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Does India Need a National Strategy for Rare Earths?

April 2013

International Strategic and Security Studies Programme
National Institute of Advanced Studies
Bangalore, India

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Executive Summary

At the global level the RE industry is in the mature phase. Growth of existing products that use RE will be mainly in large emerging economies like India and China. The continued growth of the industry will depend on how fast the advanced economies of the world move towards greener products. The automobile industry and the move towards cleaner energy systems especially in the US, Europe and Japan will decide the future growth of the global RE industry.

Through a policy of active intervention China has built up an extremely strong position in the global RE industry. It has successfully leveraged its domestic market and the maturing of the industry globally to control entire value chains for raw materials intermediates and final products. As its spat with Japan illustrates, it will use this dominant position as a part of its grand strategy to claim its rightful position in the global arena. It is betting on the fact that there will be a large demand for RE products as the advanced countries move towards a greener future. Developments in the last two to three years suggest that this judgement appears to be vindicated.

India has no major presence except maybe in the raw material part of the global RE industry. Even here Indian capabilities have withered away due to China's dominance of the industry and Indian inaction.

In a few areas like permanent magnets Indian mission organisations in the military / strategic sectors have established some capabilities due to embargo problems. However these are limited only to meeting strategic needs and have not been transformed into an industrial capability that caters to both domestic and global markets.

Our analysis also shows that as the RE industry has matured, the pace of radical breakthroughs has come down. Though this is so there are still many potential opportunities for improvements as well as possibilities of breakthroughs. China once again has a dominant presence in the R&D scene. It is poised not only to make breakthroughs happen but can utilise its significant technology and market base to capitalise on such breakthroughs should they happen elsewhere.

The western powers, especially the US, which virtually created the RE industry, have significantly eroded their leadership position in the knowledge dimension of the RE game. The closing down of many R&D centres as well as reduction in funding has severely curtailed them. Though they are trying to reverse the trend their efforts will take time. During this period of transition China will have a major advantage.

Indian R&D in RE does not seem to be a relevant issue at all. Though there may be some capabilities within the strategic and mission organisations their connections both with products needed by the military or by industry are weak and tenuous. Without conscious intervention this state of affairs will continue.

Alternative materials and technologies to RE could pose a threat to continued Chinese dominance. Identifying these materials and technologies and making investments in R&D related to them is the challenge here. Our limited review of a few key areas such as magnets, motors, and batteries suggest that though there are alternatives they still do have a number of problems for large scale use.

To identify what these materials and technologies could be and to support investments in them require more detailed knowledge from various domain experts. It is quite likely that many of these materials and technologies have already emerged and are ready to be used with some support. This should be a key component of any Indian response to the current Chinese dominant position.

The current competitive position of the major players in the RE game also suggest that collaborative efforts between the advanced economies and an emerging economy like India would be very productive. These could cover all areas from trade to technology developments.

Though the global RE industry presents a fairly bleak picture as far as India is concerned, it does present India with an opportunity to take stock and come up with a strategy to deal with the RE and other similar problems that India may face in the future.

India does have two major advantages in the RE industry. It has a large resource base in RE raw materials. It also has a large domestic market for both civilian and military products that gives it significant leverage if used wisely.

India also has a reasonable R&D base especially within the mission organisations of the country.

It however has major inadequacies in converting indigenously available knowledge and technology into commercially viable products and services. Though India has in place the institutions and infrastructure it is unable to link grand, national strategy to the more prosaic micro level industry and product development strategies that are the key to any national endeavour.

For a national level strategy to be successful India needs to understand in much greater detail the technology - product - market links in the various key industries likely to be affected by RE shortages. These industry level analysis using a dynamic life cycle approach should also study in detail the various material and technology alternatives for dealing with RE bottlenecks and even set priorities. With this micro detail available India may be in a better position to decide whether a national level strategy in RE is required and if it is required it may be able to specify the form and content of such a strategy.

Based on a first level review of the current usage of RE materials the following areas appear to be critical for more detailed studies.

Permanent Magnets for use in motors, actuators, vacuum tubes, computer hard drives and speakers for both civilian and defence programmes.

RE materials in the Phosphor and Glass industries

Rare Earth garnets for making microwave components used in radar and satellite communication systems.

Rare Earth cathodes for use in vacuum tube devices. These cathodes are used for both radar and space communications systems as well as in ion thrusters for satellites.

YAG lasers also appear to be critical products that use RE. Here again there are both military and civilian applications.

Acoustic devices for a variety of applications in the defence sector including sonar as well as noise suppression applications.

RE materials are also critical for the production of hybrid cars. They are used in the motors, batteries catalytic converters, glasses and phosphors used in automobiles. Yttrium Stabilised Zirconia (YSZ) are also used to make the oxygen sensors used for controlling combustion in auto engines.

RE catalysts are also critical for the petroleum refining industry.

Many emerging green technologies like windmills, fuel cells need large quantities of RE materials. Lower energy consuming LED and CFL lighting also need RE coatings.

The micro level detail available from these studies should provide the inputs for the crafting of a national level strategy on RE materials and technologies.

1. Background

Rare Earths (RE) are just one of many materials that may require the crafting and execution of a national level strategy.[1]

This note is based on the work carried out by the International Strategic & Security Studies Programme (ISSSP) at the National Institute of Advanced Studies (NIAS). It is a part of a number of micro-level studies on China that link technology with national level capabilities and strategies. Though the study lays emphasis on China's grand strategy in Rare Earths, a part of it can be used to look at what shortages in Rare Earth supplies can do to India. This is what this note tries to do.

Rather than making specific recommendations on what kind of Rare Earth Strategy India should pursue, the note raises a set of issues that needs be discussed in detail by relevant players in the national strategy game. One option, which in some cases may also be the right action to pursue, is to do nothing. However it is the central argument of this note that even to decide on such an alternative one still needs to go through a rigorous strategic evaluation of the various alternatives and their implications.

Materials though small in terms of their contribution to the Gross Domestic Product (GDP) are vital to the well-being of any 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 no exception to this rule. They are critical for many products that are used in the economic and military domains.

Before we decide on whether a national strategy is required or not, the first step is of course to find out the various products and industries that use Rare Earths and how these are interlinked or connected. This is best done through the construction of a value chain network that uses an input output matrix.

2. Rare Earths and the Defence Sector

Based on available data we created an input-output Matrix that captured the use of Rare Earth Materials in various intermediate and final products of direct interest to the military and defence sectors of a country. We came up with a 52 by 52 Input Output matrix for the defence sector.[2] This matrix can be converted into a network diagram that links raw materials with intermediate products and then connects these to the various products of interest.

Annexure 1 provides an integrated view of the Rare Earths value network in defence and military products. The critical nodes are easily

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[1] There are many materials that can be termed critical. All advanced countries need to review and craft strategies to identify and manage these. This becomes much more important as global connections in many critical hi technology products increase and throw up new sources of vulnerability.

[2] The data for both the Defence Network and the Economic Network was compiled from various sources on the Internet including James B Hedrick "Rare Earths in Selected US Defense Applications", Paper presented at the 40th Forum on the Geology of Industrial Minerals, May 2 – 7, 2004, Bloomington Indiana. The other major source has been Cindy Hurst, "China's Rare Earths Elements Industry: What can the West Learn?" Institute for the Analysis of Global Security (IGAS), March 2010.

identifiable from this diagram. The diagram enables us to trace in detail the way in which any two nodes are connected to each other and enables us to study the impact that any one of them would have on the other. If this can be linked to the economic or strategic importance of a node via some independent data we have a powerful tool to evaluate the impact of a shortage or a price increase in any one node on other connected nodes.

Table 1: Ranking of the Top 22 Nodes in the Defence RE Network

Node	Input into Node	Output from Node	Total Links	Rank
Permanent Magnets	4	11	15	1
RE Phosphors	6	2	8	2
Glass	4	3	7	3
Cerium	0	6	6	4
Yttrium	0	6	6	5
Nd YAG lasers	2	4	6	6
Cathodes for tubes	2	4	6	7
Radar	5	1	6	8
Travelling Wave Tubes	2	3	5	9
Klystrons	2	3	5	10
Lanthanum	0	4	4	11
Terfenol D	2	2	4	12
Zirconia YSZ	2	2	4	13
Polishing agent	2	2	4	14
Praseodymium	0	3	3	15
Gadolinium	0	3	3	16
YIG Yttrium Iron Garnets	1	2	3	17
YGG Yttrium Gd Garnets	2	1	3	18
Magnetrons	2	1	3	19
Communication systems	3	0	3	20
LED	3	0	3	21
Microwave components	2	1	3	22

The network diagram as well as the matrix can be directly used to identify the critical nodes in the network and to rank them in terms of connections at different levels. Annexure 2 provides details on the relative rankings of the 52 nodes in the defence network.[3]

Table 1 above provides details of the top 22 nodes in the Rare Earth Defence Network.

3. Rare Earths and the Industrial Sector

A second matrix to capture the use of Rare earths in intermediate and final products and industries that affect the economy was also created. This matrix was a 92 by 92 matrix.[4] Annexure 3 provides an integrated picture of the Rare Earths value network in the overall economy. Annexure 4 provides the relative ranks of the various nodes in the economic network.

Table 2 below provides details of the top 27 ranked nodes from the RE Economic Network.

These matrices and their corresponding networks represent current practice in the use of Rare Earths from the available global knowledge base. They do not address whether this usage will continue, decline or grow. This will depend critically on:

- The current position in the lifecycle of the relevant product and industry globally and in India.
- The rate of growth of these products in India which is in turn linked both to the global and Indian stages in the life cycle of these products and industries.

[3] The ranking can be based on the inputs into the node, the outputs from a node or on the total number of connections that links the node to other nodes. In our analysis we use the total number of nodes as the basis for the ranking.

[4] There will be some overlaps between the Defence Network and the Economic Network

Table 2 : 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
Fibre 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

- The underlying materials, technologies and components that go into the product and whether India buys or makes these intermediate components that go into the final product.
- Whether alternative materials and technologies are available to substitute for Rare earths in case of shortfalls in supply?

This note also does not cover new uses of rare earths or new compositions of rare earth materials that might come about from continuing research in these materials.

In spite of these limitations we can still get a fairly good idea of the various RE value chains and their relative importance from our study of the Rare Earth networks in the military and economic sectors.

This can be the basis for initiating further discussions on priorities and relative importance in the specific context of Indian security and economic needs. We can then evolve a suitable strategy.

The most critical nodes in the network are those that are connected to many other nodes in the network. 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 changes in the quantities and prices of Rare Earths.

4. Rare Earths Priorities

The network diagram for the defence sector suggests that the major intermediate and final products that are likely to be affected by RE shortages are Permanent Magnets, Radar and YAG lasers.

Various vacuum tube devices like TWTA's, Magnetrons and Klystrons that use Rare Earth magnets and that link magnets to the Radar and communications systems also appear to be critical nodes affected by RE shortages.

In the same way Yttrium based garnets are critical for the development and production of many microwave components that go into radars and communications systems.

Though Glass and RE phosphors also rank high in terms of total connections (many RE elements go into them) they are not that important from the end use point of view – limited largely to display devices like TV screens or LED screens.

Though all the Rare Earths appear in the defence network diagram, the more critical RE elements appear to be Cerium, Yttrium, Terfenol D (an alloy of Terbium, Iron and Nickel). Yttrium Stabilized Zirconia (YSZ) also appears to be important for thermal protection in jet engine and re-entry warheads.

The Network Diagram for the Economic sector suggests that Glass, Permanent Magnets, Phosphors, Catalysts, Batteries, Catalytic Converters, Automobiles, Oxygen Sensors, Fuel Cells, Motors, Oil Refineries, Fuel Additives, Light Emitting Diode (LED) Lighting, Compact Fluorescent Lighting (CFL), Wind Mills are linked and critical nodes in the network.

Most of the major nodes in the Economic Network are linked to industries and products that can be considered as crucial industries for achieving a greener world.

5. AREAS AND APPLICATIONS REQUIRING CRITICAL REVIEW

5.1 RE AND PERMANENT MAGNETS

The node with the highest rank in the defence sector is the node termed permanent magnets.

Figure 1 below provides the specific details of the Permanent Magnet value chain extracted from the overall network.

The major Rare Earth elements that go into these magnets are Neodymium, Praseodymium, Dysprosium and Samarium.

These magnets are directly used in actuators and motors for a variety of operations to be performed on missiles and satellites. Their ability to provide high magnetic fields for low weight is critical for converting electrical energy into mechanical movements in applications where weight is a premium.

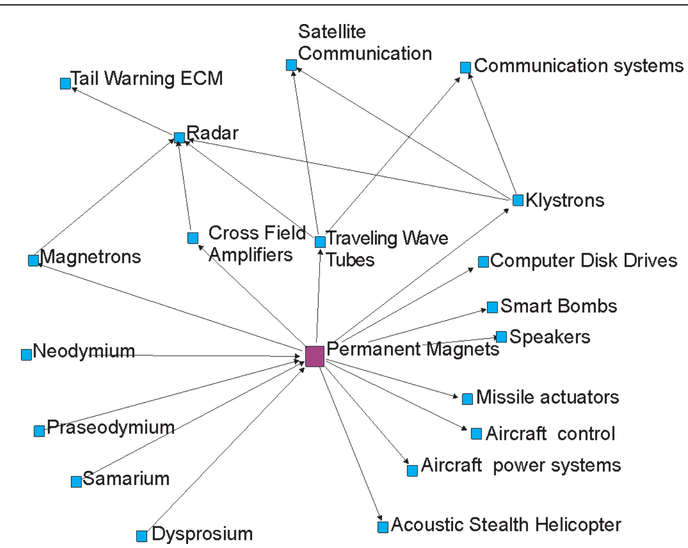

Figure 1

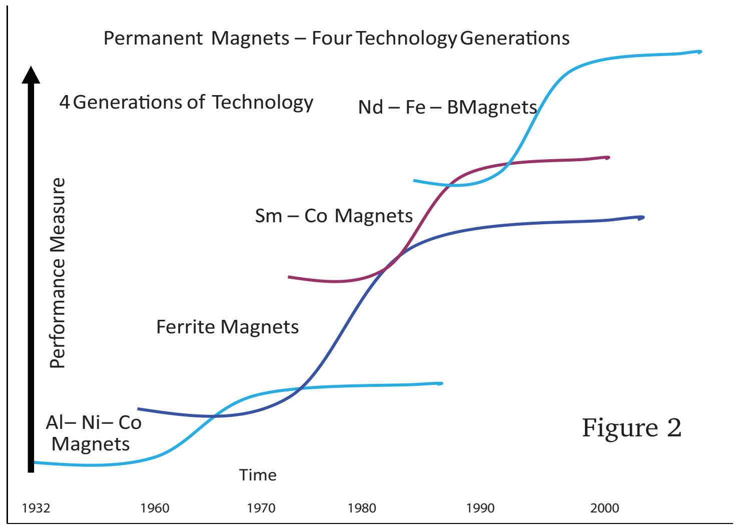

Figure 2

Over the last fifty years or so, permanent magnets have evolved through four generations of technologies.

Aluminium – Nickel – Cobalt (AlNiCo) magnets have been replaced by hard ferrites.

These in turn have been replaced by superior Samarium Cobalt (SmCo) Rare Earth Magnets in many high end applications.

In response to the perceived shortfall of Cobalt, companies in the US and Japan developed another Rare Earth based permanent magnet the Neodymium Iron Boron (Nd Fe B) Magnet. This seems to be currently the dominant technology route for making permanent magnets especially for many high end products.

Other Materials including the heavier Rare Earths as well as nano technology based RE materials are under active investigation. Following the Chinese embargo, other architectures for critical motors that may not need a permanent magnet are also being researched.

Figure 2 provides an overview of these technology cycles for permanent magnets.

Indigenous development within the strategic establishments of the country as a consequence of embargos on import of permanent magnets has been fairly successful.

Samarium Cobalt(Sm Co) magnets have been developed for use in the space programme by joint teams from DMRL and VSSC. Starting from the PSLV –D 3 flight of 1996 over 5000 of these magnets have flown on Indian satellites and rockets.[5] We do not know whether these magnets used indigenous or imported Rare Earth material.

If not already under way these capabilities in Sm Co should be easily extendible to the later generation of Nd Fe B magnets.

The need for permanent magnets for use in the space, nuclear and missile programmes will continue into the foreseeable future. These are however not likely to be huge demands

[5] H Sreemoolanathan, "Permanent Magnets for ISRO Missions", Evolution of Materials Research for Indian Space Programmes, Editors K Suseelan Nair & P PSinha, Indian Space Research Organisation, 2009, pp 163 -171.

requiring large scale expansion of industrial capabilities in all parts of the value chain though some transfer of technology to industry for limited production may be warranted.

However we can see from the Economic Network that several major and emerging industries especially those related to green technologies use permanent magnets. Automobiles, electric hybrid vehicles of all kinds as well as windmills require electric motors that need magnets.[6] These require much larger quantities of Rare Earth materials.

Currently production in these industries is with the private sector and maybe carried out with foreign collaboration.

Permanent magnets also go into speakers used in a variety of consumer electronic products like cell phones, laptops, TV sets etc. They are also used in computer disc drives. Here too the choices of technology and make buy options are decisions taken by the companies operating in these industries.

Permanent Magnets account for about 9 to 10% of the total global market for Rare Earths currently.[7] Our review suggests that there are capabilities that exist within the mission organisations of the national security complex for the production of these magnets.

These with some effort can be extended to create an indigenous industry based on Indian Technology that caters not only to the defence sector but can also be stretched to look at the commercial sectors.

The other alternative is to promote joint collaborative efforts between Indian industry and foreign partners. One of the elements of such collaboration should be to encourage the emergence of an Indian Permanent Magnets industry that uses Indian Rare Earths.

A hybrid model combining both approaches is also possible.

The question to ask is whether Government should intervene to promote the development and emergence of an Indian industrial capability in rare earth permanent magnets. If the answer to this is yes we also need to address the form and content of such an intervention.

We can see from the **Figure 2** that apart from actuators and motors for missile and space applications, RE permanent magnets also go into a number of critical vacuum tube based devices such as Magnetrons, Klystrons, Cross Field Amplifiers as well as Travelling Wave Tube Amplifiers. These in turn are intermediates for the production of radars and other communications products. Though solid state devices now substitute for some of them in some areas of application, vacuum tube based devices may still be needed.

5.2 RE and Radar Products

Radars are used everywhere both in the civilian as well as in the military sector. Early Warning, Space Surveillance, Ocean Reconnaissance, Weather, Missile navigation and control are just a few of these uses.

Figure 3 provides the network diagram for the radar value chain.

6 Many of them also need batteries for which rare earths are important. Catalysts made out of rare earths are also used in the catalytic converters that is mandatory in all cars

7 Market information is from Thomas G Goonan, "Rare Earth Elements – End Use and Recyclability", Scientific Investigations Report 2011-5094, US Geological Survey, 2011 available at http://pubs.usgs.gov/sir/2011/5094

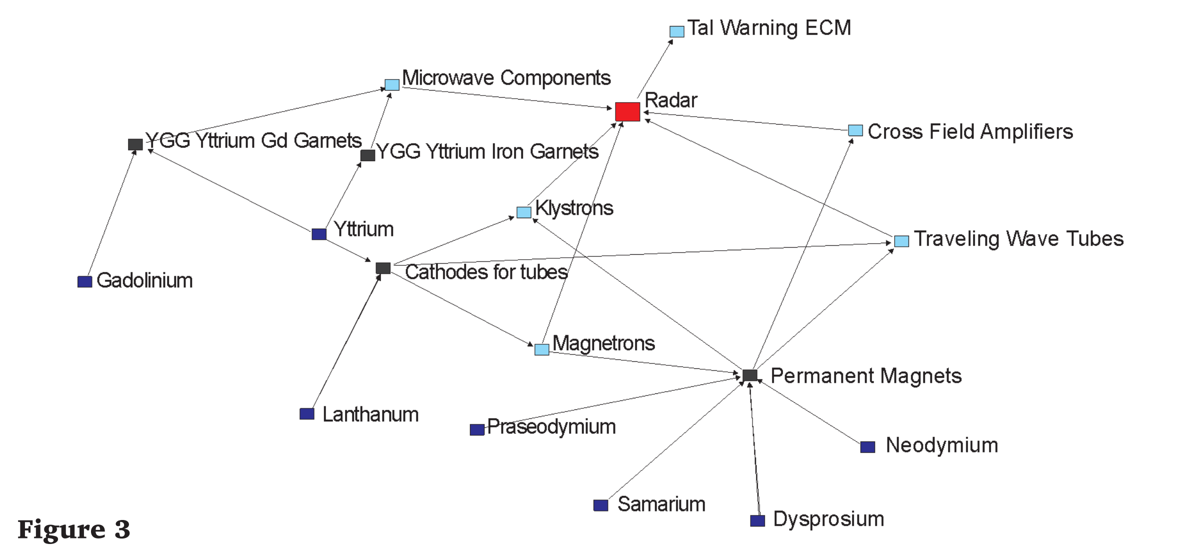

Figure 3

Apart from Permanent Magnets that go into Vacuum tube devices, Rare Earth garnets are needed for the fabrication of various microwave components that go into radars and communications systems.

Cathodes made out of Lanthanum and Yttrium combinations also appear to be critical inputs for vacuum tube based devices. These cathodes are also used in ion thrusters that go into various satellites.

This combined value chain of radar and permanent magnets together account for 14 of the top 22 nodes in the defence network.

The role of Rare Earths in Radar development depends on the form and content of an Indian Radar Programme.

Though there have been some positives in radar development, by and large these have been piecemeal operations under the aegis of different mission organizations such as space or defence.

A large number of operational requirements both in the military side as well as in the civilian side such as weather radars are most probably imported.

There is no doubt about the strategic importance of radar technologies and products.

Though there have been indigenous efforts not only to develop different radar products catering to different needs but also to indigenously develop some of the critical subsystems such as TWTAs the exact status of these developments need to be reviewed critically.

Rare earth materials become critical materials only and only if India has a major programme in the development and production of radars and communication systems. Even then rare earths are only critical if India embarks on a programme of component and sub-system level capability in these areas.

Though there is a strong case for a major radar initiative that cuts across the boundaries of various mission organizations within the national security complex, there appears to be no effort currently underway to take an integrated look both at the needs as well the capabilities required to meet these needs before deciding on a plan of action. This plan will determine whether Rare Earth material shortages will disrupt production supply chains or raise the price for buying imported products.

5.3 RE AND YAG LASERS

YAG lasers are the other important node from the defence network. These lasers, apart from their use in various defence equipment, also find application in many commercially important products especially in surgery as well as in the manufacturing sector.

It is likely that most YAG lasers in end use equipment are currently imported. In such a situation RE shortages will only impact via price increases for imported lasers.

If there is a programme to develop such lasers in the country then an integrated approach on how developments in the defence sector can be used by the civilian industry and the specific role or RE materials in such a programme need to be identified and evaluated. If there are no capabilities in the country currently to develop these lasers the question of whether India needs to invest resources to create these capabilities needs to be evaluated.

5.4 RE AND ACOUSTIC TRANSDUCERS

Terfenol D an alloy of Terbium, iron and nickel exhibit special properties that make it useful for noise suppression and other acoustic applications including sonar devices. Newer materials including some RE ones may now be available. **The criticality of these devices and the role of RE in their development and production may need to be reviewed**

5.5 RE AND YSZ PRODUCTS

Yttrium Stabilized Zirconia (YSZ) is used for its thermal properties both in the nose cones of re-entry vehicles as well in coatings used in some jet engine parts. It also finds use in many civilian products like turbines, dentistry, knives and jewelry. **Here too an integrated look at make buy options and whether there is a need to promote an industrial capability needs to be addressed.**

5.6 RE Phosphors &Glasses

RE phosphors and RE glasses are used for many display and optical equipment used in the defence sector. They are also used extensively for displays in various consumer electronic products. These include traditional CRT displays as well as the newer and more modern LED and other advanced display devices. RE use in glass accounts for 9% and RE use in phosphors accounts for about 7% of total market respectively.

CFL lights as well as LED lighting are new technologies that appear to be ready to displace traditional incandescent as well as fluorescent lighting used in most Indian homes. These new lighting products cut down energy consumption and promote a greener economy. Both CFL as well as LED lights need RE coatings to provide both white and coloured lighting. These are likely to become major markets in the country.

The role of RE and the impact of shortages or higher prices in these industries depends on whether Indian manufacturers make or buy these intermediate components. If they are made in the country shortages will directly impact the manufacture of the products. If they buy then the prices of these intermediate components will increase.

One of the questions to ask is whether active intervention into these industries for promoting Indian technology and Indian production is warranted. The technologies involved

in display devices are likely to be more complex than the technologies involved in Lighting applications.

5.7 RE and the Automobile

One of the major global trends in the automobile sector is the promotion of greener and more environmentally friendly cars and transport vehicles. RE plays a major role in many of the technologies required for achieving a greener carbon foot print.

Figure 4 provides a view of the linkages that a greener automobile has with other components using RE in its value network. Hybrid vehicles are an immediate solution for cutting down emissions. They require extensive use of RE in the different components that are needed for their production.

We have already covered the use of permanent magnets for use in the electric motors of a typical Hybrid car.

Lanthanum or Misch metal anodes are used extensively for the batteries used in hybrid cars.

Lithium ion batteries have been seen by many US manufacturers as a major breakthrough technology providing superior performance over the current Lanthanum hydride batteries. However recent problems with lithium from the safety point of view have shifted the focus back to RE based batteries. The major Japanese Automobile manufacturers see RE batteries as important for the next few generations of hybrid cars before a transition to Lithium ion batteries takes place. Given this scenario, RE usage in batteries is a growth industry for the next few years.

RE also go into the catalytic converters that are used for emission control in automobiles. Carbon monoxide, unburnt hydrocarbons as well as control over nitrous oxide emissions are functions performed by the catalytic converter. RE are used as coatings in these devices along with Platinum group materials.

For efficient operation of the engine and emission control most automobiles also use an oxygen sensor that is also made out Yttrium Stabilized Zirconia (YSZ).

In addition automobiles use RE glasses and RE phosphors for lights and dashboard displays.

The other use of RE that impacts the automobile somewhat indirectly through the

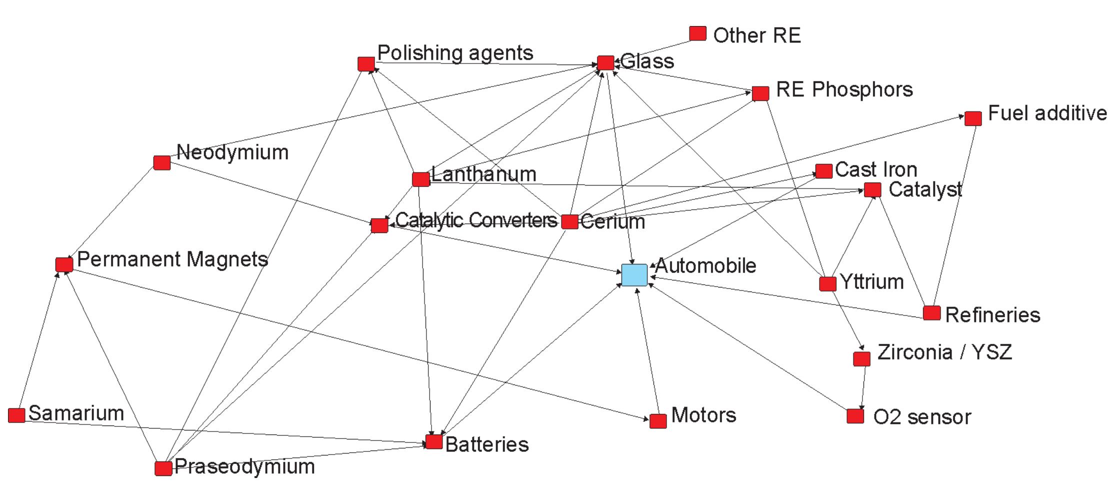

Figure 4

fuel is the use of RE in Zeolite catalysts used in high temperature cracking of petroleum crude.

This clearly indicates that currently RE are used in major components that are critical for reducing emissions and for promoting a greener environment.

Should the government intervene to cover critical technologies? What form should such intervention take?

5.8 RE AND ENERGY

RE catalysts as already mentioned are very important in the petroleum refining industry.

RE Magnets are crucial for the electric motors used in gas turbines, windmills as well as in automobiles.

Fuel Cells are also major users of RE materials.

Coupled with the use of RE in CFL and LED lighting applications RE are critical materials for promoting a greener planet.

Does India have an overall "Green Plan? Do Rare Earths have a role in such a plan?

6. THE GLOBAL RE INDUSTRY AND COMPETITIVE DYNAMICS

Annexure 5 provides a summary overview of the various developments in RE Science, RE technology and RE products.

The current Global Competitive Dynamics can best be understood through the notion of an industry life cycle approach that is in turn connected to underlying product and technology life cycles.

Figure 5 provides a conceptual overview of the current RE Industry Life Cycle. This is based the chronology of critical research knowledge, technology and product development provided in **Annexure 5.**

The Global RE industry is currently in the mature stage of the Life cycle. Demand for

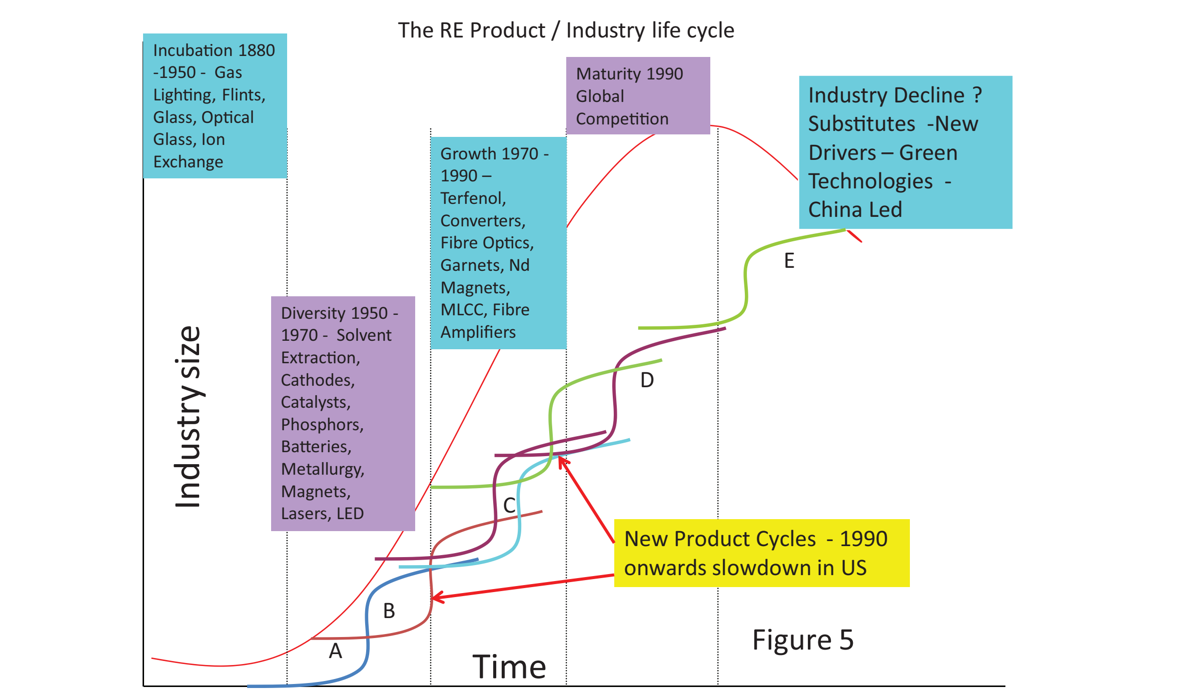

Figure 5

most of the RE based products in the advanced countries is slowing down or declining. The US, which pioneered most of the original breakthroughs in RE products as well as Japan and Europe, have reduced their R&D and even closed down research programmes in RE.

The future growth of the RE industry in these economies is likely to depend upon the role of RE in the promotion of Green Technologies and whether these would be given priority by these countries.

In contrast to these advanced powers India and China are still in the growth phase for many of the products that use RE. This means that the macro climate to transfer technology and outsource manufacturing has been and would continue to be favourable to these countries for some time to come.

China has not only set out to create a large domestic demand for RE in China but also leveraged this well to establish a dominant global presence in most of the RE-using products and industries. This position has been created via a policy of conscious intervention in order to grow the domestic industry. China obviously saw value in using its large resource base in RE materials and its large domestic market to forward integrate and establish a globally dominant position in most RE products and industries.

In addition to this strong downstream position China has also invested heavily in R&D related to RE to make sure that it can compete in the technology and invention domain as well. It has a strong and well entrenched position in all parts of the RE value chains. Even though the industry is in the mature state China is betting that as the world moves towards a greener planet the demand for RE products that are currently critical for many of these green products will continue to grow.

Though there are selective pockets especially within the Indian mission organizations that have demonstrated some capabilities such as in magnets, by and large, India has not followed a large resource base strategy in RE. Indian industry appears to be a laggard in the direct use of RE materials for the manufacture of key RE intermediate products. Research in RE within India also seems to be sporadic and unconnected to any clear plan.

The available evidence from **Annexure 5** also seems to suggest that the pace of radical breakthroughs in new Rare Earth materials and compounds is showing signs of slowing down. Even if this is so there are still improvements that research can bring to the existing inventory of RE materials, RE compounds and RE compositions. It is also possible that some new compositions and compounds with unique properties can emerge from R&D efforts. Nanotechnology research in RE could also throw up some new surprises.

Heavy Chinese investments in Rare Earth R&D suggest that the most likely place from which such developments can come about is China.

Advanced Countries have allowed much of their initial advantage in RE to erode as the industry matured and as outsourcing became the preferred route to cut costs and compete more effectively globally. This is the logical economically efficient strategy as any industry matures. However the strategic consequences could be that many industrial and national capabilities could either be destroyed or significantly eroded. Reestablishing these capabilities is likely to take time. During this transition time China would enjoy a significant competitive and

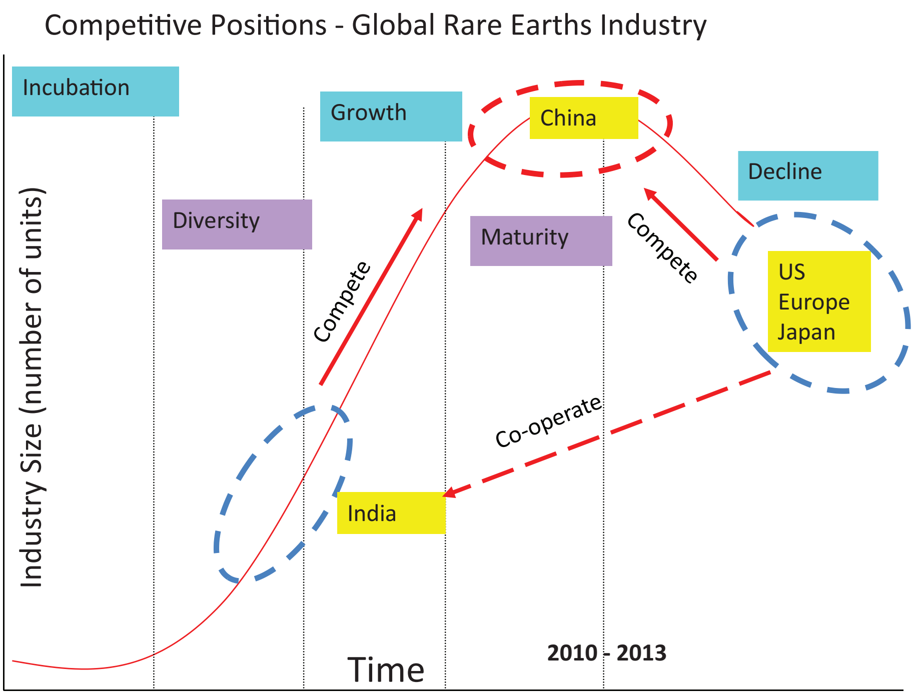

Figure 6

strategic advantage especially if the green technology markets grow.

The Chinese embargo has also stimulated research into RE substitute technologies.

In the catalyst industry for petroleum cracking non RE based catalysts are now available.[8] It is a moot point whether they will immediately substitute for the dominant RE formulations of catalysts.

Motor configurations that do not depend on permanent magnets are also under investigation. Once again how soon will these be economically viable for use in large scale is an open question.[9]

Lithium ion batteries are being considered as a superior alternative to Lanthanum Hydride batteries by US hybrid car manufacturers. The recent grounding of the Boeing Dreamliner because of fire hazards arising from the use of Lithium ion batteries has cast some shadow over the prospects of large scale use of these batteries.[10] Japanese car makers appear to still prefer the use of the earlier generation RE batteries in their hybrid cars.[11]

Figure 6 provides an overview of the current competitive dynamics of the global RE

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[8] For details of the efforts of one of the leading catalyst producers in the world W R Grace see "Catalagram – A Catalysts Technologies Publication", No. 111/Spring 2012/www.grace.com, pp 2-11.

[9] For one such approach see Aaron Sichel, "The Story of Neodymium – Motors, Materials and the Search for Supply Security", A Chorus R White Paper available at choruscars.com

[10] On January 16 2013 a fire broke out due to a leak from a Lithium Ion battery aboard a Boeing Dreamliner Aircraft in Japan, resulting in the grounding of all the Dreamliners.

[11] For details on the pluses and minuses of RE and Lithium ion batteries see Jack Lifton, "What's the Play in Lanthanum" http://www.resourceinvestor.com/2008/03/27/whats-the-play-in-lanthanum. Many Japanese car manufacturers like Toyota and Honda prefer Lanthanum Nickel Hydride batteries for their hybrid cars.

industry with the relative positions of the major countries including India represented.

India needs to move forward from a fairly inferior position to a more favourable position closer to the mature phase of the Life Cycle.[12] It could use its large RE resource base and its large market as levers to move forward. Obviously China would not be the preferred partner for this change in position. The US, Japan and Europe might view Indian efforts more favourably given their current problems with China's dominant position in RE. Though this movement is conceptually easy, the Indian record in coordinating and directing such efforts has not been very good.

7. Implications for India – Is a National Strategy on RE Needed?

China is clearly in a pre-eminent position of domination. Its belief that RE would continue to be an important industry globally appears to be currently vindicated. It would do everything in its power to retain this position.

The US industry as well as the industry in Europe appears to be in the decline phase. They need to reverse direction and reclaim their position in the global RE industry. Japan is relatively better off than the US because its industries are relatively more protected. However it does face raw material shortages and some decline in economic power.

Both at industry level as well as national level the current competitive dynamics favour cooperation between the advanced economies and India. These could cover all areas from trade to specific technologies and products catering to needs in the commercial and military sectors.

Of course in this evolving dynamic one of the uncertain elements are breakthrough discoveries either in RE which would enhance China's position or in substitutes for RE which would erode China's current position. If countries and industries can capitalize on such breakthroughs they could pioneer the creation of new products, industries and new industrial clusters.

Though the broad contours of the competition and cooperation framework for the RE industry are clear and do not favour India all is not lost.

India could use it large resource of RE and its prospects for economic growth to improve its competitive position. Though India has a reasonable base in R&D especially within the public sector mission organisations, its record in converting technology into viable products and services has not been very good. Institutional bottlenecks that are hard to breakdown and an inability to coordinate activities in complex systems are responsible for this state of affairs.

Active intervention may be needed to change this current state of affairs. The form and content of such an intervention can only arrived at after more detailed studies at the industry and product levels are carried out.

The broad RE Industry Life cycle concept addressed in this note, needs to be buttressed with a micro level understanding of the dynamics of each RE product. The micro detail should guide the specific strategies and actions that India should take. The starting point for this effort on a "RE plan" should be the priority

[12] Rahul Jain &SandeepNadkarni, "Rare Earths and Opportunities Beyond China", Minerals & Metal Review, October 2011, pp 64-68.

value chains for the defence and economic sectors that have been identified.

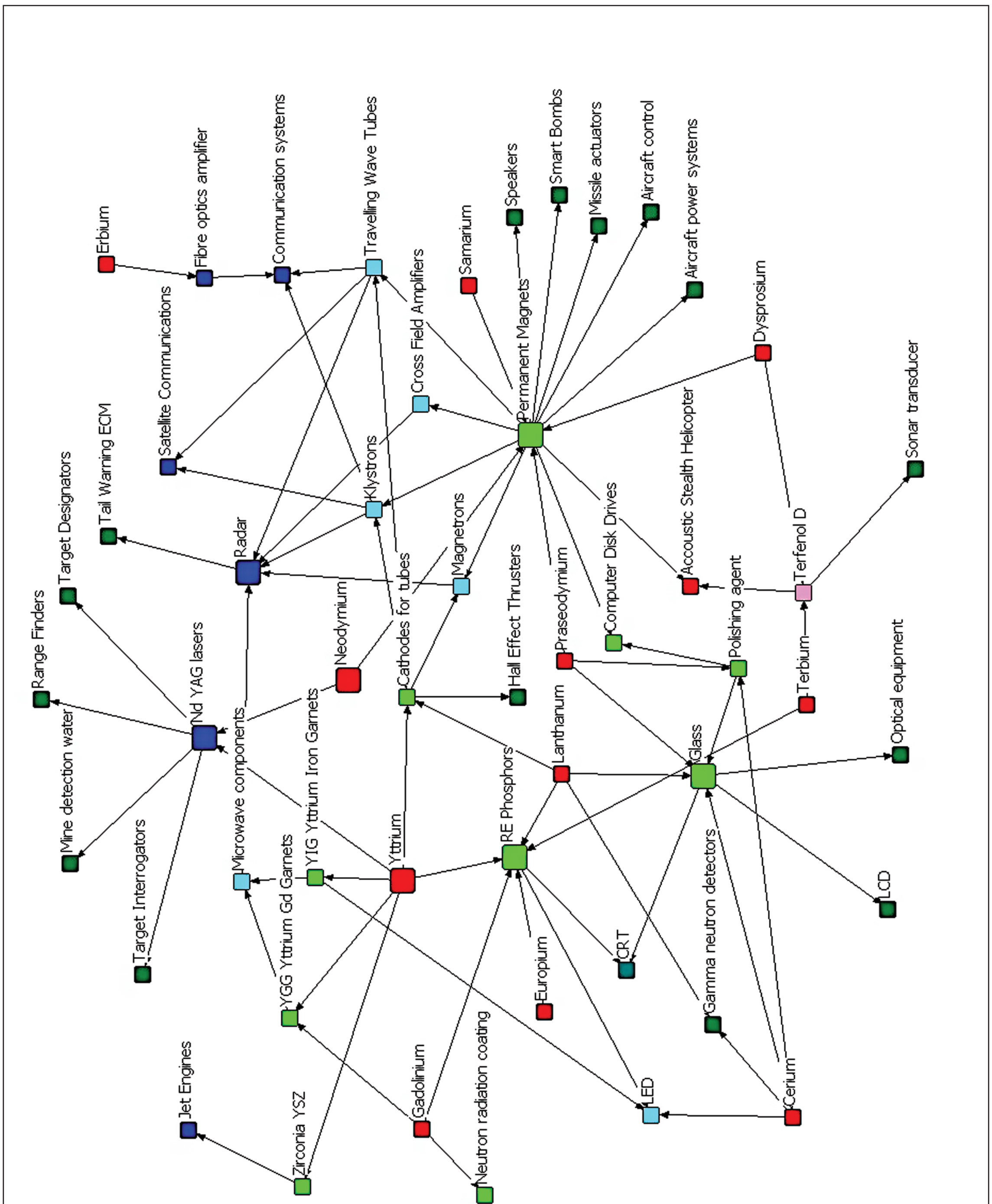
These are:

- Permanent Magnets for use in motors, actuators, vacuum tubes, computer hard drives and speakers for both civilian and defence programmes.
- RE materials in the Phosphor and Glass industries.
- Rare Earth garnets for making microwave components used in radar and satellite communication systems.
- Rare Earth cathodes for use in vacuum tube devices. These cathodes are used for both radar and space communications systems as well as in ion thrusters for satellites.
- YAG lasers also appear to be critical products that use RE. Here again there are both military and civilian applications.
- Acoustic devices for a variety of applications in the defence sector including sonar as well as noise suppression applications.
- RE materials are also critical for the production of hybrid cars. They are used in the motors, batteries catalytic converters, glasses and phosphors used in automobiles. Yttrium Stabilised Zirconia (YSZ) are also used to make the oxygen sensors used for controlling combustion in auto engines.
- RE catalysts are also critical for the petroleum refining industry.
- Many emerging green technologies like windmills, fuel cells need large quantities of RE materials. Lower energy consuming LED and CFL lighting also need RE coatings.

These studies should not only cover the materials and technology side but also include the current global and domestic product and market dynamics. Expert opinion on alternatives to the use of RE must be an explicit mandate given to these groups.

The micro level detail available from these studies should enable the crafting of a national level strategy on RE materials and technologies.

Annexure 1



Erbium
Fibre optics amplifier
Communication systems
Travelling Wave Tubes
Cross Field Amplifiers
Samarium
Speakers
Smart Bombs
Missile actuators
Aircraft control
Aircraft power systems
Dysprosium
Sonar transducer
Satellite Communications
Tail Warning ECM
Target Designators
Range Finders
Radar
Klystrons
Magnetrons
Permanent Magnets
Accoustic Stealth Helicopter
Terfenol D
Computer Disk Drives
Polishing agent
Terbium
Praseodymium
Hall Effect Thrusters
Cathodes for tubes
Neodymium
Nd YAG lasers
Microwave components
YIG Yttrium Iron Garnets
Optical equipment
Glass
Lanthanum
RE Phosphors
Yttrium
Mine detection water
Target Interrogators
YGG Yttrium Gd Garnets
LCD
CRT
Europium
Gamma neutron detectors
Cerium
LED
Gadolinium
Neutron radiation coating
Zirconia YSZ
Jet Engines

Annexure 2

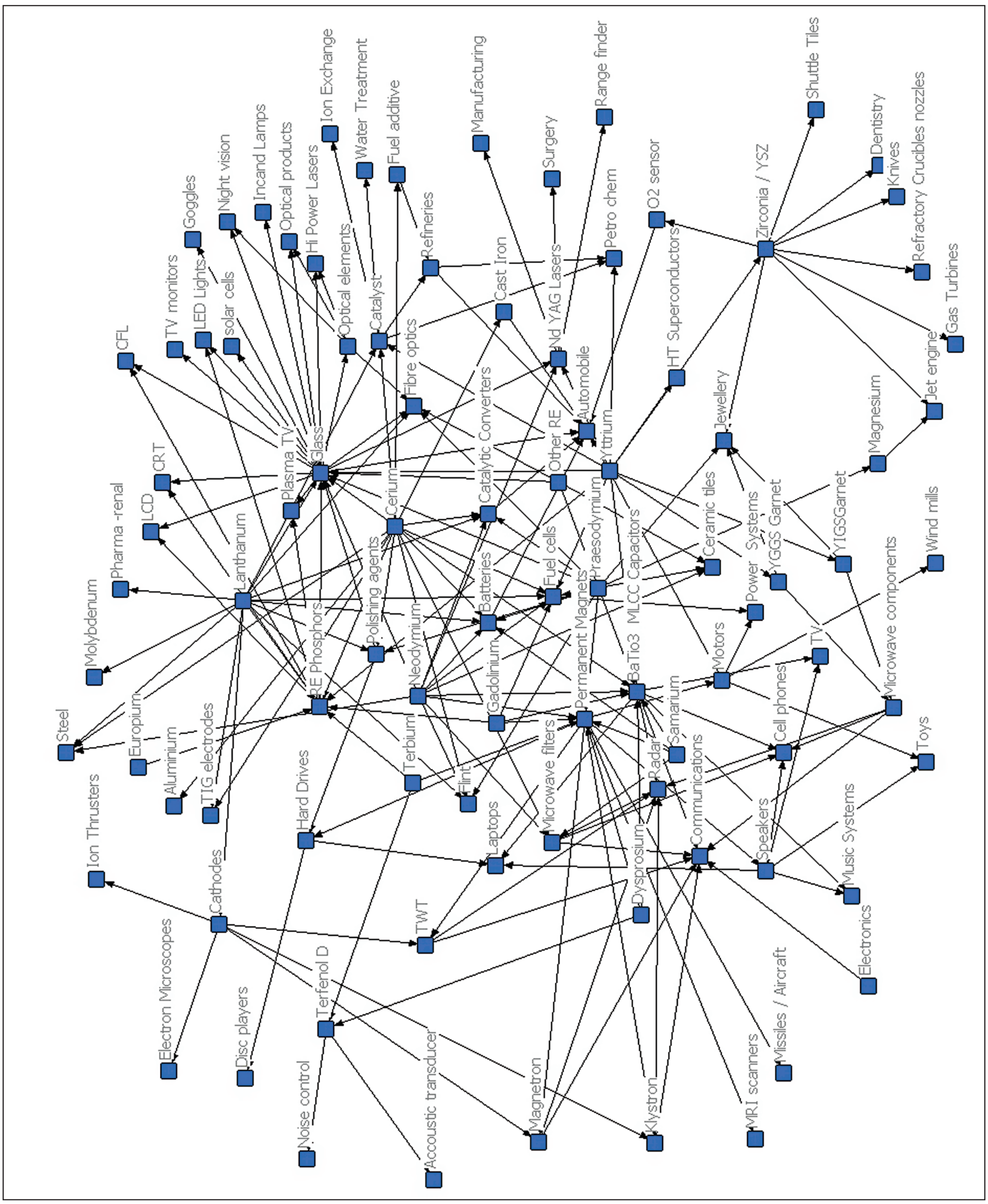
Rare Earth Defence Network Rankings

Node	Input into Node	Output from Node	Total Links	Rank
Permanent Magnets	4	11	15	1
RE Phosphors	6	2	8	2
Glass	4	3	7	3
Cerium	0	6	6	4
Yttrium	0	6	6	4
Nd YAG lasers	2	4	6	4
Cathodes for tubes	2	4	6	4
Radar	5	1	6	4
Travelling Wave Tubes	2	3	5	9
Klystrons	2	3	5	9
Lanthanum	0	4	4	10
Terfenol D	2	2	4	10
Zirconia YSZ	2	2	4	10
Polishing agent	2	2	4	10
Praseodymium	0	3	3	15
Gadolinium	0	3	3	15
YIG Yttrium Iron Garnets	1	2	3	15
YGG Yttrium Gd Garnets	2	1	3	15
Magnetrons	2	1	3	15
Communication systems	3	0	3	15
LED	3	0	3	15
Microwave components	2	1	3	15
Neodymium	0	2	2	23
Terbium	0	2	2	23
Dysprosium	0	2	2	23
Fibre optics amplifier	1	1	2	23
Satellite Communications	2	0	2	23
Accoustic Stealth Helicopter	2	0	2	23
Cathode Ray Tube (CRT)	2	0	2	23
Cross Field Amplifiers	1	1	2	23
Computer Disk Drives	2	0	2	23
Gamma neutron detectors	2	0	2	23
Erbium	0	1	1	33
Samarium	0	1	1	33
Europium	0	1	1	33
Missile actuators	1	0	1	33
Smart Bombs	1	0	1	33
Aircraft control	1	0	1	33
Aircraft power systems	1	0	1	33

Node	Input into Node	Output from Node	Total Links	Rank
Range Finders	1	0	1	33
Target Designators	1	0	1	33
Target Interrogators	1	0	1	33
Mine detection water	1	0	1	33
Speakers	1	0	1	33
Shuttle Tiles	1	0	1	33
Jet Engines	1	0	1	33
LCD	1	0	1	33
Optical equipment	1	0	1	33
Sonar transducer	1	0	1	33
Tail Warning ECM	1	0	1	33
Neutron radiation coating	1	0	1	33
Hall Effect Thrusters	1	0	1	33

ANNEXURE 3

The Rare Earth Economic Network



Annexure 4

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
Fibre 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

Node	Input into Node	Output from Node	Total Links	Rank
Steel	3	0	3	38
Ceramic tiles	3	0	3	38
YIGSGarnet	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
Incand Lamps	1	0	1	64
Goggles	1	0	1	64
TV monitors	1	0	1	64
Molybdenum	1	0	1	64
Aluminium	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
Accoustic transducer	1	0	1	64
HT Superconductors	1	0	1	64

Annexure 5

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 commercialised 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 fibre amplifier – big push to fibre 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