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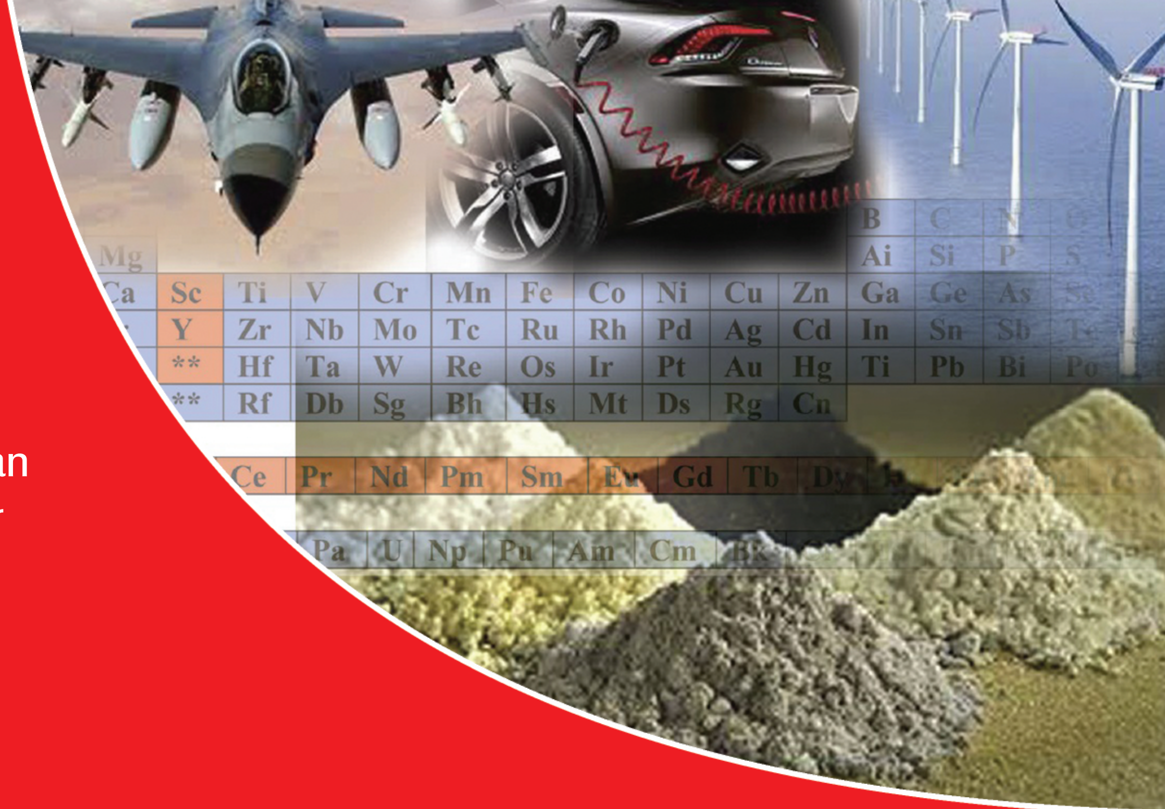

Nabeel Mancheri
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Dominating the World
China and the Rare Earth Industry

April 2013

International Strategic and Security Studies Programme

National Institute of Advanced Studies

Bangalore, India

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Executive Summary

The available evidence suggests that China's current domination of the global Rare Earths (RE) Industrial Ecosystem is the result of a well-thought out carefully crafted dynamic long term strategy.

China has cleverly used the dynamics of the transition of the RE industry from the growth into the maturity phase of the lifecycle to build a dominant presence in most value chains of the RE ecosystem.

China controls not only the raw materials but also the production of key intermediates that go into many hi-tech growth industries.

In contrast the US which actually pioneered many of the breakthrough discoveries in RE materials has allowed its once dominant position in RE to erode. It is now dependent on Chinese largesse to make sure enough RE materials and intermediates are available for its use. The US today has no industrial capacity in RE allowing global market dynamics to move all of them to China.

RE shortages and price increases will affect many sectors of an advanced economy. These include not only large economic value adding industries but also many defence products and industries.

Though the RE industry is currently in the maturity phase where a slowdown in growth is indicated, the use of RE in critical green products like hybrid cars, wind mills, lighting, fuel cells and many other advanced consumer and industrial products suggests that the industry may grow considerably.

New demand from emerging markets like China and India is also likely to fuel the growth of the RE industry.

China is well positioned to use its dominant position in RE as a part of its larger global strategic aims. Its cutting off of RE supplies to Japan as a consequence of a minor spat provides fairly hard evidence that it will use economic levers for furthering its global strategic positions and interests.

Through the tracing of the evolution of the RE industry in China the study also sheds light on how strategy is formulated and implemented in China.

There is always a long term national interest in the evolution of the specifics of a medium terms strategy via the five year plans. The strategies seem to be formulated keeping in mind both constraints and opportunities and they are adaptable to changing global conditions. The grand top down view seems to be seeded with lower level ideas on how to further Chinese global and national interests. Well-connected eminent technocrats seem to be able to access top level officials within the CPC and the Politburo and they seem to provide the micro detail for making sure the top down strategies are grounded in the realities of the dynamic global environment. In the case of Rare Earths there seem to have been close links between XuGuangxian, the father of the Rare Earth Industry in China and Deng Xiaoping the Chairman of the CPC and the head of the Politburo.

The other thing that emerges clearly from our study on RE in China is that strategy implementation is closely linked to strategy formulation. China seems to have in place methods and processes to ensure that the various arms of the government associated with the implementation of strategy, function in an integrated way to ensure that Chinese interests are well protected. The insights that we obtained from our two case studies on how this integration of thought and action take place suggest that informal networks to major power centres within the Chinese establishment play a key role. Irrespective of how the integration happens the Chinese RE industrial ecosystem has dynamic capabilities that can seamlessly connect strategy formulation with strategy implementation. Apart from the more advanced countries in the west such capabilities do not exist in many of the newly emerging economies. China appears to be well on its way to becoming an advanced economic and industrial power that seems to manage continuity with change in an adaptive dynamic way.

Though informal networks also play a role in the more advanced economies of the west most of the division and coordination of work within the government industry ecosystem are governed by more formal rules and procedures. By contrast the Chinese industry ecosystem is still largely government dominated and informal networks seem to provide the integration mechanisms for implementation of complex strategies.

Though the pace of radical breakthroughs in the discovery of new RE materials with unusual properties is slowing down there are still possibilities that such breakthroughs can happen. In case such discoveries take place they could well take place in China. Even if it were to happen elsewhere the Chinese RE ecosystem is well placed to exploit it in a major way.

China's success with its strategy on RE is of course dependent on the continued use of RE intermediates in many key industries especially those dealing with a greener future. Current and future research can throw up new discoveries and approaches that could substitute for Rare Earths in many key applications like catalysts, motors and batteries. In the mature phase of an industry such possibilities increase. However because of their special position in the Periodic Table Rare Earths have unusual properties that confer on them special advantages that may not be easily substitutable in all applications.

While eventual substitution of old technologies with new technologies will take place the crucial aspect that will determine the success of China's longer term strategy on Rare Earths is the timing of such breakthrough discoveries in key application segments. The limited insights obtained from our study indicate that in the short to medium term China is well-poised to take advantage of its dominant position in the global RE industrial ecosystem. If this were to be so it would be a vindication of the forward looking long term strategic thinking that seems to govern much of the Chinese behavior.

In the case of Rare Earths, China has successfully caught up and even overtaken major global players. However an advanced economic and industrial country is typically characterized by its ability to create new industries through radical innovations. Playing catch-up is of course important and China has demonstrated that in RE as well as in several other domains it can do so quite well. In the existing RE industry China should be able to exploit any major breakthroughs if they happen. However this is still not quite the same as creating a new industry of the future via radical breakthroughs within the Chinese ecosystem. This is the kind of advanced economic and industrial power that China aspires to become. Whether it will do so and whether its internal dynamics will allow such things to happen is an open question and a subject for future investigations.

China & the Global Rare Earths (RE) Scene – A Review

Background

China's rise as a major economic and military power is evoking concerns across the world. From the position of a laggard and follower country China has successfully transitioned into a country that has been able to catch up with the more advanced countries in many military and economic spheres of activity. It is now trying to become an innovation power house like the US. China believes that the most important key to this process of transformation is the ability of a country to generate new knowledge that will spawn the industries of the future.

Most studies that try to evaluate a country's capabilities in science and technology focus on some macro easily measurable performance indicators. These include funding for Science & 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. China has also been studied using such frameworks.

The International Strategic & Security Studies Programme (ISSSP) at the National Institute of Advanced Studies (NIAS) has taken a slightly different approach towards understanding the growth of China and the role of technology in fostering and advancing this growth. Through a number of detailed case studies we have been trying to understand China's strategies not only for creating capabilities in technology but also for trying to build globally dominant positions in many industries of strategic and economic importance. We have looked at Chinese capabilities in:

- the development of ballistic and cruise missiles;[1]
- the development of single crystal super-alloy turbine blades for use in jet engines;[2],
- the development of an Ant-Ship Ballistic Missile System that can strike an Aircraft Carrier in the high seas;[3]

Each of these studies uses a different approach though all of them address the complex organization and coordination issues that are needed for the development of high technology products and systems. Our studies reveal that China does not necessarily operate

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1 S. Chandrashekar, Sonika Gupta, Rajaram Nagappa, Arvind Kumar "An Assessment of China's Ballistic and Cruise Missiles" NIAS Study Report R4-07, 2007.

2 S. Chandrashekar, Rajaram Nagappa, Lalitha Sundaresan, N.Ramani "Technology and Innovation in China A Case Study of Single Crystal Superalloy Development for Aircraft Turbine Blades", NIAS Study Report R4-11, June 2011

3 S. Chandrashekar, R.N. Ganesh, C.R. Raghunath, Rajaram Nagappa, N. Ramani and Lalitha Sundaresan "China's Anti-ship Ballistic Missile Game Changer in the Pacific Ocean" NIAS Study Report R5-11, November 2011.

in a top down mode. In almost all the case studies that we have explored, though China has clear strategic plans these are carefully crafted and executed with the help of working level people at the lower levels of the hierarchy. China has always taken advantage of its trained manpower (engineers and scientists). Many of them hold powerful positions within the party and are well connected to the higher echelons of decision making. These powerful technocrats link the lower levels quite effectively with the higher levels of the government and the party to craft and execute industry specific strategies that are in consonance with China's Grand Strategy.

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, windmills and lighting. These are also the industries in which China is trying to build scale for future dominance.

China created a furore in the world high technology markets when after a minor spat with Japan it imposed a ban on Rare Earth exports to Japan. It has followed this up with a number of actions that further restrict exports. Such a strategy does raise global concerns.
This report is an attempt to understand China's strategy for establishing a dominant position in the global Rare Earths Industry.

What are Rare Earths?

The Rare Earth Elements include 15 lanthanides with the atomic numbers 57 to 71 in the periodic table.[4] It also includes Scandium which has Atomic Number 21 as well as Yttrium with Atomic Number 39. Both Scandium and Yttrium have physical and chemical properties that are very similar to the fifteen lanthanides. All 17 of these elements occur together. Since their physical and chemical properties are also very similar they are difficult to separate.[5]

The 17 rare earth elements are divided into two groups. The Light Rare Earth Elements (LREE) are those with atomic numbers 57 through 63 (lanthanum to europium).The Heavy Rare Earth Elements (HREE) have atomic numbers from 64 to 71 (gadolinium to lutetium).Scandium and yttrium have properties similar to the heavy rare earths and are included within this group. This is the classification used by the US Geological Survey in its many reports on Rare Earth Elements (REE). Typically, light rare earth elements are more abundant than the heavy rare earth elements in the earth's crust.

Despite their name, Rare Earths (RE) with the exception of the highly unstable promethium are fairly abundant in the Earth's crust. Since they occur together they are also generally produced together and in economic terms qualify as an industry. Rare Earths are

4 Electrons fill the 4f suborbital slots creating the RE elements. Since the 4f orbital is an inner orbit it creates special optical, magnetic chemical and other properties that make Rare Earths useful for many applications. The elements as they occur in the Periodic Table are Lanthanum (La), Cerium (Ce), Praseodymium (Pr), Neodymium (Nd), Promethium (Pm), Samarium (Sm), Europium (Eu), Gadolinium (Gd), Terbium (Tb), Dysprosium (Dy), Holmium (Ho), Erbium (Er), Thulium (Tm) and Ytterbium (Yb)

5 See http://minerals.usgs.gov/minerals/pubs/commodity/rare_earths/; for data on rare earths as well as definition of rare earth elements.

key inputs to many intermediate industries that go on to feed other industries producing a variety of products. Thus individually as well as taken together the Rare Earth Elements connect a complex interdependent network of industries. Understanding the nature of these linkages and how this network of interdependent industries (often called an ecosystem) is adapting and evolving in response to strategic, economic and technological change is essential for understanding the importance of Rare Earths to any country and to the global economy.

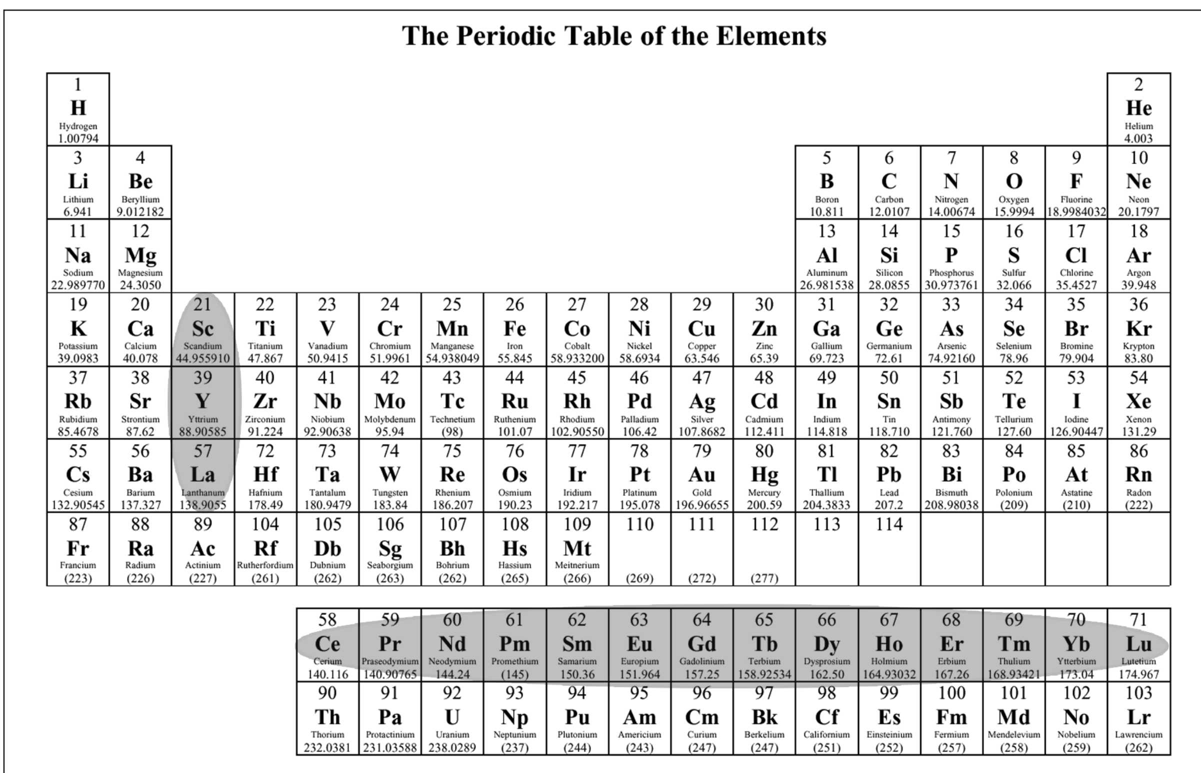
Figure 1 provides an overview of the Rare Elements and their positions in the Periodic Table of Elements.

Why are Rare Earths Important?

Rare earths are a critical component of many high technology goods such as hybrid vehicles, mobile telephones, computers, televisions and energy efficient lights. Since in many applications they are used in very small quantities higher prices for RE need not necessarily translate into higher prices for the end products.

RE 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 high growth electronic consumer products as well as in products for creating a greener planet. Figure 2 provides an overview of Rare Earth use in

Figure 1: Periodic Table of Elements. Rare Earth Elements are highlighted[6]



6 http://4.bp.blogspot.com/-ksg-e6_PkGI/TXTSvh1fPUI/AAAAAAAAAE0/CoRsBp9yfcw/s1600/periodic%2Btable.gif

Figure 2 Rare Earth Intermediate Outputs in Tonnes for the Year 2008

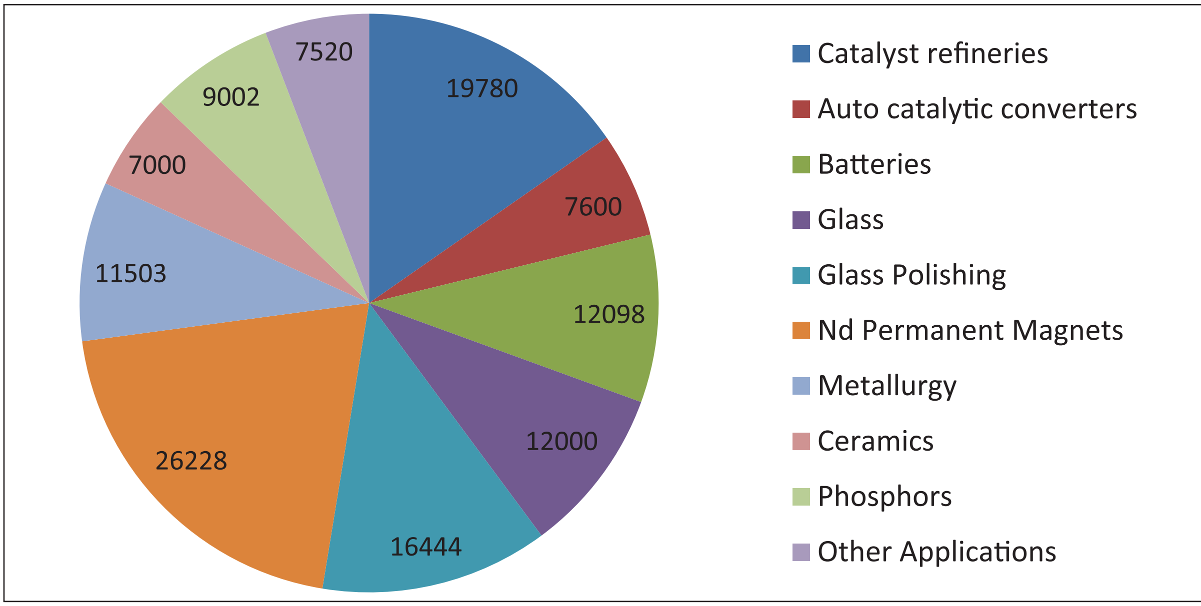
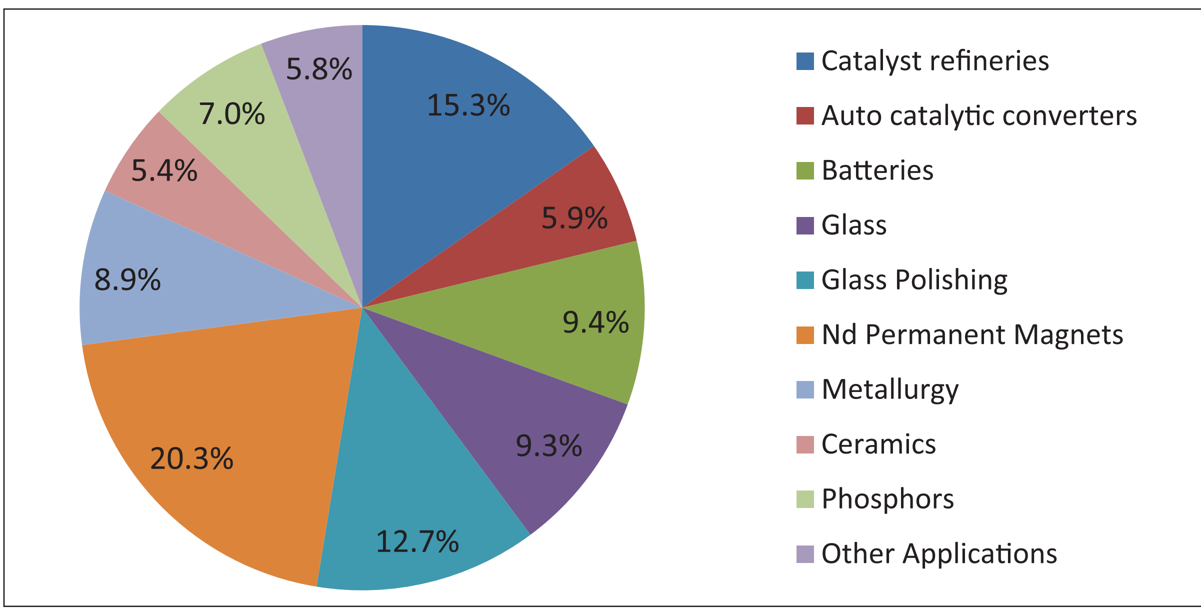


Figure 3 Rare Earth Intermediate Market Shares for the Year 2008



different intermediate industries for the year 2008.[7] Figure 3 provides the same information in the form of RE market shares for the various intermediate products. The total consumption of RE in 2008 was about 130,000 tonnes. This had increased to about 136000 tons in 2010.

Forecasts suggest that demand is likely to be between 185000 to 210000 tons by 2015.[8]

[7] Thomas G Goonan, "Rare Earth Elements – End Use and Recyclability", US Department of the Interior, US Geological Survey (USGS), Scientific Investigations Report 2011 – 5094, 2011 at http://pubs.usgs.gov/sir/2011/5094/

[8] Marc Humphries, "Rare Earth Elements: The Global Supply Chain", CRS report for Congress, Congressional Research Service R41347, June 8 2012.

Table 1: Use of Rare Earths by Application (Percentage)

Application	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Y	Other
Magnets	--	--	23.4	69.4	--	--	2	0.2	5	--	--
Batteries	50	33.4	3.3	10	3.3	--	--	--	--	--	--
Metal alloys	26	52	5.5	16.5	--	--	--	--	--	--	--
Catalytic Converters	5	90	2	3	--	--	--	--	--	--	--
Catalysts	90	10	--	--	--	--	--	--	--	--	--
Polishing Compounds	31.5	65	3.5	--	--	--	--	--	--	--	--
Glass Additives	24	66	1	3	--	--	--	--	--	2	4
Phosphors	8.5	11	--	--	--	4.9	1.8	4.6	--	69.2	--
Ceramics	17	12	6	12	--	--	--	--	--	53	--
Other	19	39	4	15	2	--	1	--	--	19	--

Typical RE Usage

Table 1 shows typical quantities of RE used in the different intermediate products.

Each intermediate product uses only some of the many Rare Earths available. Lanthanum and Cerium for e.g. are the two RE used in the catalysts for petroleum refining. Other RE elements are not used here.

In contrast permanent magnets, use Praseodymium, Neodymium, Gadolinium, Terbium, Dysprosium with Neodymium and Praseodymium dominating.[9]

A simple example will illustrate the importance of Rare Earths in today's world. Table 2 shows how REEs are used in APPLE's i phones.

A brief overview of the use of RE in each of the key intermediate industries is provided in Annexure 1. This has been the basis for generating an input output matrix and a network diagram that describes the current RE Industrial Ecosystem of an advanced economy. The information contained in this Annexure also provides us with the basic data on how the global RE industry has evolved and changed over time to reach its current status. However before we review this and examine the current dynamics of the competition between different players we need to understand the current global RE industrial ecosystem in more detail.

Table 2: Use of Rare Earth Elements in i phones

Component	Y	La	Ce	Pr	Nd	Eu	Gd	Tb	Dy
Colour Screen	*	*		*		*	*	*	*
Glass Polishing		*	*	*					
Phone Circuitry		*		*	*		*		*
Speakers				*	*		*	*	*
Vibration Unit						*		*	*

(Adapted from http://i.i.com.com/cnwk.1d/i/ne/pdfs/Elemental-table.pdf)

[9] Source: The Principal Rare Earth Elements Deposits of the United States—A Summary of Domestic Deposits and a Global Perspective, USGS Scientific Investigations Report 2010–5220)

Rare Earth Value Addition Chains, Global Demand & Global Supply

The Global RE Industrial Ecosystem Network

As we can see from our review so far RE Materials though small in terms of their contribution to the Gross Domestic Product (GDP) are vital to the well-being of any advanced economy. They often provide the primary input into a long chain of value adding products and industries. Supply disruptions in their availability or price increases could therefore have implications that go beyond the immediate industry affected by the shortage of raw material.

Rare Earth Materials are critical for many products that are used in the economic and military domains.

Using the available information on how Rare Earths are currently used we created a 92 by 92 Input Output matrix. Using this matrix we created a network diagram that linked the various RE elements with major intermediate products and then linked these intermediates to the downstream product.[10] This network diagram represents the typical Industrial Ecosystem of an advanced economy that uses RE. Annexure 2 provides the network diagram for the RE industrial ecosystem for any advanced economy and Annexure 3 provides the ranking of each of the nodes in terms of its connectivity to other nodes in the network.

The advantage with using this approach is that all the complex linkages that exist between critical input materials and their use in final products can be captured. Specific Paths linking any node in the network to any other node can also be traced. If one is interested in the connection between permanent magnets with various end products and the materials used in their production this can be easily extracted from the overall network and studied in detail.

The most critical nodes in the network are those that are connected to many other nodes. We can therefore use a combination of the network diagram and the matrix to rank the various nodes in the rare earth value network. The higher ranking nodes are the most likely products and industries that will be affected by supply side shortages. Annexure 3 provides a ranking of the 92 nodes in the network based upon the total number of connections that each node has with other nodes in the network. This could be the basis for more detailed studies on how Rare Earth shortages or higher prices would affect the industrial economy of any country.

Table 3 below provides details of the top 27 ranked nodes from the RE Economic Network.

From the network diagram and the matrix we can see clearly that RE materials are used in a large number of products and industries. Many of these represent the use of cutting edge technologies for both consumer and defence products.

10 For a more details on the networks of connections between REE and intermediate products refer to Chandrashekar, Does India need a national Strategy for rare earths?, NIAS Report, R18-2013.

Table 3: Ranking of the Top 27 Nodes in the RE Economic Network

Node	Input into Node	Output from Node	Total Links	Rank
Glass	8	16	24	1
Cerium	0	15	15	2
Lanthanum	0	14	14	3
Permanent Magnets	6	8	14	3
BaTio3 MLCC Capacitors	7	6	13	5
RE Phosphors	6	6	12	6
Neodymium	0	11	11	7
Praesodymium	0	11	11	7
Yttrium	0	11	11	7
Zirconia / YSZ	1	8	9	10
Catalyst	3	4	7	11
Fuel cells	6	1	7	11
Automobile	7	0	7	11
Communications	7	0	7	11
Batteries	5	1	6	15
Nd YAG Lasers	3	3	6	15
Microwave filters	3	3	6	15
Cathodes	1	5	6	15
Radar	6	0	6	15
Speakers	1	5	6	15
Catalytic Converters	4	1	5	21
Polishing agents	3	2	5	21
Optical elements	1	4	5	21
Fiber optics	5	0	5	21
Microwave components	2	3	5	21
Motors	1	4	5	21
Samarium	0	4	4	27
Gadolinium	0	4	4	27
Terfenol D	2	2	4	27
Other RE	0	4	4	27
Refineries	2	2	4	27
Hard Drives	2	2	4	27
Flint	4	0	4	27
Jewelry	4	0	4	27
TWT	2	2	4	27
Magnetron	2	2	4	27
Klystron	2	2	4	27
Cell phones	4	0	4	27

Some of the major intermediate industries that are significant users of RE include Glass, Permanent Magnets, Phosphors, Catalysts for Oil refining, Oxygen sensors, Batteries and Catalytic Converters. Industries that are linked to these intermediates include Consumer electronics, Oil refineries, Automobiles, Windmills, Electric Motors, Fuel Cells, Optical Equipment, Fibre Optics and the emerging industries of efficient lighting that includes CFL Lighting as well as LED Lighting.

The review suggests that RE materials are critical for many applications related to building a greener and more environmentally friendly economy. We can also see that RE materials are also critical for many defence applications.

Apart from Permanent Magnets which are used in many defence applications too, Neodymium doped Yttrium Aluminum Garnet (Nd YAG) lasers are used in many range finding applications that are part of advanced weaponry. They have now moved from defence applications into the civilian sector and are used in surgery as well as in the jewelry industry. Yttrium Iron Garnets as well as Yttrium Gadolinium Garnets are needed for building microwave components that go into advanced Communications and Radar systems.

Rare Earth Cathode elements are also needed for building the high power tubes used in many radar and communication systems. They are also used in the ion thrusters that are required by advanced satellites.

Terfenol D – an alloy of Terbium, Iron and Dysprosium has unique magnetostriction[11] properties that are used in sonar and other acoustic applications.

[11] The material expands and contracts in response to changes in the magnetic field giving it its special properties.

Among the materials themselves Cerium, Lanthanum, Praseodymium, Neodymium, Yttrium and YSZ Zirconia are clearly some of the more important nodes in the network. Our review also show that in the future the other RE like Dysprosium, Terbium, Erbium and Gadolinium may become important too. Special structural forms of RE materials like garnets, Perskovesite and Metal hydride structures would continue to be important areas of future development as would RE materials in the nanoform.

We can see from the above that RE materials are closely linked to many hi-tech sectors of an advanced economy that are vulnerable to supply chain disruptions. Whoever controls the supply side therefore has the power to disrupt the economies of advanced countries.

Global RE Supply

Table 4 below provides data on global supply of RE materials normalized to RE oxide base.

According to an US Government Accountability Office Report[12] as of April 2010 China controlled:
97 % of the RE ore;
97% of the RE oxides;
89% of the RE alloys;
75% of the Neodymium Iron Boron Magnets industry;
60% of the Samarium Cobalt Magnets industry.

There is enough evidence to suggest that in other intermediate RE industries China is trying to build dominant positions so that it can leverage its strength in RE materials as a component of its Grand Strategy. This makes the more advanced economies of the world especially the US particularly vulnerable to Chinese actions.

Before addressing issues related to national strategies and national vulnerabilities in the global RE industry, it may be worthwhile to understand in some detail the historical evolution of the global RE industry. Only through such an understanding can we try and fathom the motives of the different players that have led to the current state of affairs in the global RE industry.

Table 4: Global Supply of Rare Earths (Normalized to Oxides)

Country	Mine Production	% of Total	Reserves	% of Total
United States	None		13 Million Tonnes	13%
China	130,000 Tonnes	97.3 %	55 Million Tonnes	50%
Russia Former USSR			19 Million Tonnes	17%
Australia			1.6 Million Tonnes	1.5%
India	2700 Tonnes	2%	3.1 Million Tonnes	2.8%
Brazil	550 Tonnes	0.42%	Small	
Malaysia	350 Tonnes	0.27%	Small	
Other	NA		22 Million Tonnes	20%
Total	133,600 Tonnes		110 Million Tonnes	

[12] U.S. Government Accountability Office (GAO), Rare Earth Materials in the Defense Supply Chain, GAO – 10 – 617 R, April 14 2010, p19 available at http://www.gao.gov./news.items/d10617t.pdf

The Evolution of the Global RE Industry & Current Competitive Dynamics

Historical Setting & Evolution of the RE industrial Ecosystem[13]

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 Misch metal 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 colour to the glass.

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. 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 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 Misch Metal was added to improve the properties of nodular cast iron. The Mountain Pass Mine in California was discovered in 1949. In the early 1950's 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.

13 This account is compiled using various publicly available materials including the specific articles and websites cited in this report.

The 1960's saw the movement of RE from niche applications in selected markets into more mainstream commercial products and industries.[14] 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.

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 colour television sets that were becoming widespread in the US market. Phosphors have continued to be an important market for RE especially in various consumer electronic products. Their use in the emerging energy efficient lighting industry that includes both CFL and LED lighting will continue to be important for some time to come.

Between 1964 to 1970 another major application of RE was the development and commercialization of Neodymium doped Yttrium Aluminium Garnet Lasers (NdYAG) lasers. They were originally used for range finding applications in the defence sector but have now moved into surgery as well as general manufacturing applications.

The 1970's saw the emergence of a number of new applications for RE.

The Naval Ordnance Laboratory discovered a major magnetostriction effect[15] in Terbium based alloys. Terfenol D an alloy of Terbium, Iron and Dysprosium was developed and commercialized by the Ames Research Centre which was at that time one of the leading Laboratories in Rare Earth Research. This led to the use of these alloys in sonar and other noise suppression applications in the defence sector. They are also used in speakers as well as fuel injection systems of diesel engines.

In 1970 the Air Force Materials Laboratory (AFML) discovered Samarium Cobalt Magnets. These soon replaced the AlNiCo and Ferrite magnets in many applications where performance mattered.

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.

Rare Earth additions to glass created new forms of glass with special properties. ZABLAN Glass exhibiting special properties in the infrared became commercial in the form of optical equipment as well as fibre optics in 1975.

Work on specialty ceramics involving RE

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

15 A magnetic field applied to the material causes it vibrate or move mechanically.

such as Yttrium Iron Garnets (YIG) and Yttrium Gadolinium Garnets (YGG) that had been going on from the late 1950's began to be used in various radar and communications applications with one of the earliest patents being taken out in 1975.

The 1970's also saw the development of semiconductor LED products for lighting and other applications. The addition of RE phosphors to these as well as Compact Fluorescent Lamps (CFL) 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 1980's 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.

RE materials added as dopants for the production of Multi-Layer Chip Capacitors become commercial by about 1986.

Yttrium additions to various candidate materials with high temperature super conducting properties become important with the discovery of high temperature superconductivity. Though a subject of active research there have been no major spinoffs from this research as yet.

In 1987 Erbium doped fibre optic amplifiers become commercial and added significantly to the performance of long distance optical communications networks.

The decade of the nineties and the first decade of the 21st century have not seen major technology breakthroughs. The demand for RE has also stabilized. However work is still going on in exploring new possibilities for improvements in performance of RE alloys and compounds. There is also the fairly real possibility that some new alloy or compound that uses RE and which has some unique properties is still awaiting discovery.

The last two decades have also seen the action shift from breakthrough technologies and products towards incremental technology and product improvement. During this period China initiated a set of actions that was directed at not only catching with the advanced countries in RE technologies, products and markets but also move it into a position of dominant leadership of the global RE industry

In 1995 China in order to catch up on RE permanent magnet technology tried to acquire Magnequench a General Motors subsidiary that was making permanent magnets. After a lot of debate and discussion the US allowed the acquisition to go through but with certain conditions imposed on the takeover. In 2002 as soon as the curbs on the company were removed all the assets of Magnequench were moved to China.

In 1998 the US closed the Mountain Pass Mine for environmental reasons.

In 2005 once again a Chinese consortium tried to acquire the US Oil giant UNOCAL. Since UNOCAL owned the Mountain Pass Mine the deal was not really about oil but seemed to be linked with the Chinese desire to establish a near monopoly position in the global RE industry. Though the deal with the US did not fructify China has continued on its strategic quest of RE acquisitions for achieving global dominance.

In 2007 as a part of flexing its muscles China cut of RE supplies to W R Grace a large US producer of catalysts for the petroleum refining industry. In the same year it set in place a rationing policy for RE that favoured domestic producers. This was a message to various global companies that if they wanted access to RE material they needed to set up shop in China to get preferred treatment. Since W R Grace eventually did set up shop in China this policy seems to be working as far as China is concerned.

Though China's attempts at buying a controlling stake in two Australian RE mining companies Lynas and Arafura Resources have not been successful they have bought minority stakes in them in 2008 and 2009 respectively.

In 2010 China cut off RE supplies to Japan after a fishing trawler incident demonstrating once again that it controls the global supply chain for RE and that it will use this power in pursuit of its grand strategy.

This account of the evolution of the RE industry makes it clear that though the origins of the industry were in 18^{th} and 19^{th} 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 1960's and 1970's when a number of breakthrough technologies were developed and commercialized in the US. In the early part of the 1980's 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 controlled the global supply of RE materials and key intermediates.

Annexure 4 provides a detailed time line of the evolution of the RE industry on which this section is based.

The Dynamics of Competition in the Global RE Industry

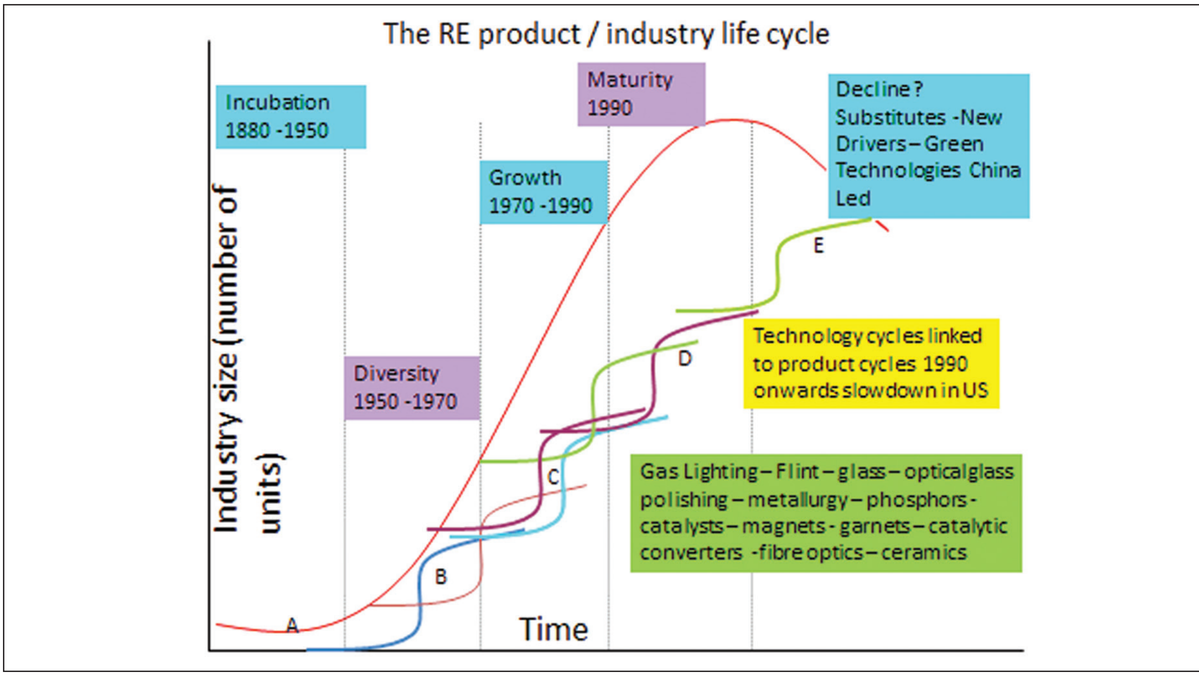
Figure 4 provides an overview of the evolution of the Global RE industry that links the various technology breakthroughs for product development to the growth of the industry via the products that they are used in.

Though conceptual the various timelines and the phases of the evolution of the industry are based on our study of the various technology breakthroughs, as well as the intermediate and final products that resulted from them.

As we can see from the above Figure the Global RE industry is in the mature phase of its life cycle. Our review shows that the pace of new discoveries and the emergence of new breakthrough products based on RE has been slowing down. Most of the research work going on seems to be related to improvements to existing products. Though this is so, the possibility of new radical breakthroughs cannot be ruled out.

The future growth of the industry will depend on the growth of existing products that use RE in the new emerging economies like

Figure 4: The Rare Earth Product / Industry Life Cycle



India and China. It is also possible that if the more advanced countries accelerate the pace of change towards realizing an environmentally friendly green economy the demand for RE could grow significantly. In the mature phase of the life cycle cost, scale and scope of operation are drivers of competitive advantage.

Figure 5 shows the relative positions of China and the US in the early 1990's when the global RE industry was in the early stages of reaching maturity.

The US not only created most of the technology breakthroughs using RE but also pioneered the commercialization of these breakthroughs. It was the world leader in RE with a complete well connected RE Industrial Ecosystem.

Figure 6 shows how the relative competitive position between China and the US had shifted by about 2005. From being a laggard in the early 1990's China has moved to hold a dominant position in the global RE industry. This has been accompanied by significant erosion in the capabilities of the US, Europe and Japan whose industrial capabilities in critical RE value chains had declined alarmingly.

What did China do to move from a laggard position in the early 1990's to a dominant position by about 2005? This is the question that we will try to answer in the next few sections.

Figure 5 Relative Competitive Position of Rare Earth Industry in the US and China (Early 1990s)

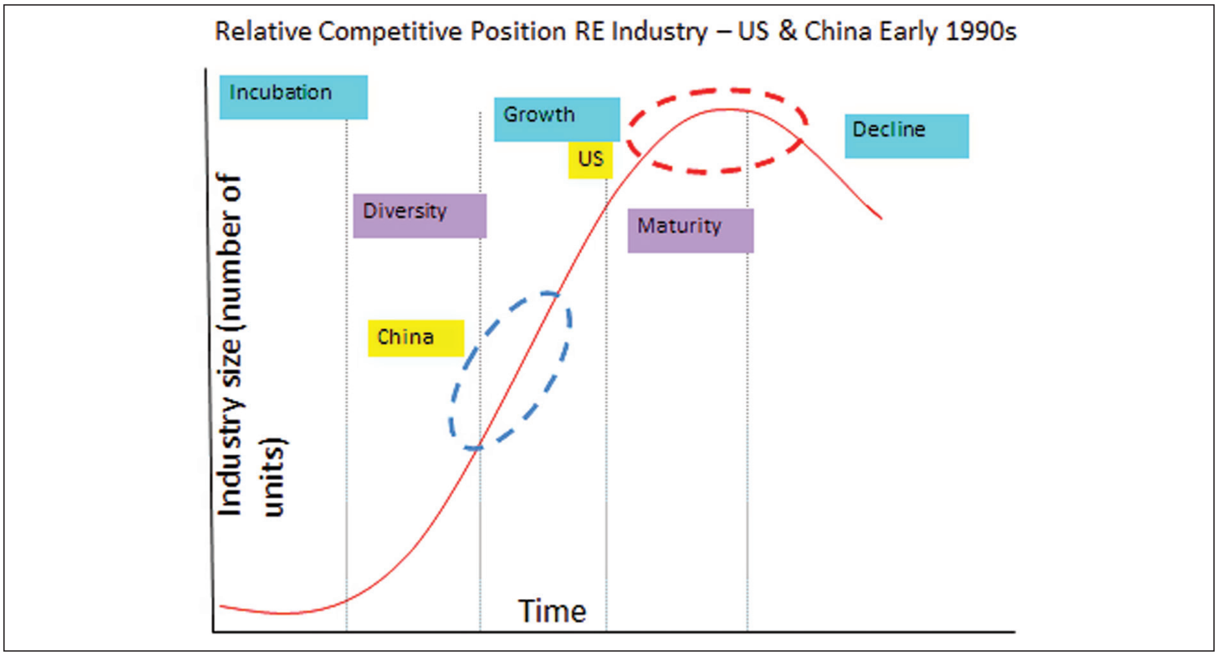
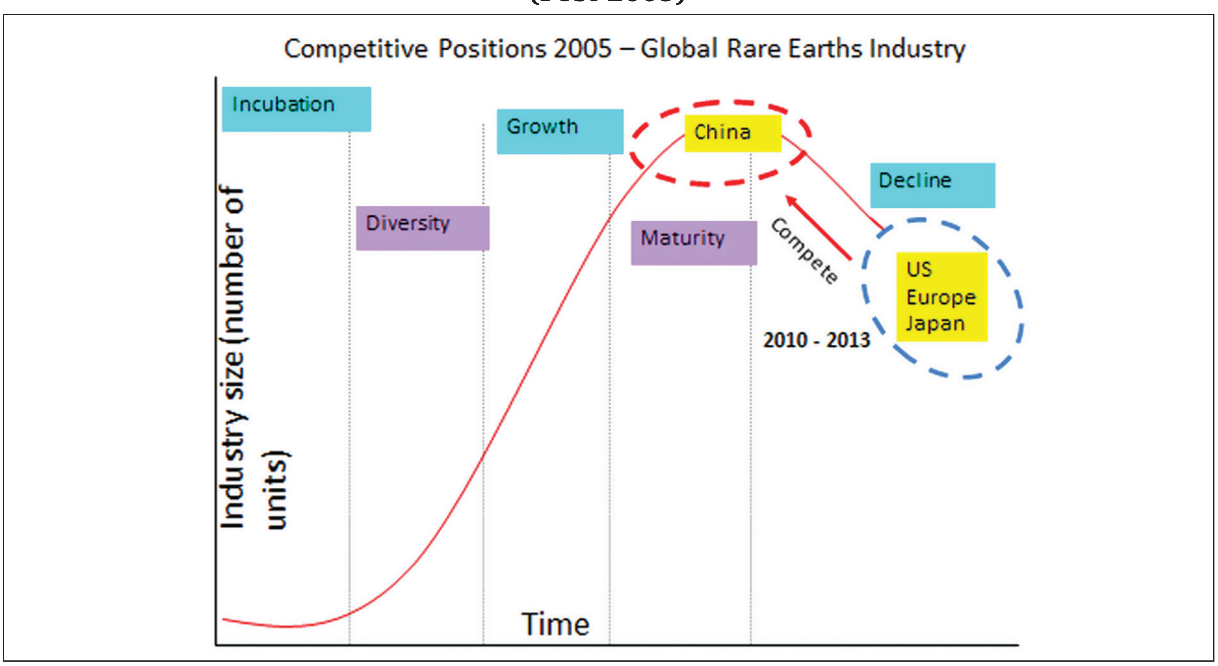


Figure 6 Relative Competitive Position of Rare Earth Industry in the US and China (Post 2005)



China's Strategy in Rare Earths

If we look at the developments that have taken place in China since the first discovery of the rare earth mines, it is clear that successive Chinese governments have planned the trajectory to reach this dominating position. It has been crafted by a number of persons who wielded power and were well aware of the value of this commodity.

Initial Focus on Mapping RE Resources and on Mining

The Iron deposits at Bayan Obo in Inner Mongolia along with which RE are also mined was discovered in 1927. In the early 1950's the Bautou Iron and Steel Company started production of steel. In 1957 the first Rare Earth Concentrates from the Bautou mines were produced.

Though production was the obvious initial focus China soon set up R&D facilities. The first dedicated R&D facility for RE, the Bautou Research Institute was set up in 1963. It remains one of the largest R&D facilities devoted to RE to date.

Evidence suggests that between 1960 and 1980 China took on a systematic exploration programme for all commercially and strategically important minerals including RE. By about 1980 the Chinese knew the location and reserves of RE materials quite well. They also must have realized that they had one of the largest stockpiles of RE in the world and that if this were used wisely it could be a source of competitive and strategic advantage. Annexure 5 provides an overview of RE mineral resources of China.

In 1972 Xu Guangxian, after being a victim of the Cultural Revolution moves out of working on the extraction of nuclear materials into RE materials. He develops the approach of Countercurrent Extraction for RE materials.[16] These methods introduced by him reduce the costs of producing RE concentrates significantly. He becomes the effective spokesman for the development of the RE industry in China.

With the winding down of the Cultural Revolution and the coming to power of Deng Xiao Ping there is a renewed focus on using China's resources to advance economic growth. The mining and export of RE materials as a part of this development becomes important. Simultaneously there is also a realization that value addition to the raw material could confer significant economic as well as strategic benefits and should be pursued as a long term strategy. For this value addition to take place both indigenous capabilities in integrating R&D with products and processes as well as selective imports of technology were identified as being critical.

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[16] This could be the same as Counter Current Decantation used in many Uranium milling and RE facilities and is a standard process used in the mineral processing industry.

Under the guidance of the Ministry of Land Resources and Planning China expanded its mining operations between 1978 and 1989.

At this time the US was the globally dominant player in the global RE industry. It occupied dominant positions in all parts of the value chain from R&D[17] through mining to intermediate and final products. China was only a lower cost alternative supplier of raw material to the global RE industry.

Deng Xiaoping and New Orientation

China's thrust for achieving world leadership in the RE industry can be linked directly to Deng Xiaoping. In 1986 he approved Program 863 – a Program promoted by three key scientists from the strategic Nuclear Programme.

The objectives set forth for this programme were for China to:

- Gain a foothold in the world arena;
- Strive to achieve breakthroughs in key technical fields that concern the national economic lifeline and national security;
- The areas identified as thrust areas included biotechnology, space technology, information technology, laser technology, automation, energy, and new materials. Many of these areas need RE materials.

In 1987 China set up the State Key laboratory of RE Chemistry and Physics. This was affiliated to the Changchun Institute of Applied Chemistry under the direct supervision and control of the Chinese Academy of Sciences. This was followed by the setting up of another Laboratory - the State Key Laboratory of RE Materials Chemistry and Applications in 1991. This was affiliated to the College of Molecular Engineering in Peking University. Along with the Bautou Research Institute these provide China with three strong research institutes working on fundamental, applied and process research in RE.[18]

There is also a shift away from just export of raw materials towards the setting up of indigenous industry for the production and export of key RE intermediates especially magnets. Coordination between the various arms of government become more complex as apart from the mining and environment related ministries the Ministries of Industry[19] as well as Trade become involved in the national RE strategy.[20]

By 1992 awareness of the importance of RE in China's grand strategy had become well-known amongst top Chinese decision-makers. This led Deng Xiao Ping to make the famous statement "The Middle East has oil, China has Rare Earths". A special RE industrial zone is set up in Bautou in 1992 to attract foreign investment in RE related facilities as a part of China's efforts to bridge the technology gap.

[17] Many of the major discoveries leading to new applications for RE were made in the US with some contributions from Japan and Europe.

[18] This seems to be unique to China with no other similar parallels anywhere else in the world. There are other facilities related to Non-ferrous research that may also work on Rare Earths.

[19] The RE Manufacturing industry in China comes under the jurisdiction of the Ministry of Information Technology and Industry.

[20] The setting up of indigenous RE industry as well as Trade in RE products would or should also involve the Ministry of Foreign Affairs especially in matters related to acquiring companies and properties in foreign countries.

The Push for Global Dominance

In 1995 China made a major move that would help achieve a dominant position in the RE Permanent Magnets industry. Two Chinese companies China National Non Ferrous Metal Export Corporation and San Huan along with a US Investment Firm Sextant MQI Holdings make a bid to acquire Magnaquench the Permanent Magnet production facility owned by the US automobile giant General Motors (GM). The US imposed certain conditions for this takeover.[21] In spite of these conditions China was able to set up a powder facility in China by 1998 and to finally transfer all Magnaquench operations to China by 2002 when the time limit on the conditions imposed by the US expired.

In 1997 another major boost to RE based technology development efforts is provided through Programme 973. In the same year Jiang Zemin makes the statement, "Improve the developments and applications of Rare Earths and change resource advantage to economic superiority".

In 1998 a big boost to Chinese efforts to establish a dominant position in the global RE Industry is given when the US closes the Mountain Pass Rare Earths Mine for environmental reasons.[22]

In 1999 a RE Functional Materials Engineering Technical Research Centre is set up at Xiyuan in Inner Mongolia. In 2000 Neodymium powder production begins in the new Magnequench production facility at Tianjin. The Bautou Research Institute sets up another research centre for RE Metallurgy and Materials in 2001.

After moving all Magnequench operations out of the US in 2002, China expands Magnequench operations to Singapore in 2004 and to Thailand in 2006. Magnequench acquired, AMR Technologies Inc. another RE company in Canada in 2005. In the same year China tried to acquire the US Oil giant UNOCAL. Though ostensibly this purchase was about oil the real intent behind this Chinese move was to acquire the Mountain Pass RE mine owned by Molycorp a subsidiary of UNOCAL. If the deal had gone through it would have substantially improved an already dominant Chinese holding of RE reserves.[23]

In 2007 China introduces a rationing system for RE materials that favours domestic companies over exports. In the same year it cuts off RE supplies to a major US catalyst producer W R Grace forcing the company to set up shop in China a couple of years later.

China also tried to buy a majority stake in the Australian RE mining Company Lynas in 2008. Though it did not get a majority stake as originally envisaged it does have stakes in Lynas as well as in another Australian RE mining company Arafura Resources Ltd.

In 2010 by cutting of RE supplies to Japan following a fishing trawler incident China has clearly sent a message to all its neighbours of using economic levers of power and control as a part of its grand array of strategic instruments.

Annexure 6 provides the time line for the various Chinese actions.

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[21] There were apparently restrictions on transfer of operations for a period of five years.

[22] China hastened this closure via its systematic policy of price undercutting for various RE raw materials making US supply unviable. While there is no hard evidence in the public domain one cannot rule out Chinese support for environmental lobbies wanting a stop to RE mining.

[23] In the mature phase of the life cycle consolidation often involves mergers and acquisitions.

China's Grand Strategy in RE

Though China started work on Rare Earths in the early 1950's internal developments and other pressing priorities prevented China from making significant investments. In spite of such constraints they did go ahead and created the minimum infrastructure that would stand them in good stead much later. A lot of effort also seems to have into survey and mapping of the various mineral resources including Rare Earths. Chinese researchers as well as decision-makers did get to know fairly early that China had a big share of the world's Rare Earth resources. With the advent of Deng Xiaoping a new thrust is given for China's development in the economic sphere first followed closely by increased focus on the strategic sector too. In the case of RE this also saw a shift in focus from the export of Raw Materials towards an increased emphasis on Value Added products. The Chinese seemed to realize fairly early on that they were significantly behind on the technology front in Rare Earths too. The 863 Plan also revealed major gaps in technology that could be bridged only with creating strong institutions within China for both basic as well as applied research. The setting up of two new R&D facilities[24] for Rare Earths to address these needs is a clear indication that the Chinese had understood the importance of bridging the technology gap and that it could not be achieved only by importing technology. As we can see from Figure 5 in the early 1990's China was far behind an advanced economy like the US in its development of industrial RE ecosystem.

In order to catch up such a laggard country has to simultaneously advance on several fronts. An advanced economy like the US had already reached the mature phase in the evolution of its RE industrial ecosystem. This means that it has successfully gone through the incubation phase, the diversity phase and the growth phase before reaching the maturity phase in the RE industry life cycle.[25]Apart from closing gaps in technology a laggard country like China also has to master the links between technology and products and markets that are necessary to catch up with a country that has gone through the growth phase and is now in the mature phase. In addition to compete with a country in the mature phase of the life cycle it requires low cost arising from both scale and scope economies in production.[26] While this is easy to conceptualize it is difficult to execute especially for a country that does a lot of central planning and strategizing. A significant degree of co-ordination amongst the different departments of a typical government has to take place not only for the formulation of a strategy but also for executing the strategy. Since an industry is also created and is involved, a new dimension is added to the already complex problem of division and co-ordination of work. This co-ordination and control is possibly the

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[24] The first R&D unit for RE was set up under the Bautou RE operations in 1963.

[25] To understand the link between the industry life cycle and strategy in greater detail see S. Chandrashekar, 'Technology and Business: The Missing Link", Management Review, April – June 1996, pp 41-51. While technology, products, markets, production and costs are all important during all the phases the focus of major effort shifts from technology in the incubation phase to products and markets in the growth phase to production and costs in the maturity phase with technology once again becoming more dominant in the decline phase.

[26] The current actions in the Chinese RE industry of consolidation with fewer and larger companies indicates that the Chinese are well aware of size, scale and scope as the drivers of low cost needed for competing in the mature or decline phases of an industry life cycle.

most difficult part that sets apart an emerging economy from an advanced economy.[27] How successful has China been in this task? Does it have in place the internal mechanisms for co-ordination, control and re-orientation that are so necessary to compete globally in the mature phase of the life cycle? This is what we will address in the next section.

[27] In an advanced market driven economy this is achieved by allowing market forces to operate with minimal intervention by the government. While China does have some market driven mechanisms government's active intervention to promote national strategy and national interests is still very much the norm.

China's Strategy Implementation – Division & Coordination of Work, Command & Control

The Chinese RE Industrial Ecosystem

The Rare Earth (RE) industry in China consists of three broad inter-related sets of activities. These are:

- Mining and processing
- Manufacturing and Applications
- Research and Development

In addition to these direct domestic value chain activities, competing globally brings in additional activities like trade, global mergers and acquisitions and increasingly foreign policy. These are particularly important as global industries reach the maturity phase and countries like China use these dynamics to push national strategies.

The Division of Work

For the utilization of RE in national development tasks specific Ministries are involved in the development of each of these sectors. These include the Ministry of Land and Resources (MLR), the Ministry of Environment Protection (MOEP) who are mainly involved in the mining part of the value chain, the Ministry of Industry and Information Technology (MIIT) which is concerned with the development of the RE intermediate and final products and the Ministry of Commerce (MOFCOM) which is involved with domestic and global trade. The Ministry of Foreign Affairs should also be involved since in the maturity phase of the lifecycle acquisitions of global companies for both technology and markets becomes important. The driver for all these components in the value addition chain is of course R&D. Some part of this R&D is carried out within companies engaged in both mining as well as product development. However capabilities in the development of innovative new products and technologies can come about only if basic and applied research is funded as public good activities. Of course these have to be linked to products, industries and markets for a viable ecosystem to function. In China this critical input into the RE ecosystem development comes under the ambit of the Ministry of Science and Technology (MOST).

Mining

The Ministry of Land and Resources and the Ministry of Environment Protection regulate and control all mining and ore processing activities and exercise oversight over companies engaged in these activities. The main responsibilities of the MLR include land and resource survey and evaluation, planning, administration, protection and rational utilization and standardizing mineral resource exploration.

In China, there are two sets of quotas that affect the rare-earth industry. One concerns the extent of mining and the other concerns the separation and smelting of rare earth products. The Chinese Ministry of Land and Resources (MLR) controls the quota concerning mining. The mining quotas are usually the more prominent, and each year, usually sometime in

March, the MLR publishes a list of the mining quotas that have been allocated to each province or region in China. Rare earth stockpiling that began in 2010 in China's primary mining region of Baotou in Inner Mongolia is also overseen by this Ministry. Over ten storage facilities are being built and managed by the government-controlled Baotou Steel Rare-Earth (Group) Hi-Tech Company.

The Ministry of Environment Protection (MEP) develops and organizes the implementation of national policies and plans for environmental protection, drafts laws and regulations, and formulates administrative rules and regulations for environmental protection. It is also in charge of overall coordination, supervision and management of key environmental issues. Since 2009 the Ministry has been in coordination with MLR in regulating and consolidating the rare earth mining and smelting companies. Presently, the Ministries of Environmental Protection, Land and Resources, Industry and Information Technology, and Commerce together implement a coordinated series of regulations to enforce policies aimed at preserving the resources and protecting the environment.

RE Intermediates Manufacturing

The second stage of processing and manufacturing of Rare Earth (RE) intermediates is more critical and a number of state organizations are directly and indirectly involved in this sector along with the companies. The Ministry of Commerce (MOFCOM) and the Ministry of Industry and Information Technology (MIIT) and to a lesser extent the Ministry of Environment Protection (MOEP) are mainly responsible for policy formulation and implementation in this sector. MOFCOM formulates the strategies, guidelines and policies of developing domestic and foreign trade and international economic cooperation, sets the quota levels for exports, drafts the laws and regulations governing domestic and foreign trade, foreign investment in China and devises relevant departmental rules and regulations. However the quota concerning the separation and smelting of rare-earth products inside China, is controlled by MIIT.

Over time the MIIT has become the architect of China's industrial policy on RE and a champion of consolidation. Not only does MIIT have control over rare-earths policy, it has also been tasked with shaping the development of emerging technologies, which will drive demand for rare earths. As a general rule, the Ministry of Industry and Information Technology is responsible for the manufacturing part, the Ministry of Land and Resources is responsible for mineral mining and exploitation part and MOFCOM is responsible for trade both in raw materials as well as intermediate RE products.

Technology, R&D & Innovation

The activities of these operating entities have to be integrated with the development and use of new knowledge via basic and applied research in RE. The Ministry of Science and Technology (MOST) takes the lead in drawing up S&T development plans and policies, drafting related laws, regulations and department rules, 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 encourage industry R&D labs, universities and research institutes to work together, augmenting each other's strengths and pooling their resources on technological challenges.

In addition to MOST direct support, the National Natural Science Foundation of China (NSFC) is an organization directly affiliated to the State Council for the Management of the National Natural Science Fund (NSFC). NSFC supports basic research and some applied research, identifies and fosters talented researchers in the realm of science and technology, NSFC cooperates with the Ministry of Science and Technology to formulate the principles, policies and plans for the development of basic research in China. NSFC undertakes other tasks entrusted by the State Council and the State Leading Group for Science and Technology and Education.

More details on how research related to research in RE is organized and managed in China is provided in Annexure 7.One measure of relative performance in any given area relates to the publication of relevant technical papers. Annexure7 also provides an analysis of technical papers on RE published in China and compares it with papers published in the US.

Medium & Long Terms Strategic Plans

The 2006 National Medium to Long-term Plan for the Development of Science and Technology (2005-2020) serves as the PRC's guiding document on innovation policy[28] and represents an important milestone in China's scientific modernization. It involves substantial government investments and incentives for key technology and engineering projects with commercial applications. The State Council in turn extends support for industries in seven emerging sectors. The sectors those are related to REEs include energy conservation and environmental conservation, clean energy, new materials, including the development of rare earth materials, special glass, functional ceramics, metal alloys and alloy steels.

Since 1980s all the major science and technology programmes of the government had a vital component related to material developments particularly 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.

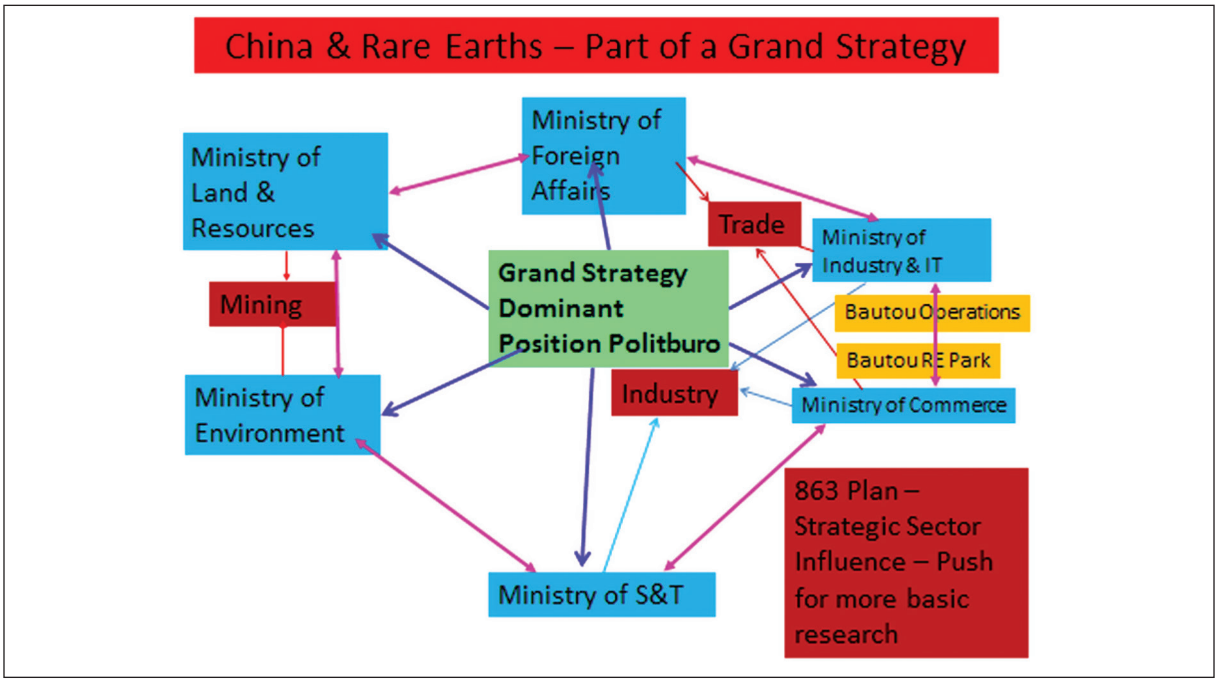
China's Creation of National Capabilities in Rare Earths

Figure 7 captures the complex coordination within the Chinese politico-bureaucratic system that must be taking place for China to have achieved a dominant position in the global RE industry between the early 1990's and 2005.

[28] What is happening in the RE industrial ecosystem of China can at best be termed incremental innovation which is the case with a follower company or industry playing catch up. While the pace of new breakthrough discoveries in Rare Earths is slowing down there are still possibilities of such discoveries. The Chinese ecosystem is currently well poised to take advantage of such breakthroughs whether they take place within China or elsewhere in the world.

Personal ties between top officials in the Politburo with the scientists and technologists are the key to many of the successes that China has achieved in the high technology front. They provide the crucial link between the lower and higher levels of decision making within the Chinese decision-making system. Two specific case studies involving important actions that China took in the RE domain are presented below to provide much needed micro detail to the macro picture presented by this figure.

Figure 7 Coordination between the Politico – Bureaucratic System in China



Case Studies on China's Strategy in RE

China's Rare Earth Strategy Case 1 - the Acquisition of Magnequench

As a part of its grand strategy on RE in order to bridge gaps in technology as well as to acquire a strong dominant position in the global RE based permanent magnet industry China targeted and acquired the US based Magnequench company. This acquisition received substantial media attention. The details available help us to piece together Chinese intentions behind this strategic acquisition.

Magnequench was set up by General Motors in 1986 as a Rare Earth permanent magnet manufacturing unit. This unit was set up in Anderson, Indiana and the first magnets appeared in the market in 1987.

General Motors put up Magnequench for sale in the early 1990s. The Sextant Group, a financial advisory and private equity firm headed by Archibald Cox Jr[29] with two Chinese state-owned metals firms, San Huan New Material and China National Nonferrous Metals Import and Export Company (CNNMIEC) bought the company. Interestingly the Sextant Group was formed on 4th October 1993 with Cox as its Chairman presumably to make this deal. Probably Cox was used as a front by the Chinese company. In the deal, the two Chinese firms held at least 62 percent of Magnequench shares. According to Web Memo No.1913[30] published by The Heritage Foundation on May 2, 2008, there were reports that the Chinese government pressured GM into selling Magnequench to Chinese interests as a condition for approving GM's bid to open an automotive production line in Shanghai.

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, lock, stock and barrel was moved to China.

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. Mr. Wu Jianchang was heading the company at that time. Archibald Cox, in the meantime, became the titular Magnequench President and CEO,

[29] He is the son of the famous Watergate prosecutor, Archibald Cox. From 1995 until 2006 he was President and CEO of Magnequench International, Inc., Anderson, Indiana and Singapore, a manufacturer of rare earth magnetic materials and magnets. In 1977 he launched Morgan Stanley International in London and served as its Chief Executive Officer until he resigned in 1988.

[30] See http://www.heritage.org/research/reports/2008/05/magnequench-cfius-and-chinas-thirst-for-us-defense-technology; accessed on 27/12/2012

and the Chinese firm held at least 62 percent of Magnequench's stock. 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. Subsequently Onfem restructured its business and completely moved to real estate hospitality and insurance businesses while integrating the mineral business with the parent company renaming it as Minmetals Land. In 2003, with the approval of the State Council of the PRC, China Minmetals Corporation officially took the controlling interests in Minmetals Land.

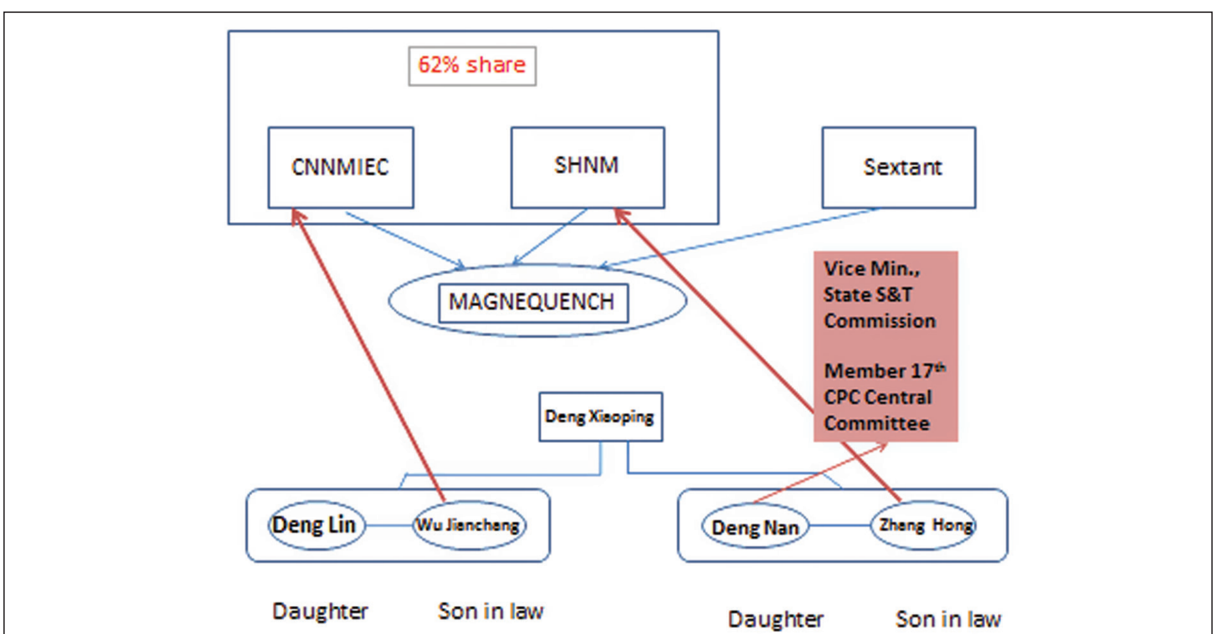
Figure 8 shows the linkages between important persons and their various company affiliations.

If we carefully look at the strategy employed by China in acquiring critical technologies, we will note the involvement of CPC members in all the decision making process. In fact we noted that in one of our earlier assessment of China's missile development, that a large number of politburo members are highly educated engineers. What we note in the case of Rare Earth decision making is that many of the CPC members are chemists, geologists, geophysicists and petroleum engineers. In addition connections to influential people matter significantly. More importantly the decision making process is not a simple top down or bottom up approach. What works in China is very different.

For example, the chairman of San Huan, Zhang Hong, was the son-in-law of former Chinese leader Deng Xiaoping[31] and took over as Chairman of Magnequench while retaining Cox as the Chief Executive Officer (CEO).

Zhang Hong is married to Deng Nan, the daughter of Deng Xiaoping. He was the Deputy Director of the Technology Sciences and

Figure 8: Personal & Organisational Networks in the Magnequench Acquisition



31 Zhang Hong now heads the Research and Development Bureau of the Chinese Academy of Sciences

Chairman of San Huan since 1985 and served as Chairman of Magnequench International, Inc. and the chairman of the Board and Director of Neo Material Technologies Inc. from 1995. After earning a bachelor's degree in physics from Beijing University in 1970, Zhang joined the Chinese Academy of Sciences (CAS) in 1973. His research activities include application of superconducting magnets. He was a visiting scientist in the Max Planck Institute in West Germany from 1978-81. Zhang participated in the development of the first installation for fusion research of China. He was awarded the National Science Congress Award and the Significant Achievement Award of the Chinese Academy of Sciences in 1978.

Zhang's wife Deng Nan was the Vice-Minister at State Science and Technology Commission during the negotiation period. She is currently Vice Chairman and First Secretary of the China Association for Science and Technology and a member of the 17th CPC Central Committee.

The other Chinese investor in Magnequench, CNNMIEC was at the time run by yet another son-in-law of Deng Xiao-ping, Wu Jianchang. He is a trained metallurgist. He is the secretary of the Party Committee in the National Association of the Iron and Steel Industry and is the 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.

The evidence suggests that the acquisition of Magnequench was a carefully crafted move by the Chinese Government. Detailed knowledge coupled with personal equations and connections with the powers that be help strategic acquisitions.

China's Rare Earth Strategy Case 2 - the Attempted Acquisition of Molycorp and the Mountain Pass RE Mine

On 23 June 2005 CNOOC Group a state-owned Chinese oil company made an offer to purchase the American company Unocal for a cash consideration of US$18.5 billion. This offer was finally withdrawn on 2 August. CNOOC Ltd is a majority-owned subsidiary of CNOOC — one of the three large state-owned Chinese petroleum companies. The company comes under the administrative control of State-Owned Assets Supervision and Administration Commission of the State Council (SASAC). SASAC takes care of the rights and obligations of shareholders on behalf of the Chinese Government.

Unocal is a relatively small U.S. petroleum company (gross revenues of $8.2 billion in 2004) with assets primarily in the Gulf of Mexico and Southeast Asia. Unocal was the 9th largest oil company in the US. It controls significant natural gas reserves in Southeast Asia. But what drove China to make a bid for Unocal was not oil. Unocal also owned Molycorp, which in turn owned the Mountain Pass RE mine, the largest producer of Rare Earths in the US. If the acquisition had gone through China would have acquired control of a significant reserve of RE outside of China. This would have given it almost monopoly control over current and future global RE materials supply.

Molycorp purchased Mountain Pass in 1951. In 1978, Unocal purchased Molycorp. In 1982, Mountain Pass Mine began processing Samarium Oxide and in 1989, it began processing Neodymium Oxide. These are critical materials for the production of two most important types of permanent magnets that dominate this industry today.

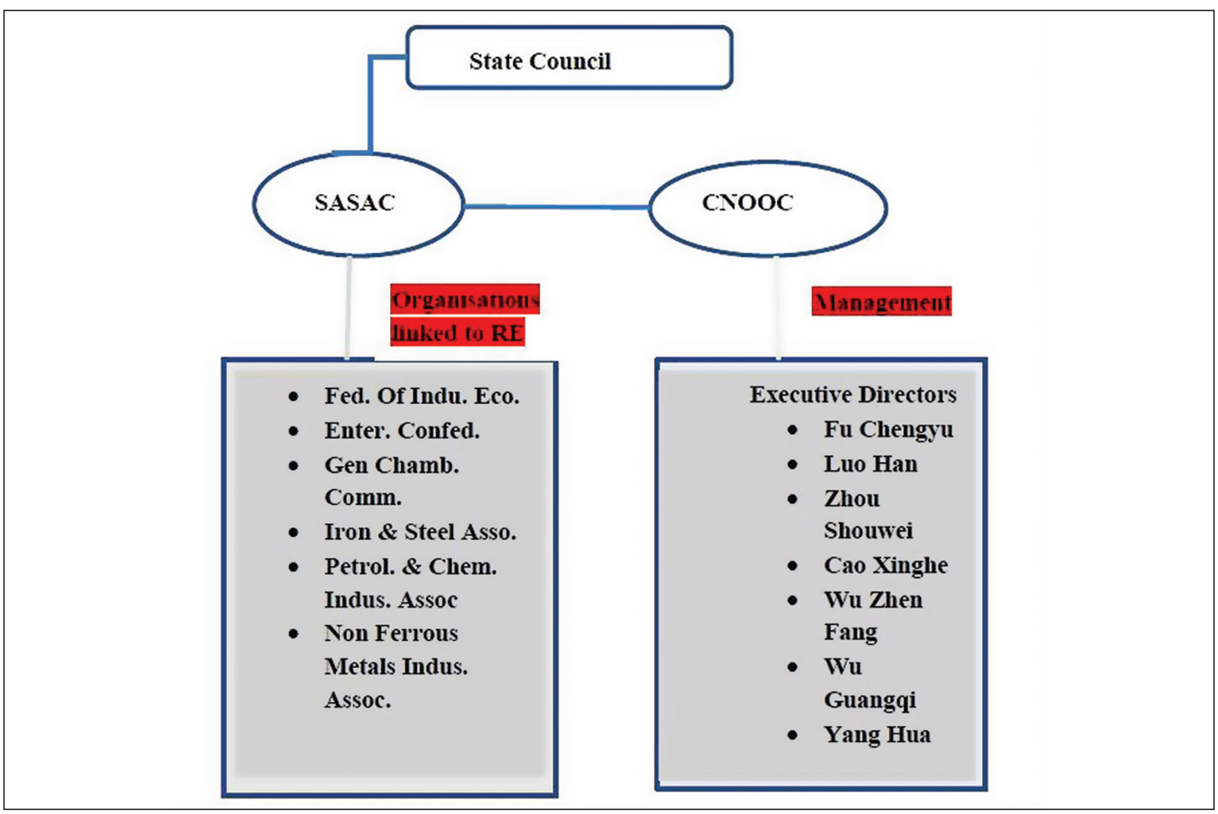
Xiao Zongwei, director of investor relations for CNOOC, mentioned at the time of the bid that "an acquisition of Unocal would not pose any threat to America's energy security. Unocal's oil and natural gas output in the United States would continue to be sold in the U.S. market -- output that represents less than 1% of the total U.S. consumption of oil and natural gas." This gave a clear indication that CNOOC was actually interested in something other than the gas and oil assets of Unocal in America.

The US government intervened and the deal was not allowed to go through.

Figure 9 shows the major stake holders in the CNOOC bidding process, the people as well as the organisations involved in decision making. The profile of each individual reveals how well networked they are, enabling them to make quick and coordinated decisions of strategic importance.

According to Long Guoqiang, an expert with the Development and Research Center of the State Council, the whole operation was code-named "Treasure Hunting Ship" targeting a major piece of U.S. energy real estate and had been discussed several times in the State Council.[32] Though the CNOOC Chairman Fu Chengyu said that the bid is simply a normal business activity based on the principles of the free market, the acquisition bid was largely funded by state organs and enterprises. The parent company (also called CNOOC), offered loans worth $7 billion, $6 billion came from a major Chinese government-owned bank (Industrial and Commercial Bank of China), and only $3 billion came from its financial advisers (JP Morgan and Goldman Sachs).

Figure 9 Major Stake Holders in Chinese Strategic Decision Making



[32] Jiang Wenran (2209), "The Unocal Bid: China's Treasure Hunt of the Century", China Brief Volume: 5 Issue: 16, December 31, 2009. http://www.jamestown.org/single/?no_cache=1&tx_ttnews%5Btt_news%5D=3878

The bid could not have been made without the approval from the State Council and the State-Owned Assets Supervision and Administration Commission of the State Council (SASAC) which owns 70 percent owner of the CNOOC. SASAC is a Special Commission of the People's Republic of China, directly under the State Council. SASAC was created in March 2003 through the merger of offices from several other government organizations. SASAC consolidates the management of nearly 200 central-level, large state-owned enterprises (SOEs) previously spread among the State Economic and Trade Commission (SETC), the State Development Planning Commission, the Ministry of Finance, the Ministry of Labor and Social Security, and the Central Enterprise Work Committee. SASAC absorbed the bulk of the former SETC offices, and a former SETC director Li Rongrong was appointed SASAC director. SASAC is responsible for managing China's state-owned enterprises, including appointing top executives and approving any mergers or sales of stock or assets, as well as drafting laws related to state-owned enterprises.

Li Rongrong, is a powerful member of the CPC with a chemical engineering degree from Tianjin University, majoring in electro-chemistry. From 1986, he had served as Vice Director of Economics Commission of Wuxi, Jiangsu Province, Director of Light Manufacturing Bureau, Director of Planning Commission of the city, and Vice Director of Economics Planning Commission of Jiangsu. Since August 1992, he had served in various posts in the State Economic and Trade Commission (SETC). He served as the Chairman and Party Secretary of State-owned Assets Supervision and Administration Commission of the State Council (SASAC) from 2003-2010. Li was a member of 16th Central Committee of Communist Party of China, and is a current member of 17th Central Committee of CPC. Forbes magazine listed him in the 61th position as World's Most Powerful People in 2009.

Apart from managing the state owned enterprises, there are a number of associations affiliated to SASAC. Some of these affiliated organisations are directly linked to the country's Rare Earth industry such as China Enterprise Confederation, China General Chamber of Commerce, China Iron and Steel Association, China Petroleum and Chemical Industry Association and China Nonferrous Metals Industry Association. Also CNOOC has memberships in some of these organisations such as China Enterprise Confederation, China General Chamber of Commerce and China Petroleum and Chemical Industry Association.

It is unlikely that Li Rongrong or SASAC directly knew about the importance of Molycorp, the Mountain Pass Mine for China's strategy in Rare Earths. Most probably the homework related to the acquisition of UNOCAL was done elsewhere possibly within the Chinese RE ecosystem[33] that may or may not have an immediate link with either SASAC or CNOOC. Irrespective of where the idea of acquisition of UNOCAL came from, the Chinese strategic decision-making system seems to be able to assimilate it and then work all the levers necessary to make sure that the appropriate entity within the bureaucracy takes

[33] The idea could have come from any one of the numerous ministries and organisations involved with RE development and management. For it to be operationalized this has to be moved through the system to higher levels before active action can take place elsewhere. Informal networks do this more efficiently than formal procedures and routines that is the staple diet for all bureaucracies.

the necessary actions for implementing the strategy. In all likelihood SASAC and CNOOC were told what to do and how to go about doing it. It is likely that either Politburo or CPC members linked to Li Rongrong familiar with the RE industry persuaded SASAC to act.

The most important person in translating the decision into action would have been the then CEO of CNOOC, Fu Chengyu. Fu is a geologist from the Northeast Petroleum Institute in China and has a Master's degree in petroleum engineering from the University of Southern California in the United States. He also serves as the Chairman of the Board of Directors of CNOOC China Limited and CNOOC International Limited, both being subsidiaries of the Company. He is also a Chairman of the Presidium of China Federation of Industrial Economics and the Vice chairman of China Chamber of International Commerce; which are affiliated to SASAC. Though he might not have planned the acquisition of Molycorp through Unocal, his education in geology and petroleum engineering from the University of Southern California where the Molycorp mine is located would have given him enough back ground information.[34]

In this instance as in the Magnequench case, connections with the CPC members, knowledge in the technological field, awareness of the global trade scenario, were important in making a bid.

The Role of Informal Networks in Strategy Formulation & Implementation in China

The two case studies provide a fairly good idea of how the Chinese strategy in Rare Earths is crafted. By looking at key individuals and organisations within the Chinese system that have been involved in these acquisition bids we can make certain inferences on how the Chinese system worked. The Magnequench case shows clear evidence of connections between the RE ecosystem and the Politburo. Family ties reinforce positions of power and influence within the Chinese RE ecosystem. In the case of UNOCAL the connections to sources of power and influence are more indirect but are nevertheless there. From these we can infer that there are closely knit informal networks of people that span the political, military, technology and academic domains that are the key to many important decisions. These networks enable the decision-making system to bridge many gaps that come about from the standard division of work and coordination of work within the organisation structures and routines that are typical of complex high technology industrial ecosystems like the RE ecosystem.[35] These divisions of work and coordination of work capabilities are difficult to acquire formally. Only some of the western advanced countries have been able to achieve this through formal methods of coordination and control. However China seems to have become fairly adept at creating viable complex ecosystems via an alternative method of using informal networks for achieving the same organizational functions of coordination and control. This seems to be a common thread running through the several cases that we have studied at NIAS in other domains as well.

[34] It is possible that SASAC and CNOOC wanted to acquire UNOCAL as a part of China's Oil strategy rather than as a part of their RE strategy. This however appears highly unlikely given our understanding of Chinese motivations and behavior as well as some public statements.

[35] Some of these organizational structure and networks in the Chinese system particularly with reference to missile technology has been studied elaborately in a ISSSP-NIAS report in 2007 on "An Assessment of China's Ballistic and Cruise Missiles", R4-07 .

The Future of the Global RE Industrial Ecosystem

The RAND Corporation carried out an interesting study trying to assess technology diffusion and acceptance in 2006[36]. The report tried to predict where each country would be in 2020 given the barriers and drivers prevailing in each of the countries studied. The report also stated that the ability to acquire a technology application does not equal the ability to implement it. Importing or acquiring technology does not guarantee diffusion into Society. Clearly there has to be some amount of preparedness on the part of the country acquiring a new technology to absorb and use the technology. It is in this context that China has clearly demonstrated its purpose in acquiring technology related to rare earth product manufacture.

Even before China acquired Magnequench and later transferred the entire manufacturing unit to China, considerable preparatory R & D work was in place in the country. If we look at the important events in China starting from 1950, (See Section and Annexure 6), mining, processing and separation of REE was already in the advanced stage. We also saw that several institutes and laboratories were working in these areas. China was actually going up the supply chain, specifically in the manufacture of permanent magnets as well as in other intermediates that use Rare Earths. Support through the 863 and 973 programs were also in place. In fact, special thrust to materials sciences and particularly RE materials properties was given in the 973 programme. The 1992 clarion call given by the Chinese patriarch that China has rare earths was actually an indication of what was coming. Obviously all the developments indicated that China saw RE as a strategic material and that it was not too wrong in this assessment. What is noteworthy is that an advanced powerful and rich country like the US missed the events unfolding in China with respect to this material.

Thus, by 2005, Magnequench became a proprietor of several important rare-earths magnet patents and production processes. Magnequench merged with a Canadian rare-earths firm, AMR in 2005. AMR is now known as NEO Materials Technologies with two divisions called Magnequench and Performance Materials. The merger resulted in Magnequench holding 62% of shares of AMR and AMR would hold 38% shares. Cox was named the chairman of AMR.[37]

In less than a decade, the permanent magnet market experienced a complete shift in leadership. By September 2007 China had 130-odd sintered NdFeB large magnet

[36] Richard Silberglitt, Philip S. Antón, David R. Howell, Anny Wong, The Global technology revolution 2020, RAND Report MG-475, 2006

[37] Cox has since joined Barclays as Chairman of Americas in May 2008.

manufacturing enterprises with an average annual growth of over 30 percent.[38] 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.

Though the US had a dominant position in the permanent magnets market in the late 1980's and the early 1990's its position today has weakened considerably. After the discovery of the new class of RE magnets (Samarium-Cobalt magnets) in the sixties by researchers at Wright Patterson Air Force Base, the US magnet industry reached its peak in the eighties. The industry was dominated by the Americans for another decade. At that time roughly 6000 people were employed by the American magnet industry which dwindled to 100 in the nineties. Today the U.S. magnet industry employs roughly 600 people[39]. There are now three Alnico producers, one independent hard ferrite producer, two Sm-Co producers. Nd-Fe-B magnets are not produced in the US today[40].

A major issue for REE development in the United States is the lack of refining, alloying, and fabricating capacity that could process any future rare earth production. One US company, Electron Energy Corporation (EEC) in Landisville, PA, produces Samarium Cobalt (SmCo) permanent magnets. EEC, in its production of its SmCo permanent magnet, uses small amounts of Gadolinium—an REE of which there is no U.S. production. In addition small amounts of Dysprosium and Terbium, required for these magnets are currently available only in China. EEC imports magnet alloys used for its magnet production from China.

The U.S.-based Molycorp Rare Earth mine has restarted mining operations in the US. The Mountain Pass mine however, does not have substantial amounts of heavy rare earth elements, such as Dysprosium, which provide much of the heat-resistant qualities of permanent magnets used in many industry and defense applications. Newer mines would typically take 12 years from initial exploration to mining.[41] The steps involved are – Initial exploration, Advanced Exploration, Environmental Studies, Pre-feasibility Studies, Feasibility studies, Permissions, Financing and Construction. In the US, even if all the required permissions are granted, it will still take at least five years to start mining operations.

It would also take at least 5 years to develop a pilot plant that could refine oxides to metal using new technologies, and companies with existing infrastructure in the US cannot start metal production without a consistent source of oxides, which has to come from China. More recently Molycorp Inc. (MCP) acquired Neo Material Technologies Inc. (NEM) in March 2012. China has 62% shares in NEM. This tie up between Molycorp and NEO actually

38 Hurst Cindy, (2010), China's Rare Earth Elements Industry: What Can the West Learn? Institute for the Analysis of Global Security (IAGS), March 2010, P.13

39 P. C. Dent, Adv. Mater. Process. 167(8), (2009), HIGH PERFORMANCE MAGNET MATERIALS: Risky supply Chain

40 A review of Rare Earth Permanent magnet and their characteristics is available in - **Rare earth elements and permanent magnets** by P.C.Dent, Jl of Appl. Physics, 2012.

41 Rare Earth Elements: A Review of Production, Processing, Recycling, and Associated Environmental Issues, EPA/600/R-12/5721August 2012, www.epa.gov/ord. See Page 3-12

has proved even more advantageous to China. The United States has the expertise but lacks the manufacturing assets and facilities to refine oxides to metals. Molycorp will be shipping all its rare earth elements mined in the U.S to factories based in China. What China could not achieve thorough its bid for UNOCAL in 2005 to acquire Molycorp and its assets, is achieved now with a zero cost and very little political ramifications. The U.S. is completely dependent on China for rare-earth-magnet materials, and now the export of U.S. rare earth assets into China will only intensify this dependence at least, for some more years.

While the Chinese were investing on the human resource development, the US has been left with a much depleted workforce in this area. As pointed out by K.A. Gschneidner Jr of the Ames Laboratory in 2010, there are not enough technically trained personnel with the appropriate expertise in the US to take care of the value chain from raw materials to major RE intermediates. In fact many of the experts in the field moved away from Rare Earths due to lack of opportunities. As already mentioned publications from Iowa State University, dwindled in the nineties and Masters Programmes on rare earth engineering were shut down.

This underinvestment in the U.S. supply chain capacity (including processing, workforce development, R&D) has left the United States nearly 100% import dependent on all aspects of the RE product supply chain.

China has abundant reserves of rare earth metals but what worries it is its inefficient use and environmental damages caused by current mining and refining process. Efficiency in rare earth refining is the major research question that is bothering the Chinese scientists. China's State Key Laboratory of Rare Earth Materials Chemistry and Applications based at Peking University recently launched an 85-million-yuan research project titled "Research on high-efficiency use of rare earth resources and rare earth green separation". This project will be funded under China's national S&T programme "National Program on Key Basic Research Project (973 Program). Partners in this project include Peking University, Tsinghua University in Beijing, and two CAS institutes, the Shanghai Institute of Organic Chemistry and the Changchun Institute of Applied Chemistry as well as Northeastern University in Shenyang[42]. Such efforts and support by the Chinese government clearly indicate that China is serious in retaining its dominant status in this area.

Patents for manufacturing neodymium iron boron magnets are currently held by Japan and China. Some of these patents do not expire until 2014. As a result, companies preparing to enter the neodymium iron boron magnet market in the United States must wait for the patents to expire. It would be interesting to watch the developments in 2014, when the Magenquench's patent for neodymium-iron-boron magnets expire.

Though we have only covered the RE permanent magnet industry in this part China is assiduously building up dominant positions in other value chains that span the global RE industrial ecosystem. It is also clear from the available evidence that they will use this RE economic lever as an element of larger Grand Strategy to advance Chinese interests in the

[42] China's New Basic Research Project on Rare Earth. http://news.nost.org.cn/tag/973/ Posted on May 25, 2012

arena of global geo-politics. This is of course based on the assumption that RE would continue to be materials of importance for emerging hi-tech industries especially those providing a greener and more environment friendly footprint. It is of course possible that new materials that are currently being researched could substitute or replace RE materials in many critical areas of use. Even if this were so such transitions in technology and product life cycles will take some time. In the short to medium term the Chinese do have a considerable degree of control over the global RE Industrial ecosystem. It also appears that they will use this dominant position in pursuit of their overall grand strategy.

Conclusions

The available evidence suggests that China's current domination of the global Rare Earths (RE) Industrial Ecosystem is the result of a well-thought out carefully crafted dynamic long term strategy.

China has cleverly used the dynamics of the transition of the RE industry from the growth into the maturity phase of the lifecycle to build a dominant presence in most value chains of the RE ecosystem.

China controls not only the raw materials but also the production of key intermediates that go into many hi-tech growth industries.

In contrast the US which actually pioneered many of the breakthrough discoveries in RE materials has allowed its once dominant position in RE to erode. It is now dependent on Chinese largesse to make sure enough RE materials and intermediates are available for its use. The US today has no industrial capacity in RE allowing global market dynamics to move all of them to China.

RE shortages and price increases will affect many sectors of an advanced economy. These include not only large economic value adding industries but also many defence products and industries.

Though the RE industry is currently in the maturity phase where a slowdown in growth is indicated, the use of RE in critical green products like hybrid cars, wind mills, lighting, fuel cells and many other advanced consumer and industrial products suggests that the industry may grow considerably.

New demand from emerging markets like China and India is also likely to fuel the growth of the RE industry.

China is well positioned to use its dominant position in RE as a part of its larger global strategic aims. Its cutting off of RE supplies to Japan as a consequence of a minor spat provides fairly hard evidence that it will use economic levers for furthering its global strategic positions and interests.

Through the tracing of the evolution of the RE industry in China the study also sheds light on how strategy is formulated and implemented in China.

There is always a long term national interest in the evolution of the specifics of a medium terms strategy via the five year plans. The strategies seem to be formulated keeping in mind both constraints and opportunities and they are adaptable to changing global conditions. The grand top down view seems to be seeded with lower level ideas on how to further Chinese global and national interests. Well-connected eminent technocrats seem to be able to access top level officials within the CPC and the Politburo and they seem to provide the micro detail for making sure the top down strategies are grounded in the realities of the dynamic global environment. In the case of Rare Earths there seem to have been close links between XuGuangxian, the father of the Rare Earth Industry in China and Deng Xiaoping the Chairman of the CPC and the head of the Politburo.

The other thing that emerges clearly from our study on RE in China is that strategy implementation is closely linked to strategy formulation. China seems to have in place methods and processes to ensure that the various arms of the government associated with the implementation of strategy, function in an integrated way to ensure that Chinese interests are well protected. The insights that we obtained from our two case studies on how this integration of thought and action take place suggest that informal networks to major power centres within the Chinese establishment play a key role. Irrespective of how the integration happens the Chinese RE industrial ecosystem has dynamic capabilities that can seamlessly connect strategy formulation with strategy implementation. Apart from the more advanced countries in the west such capabilities do not exist in many of the newly emerging economies. China appears to be well on its way to becoming an advanced economic and industrial power that seems to manage continuity with change in an adaptive dynamic way.

Though informal networks also play a role in the more advanced economies of the west most of the division and coordination of work within the government industry ecosystem are governed by more formal rules and procedures. By contrast the Chinese industry ecosystem is still largely government dominated and informal networks seem to provide the integration mechanisms for implementation of complex strategies.

Though the pace of radical breakthroughs in the discovery of new RE materials with unusual properties is slowing down there are still possibilities that such breakthroughs can happen. In case such discoveries take place they could well take place in China. Even if it were to happen elsewhere the Chinese RE ecosystem is well placed to exploit it in a major way.

China's success with its strategy on RE is of course dependent on the continued use of RE intermediates in many key industries especially those dealing with a greener future. Current and future research can throw up new discoveries and approaches that could substitute for Rare Earths in many key applications like motors and batteries. In the mature phase of an industry such possibilities increase. However because of their special position in the Periodic Table Rare Earths have unusual properties that confer on them special advantages that may not be easily substitutable in all applications.

While eventual substitution of old technologies with new technologies will take place the crucial aspect that will determine the success of China's longer term strategy on Rare Earths is the timing of such breakthrough discoveries in key application segments. The limited insights obtained from our study indicate that in the short to medium term China is well-poised to take advantage of its dominant position in the global RE industrial ecosystem. If this were to be so it would be a vindication of the forward looking long term strategic thinking that seems to govern much of the Chinese behavior.

In the case of Rare Earths, China has successfully caught up and even overtaken major global players. However an advanced economic and industrial country is typically characterized by its ability to create new industries through radical innovations. Playing catch-up is of course important and China has demonstrated that in RE as well as in several other domains it can do so quite well. In the existing RE industry China should be able to exploit any major breakthroughs if they happen. However this is still not quite the same as creating a new industry of the future via radical breakthroughs within the Chinese ecosystem. This is the kind of advanced economic and industrial power that China aspires to become. Whether it will do so and whether its internal dynamics will allow such things to happen is an open question and a subject for future investigations.

Annexure 1: Use of Rare Earth Intermediates by the Global RE Ecosystem

Catalysts

Most of the rare earths used as catalysts go into the refineries where they are used to break up the heavier fractions into lighter chain molecules. Lanthanum and cerium are the major rare earths that go into the fluid catalytic crackers. The catalyst uses a zeolite – Aluminium silicate core structure - to which rare earths have been added to provide superior catalytic action. The Zeolite structure with the rare earth addition acts not only to enhance its activities as a molecular sieve but prevents the dealuminization of the Zeolite and allows an increase in operating temperature and the yield. Most catalysts are proprietary or protected by patents. The heavier the crude the greater is the quantity of catalysts that are required.

The Rare Earth usage in Zeolite catalysts goes back to the early 1960's. The industry is more than 50 years old and is a mature industry. In the early days the rare earths were added to the zeolite as Misch Metal. Today Lanthanum and Cerium are used and the catalysts have become more specialized.

Yttrium is also used to polymerise ethylene in the petrochemical industry.

These catalysts could also find use in other ion exchange systems, water treatment and nuclear waste processing.

Catalysts account for about 15% of the total market for Rare Earths as of 2008. Demand is directly linked to the growth in the lighter fraction such as gasoline and petrol. It is expected to be stable. Because of RE shortages some of the major companies in the US such as WR Grace seem to working on new catalysts that do not require RE.

Auto Catalytic Converters

They have been in use from the early 1970's in the US. Today all automobiles across the world use them. They have shifted from two way to three way converters where CO, unburnt Hydrocarbons as well as oxides of nitrogen are taken care of.

They generally use a cordierite substrate and a wash coat that contains the catalyst. The catalyst is generally a precious metal to which often a rare earth addition is included. The RE in maximum use currently is Cerium. Cerium oxide can convert CO to CO2 if CO rich and converts back to Cerium oxide if Oxygen rich. An Oxygen sensor is therefore a necessary part of emission control system for automobile.

There are a number of companies that supply Catalytic Converters including Chinese companies. It can be considered to be a separate industry that links to the automobile industry.

Catalytic converters are also used in smaller vehicles including two-wheelers. Electric bikes in China are a major market where such converters are reported to be used in large scale.

Use of RE in Catalytic Converters accounted for 6% of the market in 2008. The major RE used for this is Cerium though Lanthanum, Praseodymium and Neodymium are also used. The specific formulations are proprietary and maybe protected by patents.

Though the industry is over thirty years old – with growth in emerging markets like China and India – makes it potentially at least a medium growth industry.

Batteries

Nickel Metal Hydride (NMH) batteries are becoming increasingly important for use in hybrid cars.

The batteries use an Alloy of generic composition La Ni5 as anode material. Specific compositions could vary around the general structure described by the LaNi5 architecture.

The use of a rare earth anode facilitates the storage of large quantities of hydrogen needed for the operation of the battery.

Rare Earth Metals either individually or as Misch metal (a combination of Lanthanum Cerium Neodymium Praseodymium) is used though Lanthanum and Cerium are dominant.

Many large Japanese and US companies dominate the market.

Apparently US automobile companies are looking to Lithium batteries as the solution for the hybrid cars. Japanese companies including Honda and Toyota see Rare earth Nickel Hydride Batteries as a better interim solution at least till all the technical problems associated with Lithium batteries are resolved.

Though these RE batteries have been around for quite some time the potential increase in the growth of hybrid cars may fuel a major demand for them which will in turn increase the demand for rare earths.

China's electric Bike industry is also a major demand driver for batteries and for Rare Earths.

Batteries accounted for 9% of the market for Rare Earths in 2008.

Fuel Cells / Hydrogen Storage

Solid Electrolyte Fuel Cells (SEFC) are becoming increasingly important as possible sources for producing green power. Rare Earths are likely to be used as anodes, cathodes, electrolytes and inter-connects between cells to form the power source.

Lanthanum, Cerium, Yttrium, Gadolinium, and Scandium are all potential candidates for various elements that go into a fuel cell. Many of them seem to be under technical investigation. Hydrogen storage and discharge properties, similar to what makes Rare Earths attractive in Batteries,-seems to be important in fuel cells. From our review most fuel cell work seems to be oriented towards the production of power and not so much into automobiles.

Demand right now appears to be fairly small. The technology appears to be still in its early incubation phase. The same properties that make Rare Earths especially Lanthanum attractive for batteries and fuel cells also make these RE materials attractive for storage of Hydrogen.

Glass

The major REs used in glass are Cerium and Lanthanum. Smaller quantities of Neodymium, Praseodymium Yttrium and Erbium are also used.

The addition of Lanthanum (actually a mixture of rare earth oxides) to glass goes back a long time and was used in the early gas mantles used to provide lighting in the 1880's.

The addition of Lanthanum and other rare earths increases the refractive index of glass, making it easier to build better lenses without much chromatic aberration. Their addition to glass also provides it with resistance to alkalis that is useful in many industrial applications.

Some special compositions of glass that contain Lanthanum like ZABLAN exhibit superior properties in the infrared. They are used in night vision equipment as well as in fibre optics for superior infrared transmission. These are emerging as new areas of importance with new glass formulations using Lanthanum. In other compositions Lanthanum also absorbs infrared making it suitable for lenses and optical components.

Cerium is used both as a de-colourizer as well as a colour additive. Along with Ti it also adds yellow colour to glass. Cerium addition to some glass compositions enables it to absorb UV Light and is used in solar cell cover glasses.

Neodymium is used as a colourant. It cuts out yellow light and therefore glasses made out of it change colour under different lighting conditions. Due to its yellow light filtering properties it is used in the rear view mirrors of automobiles and in goggles for welding applications.

Praseodymium is also used as a yellow colourant for glass. Along with Nd it is used in goggles. It is also used as a dopant in fibre optic amplifiers. Yttrium is used to provide improved heat and shock resistance to glass.

Erbium is used in fibre optic amplifiers to regenerate the optical signal for onward transmission. This is critical for all new generation fibre optic cables for transmitting signals over longer distances.

Glass accounted for 9% of the market for rare earths in 2008.

Glass / Substrate Polishing Agents

One of the earliest uses of RE oxides was for polishing glass. Though Cerium was the main ingredient the polishing was done through the use of Misch Metal – a combination of La, Ce, Nd and Pr.

This accounted for 13% of the total Market for Rare Earths in 2008.

Cerium based polish is also used to polish the discs of Computer hard drives.

This is a very mature industry and not likely to witness any major growth. However demand for RE polishing agents likely to be stable and substantial.

Metallurgy

Metallurgy applications accounted for about 9% of the consumption of Rare Earths for 2008.

Misch Metal , a combination of un-separated Rare Earths has been traditionally used in combination with iron for producing flints. Cerium is the main constituent for the spark generation.

Cerium has the largest use in Metallurgy applications followed by Lanthanum and then by Neodymium. Praseodymium is consumed to a much lesser extent than either Lanthanum or Neodymium.

Lanthanum is added to steel to improve malleability and to Molybdenum to reduce hardness and improve material properties with temperature.

Cerium is added to Cast Iron used in auto engines to improve machineability. It is also added to Magnesium castings for producing sounder casts and for improving its temperature related properties. It is added to steel to degasify it and to eliminate sulphur dioxide. Cerium is used as a precipitation hardener in the production of stainless Steel. It also finds some use in the production of Aluminium alloys and as an additive for chromium electroplating.

Both Lanthanum and Cerium – maybe as Misch metal substitute for Thorium in the production of TIG Electrodes.

Praseodymium in combination with Neodymium – earlier termed Didymium – is used as an alloying agent in Magnesium castings. These are used in the production of aircraft engines.

Phosphors

Phosphors absorb light energy in one wave length and emit it in another.

RE phosphors are used in all kinds of end products to provide the right kind of light.

Early Gaslights used rare earth mixtures in the 1880's. Carbon arc lamps which are now largely phased out also used Lanthanum

Regular Glass products for use in TV monitors, Plasma TV as well as LCD displays use these phosphors.

Europium Phosphors were one of the earliest RE to be used in lighting applications – goes back to 1965 when colour TV became a dominant product in the US.

RE phosphors have been used in backlighting applications for various instrument panels.

In Compact Fluorescent Lights these phosphors are used to provide different kind of light outputs from the basic fluorescent process.

Terbium based phosphors provide Green light, Europium provides red light and Yttrium based phosphors emit blue light. In varying combinations they can provide any required combination of lighting.

The emissions of light from fluorescent lamps can be converted to any form of required lighting by coating the lamps with a suitable combination of phosphor coatings.

LED produce colour either by having three semiconductor devices located suitably providing the three colours or by using one high efficiency blue LED – whose output is converted to white light via a Cerium doped YAG phosphor coating. This phosphor approach is seen currently as being preferred to the three diode three colour option.

Phosphors accounted for 7% of the Rare Earths market in 2008

Ceramics

The ceramics that use Rare Earths can be grouped into two broad categories – Structural ceramics and Technical Ceramics. Yttrium is the RE that is used maximally followed by Lanthanum. Cerium, Neodymium and Praseodymium are also used to a smaller extent.

Yttrium addition to Zirconia stabilizes it and provides it with superior properties. It is used both in structural forms as well as coatings in many applications such as dentistry, jet engines, gas turbines, sensors, jewelry, knives, crucible ceramics for reactive materials as well as in Oxygen sensors used in auto engine systems.

Neodymium, Praseodymium and Erbium provide unique colours to tiles used in the construction industry.

In high tech applications cerium is added to the zirconia tiles used for the space shuttle.

One major application of Rare Earths in electronics is their use as dopants in the Barium Titanate Dielectric material that is the basis of both single layer and multilayer ceramic chip capacitors. These are increasingly an important part of advanced electronic packaging systems.

In the garnet structural form Yttrium Aluminium Garnet (YAG), grown as a crystal and doped with Neodymium, is an essential part of solid state lasers which find applications in surgery as well as in general manufacturing. In defence these lasers are used in various range finding and target determination applications. Such lasers are also used to locate targets under water.

The same garnet structural form is used via Yttrium Iron Garnets (YIG) and Yttrium Gadolinium Garnets (YGG) for various microwave components such as circulators and resonators. Some high frequency wireless communication systems may need microwave filters made out of ceric oxide doped with Neodymium and Samarium.

Many garnet structures with RE additions also find applications in jewelry as stones.

Ceramics accounted for 5% of the total market for Rare Earths in 2008.

Permanent Magnets

Prior to the advent of Rare Earth Permanent Magnets Al Ni Co (Aluminium Nickel Cobalt) and ferrite magnets were dominant for most applications.

These were replaced by Samarium Cobalt magnets first introduced into the market in 1970. This was one of the earliest applications to use Samarium.

Due to problems with the supply of Cobalt in the early 1980s Hitachi and General Motors discovered and developed Nd Fe B or Neodymium Iron Boron permanent magnets which became commercial around 1986.

These magnets have become the mainstay technology route for all permanent magnet applications in industry. They have largely replaced the earlier generation Samarium Cobalt magnets.

These permanent magnets are needed in the production of electric motors of all sizes. Major industries that need them are hybrid car engines and the growing wind power turbine industry. They may also be needed in regular power plants.

Permanent magnets from rare earths are critical components in the fabrication of high power tubes such as TWT, Klystrons, Magnetrons and Power Amplifiers. These tubes are vital components that go into Radar as well as all kinds of communication systems.

Permanent magnets are also used in the hard drives associated with PC's and other disc devices like disc players. They are also essential constituents of speakers of all kinds that go into many consumer electronics products. Permanent magnets are also used in actuators used for missile, satellite and aircraft control systems.

One of the largest uses of Permanent magnets in electric motors may be the use of electric powered bicycles in China.

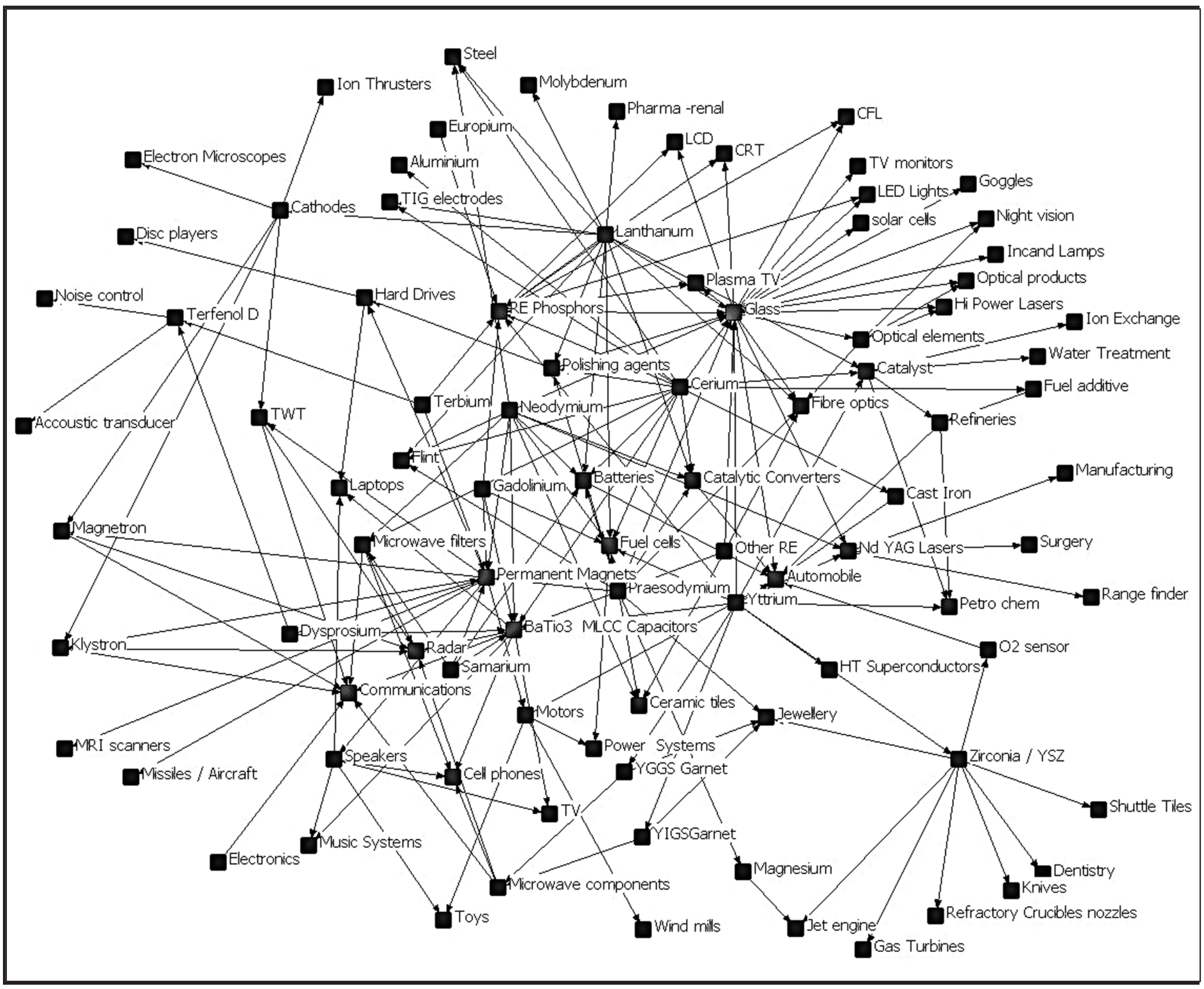
China's foray into using its rare earth position and capabilities as a part of its grand strategy has been anchored on its position both on rare earth material supply and its dominant position in the manufacture of Rare Earth Magnets. Neodymium is the largest Rare earth input that goes into permanent magnets followed by Praseodymium and Dysprosium. Small amounts of Gadolinium and Terbium are also used.

Magnets accounted for about 20% of the total market for Rare Earth Materials in 2008.

Other Uses

A number of other uses accounted for about 6% of the market in 2008.

ANNEXURE 2: THE RARE EARTH ECONOMIC NETWORK



Annexure 3: Rare Earth Economic Network Rankings

Node	Input into Node	Output from Node	Total Links	Rank
Glass	8	16	24	1
Cerium	0	15	15	2
Lanthanum	0	14	14	3
Permanent Magnets	6	8	14	3
BaTio3 MLCC Capacitors	7	6	13	5
RE Phosphors	6	6	12	6
Neodymium	0	11	11	7
Praesodymium	0	11	11	7
Yttrium	0	11	11	7
Zirconia / YSZ	1	8	9	10
Catalyst	3	4	7	11
Fuel cells	6	1	7	11
Automobile	7	0	7	11
Communications	7	0	7	11
Batteries	5	1	6	15
Nd YAG Lasers	3	3	6	15
Microwave filters	3	3	6	15
Cathodes	1	5	6	15
Radar	6	0	6	15
Speakers	1	5	6	15
Catalytic Converters	4	1	5	21
Polishing agents	3	2	5	21
Optical elements	1	4	5	21
Fiber optics	5	0	5	21
Microwave components	2	3	5	21
Motors	1	4	5	21
Samarium	0	4	4	27
Gadolinium	0	4	4	27
Terfenol D	2	2	4	27
Other RE	0	4	4	27
Refineries	2	2	4	27
Hard Drives	2	2	4	27
Flint	4	0	4	27
Jewelry	4	0	4	27
TWT	2	2	4	27
Magnetron	2	2	4	27
Klystron	2	2	4	27
Cell phones	4	0	4	27
Dysprosium	0	3	3	38
Terbium	0	3	3	38
Petro chem	3	0	3	38
Steel	3	0	3	38

Node	Input into Node	Output from Node	Total Links	Rank
Ceramic tiles	3	0	3	38
YIGS Garnet	1	2	3	38
YGGS Garnet	1	2	3	38
Laptops	3	0	3	38
Fuel additive	1	1	2	46
Power Systems	2	0	2	46
Optical products	2	0	2	46
Night vision	2	0	2	46
Hi Power Lasers	2	0	2	46
Cast Iron	1	1	2	46
Magnesium	1	1	2	46
TIG electrodes	2	0	2	46
Jet engine	2	0	2	46
O2 sensor	1	1	2	46
CRT	2	0	2	46
LED Lights	2	0	2	46
CFL	2	0	2	46
Plasma TV	2	0	2	46
LCD	2	0	2	46
TV	2	0	2	46
Music Systems	2	0	2	46
Toys	2	0	2	46
Europium	0	1	1	64
Ion Exchange	1	0	1	64
Solar Cells	1	0	1	64
Incandescent Lamps	1	0	1	64
Goggles	1	0	1	64
TV monitors	1	0	1	64
Molybdenum	1	0	1	64
Aluminum	1	0	1	64
Shuttle Tiles	1	0	1	64
Dentistry	1	0	1	64
Gas Turbines	1	0	1	64
Knives	1	0	1	64
Refractory Crucibles nozzles	1	0	1	64
Electron Microscopes	1	0	1	64
Ion Thrusters	1	0	1	64
Electronics	0	1	1	64
Water Treatment	1	0	1	64
Pharma -renal	1	0	1	64
Missiles / Aircraft	1	0	1	64
MRI scanners	1	0	1	64
Disc players	1	0	1	64
Wind mills	1	0	1	64
Range finder	1	0	1	64
Surgery	1	0	1	64
Manufacturing	1	0	1	64
Noise control	1	0	1	64
Acoustic transducer	1	0	1	64
HT Superconductors	1	0	1	64

Annexure 4: Major Events in the Evolution of the Rare Earth Industry

Time	Key Event In Rare Earth Industry
Late 18th & 19th Century	Discovery and measurement of properties of various Rare Earths (RE)
1884 to early 1900's	First commercial application – incandescent gas mantles
1903 to 1908	Commercialization of the Flint industry – Spark ignition continues to date
1912	Rare earths added to glass for providing colour - continues to date
1930	Sub orbitals – Hund's Rule links electronic structure to the Periodic Table
1934	Lanthanum Crowns a higher refractive index glass commercialized by Kodak
Manhattan Project	New Ion Exchange Technology for Metal Extraction gives RE boost.
1948	Misch Metal addition to nodular Cast Iron – Metallurgy application
1949	Mountain Pass Mine discovered in California
1950's	Cerium oxide Misch Metal used for the polishing of glass
1953	Solvent extraction Process becomes important – used for RE separation
1964	RE additions to Zeolite catalysts – Petroleum cracking – becomes commercial
1965	Europium used as a phosphor for Cathode Ray Tubes in the US – major market
1970	Lanthanum Nickel Hydride discovered – first patent for La Ni5 Battery 1975
1970	Misch Metal addition to steel – declining use in 1980's - cheaper substitutes
1970	RE phosphors improve safety in X-ray machines
1980	PrNi5 Rare Earth Nickel Hydride used in a ultra-low temperature refrigerator
1981	Cold war problems with cobalt supply lead to Nd Fe B magnet discovery
1986	Nd Fe B magnets go commercial – General Motors sets up Magnaquench
1983 to 1986	RE used as dopants for Barium Titanate MLCC Capacitors
1987	Erbium doped fiber amplifier – big push to fiber optics
1995	A consortium of companies from China attempt to buy Magna Quench
1998	Mountain Pass Mine closed for environmental reasons
2002	All assets of Magnaquench moved to China
2005	China tries to buy Unocal US Oil Company owner Mountain Pass RE Mine
2007	China cuts off rare earth supply to W R Grace major catalyst producer in US
2007	China begins Rationing RE supply - favours domestic companies
2008	China tries to buy controlling stake in Lynas – Australian Rare Earth Mine
2009	China buys stake in another RE mine Arafura Resources Ltd in Australia
2010	China cuts off Rare Earth supply to Japan following a fishing trawler incident

Annexure 5: Global Rare Earth Reserves and Production

The principal rare-earth ores are bastnäsite, monazite, xenotime, loparite, and lateritic ion-adsorption clays. However, production can come from a variety of minerals, such as xenotime, apatite, yttrofluorite, cerite, and gadolinite. Due to their strong affinity for oxygen, Rare Earth Elements (REE) are primarily present as oxides, and resources are often expressed in terms of equivalent Rare Earth Oxides (REO). Processing REOs into usable products is a very complex process and often varies significantly between deposits. Table 4 of the main report provides an overview of current Rare Earth Reserves and the production from current RE mines.

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 found in Australia, South Africa, China, Brazil, Malaysia, and India account for the second largest concentration of REEs. As per Table 4 **China holds about 50 % of the world's reserves while the United States holds about 13%.** Bastnaesite occurs as a primary mineral, while monazite is found in primary deposits of other ores and typically recovered as a byproduct. Over 90 percent of the world's economically recoverable rare earth elements are found in primary mineral deposits i.e., in bastnäsite ores[43]. Bastnäsite, the principal source of most of the world's REE, is dominated by LREE.

Monazite, a rare earth-thorium phosphate mineral, is quite similar to bastnäsite as a LREE ore. However, it contains slightly more of the HREE, especially, Yttrium, Dysprosium, and Gadolinium. Monazite has a high content of thorium, a naturally occurring radioactive element which makes it environmentally less attractive to mine.

Loparite, a lesser known LREE ore mined from Russia's Kola Peninsula, is an oxide mineral. It has a small HREE content that is similar to monazite's, but with a more balanced REE mix.

Xenotime, a HREE ore, is mined as a byproduct of tin mining and to a lesser extent, as a byproduct of heavy-mineral sands mining.

The ion adsorption lateritic clays are HREE ores. The lateritic ion adsorption clay from Xunwu, Jingxi Province, China, is mostly LREE. However it still has a much higher HREE content compared to the other LREE ores such as bastnäsite, monazite, and loparite. This ore is a significant source of the world's yttrium supply.[44]

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43 Humphries Marc, (2010), "Rare Earth Elements: The Global Supply Chain", Congressional Research Service (28 July, 2010). Viewed on 5 February 2011 http://www.fas.org/sgp/CRS/natsec/R41347.pdf

44 Rare earths in selected U.S. defense applications, James B. Hedrick, 40th Forum on the Geology of Industrial Minerals, 2004

In the mid-twentieth century, almost all rare earth mining was done at Mountain Pass, California. This was largest rare earth minerals mine in the United States and is currently owned by Molycorp a subsidiary company of the oil company UNOCAL. The Mountain Pass rare earth mine occupies 2,222 acres of land in San Bernardino County, California. The mine started operation in 1952, operating as an open pit lanthanide mining, beneficiation, and processing facility. The period of greatest ore production was from 1965 to 1995. Mining activities were suspended in 2002, but minor milling activity continues to process stockpiled ore. Overburden materials were held on site, tailings, and product storage ponds were also operated.

Rare Earth resources are dispersed widely in China. Eighty three percent of the resources are located in Baiyunebo (Baotou, Inner Mongolia), eight percent in Shandong province, three percent in Sichuan province (light rare earth deposits of La, Ce, Pr, Nd, Sm, Eu). Another three percent of the deposits are located in Jiangxi province. These contain more of the 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 seven Southern Chinese provinces are not significant.

In the late 1970s, China started increasing production of REEs, rapidly became the world's dominant producer. With the shutdown of the Mountain Pass Mine in 2002 and little development in other countries, China became the world's leading producer of REEs.

Even before this, China had spent considerable effort to mine rare earths from its different mines. Separation techniques were well developed in China and the labour being cheap, China began to be the major supplier of REE and REOs. As mentioned earlier over 80% of the RE mining was a byproduct from its iron ore mines at Bayan Obo. This had specific advantage to China because it lowered the recovery cost and provided a competitive advantage over other global producers, many of which mine deposits exclusively for REE.

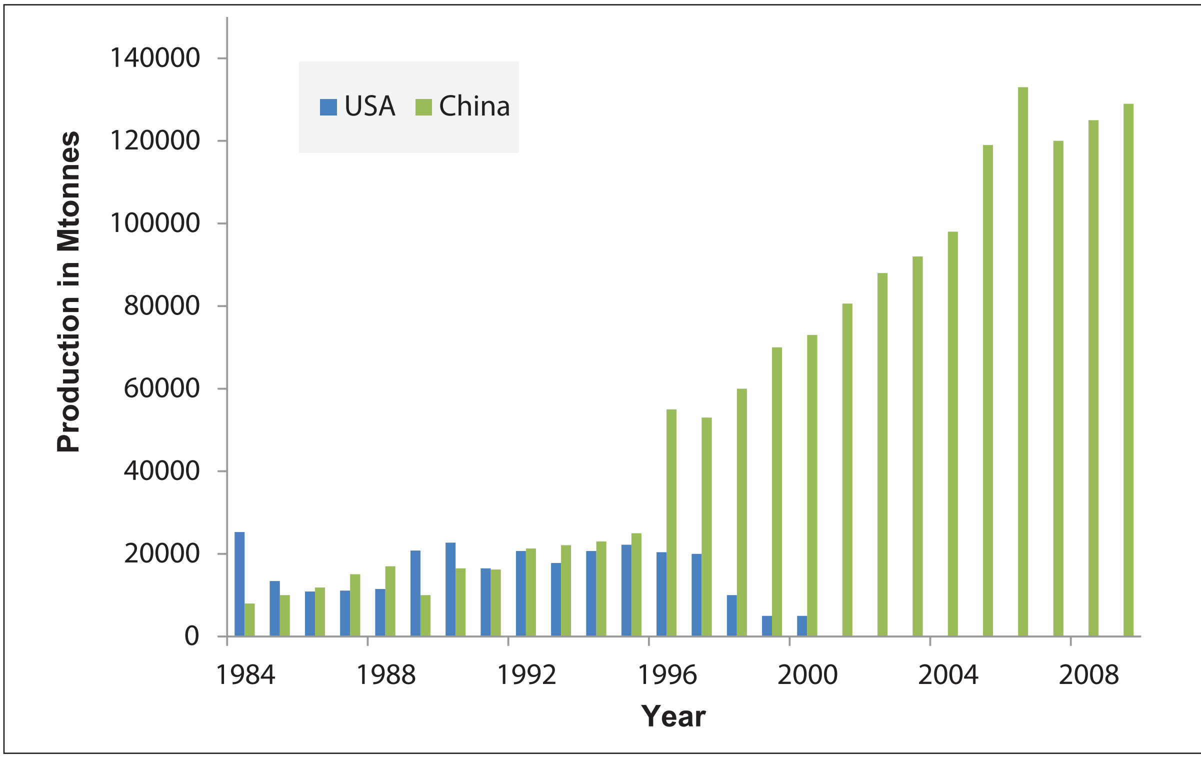
It is important to note that USA dominated the production till early nineties – so long as the Mountain Pass mine was operational. In 1989 the rest of the world production figures overtook the production in USA. The rest of the world includes mainly Brazil, China, India, Malaysia, Australia and to a small extent Sri Lanka and Thailand. All these countries excepting China produce rare earth concentrates from Monazite excepting China where the production is from Bastenesite ores.

Rare earth production data on China is not available for the early years. Figure 10 compares the production in China and USA. The data is taken from the USGS[45] and the British Geological Survey[46]. The figure should be read carefully. Rather than looking at the actual values that are shown, we need to look at the trend. This is because the data on RE production are available in different forms. Some sources give the production in terms of REOs and some others in terms of the concentrates. The data here pertain to rare earth concentrates.

[45] See http://minerals.usgs.gov/minerals/pubs/commodity/rare_earths/; for data on rare earths.

[46] World Mineral Statistics, British Geological Survey, 1984-88, 1985-89.

Figure 10 Production of Rare Earths in the US, China and the rest of the World (1985-2010)



Clearly from the year 1995 China is the major producer of rare earths.

China has not particularly given attention to environmental hazards in the mining of rare earths until recently. This has helped China to cut costs of processing. It is generally believed that one of the reasons for the closing down of the Mountain pass mines is the environmental damage it caused. But another overriding reason was also the cheap labour available at China that enabled it to dump its material into US.

The details of the number of mines operating in various provinces are provided in Table 5.

Table 5

Location of Rare Earth Mines in China[47]

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**

Inner Mongolia Baotou Steel Rare Earth Hi-Tech Co. is China's single largest producer of the metals. China, which once focused on

[47] Table is prepared from G J Orris and R I Grauch (2002), "Rare Earth Element Mines, Deposits, and Occurrences", Report 02-189 2002. Available on http://pubs.usgs.gov/of/2002/of02-189/of02-189.pdf

exporting rare earths in their raw forms, has moved up the supply chain very gradually. In the 1970s, China exported rare earth mineral concentrates. By the 1990s, it began producing magnets, phosphors and polishing powders. Now, China makes finished products like electric motors, batteries, LCDs, mobile phones etc. Most of the rare earth enterprises 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 and production in China.

Annexure 6: Important Events tracing developments in China on Rare Earths

Year	Salient Events related to Rare earths
1927	Iron deposits discovered in Bayan Obo Inner Mongolia
Early 1950's	Baotou Iron and Steel Company set up and commences production
1952	General Institute for Research in Non-Ferrous Materials (GRINM) set up
1957	RE concentrate production begins in Bayan Obo mines
1963	Baotou Research Institute of RE set up in Inner Mongolia
1960 to 1980	Exploratory Work on Mineral Resources leads to the discovery of a large number of RE deposits all over China. Chinese decision makers know that China has large deposits of RE and that it could be used to achieve strategic advantage.
1972	Xu Guangxian the father of the RE industry in China moves from the nuclear material area into the Rare Earth Area. Develops the theory of Countercurrent Extraction for separating out the Rare Earths. This reduces the costs of extraction significantly.
1983	Journal of the Chinese Society of Rare Earths started in both Chinese and English.
1986	The 863 programme initiated in China aimed at improving Chinese Technological capabilities in key areas. Though RE not explicitly identified most of the areas including the area identified as materials would have a significant component of RE research
1987	CAS Key Laboratory of RE Chemistry and Physics set up – Affiliated to Changchun Institute of Applied Chemistry
1978 to 1989	Ministry of Land Resources and Planning expands RE mining Operations
1990	Journal of Rare Earth started in Chinese and English.
1991	State Key Laboratory of RE Materials chemistry and Applications – Affiliated with the College of Molecular Engineering in Peking University set up.
1992	Deng Xiaoping declares " The Middle East has oil, China has Rare Earths"
1992	Bautou RE Industrial Development Zone set up. Encourages Foreign companies to set up shop in China. Technology transfer and assimilation become key national objectives.
1995	China National Non Ferrous Metals Import Corp., San Huan and Sextant MQI Holdings acquire Magnequench
1997	Boost to basic research in RE Materials through program 973
1997	Jiang Zemin – "Improve the developments and applications of Rare Earths and change resource advantage to economic superiority "
1998	Magnequench Powder facility set up in Tianjin, China
1998	Mountain Pass RE Mine in the US is closed
1999	Inner Mongolia Xiyuan RE Functional Materials Engineering Technical Research Centre set up
2000	Neo powder Production begins in Magnequech, Tianjin

Year	Salient Events related to Rare earths
2001	National Engineering Research Centre of RE Metallurgy and Materials CO. Ltd. Set up (Ruike Centre)- a technology enterprise of Baotou Research Institute.
2002	All Magnequench Operations moved out of the US into China.
2004	Magnequench expands operation in Singapore.
2005	Magnequench merges with AMR Technologies Inc., Canada
2005	China's attempt to acquire Molycorp's Mountain Pass Mine via purchase of Oil giant UNOCAL fails.
2006	Production facility set up in Korat, Thailand by Magnequench.
2007	China cuts off rare earth supply to W R Grace – major catalyst producer in US – forces Company to move to China.
2007	China begins Rationing RE supply – favours domestic companies.
2007	Production begins in Korat, Thailand.
2008	China tries to buy controlling stake in Lynas – Australian Rare Earth Mine. Only succeeds in getting a minority stake.
2009	China buys stake in another RE mine Arafura Resources Ltd in Australia
2010	China cuts off rare earth supply to Japan following a fishing trawler incident

Annexure 7: R&D on Rare Earths in China

State-run labs in China have consistently been involved in research and development of REEs for over fifty years. Two state key laboratories were established by Guangxian Xu in the eighties to carry out extensive work on rare earths in China. These are the State Key Laboratory of Rare Earth Materials Chemistry and Applications and The State Key Laboratory of Rare Earth Resource Utilization.

Additional labs concentrating on rare earth elements include the Baotou Research Institute of Rare Earths, the largest rare earth research institution in the world, established in 1963, and the General Research Institute for Nonferrous Metals established in 1952.

The State Key Laboratory of Rare Earth Resource Utilization 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 is located in Changchun. Research primarily focuses on Rare earth solid state chemistry and physics, bio-inorganic chemistry and the chemical biology of rare earth and related elements. Rare earth separation chemistry including clean techniques for rare earth separation, chemical and environmental issues of rare earth separation and the integration of the separation and the preparation of rare earth form core research interests here.[48]

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. Guangxian Xu, Member of CAS, is the honorary chairman of the Academic Committee. The Lab has so far undertaken a variety of national key projects of basic research on rare earth science, including "973" Project (The State Key Project of Fundamental Research), "863" Program, NSFC Fund for Innovative Research Group and many projects involving Major Program and Key Program from the National Science Foundation of China. The laboratory carries out fundamental research on rare earth material chemistry, the exploration of novel rare earth functional materials as well as the correlative theoretical methods and materials design.[49]

The Baotou Research Institute of Rare Earths, the largest rare earth research institution in the world, was established in 1963. It focuses on the comprehensive exploitation and utilization of rare earth elements and on the research of rare earth metallurgy, environmental protection, new rare earth functional materials,

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48 CAS Key Laboratory of Rare Earth Chemistry and Physics, Chang Chun Institute of Applied Chemistry, available from http://english.ciac.cas.cn

49 Peking University, College of Chemistry and Molecular Engineering: The State Key Laboratory of Rare Earth Materials Chemistry and Applications: History and Development, available from http://www.chem.pku.edu.cn/page/relab/english/history.htm.

and rare earth applications in traditional industry.[50]

The General Research Institute for Nonferrous Metals (GRINM) was established in 1952. This is the largest research and development institution in the field of nonferrous metals in China. GRINM focuses on R&D of rare earth metallurgy and materials in China and also hosts National Engineering Research Center for Rare Earth Materials.

Grirem Advanced Materials Company Ltd established in December 2001, carries out R&D on earth mineral separation and purification, high purity rare earth compound rare earth metals and alloys, luminescent materials, magnetic materials, and rare earth materials for agricultural applications.[51]

Each of the four laboratories and institutes mentioned above complement each other. 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.

The State Key Laboratory of Magnetism – Institute of Physics (CAS),[52] in Beijing has been in existence since 1928. Its primary area of research has been fundamental and applied research in magnetism and magnetic materials. More recently structure and magnetic properties of rare earth intermetallic compounds is being studied vigorously. The Institute has collaborations with universities in the U.S, Europe and Japan.

In addition to having state run laboratories dedicated to researching and developing Rare Earth Elements (REE), China also has two publications dedicated to the topic. They are the Journal of Rare Earth and the China Rare Earth Information (CREI) Journal, both put out 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 earth, 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 earth, 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 Meetings once every two years periodically. There are 15 sub-committees in CSRE, which almost cover every

[50] Baotou National Rare-Earth Hi-Tech Industry Development Zone: Rare Earth-An Introduction, available from http://www.rev.cn/en/int.htm.

[51] See http://en.grinm.com/channel.do?cmd=show&id=5&&nid=1349The General Research Institute for Nonferrous Metals

[52] See the website of the institute for more details. **http://maglab.iphy.ac.cn/web-english/e-2.introduction.htm**

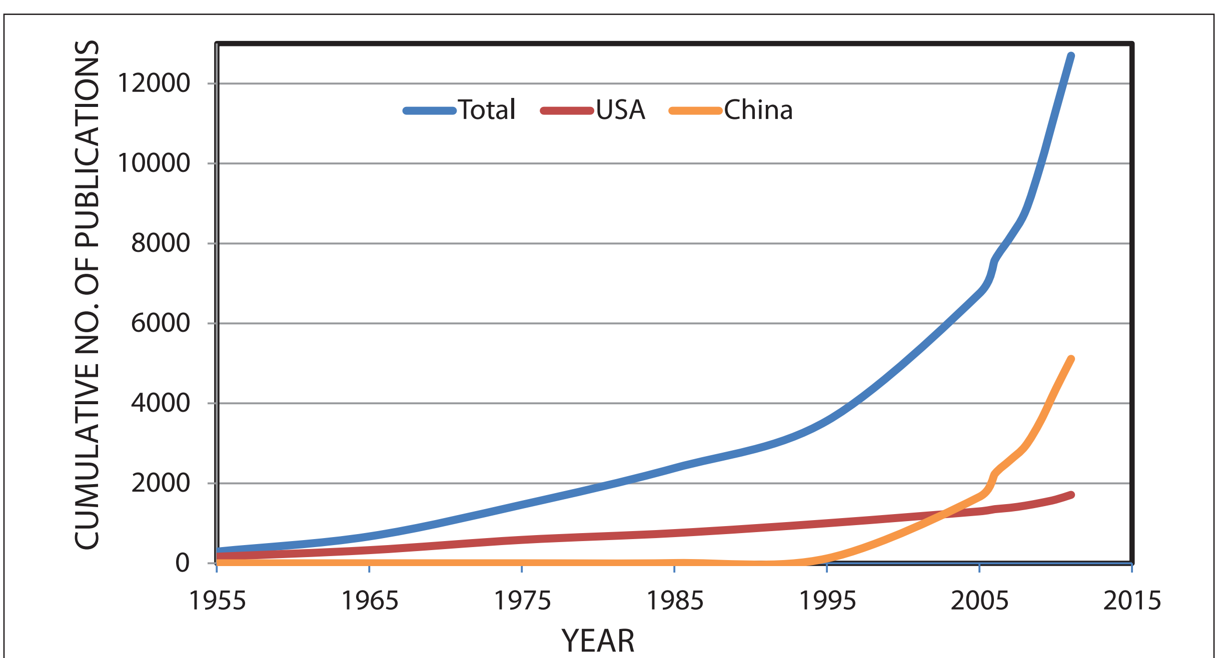
R&D field on rare earth. The names of sub-committees are (1) Rare Earth Geochemistry and Ore Dressing (2) Rare Earth Chemistry and hydrometallurgy (3) Rare Earth Magnetic Materials and Magnetism (4) Rare Earth New Materials (5) Rare Earth Catalytic Materials (6) Application of Rare Earths in Iron and Steel (7) Application of Rare Earth in Casting (8) Rare Earth Analytical Chemistry (9) Application of Rare Earth in Ceramic and Glass(10) Rare Earth Refining (11) Environmental Protection of Rare Earth Industry (12) Rare Earth Phosphor and luminescence (13) Application of Rare Earths in Agriculture (14) Rare Earth Information (15) Technique and Economy of Rare Earth Enterprises.

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. The main characteristic of the Chinese model is its tradition of centrally-planned R&D initiatives and the national mobilization of human and material resources to support their implementation. This kind of centrally planned system in China has favoured applied research directly related to economic and strategic importance over curiosity-driven discoveries and basic research. The PRC government has become a leader in a technology commercialization drive. Enterprises promote links between research institutes and commercial firms. China's conglomerates are continuously directed from the government side to set up their own research and technology development centres and take over public research institutes.

Publications on Rare Earths – the US and China – A Comparison

As we have mentioned, over the last 30 years China has put in a lot of resources to develop its RE industry and make it a dominant player in the global arena. This is reflected in

Figure 11 Trend in the Publications on Rare Earths (China and USA)



the number of publications from China. The Keyword “Rare Earths” threw up thousands of papers from China as well as the US from the SCOPUS data base. We did not refine the key word because the idea is to get a fix on the trend rather than the actual papers themselves.

Figure 11 provides an overview of the trends in Rare Earth related papers by China and the USA.

By about 1965 US publications were close to 400 on the subject while the total number of publications in the world was close to 600. In fact at this point of time there were no papers from China. We must however, note that though the Journal of Chinese Society of Rare Earth was already being published the SCOPUS does not include this journal in its list. Because of this the first papers from China appear only in 1995. In spite of this under reporting what is interesting to note here is that by about 2003, China had already overtaken the US in published papers. While the number of papers from the US have more or less remained at the same figure, Chinese papers continue to show an increasing trend.

We also noted from the SCOPUS database that the number of institutions working in this field is more or less the same for both the US and China. More than 150 institutes in China were involved in Rare Earths research. Amongst these Changchun Institute of Applied Chemistry, Chinese Academy of Sciences, University of Science and Technology at Beijing, Northeastern University, General Research Institute for Non-ferrous Metals China, Harbin Institute of Technology, Zhejiang University, University of Science and Technology of China, Central South University China, Shandong University, Tsinghua University, Jilin University, Tianjin University have at least 100 papers. In the US too 150 institutes published papers on the topic. Iowa State University is the only institute that had more than 100 papers. Argonne National Laboratory and Oak Ridge National Laboratory had a significant number of papers. This is just to indicate that China has been carrying out research and development work on rare earths at least since 1995. A significant boost was also provided to the RE industry via the 973 programme of China.

While China brings out two journals concerning rare earths, two important publications on rare earths which were brought out by the Ames Laboratory, USA stopped publications in 2002.

The Rare Earth Information Center (RIC) data base was also established at the Ames Laboratory by the U.S. Atomic Energy Commission’s Division of Technical Information in January of 1966 to service the scientific and technological communities by collecting, storing, evaluating, and disseminating rare-earth information from various sources. In 1968, the support of RIC was transferred to Iowa State University’s Institute for Physical Research and Technology through grants from the worldwide rare earth industry.

The Ames Centre also brought out two newsletters.

The RIC News was a quarterly newsletter containing items of current interest concerning the science and technology of rare earths. RIC News was free.

The RIC Insight a monthly newsletter, contained more editorial comments, provocative opinions on the future directions of rare earths, later breaking news than the RIC News, and was slanted toward the technological and commercial aspects of the rare earth field. RIC Insight was available only to supporters of the center as a membership benefit.

All the publications were stopped from 2002. This move by USA clearly indicates that the R&D priorities had changed and moved away from Rare Earths in the US. China of course took full advantage of this situation to establish a dominant position in R&D on RE. Whether this is the right strategy to adopt at the mature phase of a life cycle or whether new non RE technologies will dominate the future is still an open question. China believes that the drivers of future growth especially in areas related to green products will continue to depend in a big way on Rare Earths. If this is so and there is reason to believe that this will be so, its grand strategy in RE will be vindicated.