India's Rare Earths Industry

A Case of Missed Opportunities

S Chandrashekar, Lalitha Sundaresan

The creation of knowledge in the rare earths domain in India is confined to a few government-run complexes with no major links to commercial industry. With interaction between the research community and industry non-existent, India's position as a player in the global rare earths ecosystem is bound to be weak. Further, in the absence of a cohesive national strategy for moving the country up the value chain in rare earths into the intermediate and final product space, India continues to be a low-cost raw material supplier to the global rare earths industry.

S Chandrashekar (*chandrashekar.schandra@gmail.com*) is a former ISRO scientist and faculty at the Indian Institute of Management Bangalore. He is currently a visiting faculty at the National Institute of Advanced Studies, Bengaluru. Lalitha Sundaresan (*sundaresan.lalitha@gmail.com*) is a former ISRO scientist and a visiting faculty at the National Institute of Advanced Studies.

Global and Indian interest in the role of hi-tech materials such as rare earths for crafting strategies that further a country's development and geopolitical interests has been on the increase lately. This renewed interest has come about due to various actions taken by China to establish a dominant position in the global rare earths industry and to leverage this position to further its global interests (Mancheri et al 2013).

Because of their unique position in the periodic table, rare earth elements have many desirable properties that find use in a variety of high technology applications. Apart from their use in a number of well-established industries, rare earths are particularly important for the manufacture of key intermediates that go into a number of green energy products such as hybrid cars, energy efficient lighting, windmills and fuel cells. These new high growth industries are likely to fuel an increase in global demand for rare earth materials and products.

The value chains of the various rare earth elements and their connections with various intermediate and end use industries for an advanced economy such as the United States (US) or Japan have been well studied and mapped. Some of the major intermediate industries that are significant users of rare earths are the glass industry, permanent magnet industry, phosphors used in lighting and display devices, catalysts for the oil refining industry as well as oxygen sensors, batteries and catalytic converters for use in automobiles. Major sectors linked to these intermediates include consumer electronics, petrochemicals, transportation and green energy that include the new emerging industries of efficient CFL (compact fluorescent lamp) and LED (light-emitting diode) lighting (Chandrashekar 2013).

Rare earths are also key materials for use in a number of military and strategic systems. Rare earth permanent magnets are needed in several defence and space devices. Neodymium-doped Yttrium Aluminium Garnet (Nd YAG) lasers are used in range finding applications that are part and parcel of any advanced weapon system. Yttrium Iron Garnets as well as Yttrium Gadolinium Garnets are needed for building microwave components that go into advanced communications and radar facilities. Terfenol D, an alloy of terbium, iron and dysprosium, has unique properties that is used in sonar and other acoustic applications.

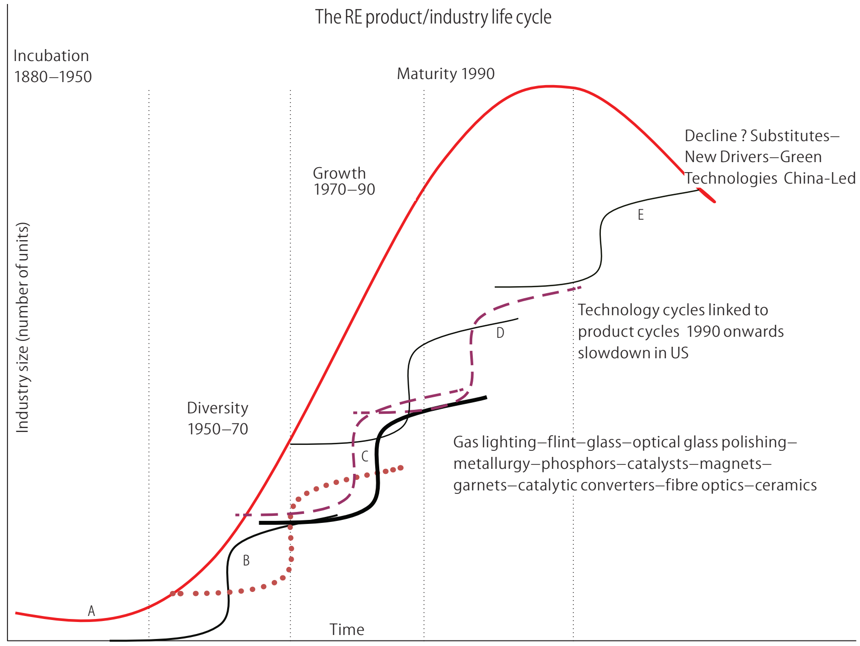
Historically, India was one of the early countries to recognise the importance of rare earths. Specific organisational and institutional arrangements were set up to regulate, manage and develop rare earth resources in the country. Over a period of time, global developments in rare earths coupled with Indian inertia may have significantly eroded India's competitive position vis-à-vis other countries in the management of a valuable national resource.

Given Chinese actions and renewed global interest in rare earths, it may be necessary for Indian decision-makers to take stock of where India is today with respect to the global rare earths industry and decide on an appropriate plan of action. This requires a deeper understanding of the various value chains in the global rare earths ecosystem and India's position in these knowledge-based value chains. Hopefully, such an analysis will also shed some light on the components of a national strategy for the management of this resource. These issues will be addressed in this article.

India and Global Industry

Rare earth resources are predominantly found in China, US, Australia and India. India occupies fourth position, with 1.3 million tonnes of rare earth oxide (REO) content. The Department of Atomic Energy (DAE), however, estimates the total rare earth reserves in India at 10.21 million tonnes. This would put India in the third position above Australia (Ministry of Mines 2012). India has also been engaged in mining and extraction activities for more than five decades. This makes it possible for India to become an

Figure 1: Rare Earth Industry Life Cycle



Source: Generated by the authors.

important player in the global rare earths industry.

In India, monazite is the principal source of rare earths. It occurs in association with other heavy minerals such as ilmenite, rutile, zircon, etc, in the beach sands and inland placer deposits (Ministry of Mines 2012). Monazite also contains thorium and uranium. Because of the presence of these radioactive elements, mining of monazite sands is carried out only by a government body, the DAE.

Indian Rare Earths Limited (IREL), an autonomous body under the DAE, is the sole producer of rare earth compounds in India. IREL has been in existence since 1949 in its current form and has also been exporting rare earth compounds for several decades. Even though IREL's name suggests that it is largely focused on the development and use of rare earths, most of its income is derived from the production and marketing of the other minerals that are contained in the beach sands such as ilmenite, rutile, sillimanite and zircon.

More recently, even the limited production of rare earths has been decreasing. In 2013–14, India produced less than a tonne of rare earth materials and sold about 4.2 tonnes mainly from its inventory. The absence of a domestic market and the fall in exports because of low-cost Chinese production have been the causes of this decline.

Most of the products using rare earth materials are currently imported into India in finished form. In spite of the fact that India was an early entrant into the mining and processing of rare earths, there has been no major effort within the country to go up the rare earths value chain (Parliament Question 2015). Currently there is no manufacturing facility in India for any of the intermediate rare earth products. In addition, separating out the various rare earth fractions into their individual elements and then converting them into the metal form for use in the making of products, increases the value addition to the raw material significantly (Shanghai Metals Market).

India and China started mining rare earths almost at the same time. In fact, there is a reference to the availability of monazite and rare earths in Southern India in a book published in 1915 (Johnston 1915). For a long time, India and Brazil were the only suppliers of rare earths; though at that time, many of the applications of rare earths were still to be discovered. China started mining rare earths in 1959. While China went ahead in building a strong domestic rare earths ecosystem, India has been primarily a supplier of rare earth raw materials and some basic rare earth compounds.

The story of how China has established a near global monopoly over rare earth raw materials and almost all intermediate rare earth products has been recounted in detail elsewhere (Mancheri et al 2013). Chinese behaviour in using their monopoly position in the rare earths ecosystem as a component of its geopolitical strategy is also becoming increasingly self-evident.

In 2010, China had cut off supplies of rare earths to Japan over a conflict between China and Japan in the East China Sea. Although there are different views (King and Armstrong 2013) as to whether China cut off supply to spite Japan, many political thinkers thought that China was using economic levers for geopolitical purposes.

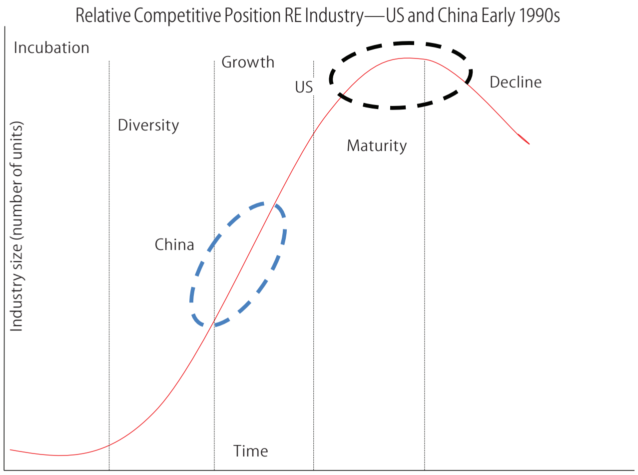
China's export of rare earth materials also came down significantly in the following years. These export curbs were meant to move production of high value addition rare earth products from around the world into China. This was the first instance where the world saw the impact of the dominant position occupied by China in the global rare earths industry. These Chinese actions have evoked concerns across the developed world about how to safeguard the supply of rare earth materials that play such a critical role in the continued development of their economies.

These Chinese moves and countermoves by the more advanced economies of the world provide a new set of potential opportunities to kick-start the moribund rare earths industry in India. In order to frame a suitable strategy for India, we must first look at the relative competitive positions occupied by the major players in the global rare earths ecosystem.

Current Competitive Positions

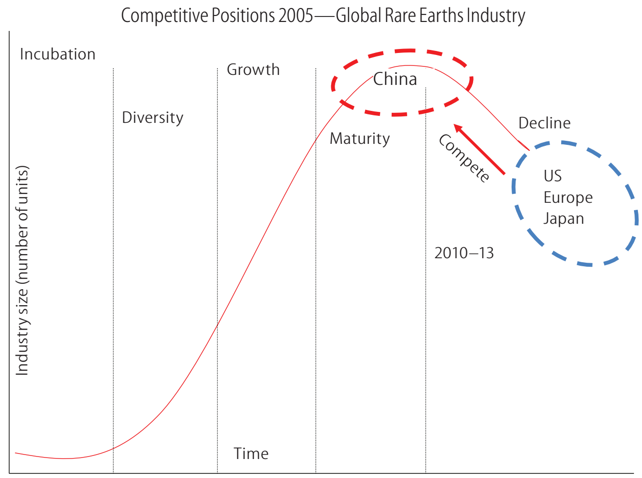
The use of evolutionary approaches exemplified by the use of 's' curves has been well-studied in the business world. As industries move from incubation into diversity, growth and maturity, the focus of strategy shifts from technology to products into markets and finally into production.

Figure 2: Global Rare Earths Industry in the 1990s



Source: Generated by the authors.

Figure 3: Global Rare Earths Industry after 2000



Source: Generated by the authors.

These connections between technologies, products, markets and industries and how they respond to competing and cooperating forces within any business environment provide a framework within which we could position the different players in the global rare earths business ecosystem (Chandrasekhar 1996).

An overview of the evolution of the global rare earths industry that links the various technology breakthroughs for product development with the evolution of an industrial ecosystem is provided in Figure 1 (p 28). This diagram is based on our study of the various technological breakthroughs as well as the intermediate and final products that resulted from them (Mancheri et al 2013).

Figure 2 shows the relative positions of China and the US in the early 1990s, when the global rare earths industry was in the early stages of reaching maturity. The US not only created most of the technology breakthroughs using rare earths but also pioneered the commercialisation of these breakthroughs. It was the world leader in rare earths with a complete well-connected rare earths industrial ecosystem.

Figure 3 shows how the relative competitive position between China and the US had shifted by about 2005. From being a laggard in the early 1990s, China has moved to hold a dominant position in the global rare earths industry. This has been accompanied by significant erosion in the capabilities of the US, Europe and Japan, whose industrial capabilities in critical rare earth value chains had declined alarmingly.

Available data on Indian capabilities, especially in the development of rare earth permanent magnets for use in the space and missile programmes, would seem to suggest that India was possibly in the early diversity phase.

These developments in the global rare earths industry led to a renewed interest in the development of the industry in India. A number of initiatives were undertaken by different entities within the country. One of them was a National Conference on Rare Earths Processing and Utilisation (hereafter, REPUT 2014) organised jointly by the Indian Institute of Metals (Mumbai Chapter), Rare Earth Association of India (REAI), and the Materials Research Society of India (MRSI) (Mumbai Chapter).

The papers presented in the conference provide us with empirical evidence on the kind of research currently going on in India in the field of rare earths. They can therefore be used to assess the current status of research and development (R&D) in rare earths. These research initiatives can also be linked to the various components of the Indian rare earths value chain. These connections (or their absence) between the content of R&D and the current status of rare earths value chain in India will enable us to make inferences about the relevance of rare earths R&D to the current Indian situation. It may also shed some light on the organisational and institutional bottlenecks that inhibit the development of an Indian rare earths ecosystem similar to those of the more advanced countries of the world.

The Indian Rare Earths Industry Value Chains

We examined the abstracts of the papers presented at the REPUT 2014 conference to make a critical appraisal of the R&D conducted within India on rare earths and the relevance of this R&D for India's position in the global rare earth value chain.

A number of entities under the DAE, led by the Bhabha Atomic Research Centre (BARC), accounted for 32 out of the 46 papers presented at the conference. These included 26 papers from BARC, two papers by IREL and one paper by the Atomic Minerals Division, the entity that is responsible for exploration activities within the DAE.

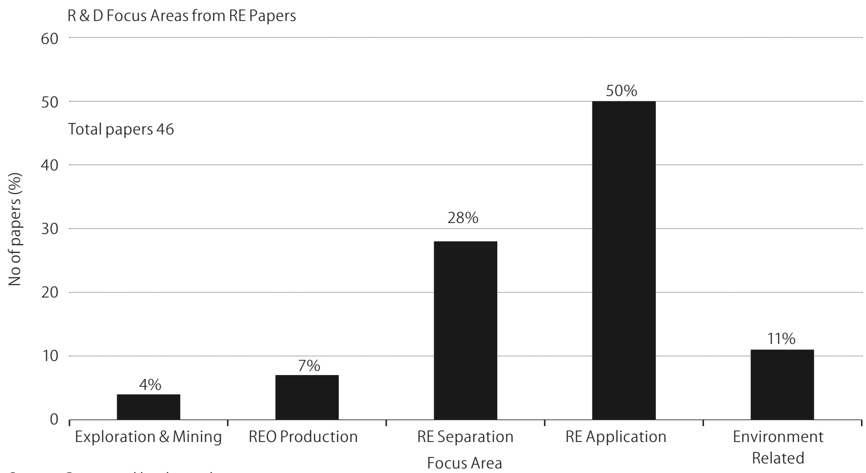
Eight papers were from the various Council of Scientific and Industrial Research (CSIR) laboratories. These included five papers from the National Institute for Interdisciplinary Science and Technology (NIIST), two papers from the Central ElectroChemical Research Institute (CECRI) and one paper from the Central Leather Research Institute (CLRI). The Defence Materials Research Laboratory (DMRL) had one paper and the universities accounted for five of the papers presented at the conference.

The research in rare earths is dominated by the DAE and the various entities (especially, BARC) that function directly under it. Other players include CSIR laboratories and a single defence laboratory, all of which come under the ambit of the science and technology sector of the country.

As we can see from the data, there was not a single paper in the conference that came from the private industry in India. There could be a multitude of reasons as to why this is so. Irrespective of the specific reason or reasons for this state of affairs, the evidence from the conference proceedings suggests that the creation of knowledge in the rare earths domain is confined to a few government-run complexes with no major links to commercial industry.

If we were to classify the papers on the basis of which part of the value chain they fall under, based on their content, an interesting story emerges. This is shown in Figure 4.

Figure 4: Papers under Different Categories



Source: Generated by the authors.

There were 23 papers (50%) that dealt with rare earth products, covering a large number of products and industries spanning the spectrum from the more traditional industries such as pigments, refractories, catalysts and alloys to more modern industries such as lasers, magnets, phosphors and other hi-tech products. This focus on products and their use is consistent with an Indian position in the diversity growth portion of the global s curve.

A closer scrutiny of the data however does raise a number of concerns regarding such an inference. The absence of any papers from industry in the conference indicates that industry in India is either not aware of rare earths-based product possibilities in the many established industries or is not interested in research related to rare earths for the products and services that it currently offers.

The knowledge creation part of the value chain takes place largely within the confines of the major public sector technology-oriented mission organisations. This is not connected in any way with industries which are the potential users and beneficiaries of this knowledge creation process. Unless this gap between the production of rare earth materials and their use in various products is bridged, the relevance of much of the product-oriented rare earths research becomes questionable.

The papers in the seminar seem to suggest that while there is academic interest in rare earth-based products, there is a total absence of any kind of industrial linkage in all these efforts. Most of these R&D efforts, therefore, are not likely to result in any kind of tangible economic benefit arising from industrial activities. Based on a simple count of the papers, at least 50% of the R&D effort will be wasted. It would therefore be more appropriate to move the Indian position in the global rare earths industry into the earlier less developed incubation phase.

The data from the papers presented at the conference also reveal a total absence of collaboration between the various science and technology departments and mission organisations that function directly under the government. There are no joint papers between any of the units operating under the DAE, CSIR and DRDO.

In 1996, the DMRL and Ministry of Defence transferred the technology of making Nd-Fe-B (Neodymium-Iron-Boron) permanent magnets to Mishra Dhatu Nigam (MIDHANI). This indigenous development was supported by the Technology Information, Forecasting and Assessment Council (TIFAC) functioning under the DST. It is interesting to note that MIDHANI was not represented in the conference. The TIFAC has also brought out a report "Handbook on Rare Earth Occurrences, Production & Application" in 2002. Obviously these efforts did not kindle any interest in the Indian industry.

Recognising the growing importance of Nd-Fe-B permanent magnets, IREL decided to establish a facility at its Rare Earths Division unit called PRYNCE (Praseodymium-Yttrium-Neodymium-Cerum) to produce 135 tonnes per annum of neodymium oxide (>95% pure) suitable for manufacture of Nd-Fe-B magnets (Nair 2001). The fact that the production of rare earths by IREL has witnessed a steep decline in recent years suggests that this initiative too has not been very successful.

The speaker from DMRL, however, did say that the organisation has been collaborating with the Department of Space (DOS). In an earlier report (Sundaresan and Chandrashekar 2014), we had mentioned that one of the successful collaborations that took place within the Indian science and technology government sector was the development of rare earth permanent magnets by the DMRL and Vikram Sarabhai Space Centre (VSSC) for use in Indian rockets and satellites. Though the magnets were developed and flown, they used imported rare earth material rather than the material processed and supplied by IREL. This seems to suggest the absence of any kind of coordinated activity between the various government science and technology establishments, especially in an area that is economically and strategically important.

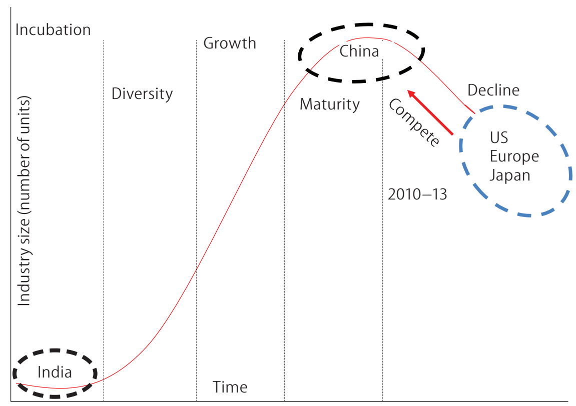
In 2011, a rare earth processing plant called Toyotsu Rare Earths India was set up in Andhra Pradesh. This is a joint venture between IREL and Toyota Tsusho Corporation (TTC), a subsidiary of Toyota Corporation. The plant is set up by Toyotsu Rare Earths Orissa (TREO). IREL will supply monazite to this plant after thorium, titanium, zirconium and uranium are removed. The plant will produce the oxides of lanthanum, cerium, praseodymium, neodymium, and cerium carbonate to be exported to Japan (Toyotsu Rare Earths India). Since the prices of rare earth oxides are much less than the prices of rare earth metals, the benefits to India are substantially lower than what they could have been.

Thus, there is no clear national strategy that connects the capabilities and needs that exist in different organisational entities that function within the science and technology sector of the Indian government. Even within the confines of government-run mission organisations, there is a visible disconnect between various users such as the DOS, DRDO and the potential materials supplier IREL. This is clearly evident from the conference proceedings which show no indication whatsoever of any kind of collaborative research between these entities.

Research pursued in rare earth mining, rare earth separation and production of different rare earth materials (37% of the papers) appears to be relevant and could add value to IREL's output. Unlike the case of product development research, this research may help IREL realise more money from its outputs. However, these capabilities do not find a place in the joint venture between IREL and TTC.

The analyses also substantiate earlier findings (Chandrashekar 2013) that there is an absence of a strategic direction in the current research efforts associated with rare earth materials. As a consequence, India does not have any major presence in the global rare earth ecosystem except as a limited supplier of basic rare earth materials.

Figure 5: India in Global Rare Earths Industry 2005



Source: Generated by the authors.

Indian Position in the Global Rare Earths Industry

Figure 5 shows the Indian position in the global rare earths industry. The absence of any real links between research and use and the total absence of any kind of rare earth-based product industries in the country places the Indian rare earths industry within the incubation phase in Figure 4.

The need for various rare earth-based products is likely to grow for some time globally and this offers a lot of value addition opportunities in the product space for rare earth materials for India. However, there are a number of structural problems within the Indian rare earths ecosystem that have inhibited the evolution of a well-connected industry that spans the spectrum from exploration and mining to the production of rare earth materials and various products based on rare earths. The US achieved such a capability in the 1970s and China achieved such a capability in the early 1990s.

The challenge of moving from the incubation into the growth and mature phases is not a trivial one and requires a substantial change in direction and strategy. In other words, India still has to go up the S curve if it wants to be a global player in the rare earths ecosystem and this needs to be done sooner than later.

If India can put together a national strategy for rare earths and bring about relevant coordination between research entities, the mission organisations and rare earth product producers in industry, there is still some hope that India can become a player of substance in the global rare earths industry. This will take some time to achieve and will require considerable investment in money, time and effort. This will also require significant improvement in national managerial capabilities that cut across mission organisations. There is also a need for strong leadership in these organisations to put these elements together. If India is not able to put together and implement such a national strategy, it runs the danger of continuing to be a low cost supplier to the global rare earths industry. Given its poor track record of linking research with products, it seems most likely that India will continue to supply rare earth raw material to the global rare earths industry.

A closer scrutiny of the recent joint venture between India and Japan will show that India continues to be a mere supplier of rare earth materials without any value addition in terms of high value materials or products. Even negotiating the implementation modalities of this arrangement took India more than two years given that a memorandum was signed by the DAE and the Ministry of Economy, Trade and Industry (METI) of Japan on cooperation in the field of rare earths on 16 November 2012.

Although there is a statement made by IREL that they will be collaborating with the Ministry of Defence and Department of Space to make rare earth permanent magnets, this will probably cater only to the strategic needs.

If, and that is a big if, India wants to be a player in the global rare earths industry, it is time that steps are taken sooner than later to identify the kind of intermediate products that need to be manufactured in the country and a clear manufacturing policy evolved. Only such an approach will maximise the economic pay offs coming out of the exploitation of a scarce resource.

Conclusions

There seems to be two distinct components of the Indian rare earths ecosystem that appear to be unconnected with each other. The first component of this Indian rare earths ecosystem relates to the DAE activities for producing basic rare earth materials that go into various downstream industries. This includes all activities from exploration to the production of REO as well as various rare earth metals and compounds. This component of the Indian rare earths ecosystem is directly linked to the global rare earths industry as a low-cost supplier of rare earth materials. It is largely exercised through IREL exports to the global marketplace. It is unconnected to the needs of the Indian strategic community and is also unconnected to any users in Indian industry.

The second component of the Indian rare earths ecosystem comprises a lot of product-oriented R&D both within the DAE and some science and technology public sector mission organisations. The available evidence suggests that even within this R&D ecosystem the connections between raw material production and the use of such materials in products required by the strategic sectors are weak or non-existent.

One would assume that the value addition of rare earths would begin at IREL and significant R&D both in rare earth separation and rare earth downstream materials production would emerge from there. This does not appear to be so.

Most of the knowledge generated for rare earth separation and downstream materials production is taking place within various BARC labs. One could postulate that with a proper strategy in place such research would move into IREL leading to value addition. The evidence from the papers as well as public knowledge about IREL suggests that this is not happening. This is indicative of fundamental structural problems in the DAE, BARC, IREL relationship that could come in the way of any value addition activities.

DMRL, a unit of DRDO, has developed the technology for Nd-Fe-B permanent magnets. Samarium Cobalt (Sm Co) magnets, the second generation permanent magnets, have been developed for use in the space programme by joint teams from the DMRL and VSSC. Starting from the PSLV–D 3 flight of 1996, over 5,000 of them have flown on Indian satellites and rockets. However, these magnets used imported rare earth material.

These fragmented capabilities that exist within the mission organisations of the national security complex in both rare earth material production and the production of magnets could be integrated and then transferred or scaled up for use in the civilian sector. This is an opportunity that could give a fillip to the emergence of new rare earths ecosystem within the country starting with this intermediate product.

The major missing component in the current rare earths ecosystem is of course the absence of any real linkages between the rare earth research community and Indian industry. As long as this situation is not remedied, India will continue to be a low cost supplier to the global rare earths industry. If these fundamental structural issues are not addressed, focusing R&D on the development of products will also be a wasted effort with no real economic benefits.

REFERENCES

Chandrasekhar, S (1996): "Technology and Business: the Missing Link," *IIMB Management Review*, April–June, pp 41–51.

Chandrashekar, S (2013): "Does India Need a National Strategy for Rare Earths," International Strategic and Security Studies Programme (ISSSP), National Institute of Advanced Studies Report R-18–2013, www.isssp.in.

Johnston, S J (1915): *Rare Earth Industry*, London: Crosby Lockwood & Sons.

King, A and S Armstrong (2013): "Did China Really Ban Rare Earth Exports to Japan?," East Asia Forum, Economics, Politics and Public Policy in East Asia and the Pacific, http://www.eastasiaforum.org, viewed on 26 July 2015.

Mancheri, Nabeel, Lalitha Sundaresan and S Chandrashekar (2013): "Dominating the World–China and the Rare Earth Industry," International Strategic and Security Studies Programme (ISSSP), National Institute of Advanced Studies Report R-19–2013, www.isssp.in.

Ministry of Mines (2012): "Rare Earths and Energy Critical Elements: A Roadmap and Strategy for India," Government of India, Centre for Study of Science, Technology and Policy (CSTEP) Report.

Nair, V R (2001): "Production of Neodymium at PRYNCE Plant," *Nuclear India*, Vol 34, Nos 7–8.

Parliament Question 1601 (2015): Rajya Sabha, "Augmenting the Capacity of IRE Plant," answered on 12 March 2015.

Sundaresan, Lalitha and S Chandrashekar (2014): "R&D on Rare Earths and Value Addition–the Indian Case," International Strategic and Security Studies Programme (ISSSP), National Institute of Advanced Studies, www.isssp.in.

Technical & Closing Report submitted to TIFAC by DMRL (1996): "Commercialisation of Home Grown NdFeB Permanent Magnet Technology."

Toyotsu Rare Earths India, http://trei.co.in/our-company.php, accessed on 10 July 2015.

Shanghai Metals Market, http://www.metal.com/metals/rare-earth/prices#1, accessed on 9 July 2015.