China and other Southeast Asian countries.

6.6 Structure of Rare Earth Industry in Nickel-Metal Hydride Battery Sector and Value Chain Links between Japan and China

The use of lanthanum and mischmetal in nickel-metal hydride (NiMH) secondary (rechargeable) batteries has grown considerably over the last decade. Mischmetal is an alloy of rare earth elements. A typical composition includes approximately 50% cerium and 25% lanthanum, with small amounts of neodymium and praseodymium. These NiMH batteries have largely supplanted nickel-cadmium (NiCad) secondary batteries in many applications. Nickel-metal hydride batteries provide higher performance and a more "green" solution for consumer products by eliminating one source of cadmium, a toxic metal (ACC, 2014). Nickel-metal hydride batteries have penetrated several high growth markets—laptops, tablets, portable communication products, and portable tools. Lanthanum provides the classic intermetallic hydride used in NiMH rechargeable batteries. One of the more common uses of these types of batteries is in laptop computers. Lanthanum nickel alloys have the outstanding hydrogen storage properties needed for longer battery life. These rare earth-based batteries account for about 32-35% of the broader battery industry.

Figure 6.10: Rare earth consumption by battery industry in Japan



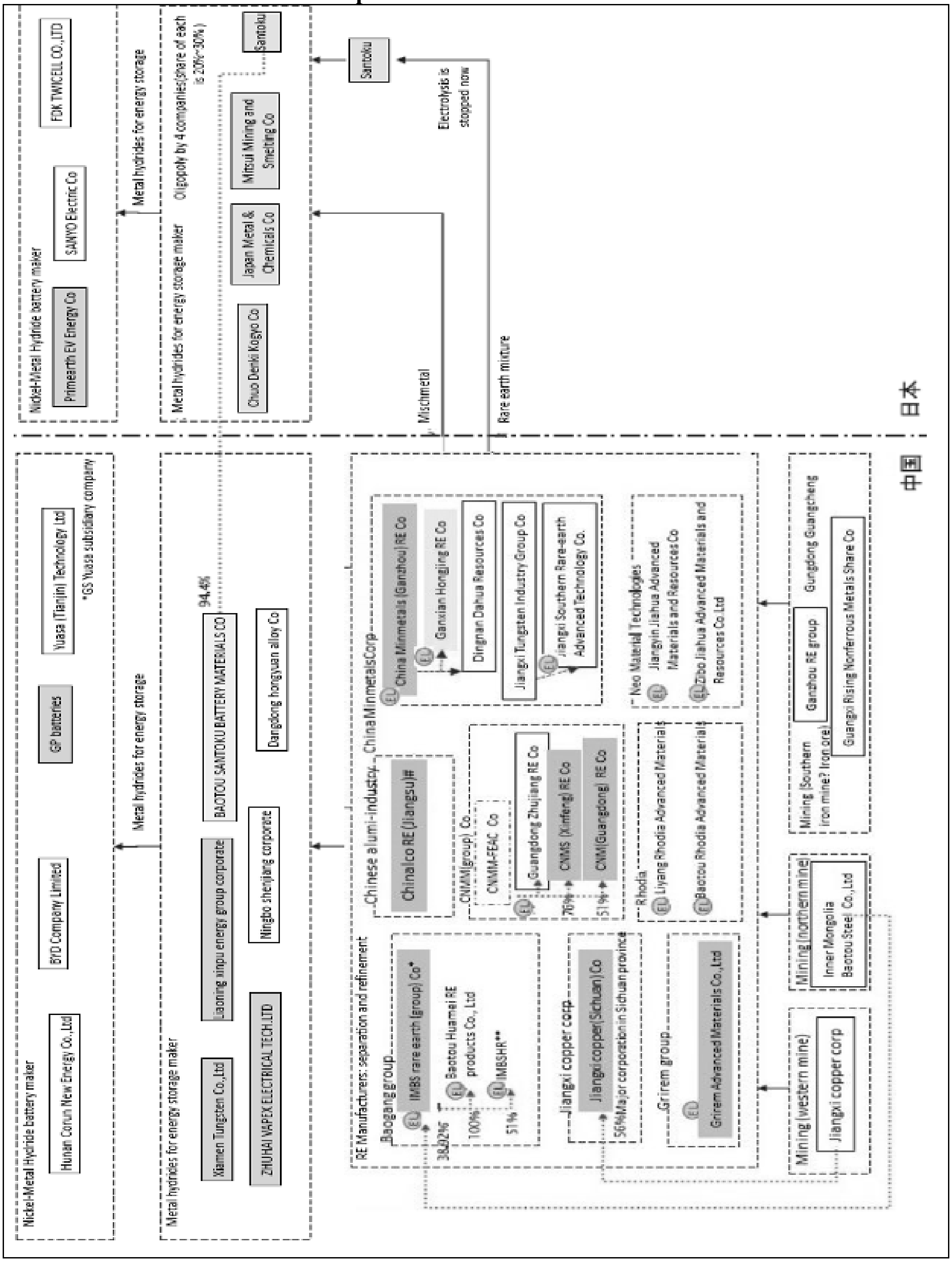
Source: Nakamura (2015)

The major Japanese automobile manufacturers see rare earth based batteries as important for the next few generations of hybrid cars before a transition to lithium ion batteries takes place. Given this scenario, RE usage in batteries is a growth industry for the next few years.

The past two decades have seen a constant evolution of rechargeable batteries that can power devices for ever-longer periods with just one charge, resulting in wireless gadgets becoming more compact and lighter. Unlike the other rare earth using sectors consumption of rare earth by battery industry has increased over the years in Japan. This is largely due to the increased production of hybrid cars and electric vehicles in Japan as they all require the high efficient rechargeable batteries. The demand in volume has increased from 3,000 tons in 2007 to 4,700 tons in 2014, about 49 percent increase in last 8 years. Almost half of all portable rechargeable batteries sold in Japan were NiMH in 2000. This percentage has fallen over time due to the increase in manufacturing of lithium-ion batteries. The share of NiMH has decreased to 22 percent of total portable rechargeable batteries sold in Japan in 2010. In 2014, 62.81 percent of total sale of rechargeable battery were lithium-ion batteries (Battery Association of Japan, 2015).

Figure 6.10 also shows marginal increases in the production of nickel-metal hydrides and the increased production of the lithium ion battery (LIB) has overtaken the Ni-MH in 2014 in terms of ampere-hour (Ah), which is a unit of electric charge, equal to the charge transferred by a steady current of one ampere flowing for one hour, or 3600 coulombs. The figure also shows unit cost per Ah for production of Ni-MH and LIB batteries and the production cost for both types have been decreasing in last few years. LIB still costs more than Ni-MH, but production costs may equalize in near future as the improved technology and large production volume of LIB creates an economies of scale in reducing the marginal costs.

Figure 6.11: Structure of rare earth industry in Nickel-Metal Hydride battery sector and value chain links between Japan and China

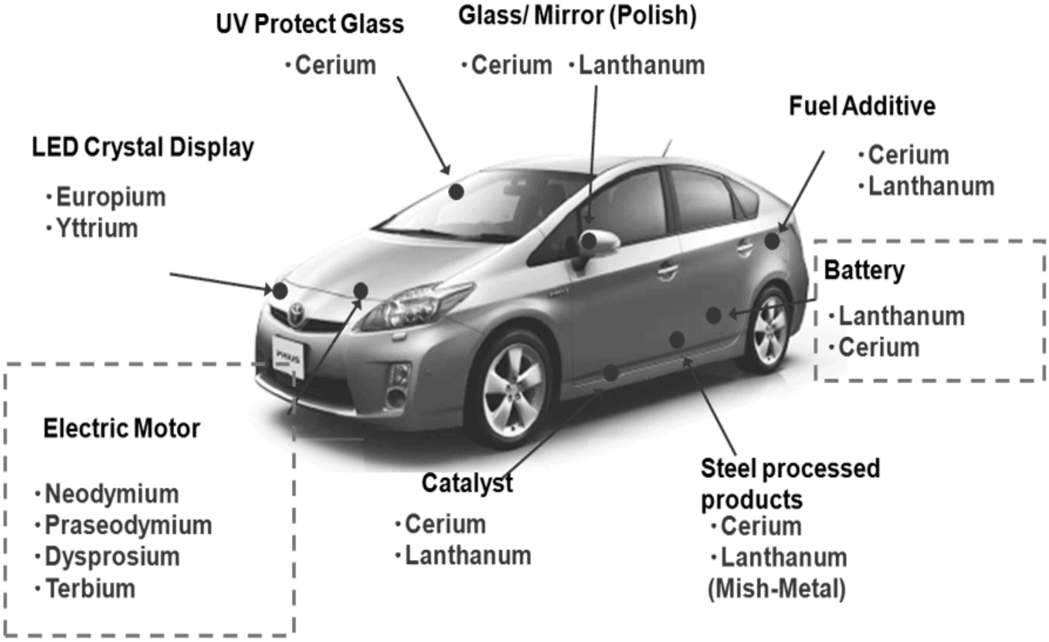


Japanese companies are dependent on Chinese rare earth processors for mischmetal or RE oxides to use as metal hydrides in energy storage. Santoku used to do electrolysis of imported rare earth mixtures from China to use as metals hydrides, but it has stopped now this process and might be importing mischmetal directly from Chinese companies. Four companies control the entire Japanese market in metal hydrides manufacturing and they have oligopoly control and supply the metal hydrides to battery makers such as Primary EV Energy Company, Sanyo and FDK Twicell. In the intermediate market of metal hydrides, Santoku has 94 percent stake in a company called Baotou Santoku Battery Material Company based in Inner Mongolia and at final product level, Kyoto-based GS Yuasa Corporation has a subsidiary in Tianjin, which is called Yuasa (Tianjin) Technology Limited. Sanyo Electric Co, a subsidiary of Panasonic, controls the world's largest share of rechargeable batteries as it holds 25 percent of the lithium-ion market, 35 percent of the nickel-metal and 35 percent of the NiCad sector. In 1996, Panasonic set up a joint venture with Toyota Motor Corp. that makes lithium-ion and nickel-metal hydride batteries for hybrid cars, including the Prius, and plug-in models. Traditionally Prius has been using nickel-metal hydride batteries and in recent years, the model has started to use lithium-ion batteries as shown the picture below.

Figure 6.12: Lithium Ion battery used Toyota Prius

In 2007, NEC Corp and Nissan Motor Co had formed a joint venture to supply lithium-ion batteries for electric vehicles made by Nissan and its French partner, Renault SA. In the same year, GS Yuasa Corp. launched a joint venture with Mitsubishi Motors Corp. to make lithium-ion batteries for electric vehicles and another venture in 2009 with Honda Motor Co. to make cells for hybrids. Industry sources expect the lithium-ion battery market to grow rapidly as demand for electric vehicles surges and manufacturers that can stay ahead in terms of technology will be in the best position to tap the growing market. Japanese manufacturers so far lead the lithium-ion cell market, and it will take time for overseas rivals to catch up.

Figure 6.13: Rare earths applications in automobile



The global developments in rare earth industry have a very immediate impact on Japan and which reflects in the consumer behavior of Japanese manufacturing industries. Compared to Europe or United States, Japanese companies are quick to formulate polices in securing stable supply of critical minerals or adapting to new changes. During the 2010 REE crisis some Japanese manufacturers forced their suppliers to increase their stockpile of raw materials to up to two years, at the very moment the prices were highest and the materials were hardest to obtain. This also contributed to drive up the prices of neodymium and dysprosium significantly during the bubble. For example, during the height of the crisis, their customers demanded that Santoku would stock 2 years of supply, forcing them to buy a year's worth of material at the highest cost. This had caused a great loss to these trading companies as the price went down in consequent years and they could not claim it from their customers (Sprecher et al, 2015).

6.7 Major Developments in Japanese Rare Earth Industry in Post Bubble Period

The major developments in Japanese rare earths intermediate production line and supply chain can be summarized as follows. This also reflects the global trends in rare earth industry at large and predictions for future.

Magnets: Rare earth based permanent magnets are the most important intermediate product in the entire rare earth industry in terms of value as well as its importance to downstream industries. This is also the most promising sector in case of future demand. Magnets will continue to dominate in value chain both in Japan and globally as there would be sustainable demand from final products along with increasing importance of new energy saving systems and alternate energy developments. The companies like Hitachi and Mitsubishi are major players in global wind turbine industry along with a couple of small players in Japan and the demand from wind turbine industry will greatly influence the RE industry. Demand for magnets from automotive is also going to become significant as the importance and sale of hybrid models are really picking up in industrialized countries along with plug in electrical vehicles.

Catalysts: In the catalysts sector the demand in Japan has been almost stable and future demand is dependent on automobile production and demand. Catalyst demand would come from developing countries like China and India rather the industrialized countries as the growth in automobile demand in developed countries has been moderate.

FCC: Fluid cracking catalysts sector was an emerging area where rare earths have been used to refine the tight crude as a result of increased exploration and production of shale gas particularly in United States and Canada. However, the recent decline in global crude oil prices have stalled many shale gas projects as under the current price levels it is not cost-effective to produce and is uncompetitive compared to traditional oil fields. If the crude prices pick up again and move above at least USD 85 per barrel, which is the threshold level under the current operating and capital costs, the shale gas producers may enter the business again and in effect the demand for REs from this sector may increase.

Phosphors: Rare earth demand from phosphor sector is dramatically decreasing as the lighting system and electronics industry shift to LEDs.

Glass: Globally there would be sustained demand from glass industry as major consumers would be again emerging countries like China and India. Most of Japanese glass manufacturers such as Hoya, Asahi and Nikon have moved their production plants to China and Vietnam. So the domestic consumption within Japan would be less robust in future.

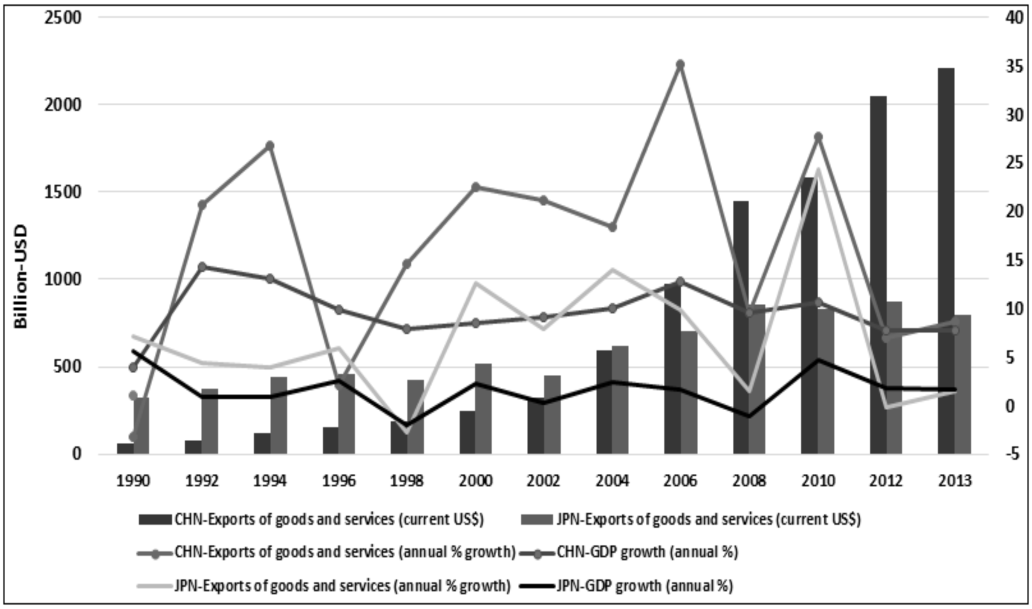
Polishing: After the great price spikes of 2010 and 2011, Japanese companies have made investment successfully to replace lanthanum from polishing agents with zirconia, a much cheaper and non-critical element. The industry experts says that companies would not use lanthanum again as they have already made investment in technology.

Battery Cells: As in the case of permanent magnets, battery cell is another promising sector where demand would increase particularly from the industrialized countries as the large number of consumers shift to hybrid and electrical vehicles. These automobiles largely use the Ni-MH batteries in effect increasing the demand for rare earths.

7 Competition with China and Value Chain Uncertainties

Japan is the third largest economy in the world by nominal GDP standards and the second largest developed economy. Japan is the world's third largest automobile manufacturing country, has the largest electronics goods industry, and is often ranked among the world's most innovative countries, leading several measures of global patent filings. However, two decades of sluggish growth and persistent deflation have reduced Japanese living standards below the OECD average. Output growth was projected to pick up to 1% in 2015. The fall in oil and commodity prices in 2014-15 had resulted in significant terms-of-trade gains that are promoting private consumption and investment. Indeed, the fall in oil prices from $85 per barrel in October 2014 to $60 in March 2015 has boosted Japanese output growth by about ¼ percentage points (OECD, 2015).

Figure 7.1: Selected economic indicators of Japan and China



Source: World Development Indicators, World Bank

As said before, Japanese economic growth has been sluggish and has not grown more than 2.5 percent in last 25 years. In some years there were negative growth such as in 1998 and 2008 probably at the peak of Asian financial crisis and global financial crisis.

As reflective of the economic growth, growth rate of exports of goods and services was also highly volatile and average growth during this period was around 6 percent. However, services sector contribution to overall growth and export growth has been more intensive compared to manufacturing growth. The total exports of goods and services has grown moderately compared to the overall economy and in absolute terms the total exports grew from USD 319 billion in 1990 to USD 859 billion in 2008. Since then the total exports have declined moderately to USD 795 billion in 2013. In comparison to Japan, Chinse GDP and export has grown exuberantly and in most of the economic indicators, China has overtaken Japan in 2010. In 1990, Chinse total export of goods and services was just USD 57 billion, just 17 percent of Japanese exports. However, by 2013, Chinse export of goods and services has grown to USD 2.213 trillion.

The global demand for Japanese products is what drives Japan's demand for REEs. For example, Japan is a major producer and exporter of sintered rare earth magnets and NdFeB alloys, nickel-metal hydride batteries, auto catalysts, digital cameras, phosphor lamps, and others. The country is also the largest producer of hybrid electric vehicles (HEV). Rare earth minerals are essential for these industries in Japan and manufacturing is the backbone of Japanese economy. But the major worry to the government and companies in Japan is losing the competiveness and market share in overall as well as RE based products to emerging countries like China and South Korea, making uncertainties in their value chain.

China has overtaken as the second largest economy in the world in terms of GDP since 2010, the largest exporter since 2009, and second largest trading nation. The impact of China's trade expansion is felt by various nations around the world in various fields. On the one hand, exports from China constitute a threat to other exporters in the same industry. On the other hand, China's insatiable demand for raw materials and other goods leads to the expansion of exports around the globe.

7.1 The Impact of China's Trade Expansion as Discussed in the Literature

Kuroda (2001), which was published shortly before China's entry to WTO, was widely accepted in Japan then, with its vivid description of rising Chinese industries and firms. He argued in this book that "China is a disrupting factor in the flying-geese development pattern of East Asia." What he meant by "flying-geese development pattern" was that the locus of exporting industries shifted from one nation in East Asia to another according to the order of per capita GDP levels of Asian nations. That means that an export industry of Japan, after its loss of comparative advantage caused by the rise of wages in Japan, will move to South Korea or Taiwan, and when the industry lose its comparative advantage even in these nations, it will further move to Malaysia, Thailand, or to Indonesia. The industry will even move forward to China, and then to Vietnam, Myanmar, and Cambodia. But Kuroda found that China had a richer base of supporting industries than Thailand and Malaysia and ampler supply of skilled workforce. Therefore, China had the potentiality to host more technologically-sophisticated industries than the South East Asian countries, even though its wage level was lower than in South East Asia. Therefore, Kuroda argues, China will compete in relatively technology-intensive industries with Thailand, and even with South Korea and Taiwan, while competing with Vietnam and Myanmar in labor intensive industries. China is like a gigantic bird that appears in a flock of geese and disrupts their flight.

Greenaway, Mahabir, and Milner (2008), with a similar concern with Kuroda (2001), made an empirical analysis of exports by Asian nations using the data of 1990-2003. They created a gravity model of export trade by Asian nations and checked whether China's exports had displaced the exports of other Asian nations. Their conclusion was that China's displacement of low income nations in Asia, such as Bangladesh, India, Pakistan, Cambodia, and Vietnam, was not significant, but quite significant in the cases of Japan, South Korea, and Singapore. A one percent rise in China's exports led to a 0.4 percent drop of exports by these countries. The growth of exports to China from these countries was not enough to compensate for the displacement effect.

The development of Chinese and Asian economies since 2002 largely followed Kuroda's prediction. China did compete with richer nations in Asia, such as Thailand, Malaysia, South Korea, Taiwan, and even with Japan. What Kuroda did not anticipate, however, was that labor shortage became a big problem in coastal China since 2004. China experienced a steep rise in its wages, and now it is on a par with Thailand. Some industries have shifted their production bases from China to Vietnam, Bangladesh, etc.

China did displace the exports from other Asian nations, but the impact of its emergence as a big importer was even larger, leading to the rapid expansion of other Asian nations and the rise of China's share in their exports.

The limitation of the discussions made by Kuroda and Greenaway et als. is that they confine their scope of discussion in Asia, while China's impact has not been confined to Asia. Shafaeddin (2004) discussed China's impact on the exports of Asia, Africa, and Latin America. Based on an in-depth analysis of trade data until 1998, he concluded that China had a strong competitiveness in labor-intensive industries and was beginning to acquire comparative advantage in capital- and technology-intensive industries. With their similar export structure with China, he argues, South Asia, Africa, and Latin America, could not expect too much expansion of exports to China.

It turned out, however, that these nations benefitted a lot by China's trade expansion. The share of exports to China within the total exports by 30 African countries has increased from 2.3% in 2000 to 12.2% in 2011. The same share for 28 Latin America and Caribbean countries has increased from 1.5% in 2000 to 11.0% in 2011. In the case of India, China's share has increased from 3.2% to 7.8% during the same period.

Lall, Weiss, Oikawa (2005) discussed the impact of China's trade expansion on Latin America using the trade data of 1990-2002. If China's share in the global export market of a certain item increases while the share of a Latin American country drops, then, according to their definition, China is regarded as constituting a "direct threat." When both the shares of China and a Latin American country increase, but China increases faster, then China is a "partial threat." If China's share decreases while a Latin American country's share increases, then China is a "reverse threat." They checked whether China is constituting a threat or not for each item of 3-digit SITC classification, and their conclusion was that on average, 11% of Latin American nations' exports face "direct threat" from China, while 27% face "partial threat." In sum, they argued that China was not a big threat to LA, but LA's exports to China tended to concentrate in primary goods. This would have a long-term negative effect on the economic development of Latin America, because primary goods exports have little spillover and learning effects.

7.2 The Impact of China’s Export Expansion

The world economy has changed a great deal since the period studied by the literature cited in the previous section, especially after the global economic crisis that followed the Lehman shock in 2008. Now the impact of China’s rise as a trading nation is felt not only in Asia and Latin America but also in Africa, Oceania, and Europe. Adopting the method used by Lall, Weiss, and Oikawa (2005), we calculated the changes of shares of each country in the global export of a certain item that might be related to China’s rise as an exporter of the same item. we selected the items (in 2-digit HS classification) in which China is an important exporter. The criteria to be judged as an “important exporter” is that China had more than 11 percent share in global exports of the item either in 2000 or in 2011. The threshold of 11 percent was chosen because in 2011 China’s share in total global exports was 11 percent. Therefore, having more than 11 percent global share means that China has a “revealed comparative advantage (RCA)” in that item.

Table 7.1 shows the result of the calculation. Among 24 items in “animal and vegetable products and food” (HS01-24), China had more than 11 percent global export share in 6 items either in 2000 or in 2011. In “vegetables” (HS07), China’s share increased from 8 percent to 14 percent, while Spain’s share and Mexico’s share dropped by 4 and 3 percentage points, respectively. Among chemicals (HS28-38), China was an important exporter only in two items, i.e. “inorganic chemicals” (HS28) and “explosives, pyrotechnics, matches” (HS36). The rapid increase of exports of rare earth oxides is one of the reasons of the increase of China’s share in inorganic chemicals exports. In “articles of leather, animal gut, travel goods” (HS42), “furskins; manufactures thereof” (HS43), and “manufactures of plaiting material, basketwork” (HS46), China’s shares are very large and even growing. Among textiles (HS50-63), China is an important exporter in 11 items. China is taking away market shares from OECD member countries, Taiwan, and Mexico. In footwear, headgear, umbrellas, and walking sticks (HS64-66), China’s shares are very large and growing. China is displacing Italy, South Korea, and Taiwan in these items. In base metal products (HS72-83), China became an important exporter in four items, but its share dropped significantly in three items. In machinery (HS84-91), China became an important exporter in ordinary machinery, electric machinery, and ships. In musical instruments, furniture, toys and sports requisites, China’s shares are very large.

To sum up, China strengthened its comparative advantage in its conventional export items, such as textiles and light industry goods, gained comparative advantage in some items of machinery, but lost comparative advantage in some base metal products. The table also shows that China's competitors are not only the richer Asian nations but also Europe and the US. Judging from the changes in global export market shares, China's main competitors in various export items were the United States, Italy, South Korea, Taiwan, Japan, and France.

So, in the next section we analyze how the overall trade expansion of China has affected the Japanese domestic demand as well as exports and particularly the exports where rare earths are used as inputs in manufacturing or as intermediate products.

Table 7.1: Changes in China's and other countries' shares in global exports

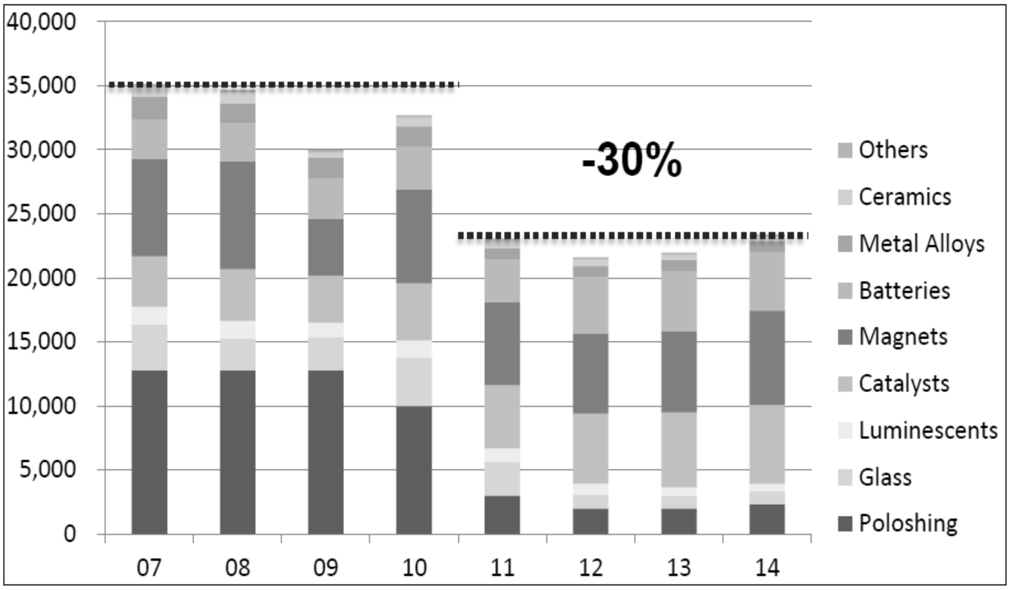
Item	HS code	China's share 2000	China's share 2011	Economies which experienced largest export share changes in each item			
Total Export		4%	11%				
Fish, crustaceans	03	6%	12%	Canada(−3)	Thailand(−3)		
Products of animal origin	05	23%	21%	Germany(+2)			
Vegetables	07	8%	14%	Spain(−4)	Mexico(−3)		
Vegetable plaiting materials	14	14%	10%	Malaysia(+7)			
Meat, fish preparations	16	13%	18%	Denmark(−3)	France(−3)		
Vegetable, fruit preparations	20	7%	12%	USA(−3)			
Inorganic chemicals	28	7%	13%	USA(−5)	Australia(−3)	Germany(−2)	Japan(−2)
Explosives, pyrotechnics, matches	36	20%	19%	France(+4)	UK(+3)		
Articles of leather, animal gut, travel goods	42	36%	41%	Thailand(−3)	Mexico(−2)	Philippines(−2)	
Furskins; manufactures thereof	43	13%	25%	USA(−3)	Germany(−3)	Greece(−3)	Spain(−3)
Manufactures of plaiting material, basketwork	46	61%	72%	Indonesia(−5)	Philippines(−9)		
Silk	50	42%	52%	India(−5)	South Korea(−4)	Italy(−3)	
Wool, fabric thereof	51	11%	19%	Italy(−5)	France(−3)		
Cotton	52	13%	23%	Italy(−4)	Germany(−3)	France(−3)	
Vegetable textile fibres	53	21%	32%	Belgium(−5)	Italy(−4)		
Manmade filaments	54	5%	28%	South Korea(−9)	Taiwan(−5)		
Manmade staple fibres	55	12%	27%	Taiwan(−5)	Germany(−5)		
Special woven or tufted fabric, lace, tapestries	58	10%	36%	South Korea(−8)	Taiwan(−3)	USA(−7)	
Knitted or crocheted fabric	60	10%	35%	South Korea(−5)	Taiwan(−13)		
Articles of apparel, knit or crochet	61	19%	41%	USA(−5)	Italy(−4)	Mexico(−4)	
Articles of apparel, not knit or crochet	62	21%	34%	Mexico(−5)	USA(−3)		
Other made textile articles	63	21%	41%	Mexico(−5)	Portugal(−4)	USA(−3)	
Footwear	64	26%	37%	Italy(−9)	Brazil(−3)		
Headgear	65	25%	48%	Itay(−5)	South Korea(−7)	Taiwan(−8)	
Umbrellas, walking-sticks	66	62%	78%	Italy(−4)	Taiwan(−6)	Indonesia(−2)	
Feathers, artificial flowers	67	64%	70%	South Korea(−3)	Thailand(−4)		
Ceramic products	69	10%	31%	Italy(−11)	Spain(−4)	Japan(−4)	
Ariticles of iron and steel	73	6%	17%	USA(−4)	Canada(−3)		
Lead and articles thereof	78	15%	2%	UK(+3)	South Korea(+5)	Mexico(+3)	
Zinc and articles thereof	79	12%	2%	Belgium(+4)	India(+5)	South Korea(+3)	Spain(+3)
Tin and articles thereof	80	26%	2%	Indonesia(+15)	Malaysia(+5)	Thailand(+3)	Singapore(+3)
Other base metals, articles thereof	81	11%	20%	Russia(−4)	USA(−3)	Canade(−3)	
Tools, cutlery of base metal	82	8%	18%	UK(−5)	Russia(−4)		
Miscellaneous articles of base metal	83	7%	21%	USA(−7)	Mexico(−3)	Italy(−3)	Canada(−3)
Machinery	84	3%	17%	Japan(−3)	USA(−6)	UK(−3)	
Electrical machinery	85	5%	21%	Japan(−7)	USA(−7)		
Railway, rolling stock	86	22%	34%	Canada(−8)	USA(−5)	France(−4)	
Ships, boats	89	4%	24%	France(−5)	Japan(−12)		
Clocks and watches	91	13%	8%	Hong Kong(+15)	Switzerland(+2)		
Musical instruments	92	11%	25%	Japan(−11)	South Korea(−6)	Taiwan(−4)	Malaysia(−3)
Furniture	94	10%	31%	Canada(−6)	Italy(−6)	USA(−3)	
Toy, sports requisites	95	29%	37%	Japan(−7)	Taiwan(−5)	USA(−3)	
Miscellaneous manufactured articles	96	12%	34%	Japan(−9)	USA(−4)	Taiwan(−4)	

Source: Calculated by the author using UNCOMTRADE and PC-TAS. The data on the amount of exports from Taiwan, which are taken from the International Trade Division, Republic of China, are added to these data.

7.3 Rare Earth Demand by Application in Japan

As reflective of the sluggish economic growth and moderate increase in exports, overall demand for rare earth based intermediate products has been in decline in Japan during the last few years. Moreover, China has overtaken Japan as the leading manufacturer and exporter in the final product category where many of these RE based products are used as inputs. Figure 7.2 shows that rare earth demand across all sectors in Japan declined by about 30 percent between 2010 and 2014. However, individual product categories show some interesting pictures.

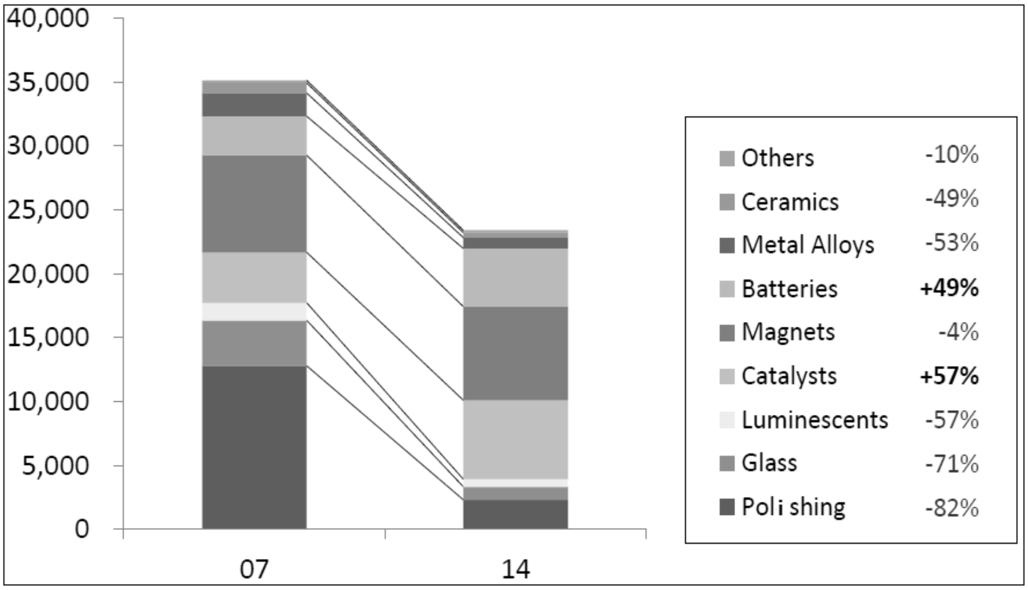
Figure 7.2: Rare earth demand by application in Japan



Source: Nakamura (2015)

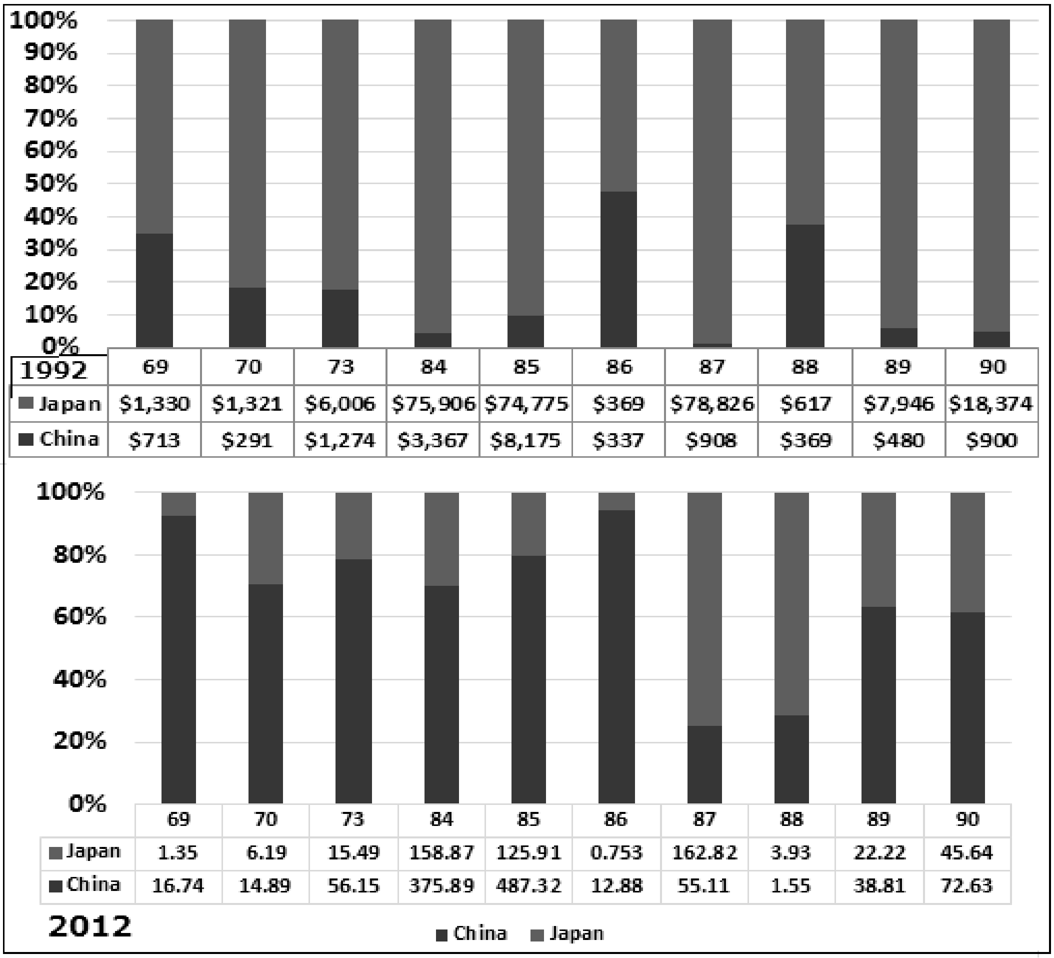
Figure 7.3 shows that the largest decline in demand for rare earths is in polishing powder as there is 82 percent decline in demand between 2007 and 2014. This is followed by a 71 percent decline in glass industry, 57 percent decline in luminescent sector, 53 percent decline in metal alloy industry and 49 percent decrease in ceramics sector during 2007-14. However, the figure shows an increase in demand for rare earths in certain sectors such as catalysts and batteries. The magnet sector shows a moderate decline, but this will soon change as there are new and increased usage of magnets in different applications and emerging industries in Japan. The declining sectors are those which China has overtaken Japan in exports and many Japanese companies have shifted their manufacturing base to China to procure the resource and to take advantage of low labor cost. Japanese automobile sector is still competitive and leads the global market, which is reflected in robust demand in battery and catalysts industry. Decline in polishing demand is largely attributable to the Japanese companies started to use zirconia, instead of cerium as a polishing agent and declining demand in luminescent is attributable to the development in LEDs, as LED lighting require less of REs compared to the fluorescent based lights. The demand for magnets is expected to increase both in Japan and globally with increasing applications in electronics, electrical and new energy products as well critical defense applications. Also, facing increasing competition from China and South Korea in traditional sectors, manufacturing in Japan now focuses primarily on high-tech and precision goods, such as optical instruments, hybrid vehicles, and robotics and most of these final products use the RE based magnets, which would also eventually increase the rare earth demand in magnet sector in Japan.

Figure 7.3: Rare earth demand by application in Japan



Source: Nakamura (2015)

Figure 7.4: Comparison of China’s and Japan’s exports in final product category in 1992 and 2012 (HS Code 69-90)



1992	69	70	73	84	85	86	87	88	89	90
Japan	$1,330	$1,321	$6,006	$75,906	$74,775	$369	$78,826	$617	$7,946	$18,374
China	$713	$291	$1,274	$3,367	$8,175	$337	$908	$369	$480	$900

2012	69	70	73	84	85	86	87	88	89	90
Japan	1.35	6.19	15.49	158.87	125.91	0.753	162.82	3.93	22.22	45.64
China	16.74	14.89	56.15	375.89	487.32	12.88	55.11	1.55	38.81	72.63

Source: Author’s calculations based on the UNCOMTRADE database 2015

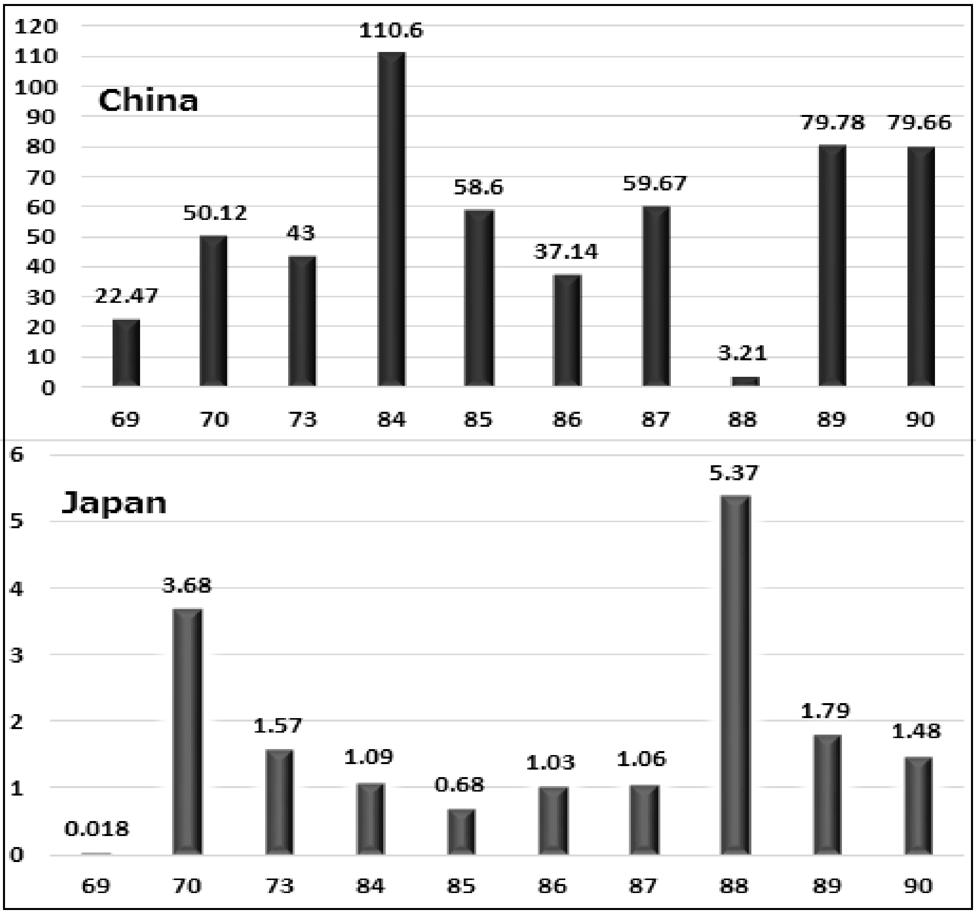
Figure 7.4 shows China’s and Japan’s exports in major manufacturing product categories (HS code 69 to 90) and compares the year 1992 and 2012. In each product category, the graph represents a 100 percent stacked column and compares the percentages that each country contributes to the total. Total is calculated by adding both countries’ exports in each product category for the year 1992 and 2012. The figure also shows export values in US dollar terms, which is depicted in millions for the year 1992 and in billions for 2012. The data shows that China was not a major exporting country in

1992 across all product categories and by 2012, China has overtaken Japan in all product categories barring HS-87 (vehicles other than railway, tramway) and HS-88 (aircraft, spacecraft, and parts thereof). However, China has increased its share in export in both product categories. In all these product categories rare earths are an important input in the value chain at varying degree of quantity.

For example in the ceramic products (HS-69), rare earth elements are widely used in manufacturing, covering wide areas such as colorants in glazes, refractories, electronic ceramics, and other applications. Yttrium oxide is used in advanced ceramics as a sintering agent for structural components and coatings made of silicon nitride, sialons (Si-Al-O-N ceramics) or zirconium oxide. Yttria stabilized zirconium oxide coatings are used as thermal barriers in jet engines. Cerium oxide is also growing in importance as a sintering agent. Lanthanum oxide is used in technical ceramics. Yttrium oxide is used as an additive in yttrium-stabilized zirconium oxide (YSZ) and is the primary rare earth compound used in refractory ceramics. YSZ oxygen sensors are used to measure the oxygen content in automobile exhaust gases, molten glass and molten steel. They are also used to control industrial furnaces and as aqueous pH sensors in primary water systems of nuclear reactors, geothermal power, and other high-temperature or high-pressure solutions. Rare earth oxides are consumed in electronic ceramics, including electro-optical applications such as microwave garnets and laser dopants. Neodymium oxide, praseodymium oxide, didymium oxide and lanthanum oxide are used in manufacturing temperature-compensating capacitors, resistors and thermistors (ACC, 2015).

China has utilized well its resource abundance in rare earths to move up in the value chain and has become the lead exporter in these products.

Figure 7.5: Export growth rate of China and Japan between 1992 and 2012 in select product categories



Source: Author's calculations based on the UNCOMTRADE database 2015

Across all product categories, China's export growth was in double digits while Japan grew modestly in single digit between 1992 and 2012. In ceramics products (HS-69), China's export was USD 713 million in 1992 which increased to USD 16.74 billion in 2012, a 22.47 percent growth over 20 years. While for Japan, the export was USD 1.33 billion in 1992 in same product category and in 2012, the export was USD 1.35 billion, which was almost equal as in 1992 with a 0.08 percent growth rate.

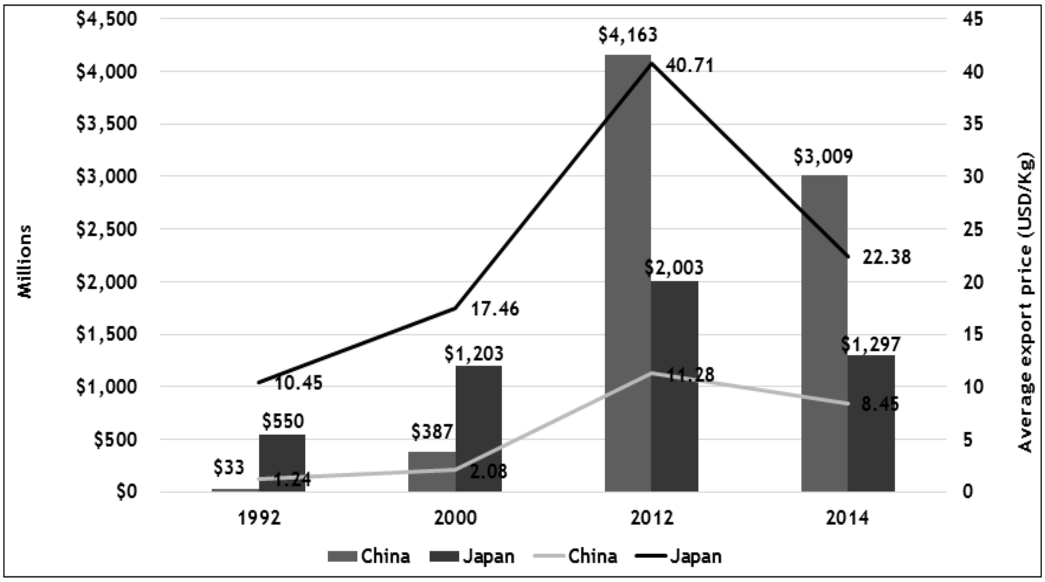
Even in the established sectors, where Japanese companies had long experience and technological advantage, Chinese companies have taken the global market. For example, in nuclear reactors, boilers and machinery items (HS-84) market, where Japanese nuclear equipment manufacturers such as Mitsubishi Heavy Industries, Itochu, Toshiba, Sojitz, Hitachi and Japan Steel Works are facing huge competition from Chinse companies in overseas market. Japan had exported USD 75.9 billion worth of commodities in this sector (HS-84) in 1992, where China's export was USD 3.36 billion. The situation has changed completely by 2012, where China's export was equal to USD 375 billion, a 110.6 percent growth in last 20 years and Japan's export was USD 158 billion, a 1.09 percent growth over 20 years.

In electronics and electrical equipment market (HS-85), where Sony, Toshiba, Panasonic, Hitachi, Sharp etc. used to be the global leaders, currently China is far ahead of Japan in exports. In this category, China had exported just USD 8.17 billion in 1992 and Japan's export was USD 74.77 billion. China's export has increased to 487 billion in 2012 with a 58.6 percent growth over 20 years and Japan's export increased to 125 billion with a 0.68 growth rate over same period.

Two sectors that China still drags behind Japan are vehicles other than railway, tramway (HS-87) and aircraft, spacecraft, and parts thereof (HS-88) and China is trying to catch-up very fast in the automobile sector. In 1992, Japan's export of vehicles valued USD 78.82 billion, whereas China's export valued USD 908 million. By 2012, Japan's export has increased to USD 162 billion with a growth of 1.06 percent, whereas China's export increased to USD 55.11 billion with a 59.67 percent growth over 20 years.

The following figure shows exactly how China has moved up in the value chain in rare earth sector by utilizing its resource advantage replacing Japan in international market.

Figure 7.6: Japan's and China's export of electro and permanent magnets, NdFeB magnet film, Other NdFeB alloys, Ferroalloy containing rare earths



Source: Author's calculations based on the UNCOMTRADE database 2015

As explained elaborately in the section 6.2 and 6.21, the permanent magnets are the most critical and promising sector in rare earth intermediate industries. Permanent magnets have a wider range of applications compared to any other intermediate products in rare earth industry. Permanent magnets are indispensable components in many industries such as consumer electronics, wind turbines, automobiles and very critical applications in defense industries. China was a minor exporter of permanent magnets in 1992 with an export value of just USD 33 million and Japan's export was equal to 550 million as most of modern industries such as electronics industry, hybrid and electrical vehicles and wind energy industry were in infant stage in early 1990s. Exports of permanent magnet grew along with the new developments of industry, where the use of these magnets became indispensable. In 2000, China's export was valued USD 387 million, still far behind Japan's export of USD 1.2 billion. The sector changed completely in 10 years and by 2012 China overtook Japan as the lead producer and exporter of these magnets and alloys. China had exported USD 4.16 billion worth of RE magnets and related products in 2012, double the amount of Japan's export of USD 2 billion. How

China achieved this technological and export capability is explained in detail in the previous chapter. There is also a great price difference between China and Japan in magnets sector which is reflected in the average export price per kilogram as depicted in the graph. This also makes Chinse products cheaper to outside world, making Japanese companies in a disadvantageous position.

In 2014, the export value has declined for both countries compared to 2012, but still China's export was worth of USD 3 billion and Japan's export was equal to USD 1.2 billion. The export volume of China's rare earth products reached about 29,000 tons (of which, rare-earth permanent magnet products accounted for 75.5%) in 2014, accounting for 32.1 percent of the total output and the remaining is consumed within China. Zhong Ke San Huan is the largest NdFeB manufacturer in China with an annual production capacity of 14,000 tons sintered NdFeB and 1,500 tons of bonded NdFeB. In February 2015, the company had signed an agreement with Hitachi Metals to set up a high-performance NdFeB manufacturing plant in China, with a design capacity of 2,000 tons per annum.

7.4 Rare Earths Transition in China and Moving up the Value Chain

To maximize the benefits of China's rich endowment of rare earths to the Chinese people through downstream job creation, China has continuously pursued technology upgradation and scaling up the production. In 1970s, China was exporting rare earth mineral concentrates, and in the 1980s, it started to export mixed rare earth chemical concentrates by technological upgradation, in early 1990s, the country started to export separated rare earth oxides and metals and in late 1990s it moved to RE based intermediate products such as magnets, phosphors, polishing powders. Staring from 2000s, the country started exporting electric motors, computers, batteries, LCDs, mobile phones, EVs, hybrid vehicles replacing many developed countries like Japan as the leading exporter in these sectors (Kingsnorth, 2015).

China has achieved a complete industrial system from mining to end-product utilization with the ability to produce over 400 varieties of rare earth products in more than 1000 specifications. In 2015, China produced more than 100,000 tons of rare earth smelting separation products, accounting for more than 90 percent of the world's total output. Since 1990, domestic consumption of REO for high value-added product manufacturing in China has increased at 13 percent annually, reaching 80,000 tons in 2012. The Chinese government, determined to become a world leader in green technology, plans to invest billions of dollars over the next few years to develop electric, hybrid vehicles and its own aircrafts. A group of 16 big state-owned companies had already agreed to form an alliance to do research and development and creates standards for electric and hybrid vehicles.

Clean energy technologies currently constitute about 20 percent of global consumption of critical materials. As clean energy technologies are deployed more widely in the decades ahead, their share of global consumption of critical materials is likely to grow. Green energy technology is expected to become the largest consumer of rare earth elements in the future. Since 2009, China has become the world's top investor in clean energy technology with an investment of over 34 billion. Since 2005, the country's wind generation capacity has increased by more than 100 percent a year. In 2009, China became the largest manufacturer of wind turbines in the world, with 17 of its 40 turbine manufacturers being state-owned, 12 private Chinese firms, and 11 joint ventures or foreign owned (The Pew Charitable Trusts, 2010).

While no permanent magnets are used in either traditional geared and electrically excited gearless drivetrains, reportedly 650 kg/MW are used in low speed direct drive machines with permanent magnet excitation. Substantially smaller permanent magnets are used in hybrid drivetrains, with 160 kg/MW in medium speed single-stage and 80 kg/MW in high speed multi-stage gearbox machines. In terms of rare earth content, PMSG-DD machines with 250 kg of neodymium, dysprosium, praseodymium and terbium use up 10 times more rare earths per MW of power produced than hybrid designs (Bartekova, 2014). In fact, there is a lack of consensus on permanent magnet content in wind turbines, opinions on permanent magnet content within direct drive generators ranging from 500-625 kg/MW (Constantinides, Steve, 2010) through 600-800 kg/MW (Jensen et al., 2013), up to 1000 kg/MW reported by various consultancies (cited in Bartekova,2014).

Table 7.2: Generator Types in Wind Turbine Technologies and Their Respective Permanent Magnet and Rare Earths Contents

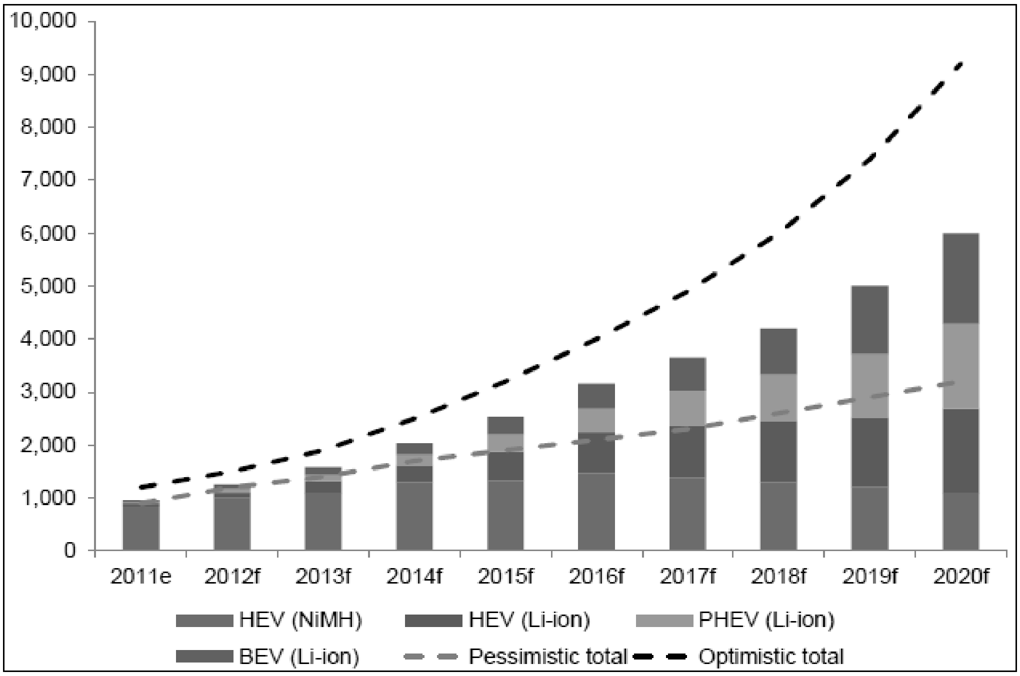
Wind Turbine	Gearbox	Generator	Permanent Magnet	Rare Earths
Geared Drivetrain	Single Stage	Induction (IG)	-	-
	Multi-Stage	Wound Rotor Induction (WRIG)	-	-
		Squirrel Cage (SCIG-MG)	-	-
		Doubly Fed Induction (DFIG-MG)	-	-
Direct Drive	-	Electrical Excited Synchronous (EESG-DD)	-	-
		Permanent Magnet Excited Synchronous (PMSG-DD)	650 kg/MW	250 kg/MW (Nd, Dy, Pr, Tb)
		High Temperature Superconducting (HTS)	-	YBCO: 0.1 kg/MW (Y, La, Ce)
Hybrid	Single-Stage	Permanent Magnet Synchronous (PMSG-SG)	160 kg/MW	45 kg/MW (Nd, Dy, Pr, Tb)
		High Temperature Superconducting (HTS)	-	YBCO: 0.02 kg/MW (Y, La, Ce)
	Multi-Stage	Permanent Magnet Synchronous (PMSG-MG)	80 kg/MW	25 kg/MW (Nd, Dy, Pr, Tb)

Source: Bartekova (2014)

China has doubled its installed wind power capacity every year since 2006 and is now the world's largest producer of wind turbine. By 2020, China is expected to boost its wind power capacity to 200 gigawatts (GW) or more, up from 12 GW in 2008. The annual growth rate will be about 20 percent (China Daily, 2009). After a slowdown in 2013, the wind industry set a new record for annual installations in 2014. Globally, 51,473 MW of new wind generating capacity was added in 2014 according to the global wind market statistics by the Global Wind Energy Council (GWEC). The record-setting figure represents a 44% increase in the annual market, and is a solid sign of the recovery of the industry after a rough patch in the past few years. Total cumulative installations stand at 369,597 MW at the end of 2014. China's installed wind power capacity was about 114,609 MW at the end of 2014 and account for 31 percent of global installed cumulative capacity. In China at the end of 2015, GWEC expects similar numbers as in 2014. After that, while the market may contract a bit, it's not unreasonable to assume that China alone will install on the order of an additional 100 GW by the end of 2019, exceeding the country's 200 GW target for 2020 by a healthy margin, and a year ahead of time.

An additional production of 250.5 GW will require 167,000 tons of rare earth minerals. China has announced that in the next ten years it will construct some 133 gigawatts of wind turbine generated electricity. It seems that data on the amount of rare earths in wind turbines vary, ranging from 0.2 to 3.3 kilogram of neodymium content per kW of rated capacity. A 3 MW wind turbine can use up to 2,700 kilogram of NdFeB magnets and NdFeB magnets are a critical component for some models of the new generation wind-powered turbines (Table 7.2).

Figure 7.7: Forecast of world production of EVs/HEVs by type, 2010 to 2025 (000 units)



Source: Shaw and Constantinides (2012)

Hydrogen-fuel based cars, for example, require platinum-based catalysts; electric-hybrid cars need NiMH or Lithium batteries; and rhenium super alloys are an indispensable input for modern aircraft production. In particular, HEV motor systems often rely on NdFeB magnets. In 2009, China produced 19,000 tons of rare earth hydrogen storage materials and consumed 7,900 tons of rare earth, accounting for 41% of the total consumption. Since November 2009, China has also become the largest auto market in the world. China's automobile industry has been in rapid development since the early 1990s. In 2009, China produced 13.79 million units of automobile. The Chinese are also investing big in electric cars, hybrid cars and the underlying industry. The Chinese are already one of the largest producers of lithium-ion batteries, and as the main application in car batteries, lithium-ion demand is growing fast. Rare earth hydrogen storage materials are major raw materials for the production of nickel-hydrogen battery. As nickel-hydrogen battery shows positive development prospects in the electric tool and electric vehicle sectors, it was forecast that China's hybrid electric vehicle market will witness exceptional growth with an annual growth rate of 12 percent (China Research and Intelligence, 2010). The global production of EVs/HEVs could reach 3.2-9.2 million by 2020 (Shaw and Constantinides, 2012).

The Chinese government, determined to become a world leader in green technology, plans to invest billions of dollars over the next few years to develop electric and hybrid vehicles. A group of 16 big state-owned companies had already agreed to form an alliance to do research and development, and creates standards for electric and hybrid vehicles. The plan aims to put more than a million electric and hybrid vehicles on the road over the next few years in what is already the world's biggest and fastest growing auto market. The announcement, analysts say, is another example of how China seeks to marshal resources and tackle industries and new markets. The plan also underlines what China describes as its growing commitment to combating pollution and reducing carbon emissions.

According to Reuters, global sales of hybrid electric cars are forecast to reach 3 million units in 2015 with a total REM requirement of 33,000 tons. One of the largest growth areas is expected to be the production of hybrid vehicles, such as the Toyota Prius. Each hybrid car contains 16 kilogram of rare earths, predominantly in its batteries and electric motors. It is estimated that the motor in the average Prius hybrid uses about 193 grams, or about 7 ounces, of neodymium and 24 grams of dysprosium, while the fully electric Nissan Leaf uses about 421 grams of neodymium and 56 grams of dysprosium. Toyota and others had plans to use induction motors in EVs in case the price of Nd becomes unsustainable or supplies are undependable (Shaw and Constantinides, 2012).

Table 7.3 : Annual sales of Toyota Prius worldwide and by region (in thousands)

Year	World	Japan	U.S.A	Canada	Europe	Other
1997	0.3	0.3				
1998	17.7	17.7				
1999	15.2	15.2				
2000	19.0	12.5	5.6	0.2	0.7	0.01
2001	29.5	11.0	15.6	0.4	2.3	0.2
2002	28.1	6.7	20.1	0.2	0.8	0.2
2003	43.2	17.0	24.6	0.3	0.9	0.4
2004	125.7	59.8	54.0	1.9	8.1	1.9
2005	175.2	43.7	107.9	2.0	18.8	2.9
2006	185.6	48.6	107.0	2.0	22.8	5.3
2007	281.3	58.3	181.2	2.6	32.2	7.0
2008	285.7	73.1	158.6	4.5	41.5	7.7
2009	404.2	208.9	139.7	4.6	42.6	8.4
2010	509.4	315.4	140.9	3.0	42.0	8.1
2011	368.4	197.4	128.1	1.6	24.9	16.6
2012	362.8	176.9	147.5	3.4	19.4	15.7
2013	315.5	145.2	145.2	2.1	11.6	11.3
2014	242.0	101.9	122.8	1.8	6.7	8.8
2015-till July	118.3	43.7	65.4	1.0	4.0	4.3
Total	3,527.1	1,553.4	1,564.2	31.5	279.4	98.7

Source: Toyota Corporation, http://newsroom.toyota.co.jp/en/detail/4063130/

The Chinese government had announced in 2010 that it will spend around USD 14.7 billion through 2020 on alternative train and drive vehicles, with the bulk of the money going towards all-electric vehicles. Pike Research, projected that between 2010 and 2015, China will have 1.85 million hybrids and EVs sold, with 1 million EVs on the road. In the U.S. more than 2.3 million hybrids will be sold along with 840,000 plug-in and all-electric vehicles between 2010 and 2015. At the 2010 Beijing Motor Show, more than 20 electric vehicles were on display, most of which came from native automakers. As of May 2010, at least 10 all-electric models have been reported to be on track for volume-production. The first mass produced plug-in hybrid car (BYD F3DM), all-electric minivan (Luxgen 7 MPV EV) and all-electric long-range bus (500 km range Zonda Bus) are Chinese (Gartner, 2010).

Many of the rare earth minerals and metals are also used in sectors such as semi-conductors. The semiconductor industry is dominated by Chinese Taipei, South

Korea, United States and Japan. The role of the semi-conductor industry is one of a technology enabler and is widely recognized as a key driver for economic growth throughout the electronics value chain. The semiconductor market represented USD213 billion in 2004 and the industry was one enabling factor in the generation of USD1200 billion in electronic systems business and USD 5000 billion in services, representing close to 10% of world GDP that year. The semi-conductor industry is also a high-growth industry, experiencing 13% growth on average per annum over the last 20 years (Korinek and Kim, 2010).

There are numerous examples that point to China's anticipated increase in rare earth consumption. In 1990 it produced less than 3 percent of global manufacturing output by value; its share now is nearly a quarter. China produces about 80% of the world's air conditioners and 70% of mobile phones (Economist, 2015). For example, at the end of July 2015, China had more than a billion cell phone connections. In 2012, China had overtaken the United States to become the world's largest global smartphone market in terms of shipment. In that year, smartphone shipments from China were estimated to have reached 208 million units, accounting for almost 21 percent of the entire global smartphone market share. By the end of 2012, the number of smartphone users in China had reached 380 million, smartphone sales to end users were also reaching new levels, with sales around 169 million units sold in total that year. The statistic shows a forecast for China's smart device shipment from 2012 to 2016 which includes desktops, laptops, tablet PCs and smartphones. In 2012, the shipment of smartphones reached 208 million units and it was predicted that by 2016, the shipment would be 426 million units of smartphone, which was 397 million units in 2015. China is currently responsible for 38% of global smartphone shipments.

By 2017, there will be an estimated 1.5 billion smartphones in the world. They contain more metals, in greater amounts and often at higher grades, than their predecessors. For example, 4G smartphones use 6 to 10 times more gallium than a regular cellphone just several years before. (Abraham, 2015). China's mobile phone industry has high growth rate, raising its share on the global mobile phone market. Revenue for the smartphone manufacturing industry in China is estimated to increase at an average annual rate of 58.1%. In 2015 alone, revenue is expected to grow 28.8% to reach $98.2 billion, mainly driven by increased exports and growing demand for third- and fourth-generation (4G) smart phones. Exports are estimated to account for 74.8% of industry revenue in 2015.

The rare earth metals are critical for the production of smart bombs, laser targeting systems in tanks, and silent technology used in helicopter blades. The rare earth metals of most concern to the military and the defense are neodymium, samarium, and yttrium. Neodymium is an essential metal in a magnetic alloy which was developed separately by General Motors in Detroit and Sumitomo Special Metals Co. in Japan in the 1980s. Now it is used in speaker magnets, disk drives, motors, and, more importantly, in missile weapons systems like the Joint Direct Attack Munition (JDAM). Neodymium is also used in magnets for hybrid-electric motors being developed to cut fuel use in U.S. Navy destroyers. Samarium is needed for magnets being used by Lockheed Martin Corp.'s SPY-1 radar systems on Aegis destroyers. China is the only supplier in the world for yttrium which is needed for the laser gun sights in the General Dynamics Abrams tank (RC Zar, 2010).

The DDG-51 Hybrid Electric Drive Ship Program uses neodymium iron boron magnets which help power the guided destroyers. Night vision goggles and rangefinder equipment use rubidium to increase accuracy and visibility. The Aegis SPY-1 Radar uses the samarium cobalt magnet to withstand stresses as it has the highest temperature rating of any rare earth magnet. Even with a threefold increase in REE demand over the past ten years, demand is expected to increase even further, by anywhere from 8 to 790 percent over the next five years (Kientz, 2010).

Rare earth elements are needed for China's expansion of its own military needs (aircraft carriers, nuclear-powered submarines, and ballistic missiles). Home-grown manufacturing needs will further tighten the exports from particularly the more critical heavy rare earths. Not surprisingly, these measures have raised real concerns outside China regarding the future availability of the refined products. The rare earth supply chain for the manufacturing industries including defense industries in developed countries are dependent on China, where China wants to keep the rare earth metals for their own rapidly expanding market.

8 REE Pricing and Price Movements

Despite the rising demand and the historical high prices (before the current slumps in international commodity market), mine capacity expansions and new mine production have not kept pace at least in the rare earth sector. Overall, the price of minerals is driven by multiple physical, financial and political factors. When deciphering price data and trends, it is helpful to know whether there is a market surplus or deficit and the extent of the imbalance. Physical parameters (e.g., stock changes, closures of old mines and the start-up of new ones) are in turn influenced by general economic conditions and financial forecasts (e.g., inflation and exchange rates) that inform investor sentiments. Unanticipated shocks, such as monopolistic or oligopolistic pricing (e.g., export quotas); geopolitics and natural disasters, also play a role in affecting physical and financial parameters.

8.1 Negotiated Pricing and Metal Exchanges

Most rare, precious, minor and specialty metals and their alloys are traded through bilateral contracts based on negotiated pricing between parties. The fragmented nature of some of these markets and the remoteness of some producers has resulted in traders playing a dominant role. Regionally, traders account for a large part of the specialty metal supply coming out of regions such as China, the former Soviet Union and Africa. The nature of the process limits price disclosure in these markets and the prices of specialty metals quoted by traders and consultants vary widely in their reliability (U.S Department of Energy, 2010). To understand the price behavior and volatility of key materials, it is also important to examine the ways in which these commodities are bought and sold, in conjunction with whether they are produced as a co- or by-product of other specialty metals (e.g., REEs) or a by-product of a major metal. Both aspects influence the price behavior and volatility of a mineral. The influences of these factors can be gleaned from a comparison between the historical price trends of commodities produced as a by-product of metals traded on major exchanges and commodities mainly transacted through bi-lateral contracts.

Table 8.1: Purchase Option and Source of Price information for REEs

Minerals	Purchase option	Source of price info
Rare Earth Elements	Negotiated purchase, not traded on metal exchanges and therefore no spot market; however, illegally traded REEs are sold through less formal channels and may possibly be sold on the spot markets	Trade journals and websites based on information from producers, consumers and traders

In case of rare earth elements, the demand/supply equation has been wildly swayed, and prices have been highly volatile in last five years in RE market. It has been widely reported that the Chinese authorities had a plan to implement a 'fully unified pricing mechanism' in order to control the price of rare earths throughout the country. On closer inspection, the proposed mechanism seemed to apply only to the Fujian, Guangdong, Hunan and Jiangxi provinces, and the Guangxi autonomous region, at this time. These five jurisdictions are adjacent to one another in the southeast of China, an area whose elution deposited/ ion-absorbed clays are rich in the heavy rare earth elements. Inner Mongolia and other northern jurisdictions, which predominantly produce light rare earths, do not appear to be covered by the announcement. It would thus appear that the change is an attempt by the authorities to specifically control the prices of the more valuable heavy rare earths (Hatch, 2010). Some would argue that China is already well in control of rare earth pricing with more than 90 percent market share.

Are the Chinese looking to actively manipulate the price of rare earths? To assume that the Chinese are working to throttle back rare earth supply and raise prices would be at least incorrect in the current contexts. However, China has tried to manipulate the supply in the past that had an effect on prices. There are also some Chinese rare earth companies that recognize they will get the best pricing for material outside China and would like to use their expertise to help establish operations outside China. This would allow Chinese companies to more directly to reap the benefit of worldwide demand. Problems associated with pricing of rare earths affect different parts of the supply chain differently. Supply risks, at least in the short-to-medium term, are less associated with the prospect of increasing prices because in most cases the cost of these elements is a small part of the final product manufacturing cost. However, in the last two years the price of many rare earth elements has decreased dramatically and many of the Chinese producers reported loss in 2015, which in some cases has had a more significant impact on the price of the final product.

8.2 Rare Earths Price Movements

Rare earth prices remained static for decades due to plentiful supplies, lulling the high-tech industry into a false sense of security. After Beijing cut export quotas by 70 percent for the second half of 2010, prices of some rare earths went up as much as 850 percent. When China had exported 6100 tons of medium-end and low-end rare earth products in 1990, the average price was less than 5000 USD/ton. In 2009, China had exported 36,100 tons of rare earth smelting and separation products, rising by 16.67%. The export value amounted to USD 310 million and the average price was 8,959 USD/ton (China Research and Intelligence, 2010:3). Low priced rare earths from China in 1990s contributed to cuts at the Mountain Pass mine in U.S, which was one of the main source of supply for many years before it closed in 2002. The low prices also discouraged new entrants to the industry until the prices started to increase from 2009 onwards.

The prices have been historically low particularly for light and medium elements as supply from China increased substantially until 2000. The 1992 was the year when Deng Xiaoping famously stated, “the Middle East has oil, and China has rare earths”, since then, China has not only remained the world’s largest REO producer, but has also successfully moved its manufacturers up the supply chain. During this period rare earth investment at state, provincial and local levels also increased as china dominated the market. When the prices were fallen too short at the international market, the Mountain Pass mine in California, the main supplier of REEs till mid-1990s, was unable to cope with the escalating cost and finally shut down its operation in 2002.

Figure 8.1: Rare earth prices in 2000s

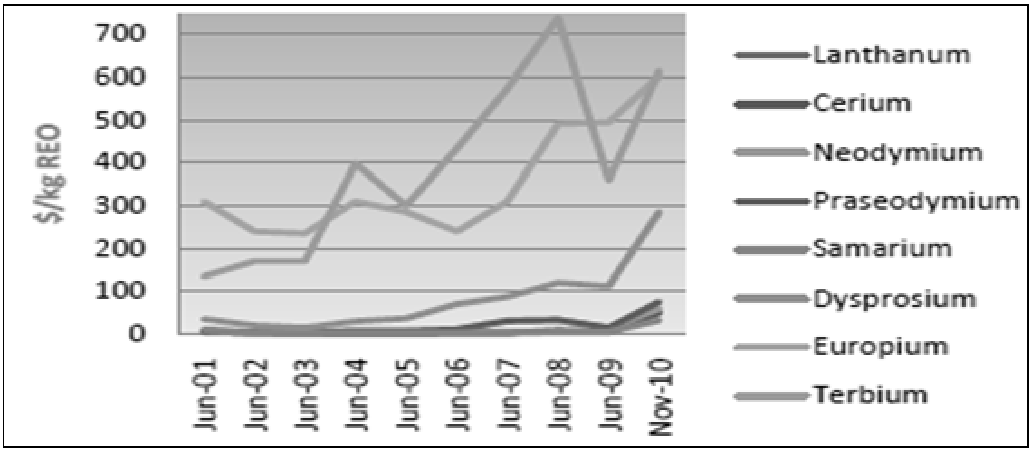


Figure 8.1 shows that prices remained at lower levels until 2006, but witnessed marginal increases in next two years. The major drivers that had an impact on prices during this period were the high level of competition within China and a handful of powerful buyers such as Japan, USA and Europe. As we have seen in the previous chapter Japan's consumption has increased until 2006 and demand was at its peak during this period. During this period the number of producers in China had also reduced to around 200 companies by mergers and acquisition and competition among them was intensive to secure orders. Compare to 1990s, China had also started this time the temporary crack down of companies on environmental grounds which resulted in the temporary closure of multiple producers. Increasing costs within China due to implementation of environmental compliances, as well as increasing labor, energy and chemical costs and tightening demand compare to robust supply also contributed in increasing prices.

Then came the global shock of financial crisis hitting markets hard. The period between 2007 and 2009 saw a decline in prices across elements largely as the result of fall in demand due to global financial crisis while global supply almost remained at the same level. The period between 2000 and 2007 marked the peak in China's rare earth industry. However, due to the global economic downturn and sharp decline in international demand price fell sharply till 2009. Also contributed by oversupply on the international market and price wars among Chinese suppliers, in particular smaller players. However, by mid of 2009, as the economies started to recover, the prices had started to increase again not only because of the global recovery but a number of internal policies that China adopted related to rare earth industry. China started the consolidation of production and tightening of export quota, which induced the prices to increase within China and consequently increasing the international prices. This was the time the Chinese government started restricting supply of the minerals by various means. Since 2005, the Chinese government has been imposing export quotas on many of the rare earth metals, resulting in reduced global supply. Higher prices are a natural result of such supply restrictions. China's exports of rare earth metals burst through the $100,000-per-tonne mark for the first time in February 2011, up almost nine fold from a year before, while the volume of trade stayed far below historical averages and each ton fetched US$14,405 on average. According to Reuters calculations based on data from China's Customs office, the apparent price rises have averaged US$10,000 per ton per month but accelerated in February 2011, galloping ahead by US$34,000 per ton (Miles, 2011).

Figure 8.2: Rare earth oxide prices-LREEs (USD per kilogram)

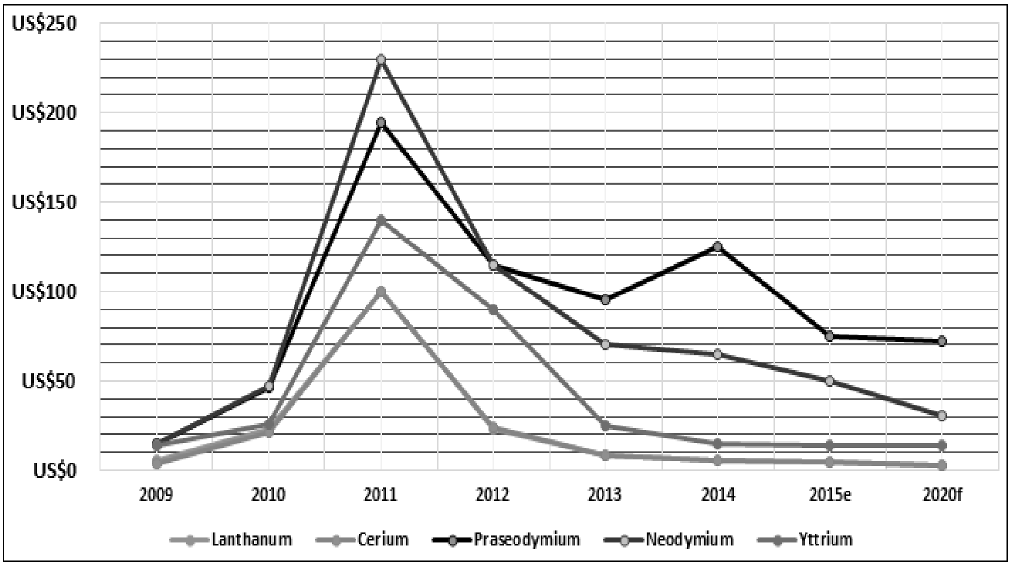
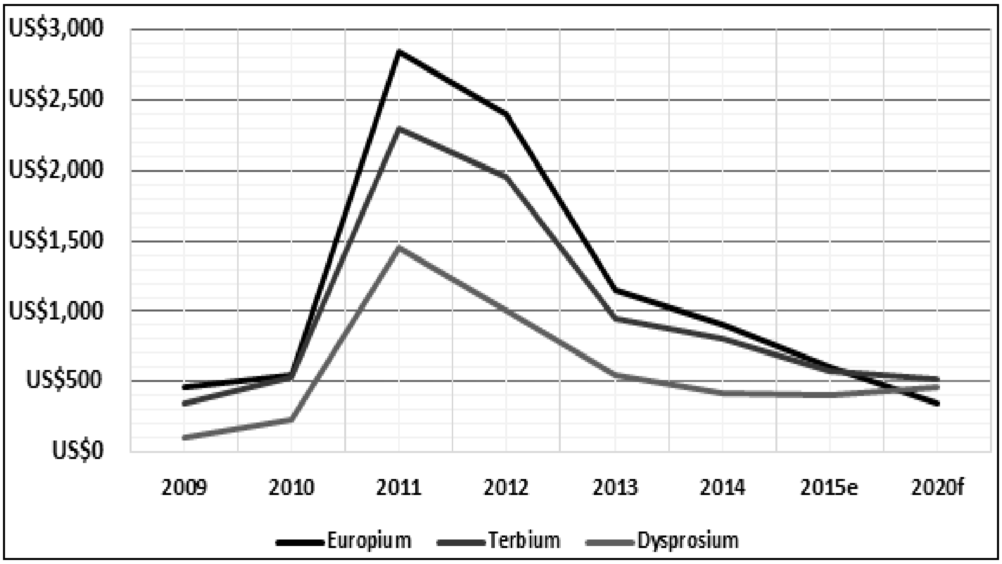


Figure 8.2 illustrates the historical average prices and forecasts of individual rare earth oxides between 2009 and 2020. The figure covers the light rare earths and reveals that there is a considerable gap between the individual RE oxide prices. The most critical

among the light rare earths are neodymium and praseodymium. These two elements are very close in chemical characteristics and historically the prices have been close for both elements as oxide is shipped as a mixture of both. The technology to separate the mixture is also comprehensive and not widely available except in China. However, since 2012, the market has witnessed sharp differences between neodymium and praseodymium prices and it is forecasted that the prices will remain so until 2020 with praseodymium fetching higher prices compared to neodymium prices. The Chinese export restrictions and cut in export quota peaking in 2010 are reflected in the price data as there was a sharp increase in prices across all elements starting from 2009 and particularly in 2011. The quota policy of China on rare earth exports had pushed prices higher during this period. The quota policy had also resulted in an unexpected fall in China's export of LREEs largely because most of the exporters preferred to export high priced heavy elements for profit reasons. This has resulted in a greater scarcity of light rare earths until 2012 and the price of LREEs rose much more than the HREEs. Rare earth oxide and rare earth metal prices track closely, with the prices for metals always higher (though relatively more so for some rare earth elements than others) (British Geological Survey, 2010).

Competition among Chinese producers for a limited market also caused major price swings, causing "liberties" being taken with environmental and business practices. The industry was also profitable, and since mining ionic clays is relatively easy, which also resulted in illegal mining in Southern China. Perhaps worst of all, this industry produced a lot of different oxide products, at many different price points, and the quota did not differentiate between them at all and prices began to rise, and then rise faster. Because the quota system did not differentiate, the least expensive and most common saw the most dramatic price increases. Cerium, for example, jumped from on average USD 3.88 per kilogram in 2009 to USD 90 per kilogram in February 2011, while the average price of lanthanum increased tenfold between 2009 and 2011. Unlike the conventional metals, rare earths are not traded at the exchange. As a result, pricing is highly obscure, and there is no way for either producers or consumers to hedge prices. The sharpest increase was for neodymium as prices quintupled from 15 dollar in 2009 to 230 dollar per kilogram in 2011. However, the situation has started to change from 2012.

Figure 8.3: Rare earth oxide prices-HREEs (USD per kilogram)



The heavier rare earths (e.g., dysprosium, terbium and europium) are more expensive, and historically prices have risen steadily for these elements since 2003 due to China's rising domestic demand and escalating export controls. However compared to light REEs, dysprosium and europium recorded relatively modest increases of 7 and 23 percent during the spikes. As discussed before the heavy rare earths like dysprosium and terbium are in short supply, mainly because they have emerged as the miracle ingredients of green energy products. Tiny quantities of dysprosium can make magnets in electric motors lighter by 90 percent, while terbium can help cut the electricity usage of lights by 80 percent. According to a United States Energy Department report, dysprosium has become the most important element for clean energy technology. Its price is now above 400 USD per kilogram a pound compared with 100 USD per kilogram in 2009. The price has gone up to 1450 per kilogram in 2011. Terbium prices had quadrupled from 2003 to 2008, peaking at 407 USD a pound, before slumping in the global economic crisis to 205 USD a pound. The price was around 350 USD per kilogram in 2009, which peaked to 2300 USD per kilogram in 2011 and currently selling around 600 USD per kilogram making it one of the most priced RE elements along with europium.

When the prices went up so high in 2010 and 2011, users worked quickly to reduce or eliminate their need for these elements in their products. In some cases, the use of the REs were reduced or eliminated temporarily, through technological or material substitutions and in many cases, however, the reduction and elimination has been made quasi-permanent. The industry also witnessed a dramatic reduction in demand and major importers like Japan and US cut short their imports. Prices collapsed almost more quickly than they had risen. At the current price level, it is uncertain whether any producer, Chinese or otherwise, can make money and most Chinse producers have reported loss in last financial year. Unable to cope with the low prices and escalating cost at its manufacturing plant in the U.S., Molycorp, the major non-Chinese producer has suspended its operations since August 2015. Prices are now almost at the same level as in the days of 2009.

While the long-term price of the light rare earths remains open for debate, the Chinese production quota, the regional based ad-valorem tax system and consolidation of the industry will probably continue to tighten the supply of heavy rare earths like terbium and dysprosium keeping the prices at top for these elements. The prices of dysprosium oxide, used in hybrid vehicles, lasers and nuclear reactors is projected to rise to an average USD 500 in the next few years. The price uncertainty has been a cause for concern in importing nations, which have become reliant on affordable REMs from China. The consolidation of industry and China's clampdown on illegal mining will have considerable impact on prices in longer terms.

There would be a number of factors that would affect the prices within China as well as for international customers. There would be enough supply in the international market, assuming the current trend continues unless China takes some drastic steps in curtailing the production with developments of new projects outside China. The challenge for future will be the right 'balance' between demand and supply and issues such as: Can the rare earths industry in China be successfully controlled? Will the new non-Chinese projects be successfully built and commissioned?

9 The Current Situation in the International Market

It is unwise to expect the market to correct the problems in rare earth industry especially when a single country, itself not a free market democracy, has the complete monopoly power over the resources. Rest of the world including major consumers such as Japan, U.S and E.U have no option but to depend on China for oxides to intermediate products to run their industries. The global market related to rare earths is so intricate and unpredictable that investors are reluctant to make an investment any upcoming projects.

In recent years, the Chinese government has been exercising strict measures over mineral output by controlling the legal exploitation of minerals and cracking down of illegal mines. Still, an average 200 thousand tons of minerals are in the market on an annual basis. The Chinese government's rare earth output quota in 2015 remains as same as 2014, among which there is a marginal increase in terms of the output of light rare earths while that for heavy rare earths remains the same as in 2014, which was close to 18000 tons in 2014 (Chen, 2015). Like many other industries, China is facing a huge overcapacity problem in rare earth industry as it was one of the least regulated industries by any standards including environment. It is estimated that the annual capacity of rare earth separation nationwide is more than 450 thousand tons and the actual output is between 200 and 300 thousand tons, where the actual demand on a global scale is about 120-150 thousand tons per annum (Chen, 2015). This unbalanced supply-demand relationship is the major reason for the lower price and this in fact cause other projects outside China financially unviable and uncompetitive.

The rare earth prices have been falling since its peak in 2011 and have not changed much in 2014 and 2015. In the first quarter of 2015, there was an increased supply from the separating enterprises and this has lowered the price further, especially dysprosium oxide and praseodymium oxide and neodymium. The dominant tendency for the rare earth market in 2015-16 is mixed. The abolition of export quota on rare earths in January 2015 by the Chinese government in compliance with the WTO ruling has pushed the price further downward. The removal of export tariff of 15 to 20 percent from May 1st 2015 had also negatively affected the prices (Argus, 2015). However, the plan to impose a new resource and environment tax later 2015 may push the price little upward starting from the end of 2015. The tax reform is expected to adjust resource tax on rare earths from quantity based collection to ad valorem based collection. This is expected to be more realistic to the international market conditions.

The problems also exaggerate due to sluggish demand as both domestic and external demand has been weak in last two years. The demand from downstream deep processing industries such as fluorescent powder and NdFeB and traditional application such as ceramics and metallurgical industry are weak. The selling prices for refining and separation enterprises have dropped compared to their purchasing prices, which in fact negatively impact their profit margin. Consequently, the purchase of raw materials is not active. The price rise of minerals in 2016 is very likely on conditions that there are substantial adjustment on mineral resource tax and good market anticipation. However, there is least possibility for drastic changes. Based on the supply-demand relationship, excess supply situation remains unchanged in the overall rare earth market.

The expectation for an increased rare earth price is limited since Chinese economic growth is moderating with a less robust manufacturing industry. Moreover price war among domestic companies fighting for orders and unhealthy competition shall not be ignored. The demand from other major consumers like Japan or U.S. who contribute about 20 percent of global consumption remains weak and will not be in a position to alter the market.

The impact of Chinese interventions in the domestic industry such as implicit assistance to domestic downstream processors of the targeted sector will have an impact on the prices. China is seeking sustainability and prices will respond to market demand and supply from a sustainable base. Scholars argue that real price for rare earths is about four times higher than the current China price. The price would reach that level if China completely restructure the industry with an environmentally sound, worker friendly policies and prevent the illegal mining operations completely. Increasing prices of rare earths resulting from market friendly China policies may negatively impact the growth prospects of a set of green industries such as electric cars to wind turbines, who have grown up over the past ten years in reliance on that China price (Harris, 2010). However, sharp increase in price or fear of supply shortage may bring technological shifts as happened in permanent magnet and tantalum industry. When the tantalum price increased sharply in the late 1990s, capacitor designers improved niobium capacitors and multiple ceramics capacitors in order to replace the tantalum components. The demand for tantalum, and its price, fell sharply as a result (OECD, 2010).

9.1 Illegal Mining and Overcapacity

There are many dimensions in the forms of impact that the rare earth industry creates, which directly or indirectly take a toll on the environment.

Firstly, rare earth minerals are a non-renewable resource; over-exploitation not only causes environmental degradation but also leads to oversupply, breaking the equilibrium in the demand-supply curve. In this context illegal mining and trading play an important role. China, as mentioned earlier, had no interest in regulating the industry in its blind pursuit of industrialization, which helped illegal mining to flourish.

Table 9.1: China's Production Quota and Export Quota

Year	Production Quota	Illegal Mining	export quota	Percentage Used
2010	89,200	25-30,000	30,258	131.6
2011	93,800	25-30,000	30,246	61.6
2012	93,800	25-30,000	30,996	52
2013	93,800	45-50,000	30,999	73
2014	105,000	45-50,000	30,610	90
2015	105,000	45-50,000	--	--

Source: Kingsnorth (2015) and MOFCOM (2014)

However, in recent years, the Chinese government has been controlling mineral output by setting legal exploitation limits and cracking down on illegal mines. Still, an average 200,000 tons of minerals are in the market on an annual basis. The government maintained the mandatory plans for rare earth output in 2015 at the same as 2014, which was equal to 87,100 tons of light REEs and 18,000 tons of heavy REEs. Like many other industries, China's REE industry is facing a huge overcapacity problem as it was one of the least regulated industries by any standards, including environmental. It is estimated that the annual capacity of rare earth separation nationwide is more than 450,000 tons and the actual output is between 200,000 to 300,000 tons, while the actual demand on a global scale is about 120,000-150,000 tons per annum (Chen, 2015).

This unbalanced supply-demand relationship is the major reason for the lower prices, and causes other projects outside China to be financially unviable and uncompetitive.

Falling prices, driven down by high volumes of illegal REEs on the market, have helped to drive up export volumes but producers are struggling with the low prices. Illegal REEs remain a problem for state-owned producers (and emerging producers outside China) but the Chinese government's mandate to stamp out illegal activity is clear. The campaign to clamp down on illegal production is likely to be a gradual process but it will also provide officials with more control of exports (Seah, 2015).

In the REE industry, illegal trading has been so common that the Chinese government export statistics do not match the import statistics from other countries.

Fear of over-exploitation strongly exists in the minds of authorities. The future of the industry has become a question mark. Officials are trying to calculate how long these minerals will last at the current levels of consumption, environmental degradation and illegal trading. According to Chinese authorities, an estimated 30-plus percent of all rare earth materials are produced outside of regulated and legitimate supply chains in China. Professor Dudley Kingsnorth's most recent estimate is that, in 2014, 40-50 per cent of NdFeB magnets produced globally were from illegal REE sources, and the Chinese REE magnet industry's demand for Nd/Pr exceeds the production quotas by 10,000 tons, effectively condoning illegal mining and processing (Kingsnorth, 2015).

Illegal mining and production, which constitutes one-third of production, is impacting the viability of the Chinese domestic REE industry. The current state of the global market, characterized by oversupply and a weak market price, owes much to the significant volume of illegal materials being exported from China each year. China's Ministry of Industry and Information previously estimated that as much as 40,000 tons or 36 per cent of overall global rare earth production is being exported from China through illegal channels each year (Argus, 2015).

9.2 Problems in Developing Alternative supply

The major problem the industry faces now is the low market price–even below the cost of production—along with oversupply by illegal sources in China. Everybody expects a good price and even the Chinese wanted a little increase in prices.

Unless China takes some concrete measures without discriminating between domestic users and international customers, it is unwise to expect the market to correct the problems. Even though China applied a number of restrictions on export of REEs, there was enough supply to meet international demand, and several times even the allocated quotas were not fully exported due to lack of demand from abroad (Table 8.1). As a result the prices for most of the REEs have declined almost to the level of pre-bubble time of 2011.

The market has been unpredictable in the last couple of years and the rare earth prices did not make much sense. Studies have revealed that the REEs exist in an elastic market where the market prices are set by the nature of the commodities they are used in, and prices are controlled by users replacing suppliers when prices rise too far (Branch, 2013). The WTO ruling against China has pushed the prices further down, with an increased supply from China. In 2014, China's rare earth export rose by 70 per cent compared to the 2012 quantity. The impact was already visible in the market. The prices of REEs such as cerium, lanthanum and ytterbium plunged by almost 40 per cent in 2014 and the average price of REEs has fallen back to the levels of 2010. Falling prices have helped drive up export volumes, but producers are struggling with low prices and weak demand.

China's cutting of export quotas by 40 per cent in 2010 and the consequent price spikes in 2011 has led to the emergence of a large number of REE projects outside China. However, it would be difficult for them to survive and compete with Chinese companies unless there is an upward movement in the prices. These companies currently face financial constraints and huge difficulties in raising capital. The global market related to REEs is so intricate and unpredictable that investors are reluctant to put a single penny to any of these upcoming projects.

Table 9.2: Non-Chinese Rare Earth Projects

No	Non-Chinese Rare Earth Enterprises	No	Non-Chinese Rare Earth Enterprises	No	Non-Chinese Rare Earth Enterprises
1	Molycorp Inc	17	Canada Rare Earth Inc	33	Korea Resources corp
2	Lynas Corp Ltd	18	Matamec Exportaions	34	Appia Energy Corp
3	Frontier Rare Earth Ltd	19	Stans Energy Corp	35	Promac Ltd
4	Arafura Resources Ltd	20	Rimbal Pty Ltd	36	Tantalus Rare Earth
5	Rare Element Resources	21	Geomega Resources Inc	37	Commerce RE Corp
6	Ucore rare Metals Inc	22	Ausamerican Mining	38	DNI Metals Inc
7	Hastings Rare Metals	23	Star Mineral Group Ltd	39	Quest Rare Minerals
8	Northern Minerals Ltd	24	GBM Resources Ltd	40	Search Minerals Inc
9	Peak Resources Ltd	25	Tasman Metals Ltd	41	Galileo Resources
10	Namibia Rare earth Inc	26	Texas Rare Earth Corp	42	Fer-Min-Ore Ltd
11	Crossland Metals Ltd	27	Hudson Resources Inc	43	Greenland Minerals
12	Pancontinental Uranium Corporation	28	Great Western Minerals Group Ltd	44	Rare Earth Minerals PLC
13	Avalon Rare Metals Inc	29	Pacific Wildcat Corp	45	MBAC Fertilizer Corp
14	Navigator Resources Ltd	30	Mining Ventures Brazil	46	Araxa Metals Inc
15	Alkane resources Ltd	31	Mkango Resources Ltd	47	Seltenerden Stokwitz
16	Pele Mountain Resources	32	AMR Minerals Ltd	48	Montero Mining Ltd

Most of these junior mining and processing companies who entered the rare earth business seeing prices climbing sharply in 2011 and 2012 are now doubtful about the future prospects (Machacek and Fold, 2014). Their share prices are on a downward trend. Companies like Lynas of Australia and Molycorp of US are in trouble as investors have lost interest. Since the WTO ruling, share prices of Lynas and Molycorp have fallen manifold, they continue to experience problems in achieving Stage 1 design capacity. Lynas is somehow managing the constraints and gradually increasing production, but Molycorp has suspended its production since August 2015.

This shows the problems in REEs lie elsewhere. It has proved more economical to export these minerals to China for further processing and value addition as Molycorp does, shipping REEs mined in the US to factories controlled by China. If these non-Chinese projects can succeed it will also serve China's own interests, addressing concerns about the fast depletion of their reserves, and environmental pollution.

For others, except China, REEs are not just a resource issue. For example, just two industries (phosphate and uranium-thorium) in the US dump their rare earth composites as waste due to regulatory issues, which in fact can contribute to 85 per cent of global demand each year (Kennedy and Kutsch, 2014). These resources are easy and inexpensive to recover (Emsbo et al, 2015).

If any government is worried about China's dominance and their dependence on China for various rare earth based products, the one possible solution is state support, financial incentives to the domestic mining and processing companies, and facilitating vertical integration in the supply chain. Collaboration among REE producers (mining, concentrating and separations) with active participation and support by customers, including cross-shareholding and buy-back agreements, are necessary for these new ventures to succeed outside China. Buy-in and collaboration by government and other regulatory entities are also additional options. International customers dealing with Chinese supply should ensure the sustainability and legitimacy in REE supply chains, rather than price-driven strategies.

Notable examples of international collaboration and buy-in agreements to develop non-Chinese supplies include (1) The Japanese Government agency JOGMEG's efforts, along with Sojitz Corp, to financially support Lynas and JOGMEG's collaborative business partnership with Kazakhstan's nuclear agency.
(2) The strategic partnership of state-owned Korea Resources with Frontier Rare Earth, a Canadian company to develop the Zandkopsdrift rare earth project in South Africa and (3) German-based Tantalus Rare Earth's agreement with German steel-maker ThyssenKrupp to supply up to 3000 tons of REE oxides annually for financially backing the company.

These kind of supply chain commitments would ensure stable supply as predictability of raw material supply for manufacturing industry is becoming increasingly difficult. Mining and processing steps of critical raw materials often focus on risk countries such as China. As said earlier huge overcapacities in REE production will prevail and even if China consolidates the industry fully, overcapacity of around 100 percent will remain in China. China's ability to influence production and price will remain a challenge to projects outside China as China remains in a position to increase low-cost production to push prices downward. Low-cost production and restrictive regulations are used as instruments to gain control on downstream industry. The global downstream industry is also incentivized by supply security and low price of REEs to move production to China.

10 China's Endeavor to Control the Rare Earths Industry

As has been pointed out in Chapter 2, China commanded more than 95 percent of global rare earths supply during 2002 to 2011. This fact has provided China with a monopoly power. The Chinese government tried to take full advantage of the power and increase the value added of the domestic rare earths industry. It drastically reduced the quota of rare earths exports in their primary form, i.e. rare earths oxides, and imposed export duties. As a result of these policies, international rare earths prices increased rapidly and their supply became instable outside China, prompting some users of rare earths materials such as magnet manufacturers to consider erecting factories in China to secure supply and enjoy relatively cheap prices. Thanks to the ample supply and cheapness of rare earths, China's domestic rare earths application industries grew rapidly. In the case of NdFeB permanent magnets, for example, China took over the No.1 position from Japan in 2006, and in 2015 China produced more than 80 percent of the global production[4]. In 2010, China allegedly tried to use its monopoly power to put pressure on Japan regarding territorial disputes over the Senkaku/Diaoyu Islands by temporarily suspending rare earths exports to Japan.

The power, however, has been slipping away from the hands of the Chinese government since 2011. The endeavor to control exports has substantially been frustrated by rampant smuggling. The use of export quotas and export duties has been judged as violations of WTO rules by the panel on the dispute over China's rare earths exports in August 2014. Even within its borders, the government has failed to control rare earths mining, leading to an oversupply and a drop in rare earths prices.

However, the Chinese government has not abandoned its plan to tighten its grip over domestic rare earths production by consolidating the industry into a few industrial groups. In this chapter, the policies taken by the Chinese government to tighten its control over the rare earths industry will be reviewed. The outcome of the policies will be examined by analyzing export and price data.

[4] Based on the data provided by Neomag Corporation (www.neomag.jp).

10.1 Consolidation Plans and Policies

The exploitation of ionic absorption clays in southern parts of China expanded rapidly in late 1980s. Ganzhou City in Jiangxi Province alone had more than 1,000 small rare earths mines then (*Jingji cankao bao*, February 10, 2011). Fearing the waste of resources caused by rampant mining by the small rural mines, the central government in 1991 declared that ionic absorption clays in southern China would be kept under the protection of the state, and their mining, refining, and processing would be controlled by the central government. This policy, however, has never been effective.

In 2002, the former National Economy and Trade Commission proposed to organize the country's rare earths industry into two big groups, the northern group and the southern group. The northern group would be led by Baotou Steel Rare Earth Corporation. By the end of 2010, all the small rare earths mines around Bayan Obo had been either merged with Baotou Steel or closed. In 2012, by merging 13 rare earths firms in Inner Mongolia with Baotou, the Northern Rare Earth High-tech Group was created (*21st Century Economic Herald*, August 10, 2012). The plan to create a single southern group, however, has not been realized.

In 2007, the government decided to tighten its control over rare earths production by putting them under the "directive plan" of the government. "Directive plans" were the means by the state to run the economy during the planned economy period, but it has been rarely used after the Chinese government's decision in 1993 to transform the economic system into a market economy. The strong government intervention in the rare earths industry as shown by the introduction of directive plans is very exceptional in current Chinese economy. With directive plans, the government has been controlling the production volume of state-owned rare earths mining enterprises, but the small private rare earths firms have never been controlled by the plans.

In November 2009, China's Ministry of Industry and Information Technology promulgated the "Rare Earths Industry Development Plan of 2009-2015." This plan aimed to raise export prices of rare earths and to promote the development of domestic rare earths application industry. Based on this plan, the Chinese Government reduced the export quota of rare earths from 50 thousand ton in 2009 to 30 thousand ton since 2010.

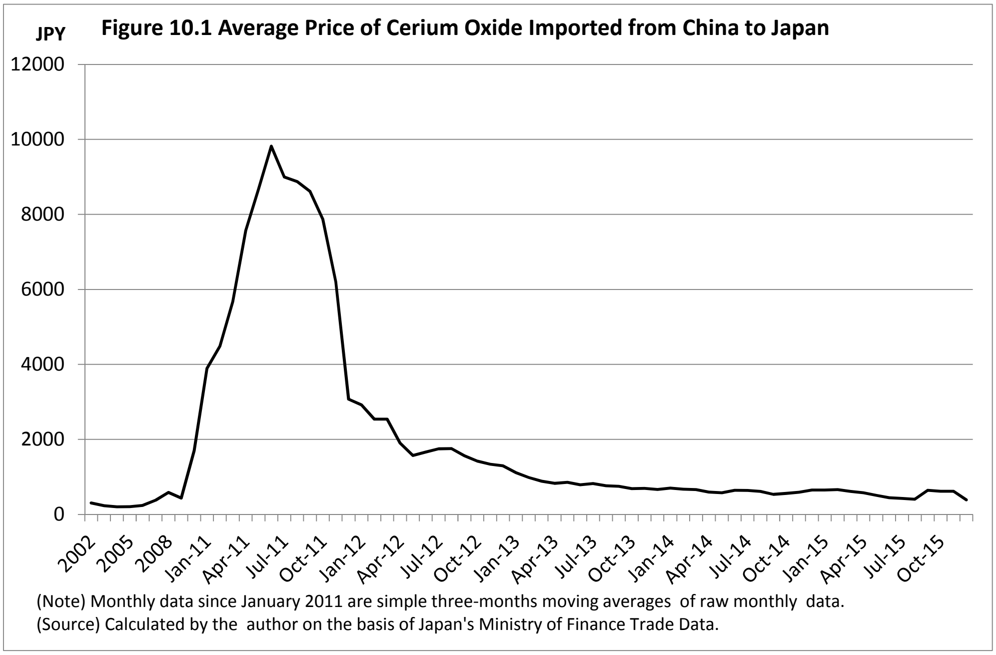
The plan also proposed to reorganize the industry and consolidate firms to create a "national team."

The tightening of restrictions on rare earths exports resulted in a steep rise of rare earths prices. For example, Japan's import price of cerium oxide jumped from JPY434 per kilogram in 2009 to JPY11,853 per kilogram in July 2011.

In May 2011, the State Council issued its "Opinions for Promoting the Sustainable and Healthy Development of Rare Earths Industry," which showed the government's resolution to tighten the control over the industry. The Opinions declared that the industry must be reorganized into big corporate groups. When the Opinions were issued rare earths industry in northern China was about to be monopolized by Baotou Steel Rare Earth Corporation, so the focus of the Opinions was the integration of the scattered rare earths industry in southern China, in particular the ionic absorption clay mines in southern Jiangxi. The Opinions required that within one or two years, more than 80 percent of the southern ionic absorption clay resources must be controlled by the top three firms (*21st Century Economic Herald*, May 23, 2011). Based on the Opinions, export duties for rare earths were increased, and rare earth ferroalloys were included in export quota restrictions. In the same year, the resource tax levied on rare earth mining was raised from RMB0.5-3 per ton of rare earth resource to RMB30-60. This amount of tax translates into RMB5-36 per kilogram of rare earth products such as oxides (*Jingji cankao bao*, June 6, 2013).

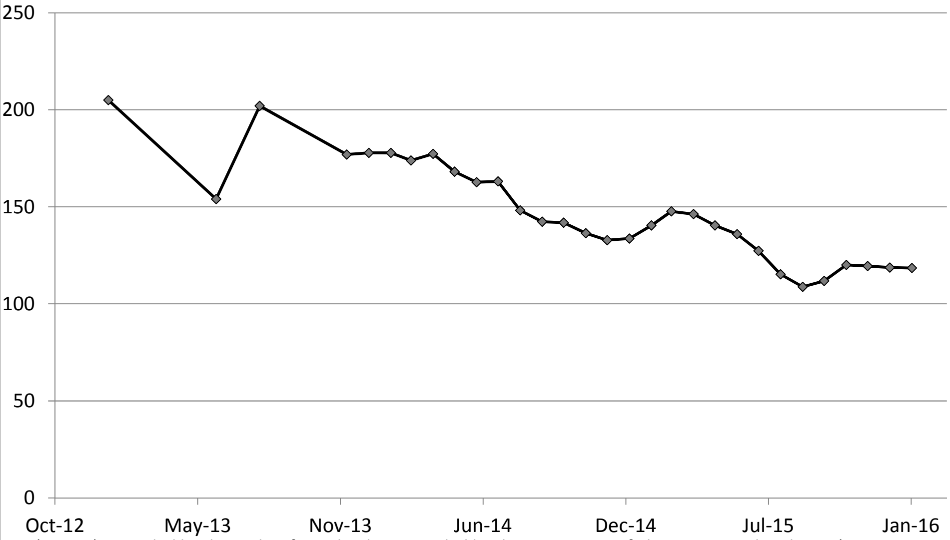
10.2 Failure to Control

As mentioned earlier in this Chapter, the Chinese government's endeavor to enhance domestic value added of its rare earths industry has been successful, but the power as the monopolist of rare earths supply that seemed to reside in the hands of the government during 2010-2011 rapidly eroded. Figure 10.1 shows the average price of cerium oxide imported from China to Japan. After jumping from JPY433 per kilogram in 2009 to around JPY10,000 in mid-2011, the price collapsed in the autumn of 2011, and decreased to around JPY400-600 in 2015, almost the same level as in 2009.



The downward trend of cerium oxide is shared by other rare earth products. Figure 10.2 shows the changes in the "Rare Earth Price Index" calculated by the Association of China Rare Earth Industry. This index is based on the reports of more than 20 Chinese rare earth suppliers on the prices of more than 30 types of rare earth oxides and rare earth metals. This index is normalized to make the average price of 2010 as 100. The index was 118.5 on February 26, 2016, which means that after a period of price hikes, the average price of rare earths are only 18.5% higher than the average of 2010.

Figure 10.2 Rare Earth Price Index in China (2010=100)



(Source) Compiled by the author from the data provided by the Association of China Rare Earth Industry (www.ac-rei.org.cn)

It is an ironic fact that the Chinese government's attempt to take advantage of China's position as a monopolist in global rare earth supply resulted in the erosion of China's monopoly power. The price hike during 2010-2011 caused by the Chinese government's tightening of export control induced the resumption of production of Mountain Pass and other rare earth mines and explorations for new resources in various parts of the world. It also prompted the expansion of illegal mining of rare earth in China. Illegal mining is connected with illegal exports of rare earths that bypass export quota restrictions and export duties by disguising rare earth products as some other materials such as alloy powder for negative electrodes or alloyed nickel (*Jingji cankao bao*, December 9, 2013). These illegal exports can be called "quasi smuggling," because when they go through the customs of the importing countries, they will be reported correctly as rare earths.

From Table 10.1 we can measure the magnitude of such "quasi smuggling." It shows the volume of the exports of "compounds, inorganic or organic, of rate-earth metals, of yttrium or of scandium or of mixtures of these metals" (HS2846) from China (reported by Chinese customs) to the rest of the world and the sum of the volume of imports of the same item from China reported by other countries. It shows that in 2008 and 2009, the volume of rare earth exports reported to Chinese customs was roughly the same with the total volume of rare earth imports reported by the rest of world. But in 2010, when China reduced its export quota, China's export amount fell far short of the total amount of imports reported by other countries. The export volume reported by Chinese custom was 33,551 ton, which was roughly the same with the export quota, but the total volume of imports reported by the trade partners was 50,141 ton, implying that more than 16,500 ton of rare earth was quasi-smuggled. The gap of the two existed even in the case of Japanese import from China, implying that nearly 3,800 ton was quasi-smuggled from China to Japan in 2010. It is also noteworthy that in that year, when it was reported that China suspended the exports of rare earth to Japan, Japan's rare earth imports from China increased by 7,210 ton compared to the previous year.

Table 10.1 Export and Import Volume of Rare Earth

(ton)

	China's exports	Imports from China	China's exports to Japan	Japan's import from China
2007	41,895	74,830	18,554	26,488
2008	48,025	46,268	22,504	24,793
2009	38,573	38,192	10,520	11,174
2010	33,551	50,141	14,590	18,385
2011	13,620	31,509	6,321	11,399
2012	13,509	18,457	3,952	5,028
2013	19,386	23,915	4,714	6,074
2014	23,990	27,091	8,948	9,538

(Source) Compiled by the author from Uncomtrade data.

In 2011, the gap became even wider, implying that more than 17,800 ton of rare earth was quasi-smuggled, which was greater than the amount of legal exports. In that year, the amount of export quota was set at 30,000 ton, but the actual amount of quota allocated to exporting firms was only 18,600 ton (*Jingji cankao bao*, August 9, 2012). Apparently, a half of total exports or even more in that year was made without being allocated export quota. The increase of resource tax in 2011 might have given incentives to illegal mining that evades resource tax (*Jingji cankao bao*, June 6, 2013).

The gap between China's rare earth exports and other countries' imports from China has narrowed since 2012. This may be the result of the tightening of Chinese government's control over illegal rare earth mining. But it may also show that, with the sharp drop of rare earth prices, the incentives for illegal mining and quasi smuggling have been reduced.

10.3 Further Efforts to Tighten Control

The lesson which the Chinese government has taken from the rapid rise and fall of rare earth prices during 2010-2011 is that only by tightening the control over domestic production it can enjoy monopoly. Therefore, the policy was focused on cracking down on illegal mining and production. It was estimated that in 2012 illegal production of rare earths amounted to more than 40,000 ton. In particular in the case of middle and heavy rare earths mined in southern provinces, it was estimated that 70 percent of the resources came from illegal mines (*Jingji cankao bao*, August 9, 2013).

The measure to tighten control was to pursue the policy of reorganization by big corporate groups. The central government hoped that vertically-integrated state owned enterprises (SOEs) that were governed by the central government such as China Minmetals, Chinalco, and Northern Rare Earth High-tech Group (Baotou Steel) would lead the reorganization process, but the local governments of southern provinces that are endowed with middle and heavy rare earth resources were reluctant to hand over the mining rights owned by local SOEs to central SOEs (*21st Century Economic Herald*, September 13, 2013). Finally, in December 2013 the central government compromised with local interests and allowed three local SOEs, namely Ganzhou Rare Earth, Rising Nonferrous Metals (Guangdong Guangsheng Nonferrous Metals), and Xiamen Tungsten, to enter the rank of the state-designated six major firms along with the three central SOEs (*Jingji cankao bao*, January 3, 2014).

As mentioned in Section 4.1, the appellate body of WTO supported the report by the panel on disputes over China's measures related to the exportation of rare earths, tungsten, and molybdenum, which judged that tariffs and quotas imposed by the Chinese government upon exports of these items were inconsistent with China's Accession Protocol upon entering the WTO. Being forbidden the use of these border measures, China had to rely on the control over domestic mining and production of rare earths to prevent their depletion.

Each of the six state-designated firms was allocated its "territory" over which it was expected to take full control of rare earth industry. The northern Group's territories are Inner Mongolia and Gansu Province. Chinalco is in charge of Jiangsu, Guangxi, Sichuan, and Shandong Provinces. China Minmetals' territories are Hunan Province and a part of Fujian Province. The three local SOEs take charge of their own provinces: Ganzhou Rare Earth takes Jiangxi Province, Xiamen Tungsten takes Fujian Province, and Rising Nonferrous Metals takes Guangdong Province (*Jingji cankao bao*, August 12, 2014).

According to the plan made by the Ministry of Industry and Information Technology, the six major firms would command 93 percent of domestic rare earth production in 2015 (*21st Century Economic Herald*, October 15, 2015). However, the goal of recovering monopoly power over rare earth supply is far from achieved. That is because, firstly, illegal mining has yet to be curbed. In 2014, other than the directive plan to produce 99,300 ton of rare earth oxides, more than 40,000 ton of rare earth oxides were produced illegally (*Jingji cankao bao*, August 10, 2015). Even with all the efforts to tighten control, the amount of illegal production did not decrease. Secondly, the competition between the six major firms is quite fierce. The government's plan to let the six major firms monopolize rare earth industry in each territory has some major exceptions from the start. Although Sichuan Province was designated as the territory of Chinalco, the Maoniuping Rare Earth Mine in Sichuan, which has the second largest reserve of rare earth resources in China, is owned by Jiangxi Copper Corporation, which merged its rare earth business with Ganzhou Rare Earth and created the Southern Rare Earth Group in March 2015 (*21st Century Economic Herald*, March 18, 2015). Besides this, the municipal governments of Baotou and Ganzhou offer subsidies to NdFeB magnet manufacturers to attract more high value-added activities to their cities. Such subsidies will exacerbate the overcapacity and price competition in the rare earth industry (*21st Century Economic Herald*, February 5, 2015).

The weakness of the monopoly power exercised by the six major firms can be confirmed by the continuous decline of the Rare Earth Price Index. Some attempts were made by the firms to restrict their production volume and curb the decline of price, but so far they were not successful. However, we cannot rule out the possibility that in some day in the future the six firms and the state will have tighter grip of the industry and the power to control prices.

11 **Conclusions**

For China rare earth is the wild card now. The Chinese government has stated that its reserves of rare earths are finite and, therefore, they will be developed for the prime benefit of China's manufacturing industry. To help generate manufacturing jobs and move up the value chain, a series of measures has been implemented to conserve resources and to maximize the benefits of its rare earths endowment. This would largely affect the downstream industries in other countries particularly the industrial nations such as Japan and United States. With a near monopoly in REO production and its effects on industrial end users across the globe will be heavily influenced in the short and medium term by China's production and export policies.

China has officially cited environmental issues as one of the key factors for its recent regulation on the industry, but non-environmental motives have also been imputed to China's rare earth policy. Most of these policies are intended to help Chinese manufacturers to move up in the supply chain, so they can sell valuable finished goods to the world rather than just raw materials. Although often needed only in small quantities, these metals are increasingly essential to the development of technologically sophisticated products. They play a critical role in the development of innovative environmental technologies to boost energy efficiency and reduce greenhouse gas emissions. Hydrogen-fuel based cars, for example, require platinum-based catalysts; electric-hybrid cars need lithium batteries; and rhenium super alloys are an indispensable input for modern aircraft production. In addition, there are few substitutes available in the short-term for these raw materials.

The study found that, a major issue concerning rare earths industry is the balance between demand and supply. Due to the absurdity between the supply and demand of individual rare earths, there always exists a situation in which there is a shortfall of some rare earths while others are in surplus. On the basis of known analyses of major resources it is considered that some of the 'heavy' rare earths are more likely to be in short supply in longer term.

Although production of some strategic minerals is very concentrated, this does not necessarily suggest that future production will be similarly geographically restrained as we see around 50 new mining projects are already underway for producing rare earths. The future production situation is mixed. For some strategic minerals, the reserve base is more geographically concentrated than the present production. For others, the raw materials are more widely dispersed. In the case of some of the most concentrated raw materials, particularly those largely found in China, such as rare earths, the future reserves are less concentrated than present production would suggest.

Since early 1990s, Chinese rare earth producers had an unregulated approach to the supply in the international market. This has been exploited by a concentrated number of buyers who have collaborated to force prices down. As China gradually increased its control of the resources by restricting supply with tightening market, rare earth prices improved significantly over the years. Whilst the next 5 to 10 years, global supply would be marginally higher than the demand, China's rare earth production quotas, cracking down on illegal production and tax system will play a critical role in the supply chain development of rare earths outside China.

There are few basic features of Chinese supply that we can derive from the above analysis. The main aspects include, China still hold more than 36 million tons of rare earth oxide reserves, excessive secondary processing capacity and easy availability of cheap processing chemicals, and heavy investment in research and technology. However the supply of Chinese heavy rare earths is finite with 15- 20 years of mine life and Chinese are rigorously regulating the mines.

To control the supply China has introduced a number of measures such as restructuring the resources tax in 2015 and consolidation of the entire industry into six large groups. According to plans, the Chinese government had plan to bring down the number of rare earth companies to around 20 major producers and processors and this process is expected to complete by mid-2016. These measures will have short – medium term repercussions in the international market.

There is no rare earth source that can match the Baotou tailings dump, the largest producer of rare earths in the world. Several new overseas mine projects are in the pipeline but few are likely to be able to compete with China on prices. Besides, it would require at least a decade before new mines can make an impact on the global market and the study shows that China will continue to control the global market for some time to come.

China's control over rare earth elements has already increased foreign dependence on China for finished goods along with foreign companies shifting their operations to China to take advantage of cheap availability of resources. China has adopted various policies to further develop the rare earth industry. China's vision is to increase industrial utilization of rare earth elements and dominate the market of rare earth applications, which they have achieved some extent as explained in Chapter 7.

China had recognized the strategic value of its RE resources long before the days of Deng Xiaoping. With skill, patience and investment, China has transformed the rare earth industry into what it is today. Government support of advanced curricula in RE sciences has produced thousands of technical professionals employed in RE industry today.

Rare earth industry is also part of the economic cycle like any other sectors and market fundamentals are not outside of the industry. If China causes a shortage of rare earths, it would naturally increase the prices and this will serve as an incentive for others to enter the market, leading to greater supply as happened in 2010-2011 bubble. The United States, for example, has 13 percent of known rare earth reserves and could get back into the production and refining business if price rises a little more. After China, Russia has the next largest reserves (19 percent), and it is at least as likely (if not more so) to play games with export restrictions, and have more lax safety and environmental standards as well.

The perceived supply shortage of rare earths has passed now, which was the dominating concern until recently. High-technology and environmental applications of the rare earth elements have grown dramatically in diversity and importance over the past two decades. Many of these applications are highly specific and substitutes for REE's are inferior or unknown. REE's have acquired a much greater level of technological significance recently. The demand from new industries such as wind turbine, solar panel and electric vehicle production will keep pressure on prices and that encourage new mining ventures to come online in next 10 years. Countries like U.S would take concrete actions if there is a threat to supply as the issue carries national security implications because of the rare earth content in many advanced military weapons.

China has been strategically motivated in the development of many new high tech applications which have helped quadruple the size of the RE market since 1990. Chinese economy will continue to grow robustly for the foreseeable future and disposable income for automobiles, personal electronics, etc. will drive the internal demand for REs significantly. China has already overtaken U.S as the largest auto market and leads in wind power generation. So to meet the increasing domestic demand for REEs, China may gradually reduce exports.

Policy changes introduced by the Chinese government, such as the introduction of a new resources tax, the removal of export quota, continuing a stable production quota and the consolidation of industry, along with stockpiling strategies, have not had any immediate impact on the market, and international customers are delaying purchases anticipating a continued product surplus and weakening market price.

This has led to a decline in exports in first half of 2015 as consumers continue to leverage off existing REE inventories, leaving suppliers struggling to turn a profit. It also seems that by intensifying Chinese state policy on strategic stockpiling of resources, especially the more critical heavy rare earths (HRE), China wants to have a role in deciding the prices of critical minerals, a similar strategy the US follows in the oil sector with its strategic reserves. So, by increasing or releasing its strategic reserves, China would be in a position to alter the supply and so the rare earth prices in future.

In the long term, the new tax introduced in May 2015 is expected to increase the price of REEs particularly that of HREs as the tax rate is applied differently to LREs and HREs in concentrate form. The new tax is yet to affect prices, as there is already an oversupply of processed rare earth oxides. Also, there is a time gap in the new tax rate's effect on prices as it is imposed on the concentrates, while the price is calculated on the basis of processed rare earth oxides. The prices may eventually increase as the miners adjust to the tax and pass the extra cost to consumers.

China has cleverly used the dynamics of the REE industry to build a dominant presence in most value chains. It controls not only the raw materials but also the production of key intermediates that go into many hi-tech growth industries. Even if there are a considerable number of mining permits, and concentrate/oxide production outside China, this will not solve the problem unless China takes a concrete step to regulate the industry and reduce the price differences to domestic manufactures and international customers.

Chinese internal demand for RE materials and technologies is forecasted to continue to grow robustly compared to developed countries for the foreseeable future. This will continue to drive Chinese policies to limit RE production and exports to better manage its natural resources. As the Chinese government's hold on the REE industry becomes stronger by integrating all REE enterprises under six large existing SOEs, and controlling the whole supply chain, it is difficult to expect a better market in near future.

If China is sincere and succeeds in implementing environmental regulations, raising labor standards and preventing illegal mining and smuggling, this would naturally increase the prices for domestic resources, which can compensate the loss-making state owned enterprises. This would reduce the huge imbalance between domestic price and international price. In the longer term this would also help China cut its overcapacity, create a better environment and better price for what it produces. This would also prompt investors to provide financial support to the new REE projects as explained in Table 8.2 and progress towards commercialization by reducing dependence on depleting Chinese resources. It would be a win-win situation for China and the world.

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