सत्यमेव जयते

Government of India
Ministry of Mines
New Delhi

RARE EARTHS AND ENERGY CRITICAL ELEMENTS: A ROADMAP AND STRATEGY FOR INDIA

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Photographs Courtesy: Indian Rare Earth Limited (IREL)
Cover page: IREL Plant across the River Periyar, Kerala
Back page: IREL Dredging Operation

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Foreword

Rare Earth Elements (REEs) and Energy Critical Elements (ECEs) are extensively used in clean energy applications like wind energy turbines, hybrid car batteries/electric motors, solar energy collectors, thin film technologies and in defense-related systems. There is a need for development of an appropriate strategy for their indigenous production, based on the analysis of availability, identification, exploration and discovery of economically extractable deposits. It is critical to develop processes for their recovery in usable forms in order to ensure long term national raw materials security.

In view of the increased demand of REE and near monopoly of supply from China, there is a need to develop national policies and implementation strategies for ensuring indigenous supply of REE. Ministry of Mines has taken an initiative to review the status of availability of REEs and ECEs with regard to their exploration, extraction and processing technologies in association with the Center for Study of Science, Technology and Policy (CSTEP) Bangalore. As this is an important area of concern, it calls for a cooperative R&D effort cutting across several organizations. A Steering Committee was constituted by the Ministry of Mines with the ultimate intention of preparing a strategy paper for the Govt. providing short, medium & long term options along with proposals for specific policy & legislative interventions.

The report is an outcome of detailed discussions held between the members of Steering Committee during its meetings and is a product of extensive data collection and analysis. It also reviews India's present production, consumption, reserves, recycling etc. and suggests policy initiatives and interventions required from the Government.

We believe that REEs and ECEs are going to play a major role in renewable energy applications and information technology products. If India is to be self-reliant in these products—which it must, if it is to minimize Green House Gas emissions—then it must adopt novel routes that do not emphasize only economic viability but also self-reliance.

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Government of India
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Acknowledgements

This report is an outcome of the contributions made by the members of Steering Committee constituted by Ministry of Mines for coordinated efforts to review the status and availability of the Rare Earth Elements (REEs) and Energy Critical Elements (ECEs) in India to ensure long term national raw materials security. The report has been finalized by Dr. R. Krishnan, Chief Advisor, Dr. Mridula D. Bharadwaj, Principal Research Scientist, Dr. N. Balasubramanian, Advisor of Center for Study of Science, Technology and Policy (CSTEP) Bangalore and Shri A.K. Bhandari, Sr. Advisor, Centre for Techno Economic Mineral policy Options (CTEMPO) based on the inputs and discussions with the members. The report has been drafted under the directions of Shri Vishwapati Trivedi, Secretary (Mines) Govt. of India and Dr. V.S. Arunachalam, Chairman, CSTEP, Bangalore.

Thanks are due to Shri S. Vijay. Kumar, the then Secretary (Mines) for initiating and providing guidance during the early phase of the study. Dr. A. K Suri, Director (Materials group) BARC, Dr. R.N.Patra, CMD, Indian Rare Earths Limited, Shri C.K. Asnani, Director (Technical), IREL, provided data on the current status of REE extraction, separation, and value added materials. Dr. B.D. Pandey (Chief Scientist), Dr. K.K. Sahu (Principal Scientist) National Metallurgical Laboratory- Jamshedpur provided inputs on the R&D efforts for the recovery of Rare Earth (RE) Metals and Lithium by Recycling Electronic Waste and other resources. Dr. T Subbaiah, Chief Scientist, IMMT Bhubaneswar, outlined the plans of IMMT to develop the process know how to recover REE values using Bio-mimetic techniques. Dr. T. L. Prakash, Director, Centre for Materials for Electronics Technology-Hyderabad, gave an account of the studies initiated by CMET towards recovery of REEs from e-waste and necessity for a policy on e-waste in India. Dr. K Rajaram, Dy. Director General, Dr. M. S. Jayaram, Director, Geological Survey of India, provided inputs on the status of occurrence and exploration of primary sources of REEs in India. Dr K Muraleedharan, Director of Materials, Defense Research and Development organization (DRDO), Dr. P.B. Maithani, former Director (Atomic Minerals Division) Hyderabad and scientists of CSTEP provided valuable inputs during the course of the study. We would like to thank Ms. Bhargavi Kerur, Member Technical Staff, CSTEP for designing the layout and developing the final form of the report.

The contributions of all the steering committee members are gratefully acknowledged.

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Executive Summary

An initiative was taken by Ministry of Mines (Centre for Techno Economic Mineral policy Options- CTEMPO) to review the status of availability of Rare Earths and Energy Critical Elements with regard to their status in exploration, extraction and processing technologies along with the Center for Study of Science, Technology and Policy (CSTEP), Bangalore.

As this is an important area of concern, it called for a cooperative research effort cutting across organizations. A Steering Committee was constituted by the Ministry of Mines in August 2011, chaired by the Secretary (Mines) and co-chaired by Dr. V.S. Arunachalam, Chairman- Center for Study of Science, Technology and Policy (CSTEP), Bangalore, with members from DST, GSI, DRDO, BARC, IMMT, NML , DAE, IREL and Mr. A. K. Bhandari of C-TEMPO as Member Secretary to prepare a position paper on current status of Rare Earths and Energy critical Elements like gallium, indium, germanium, selenium, lithium etc. in India (Annexure 1).

This report reviews India's production, consumption and reserves, and also suggests policy initiatives and interventions required from the Government for the growth of this sector. The report has been drafted and finalized by CSTEP and C-TEMPO after incorporating the suggestions made by members of the Steering Committee.

The supply chain for rare earth elements generally consists of exploration, mining, extraction and manufacturing. Necessary initiatives need to be taken for value-added refining, metal/alloy production and manufacturing components for end-use.

Exploration

In India, monazite has been 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. It also contains thorium and uranium. Although India possesses large deposits of monazite, the heavier rare earths are not present in sufficient quantities in this mineral. Concentration of REEs in hard rock has been recorded in association with carbonatites, syenites, albitites, granites, pegmatite, apatite, phosphorites and carbonaceous schists in various parts of the country. Fresh sources of REEs from primary rocks need to be explored. There is a need for further exploration with modern concepts and tools including remote sensing capabilities. This will help GSI and AMD to generate more detailed and accurate data on unexplored areas. This will be useful for locating suitable target areas for further search of economically exploitable deposits of REE. The occurrence of some of these minerals, particularly the economically exploitable ones is described in Chapter 2.

ECEs have not been a primary target of domestic mineral exploration and hence there is limited knowledge of what geological characteristics indicate the likelihood of their deposits. Lithium is usually extracted from brine. It also occurs in spodumene associated with granites and pegmatite in crystalline terrains. The occurrence of spodumene in Purulia district West Bengal and in parts of Rajasthan needs to be explored. A brief review of occurrences of ECEs is also reported in Chapter 2.

Extraction

The ECEs namely germanium, gallium, indium, selenium, tellurium etc. are not found in concentrations high enough to warrant extraction of these elements as primary products. Most of these metals are produced as by-products during the production process and smelting of base metals like lead, zinc, copper, aluminium and tin. A complicating factor is that they exist in very low percentages, even in potentially economic ore deposits in which they occur. Their production is technology intensive.

Gallium is extracted as a by-product from the Bayer-liquor during the processing of bauxite to alumina. Though laboratory and pilot scale studies for extraction of gallium have been carried out, no gallium is produced by NALCO. ***Indium*** is essentially obtained as a by-product during zinc refining. Hindustan Zinc Limited (HZL) is yet to make efforts to recover this metal. Both ***selenium and tellurium*** are byproducts of the electrolytic refining and smelting of copper. Selenium is currently produced only in small quantities in India.

In case of ***REE*** the key issue is the separation of the individual elements. State of the art rare earth metals extraction techniques and facilities have to be pooled and the gap in the areas needs to be identified. National Metallurgical Laboratory has carried out analysis of blast furnace slags from two different sources. It contained Yb and Lu in levels similar to that in bastanasite. With large scale availability of such slags, a good amount of valuable REEs can be recovered.

Process Metallurgy Research and Development has remained dormant in the past few decades. Only a few institutions are carrying out studies in this area. There is a compelling need to reactivate this area of technology by drawing attention of process metallurgists to solve this pressing problem.

Reduce, Recycle and Substitute

As REEs and ECEs are scarce, it is natural to look for a reduction in their consumption, their substitution with other elements and also recycling of end of life components containing these elements.

Recycling normally is a cheaper and quicker way to get materials than going in for costly exploration activities that are time consuming too. Realizing the vast potential for recovery of valuable and critical elements from wastes, many countries have started banning export of end of life products that contain these elements. The US has recently tabled a 'Responsible Electronics Recycling Act' with a view to recycle RE material from them. Belgium had taken a big lead in this direction.

In India, recycling technologies for recovery of REEs and ECEs from e-waste are yet to be developed. CMET, Hyderabad has initiated studies for recovering REs from spent Ni-MH batteries. Chapter 3 describes some of the international activities in this area.

Partial substitution of scarce materials is a promising area of research in Materials Science. Radical approaches are needed to substitute or replace rare earth elements totally as is being attempted in the case of replacing permanent magnet motors with induction motors. In this context, nano technology has come in handy to a certain extent with regards to magnetic materials. Nano technology has a great potential but it is not fully exploited, more so in our country. A few achievements in this area are given in chapter 4.

Policy Initiatives

The stockpiling of a rare commodity to the extent possible to tide over the immediate supply concerns is one possible option. To secure the supply of raw materials for both the medium term and long term, there is a need for entering into bilateral agreements with countries with which we have MoUs in exploration and sharing of data. Countries like Afghanistan, Mozambique and Ukraine hold potential for rare earths and ECEs and Bolivia for lithium. India should use the Joint Working Group (JWG) route to acquire assets in these countries. Government should take an aggressive role in the acquisition of assets abroad by Indian entities. This needs creation of government. backed wealth funds to support acquisition abroad.

There is an urgent need for cooperative research in geological modelling of the mineral deposits, ore forming systems, basic geochemistry and development of indigenous extraction and processing technologies of these elements. The option of collaborating with foreign laboratories should also be kept open.

The availability of ECEs i.e. indium, gallium, selenium and tellurium etc., is strongly influenced by the commercial attractiveness of the main metals of which they are the by-products. Government should facilitate and frame market activity to ensure their supply. This involves creating an environment where the domestic producers are encouraged to produce these metals by incentivizing through fiscal measures. Chapters 5 and 6 discuss these aspects in detail.

The report highlighting the issues surrounding the REEs and ECEs with regard to their supply chain vulnerability is intended for the policy makers for evolving strategies and providing financial assistance for implementation of the recommendations.

Chapter 1: Introduction

The Rare Earth Elements (REEs) are a unique group of elements that exhibit special electronic, magnetic, optical and catalytic properties. In view of the increased demand of REEs and near monopoly of supply from China, there is a need to develop national policies and implementation strategies for ensuring indigenous supply of REEs. An initiative has been taken by Ministry of Mines to review the status of availability of Rare Earth Elements (REEs) and Energy Critical Elements (ECE) in the country with regard to the status of their exploration, extraction and processing technologies.

As this is an important area of concern involving multifarious activities, it called for detailed discussions involving all concerned agencies. Accordingly a Steering Committee was constituted by Ministry of Mines to develop a position paper and roadmap on the status and availability of these elements. The Steering Committee was chaired by Secretary (Mines) and co-chaired by Dr. V.S. Arunachalam, Chairman- Center for Study of Science, Technology and Policy (CSTEP), Bangalore and comprised members from GSI, DRDO, BARC, IMMT, NML , AMD , DAE, IREL with Director, C-TEMPO as Member Secretary. (Annexure-I)

Increasing concern about the effects of greenhouse gases has caused countries around the world to explore clean energy technologies to reduce emissions. The search is all the more critical for India with its present level of population and anticipated increase in GDP. There is no other option than to look for clean energy technologies for electric power generation to meet the anticipated growth of our country.

India has ambitious plans for generating solar power of 30,000 MW and wind energy of 50,000 MW by 2030. The main components in solar PV technology are silicon, both crystalline and amorphous, cadmium telluride and copper- indium- gallium- selenide. With respect to the wind energy, the critical component is the high strength RE permanent magnets. In hybrid and electric vehicles, REEs like lanthanum are used in the Ni-MH battery pack. The household fluorescent lamps, CFLs and the LEDs require REE based phosphors. Portable electronics and high performance alloys also require REEs.

India has placed great emphasis in developing nuclear, solar thermal (CSP) and photovoltaic (PV) and wind power in an effort to reduce 2005 emission levels by 20-25% before the year of 2022. Further reduction in emission levels can be achieved by switching to energy efficient technologies wherever possible, especially in energy guzzling industries such as cement, iron and steel. All these will require increased use of REEs. Table 1 gives a summary of potential RE markets in India.

Table 1: Potential RE Markets in India

End Use	REE required	Present status	Expected (2030)
Magnets for wind turbines	Nd , Pr, Dy, Tb (high strength magnets have 30 % RE)	12,000 MW of wind power capacity	~ 50,000 MW
EV, Hybrid vehicles (batteries, motor, catalytic converter)	La (15 kg per car) Nd (1 kg per car), Dy, Tb, Ce	Negligible EV	Up to 1 million vehicles
LED	Y, Eu, Tb	Negligible	~ 1 million bulbs
Al, Steel, Mg industry, grain refinement	Ce, La , mischmetal		Huge growth rate
Screens brighteners (cell phone, computers, TV screen)	Eu	mostly imported	Huge growing market
Other magnets	Pr, Sm, Gd	mostly imported	Computer hard disks, microphones

Nuclear Power

The Government of India has already revealed its plan to increase the electric power production through nuclear technology from the present 2% to 22% of the energy mix by 2030. The signing of the Indo-US Nuclear Agreement enables India to import natural uranium from US and other countries subject to IAEA safeguards. However, there are still some concerns about obtaining nuclear enrichment and reprocessing technologies along with the associated equipment. India is following Homi Bhabha's three stage nuclear power programme as a closed cycle operation by reprocessing spent fuel from thermal reactors to extract plutonium and by utilizing thorium in a fast reactor system. The fast reactor is fuelled either by enriched uranium or plutonium. It was believed until recently that the country was lacking in sufficient quantity of natural uranium. Present projections of the Department of Atomic Energy have temporarily alleviated the short-term uranium shortages by the discovery of natural uranium reserves within the country. But, until confirmation of the quantity is established, uranium deserves to be in the energy critical elements list. Based on need for nuclear reactors, gadolinium, which is required for control purposes and niobium used as an alloying addition to zirconium for structural applications, can also be included in the critical elements list. Concerns over the safety of nuclear plants, after the recent Fukushima tragedy, have led to some uncertainty with regards to the projected growth rate of nuclear power in the country. Until these concerns are addressed and the public is reassured, the growth rate of nuclear power in India is likely to be uncertain, although it is expected to grow.

Solar Energy

Among the other clean and renewable energy sources, solar photovoltaic (PV) and concentrated solar thermal technologies (CSP) have developed significantly. Due to the initial high cost of generation of electricity per kWh, demand was not great during the first few years of solar energy production. But recently, due to the vast production of cheap PV panels in China, the cost of electricity per kWh has drastically reduced. Among the four viable CSP technologies (parabolic trough, solar tower, dish Sterling and Fresnel system), only parabolic trough has matured and emerged as a frontrunner in CSP technology. Due to the vast importance of reducing greenhouse gas emissions, the Government has embarked on a major National Solar Mission, where it has projected establishing grid connected solar power stations to generate 20,000 MWs by 2022 and an additional 2000 MWs of off-grid solar power. Half of the 22 GWs would be based on CSP technologies, while the rest would be photovoltaic. A solar photovoltaic cell operates with panels of crystalline/amorphous silicon or thin films of CdTe (cadmium-telluride). CIGS could be a serious competitor. Present indications are that the solar PV technology may turn out to be cheaper than CSP. Intense R&D activity is currently in the use of CIGS (copper-indium-gallium-diselenide) films. Thus, gallium, indium, tellurium and selenium can be included in the critical elements list. Cadmium, however, is likely to be replaced due to its high toxicity. On the other hand, CSP technologies do not have any constraint with regard to energy critical elements.

Wind Power

Another viable clean energy technology is wind power. The Indian Government has come out with an ambitious plan of setting up wind mills to generate 40,000 MWs of electricity by 2020. Wind mills operate with compact, permanent magnets in their motors which are mounted at heights of 80 and 100 metres. These largely consist of Nd-Fe-B. Neodymium is not that easily available.

Transport Sector

The same permanent magnets used in windmills are required for all electric vehicle motors, but need to operate at slightly elevated temperatures. Nd-Fe-B magnets lose their magnetic strength at such temperatures. The addition of dysprosium raises the Curie point of the magnetic material such that it becomes suitable for electric vehicles (EV). The projected growth of hybrid and electric vehicles in the near future would increase the demand for these magnets, thus placing Dy on the critical elements list.

Consumer Goods

In the common consumer goods, fluorescent lamps use a lot of rare earth based phosphors including europium, terbium and yttrium. Considering the huge consumer market for fluorescent lamps, it would not be out of place if these three rare earths are also included in the critical elements list. Other demands for rare earths are in petroleum cracking, catalytic converters for automobiles and as alloy additions in metallurgical industries.

Batteries

For almost all clean energies, efficient battery systems are required for energy storage. Lithium based batteries have been the leader in electric vehicle applications; whereas the sodium sulphur batteries are best known for renewable energy storage for grid integration. Intensive research is on to improve battery performance. Unfortunately, India does not have any significant natural lithium reserves, and thus needs to be in the critical elements category.

Overview of REE

Several rare earth elements such as La, Ce, Nd, Dy, Eu, Y and Gd along with ECEs such as Li, In, Te and Ga, (Fig.1) need a careful study with respect to their mineral resources, economic and environment friendly extraction processes, purification and consolidation into end products in a 'mineral to market' route.

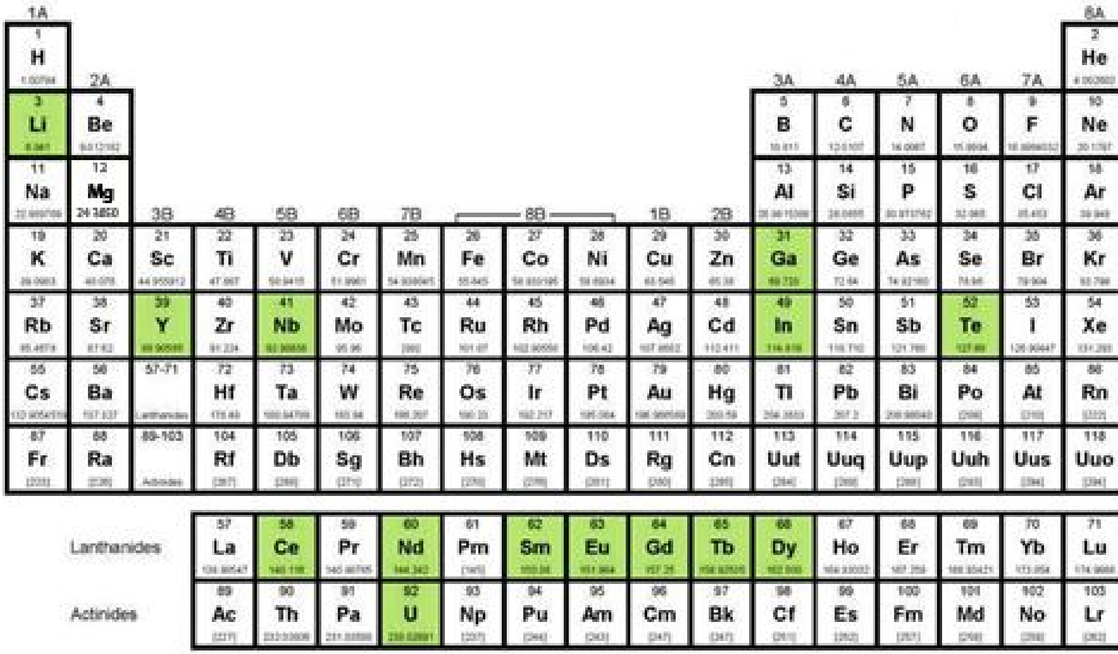

Figure 1: Rare Earth and Energy Critical elements are shown in the periodic table. The more critical ones are shaded here.

An overview of rare earths is necessary before we move on. The first 5 elements in the lanthanide series (La to Pm) are called Light Rare Earths (LREE), while the remaining elements are grouped as Heavy Rare Earths (HREE). The terming of the lanthanides, along with Y and Sc, as “rare earths” is a misnomer. In fact, the concentration of the rare earths in the earth’s crust is as high as some other elements including that of copper. The only difference is that rare earths do not occur as separate minerals amenable for easy exploration and mining and are widely distributed across the earth’s surface. Unlike base metals like iron, copper and aluminium, rare earths were not in use or in great demand throughout much of human existence, and hence not much attention was paid to their exploration, extraction and purification. Rare earths have risen in importance with their role in many important industries such as electronics, petroleum and clean-energy. The coining of the word “rare earths” to these set of elements may be due to their lack of mining in most countries combined with geo-political concerns which inhibited their mining.

China has been the major supplier of rare earths all over the world. Even though it has only 37% of global RE resources, it has captured the worldwide market to the extent of 97%. The low cost and efficient production process enabled China to monopolize the rare-earth market, forcing rare earth operations around the world to close down. Indian Rare Earths Ltd. (IREL), which was once a leader in export of rare earth compounds had to shut down its operation in 2008. But, over the last couple of years China has imposed restrictions and curtailed its export by over 30% citing domestic demands as the reason. This unexpected decline has restarted rare earth operations once again throughout the world. IREL has also reported that it would be able to supply REs from the last quarter of 2012.

As regards ECEs, demand for lithium may exceed supply in the near future. The major known reserves of lithium are in South American countries, and should they tend to throttle its supply, the world may face a situation similar to that of rare earths. From the worldwide criticality and general instability of supply, local efforts to determine additional mineral sources in the country must be immediately undertaken to jumpstart production. ECEs like tellurium, gallium, indium etc. are obtained as by-products in the extraction of base metals. Normally, the base metal manufacturers do not extract these, as the extraction processes require considerable investment. Unless the market is there, they cannot justify extracting these elements to their shareholders.

Global view

The US "Critical Materials Strategy" published by the US Department of Energy addresses Li, Mn, Co, Ni, Ga, Y, In, Te, La, Ce, Pr, Nd, Sm, Eu, Tb and Dy as key materials [1,2]. Dy, Eu, Tb, Y and Nd are listed as the most critical followed by Ce, La, Te and In for the short term. In the long term, lithium is added to this list. Likewise in the European Union, the Joint Research Centre Institute for Energy and Transport has brought out a report titled "Critical Metals in Strategic Energy Technologies" in 2011 [3]. It has placed Dy, Nd, Te, Ga and In in the high risk category, Nb, V, Sn and Se in the medium risk category and Ag, Mo, Hf, Ni and Cd in the low risk category.

References

1. *Critical Materials Strategy, U.S. Department of Energy, December 2010.*
2. *Critical Materials Strategy, U. S. Department of Energy, December 2011.*
3. *Critical Metals in Strategic Energy Technologies, JRC Scientific and Technical Reports, 2011, ISBN-978-92-79-20698-6.*

Chapter 2: Primary Sources of REEs & ECEs

Rare Earths (Res) are relatively plenty in earth's crust with cerium being the 25th most abundant element with a concentration of 68 ppm (similar to copper). However, because of their geo-chemistry, rare earth elements are dispersed and not found in concentrated and economically exploitable forms. The few economically exploitable deposits are known as rare earth minerals.

Rare Earths (RE) are a group of 17 elements starting with lanthanum in the periodic table of elements and including scandium and yttrium. They are moderately abundant in earth's crust but not concentrated enough to make them economically exploitable. The REEs find key applications in defence, electronics, energy systems etc. For instance, magnets made from rare earths are many times more powerful than conventional ones. Along with energy critical elements (ECE) such as lithium which has become ubiquitous as a battery material, REEs have emerged as strategic elements essential for sustainable energy systems.

Worldwide Resources

It is well known that monazite crystals are a good source of REEs but such crystals are very rare to find. Weathering of pegmatite rocks containing monazite leads to placer deposits in beach sands.

The other source of REs worldwide is the carbonates and fluorinated carbonates in the form of bastnasite. Bastnasite and monazite are the most important rare earth bearing minerals. Xenotime, another phosphatic mineral is of considerable importance, as it has a better content of heavier rare earths as compared to monazite and bastnasite. The composition of these three minerals is given in Table 2 (1). Table 3 gives the world resources of rare earths (2). India occupies 4th position with 1.3 million tonnes of REO content. However, the Department of Atomic Energy has estimated the total RE reserves at 10.21 million tonnes (3).

Fearing a supply chain constraint, companies like Molycorp's Mountain Pass have started processing existing tailings stockpiles. It is estimated that Molycorp would produce about 20,000 tonnes of REEs by 2013. Mount Weld mine in Australia is expected to start production this year. Based on a US States DOE communication, the Critical Materials Strategy Report 2011 lists the production of REE in 2010 and their projected availability by 2015 (Table 2).

Table 2: Composition of Bastanite, Monazite and Xenotime

Element	Bastnasite	Monazite	Xenotime
	Wt% on REO basis		
Lanthanum	32	22	8
Cerium	49	47	15
Praseodymium	4	5	2
Neodymium	13	18	6
Samarium	0.5	3	1.5
Europium	0.1	0.02	0.5
Gadolinium	0.3	1	2.3
Terbium	0.02	0.1	0.6
Dysprosium	0.1	0.2	5.3
Holmium	0.03	0.1	1.3
Erbium	0.03	-	4.5
Thulium	0.02	-	0.7
Ytterbium	0.01	-	4.9
Lutetium	0.01	-	0.7
Yttrium	0.3	0.4	47

Table 3: World Resources of Rare Earths (By Principal Countries)

Country	Resource Base
Australia	5800
China	89000
CIS nations	21000
India	1300
Malaysia	35
Thailand	NA
USA	14000
Other countries	23000
World : Total	150000

Table 4: Current and Projected Future Rare Earth Supply (Tonnes)*

		Potential Sources of Additional Production between 2010 and 2015									
		United States		Australia			Vietnam	South Africa			
	2010 Production[67]	Mt. Pass Phase I[70]	Mt. Pass Phase II	Mt. Weld[71]	Nolans Bore[72]	Dubbo Zirconia[73]	Dong Pao[74]	Steenkamps-kraal[75]	Russia & Kazakhs-tan[68]	India[69]	Total 2015 Production Capacity
La	31,000	5,800	6,800	5,400	2,000	510	970	590	140	560	54,000
Ce	42,000	8,300	9,800	9,800	4,800	960	1,500	1,300	290	1200	81,000
Pr	5,900	710	840	1,100	590	110	120	140	20	140	9,800
Nd	20,000	2,000	2,300	3,900	2,200	370	320	450	44	460	33,000
Sm	2,800	130	160	480	240	56	27	68	5	68	4,000
Eu	370	22	26	84	40	2		2	1	0	550
Gd	2,400	36	42	170	100	56		45	1	30	2,900
Tb	320	5	6	21	10	8		2	0	0	370
Dy	1,600	9	10	21	30	53		18	1	0	1,700
Y	11,000	0	0	63		410	21	590	0	0	11,000
Others	2,000	15	18	0	0	0	25	0	3	25	2,000
Total	120,000	17,000	20,000	21,000	10,000	2,600	3,000	2,700	500	2,500	200,000

* Critical Materials Strategy, U.S. Department of Energy, December 2010

Indian Context

Exploration of primary source of Rare Earths has not been given due thrust by Geological Survey of India (GSI) in the past, though the Atomic Minerals Division (AMD) has carried out some exploration for REs in the granite, pegmatite and inland placers limited to their association with radioactive minerals.

Primary Rare Earth minerals occur with silicates, carbonatites and alkaline rocks. Bastnaesite and monazite are two major minerals exploited commercially for their REE contents. Other minor sources of REE include apatite, britholite, ancylite, allanite and xenotime.

The major deposits hosting REs in economic concentration are of following types:

- Plutonic – Albite - Riebeckite and potash granites. Syenites and ultrabasic alkaline rocks.
- Hypabyssal / volcanic – Carbonatites
- Pegmatite - Granitic, syenitic.
- Pneumatolytic / hydrothermal - Quartz mica zones, Greisen zones, silica zones.
- Metasomatic - Albitites
- Secondary deposits - Eluvial, Alluvial and Colluvial.
- Clays, Laterites and bauxites.
- Industrial sources - Tin slag and waste of alloy industries.

Bastnasite, Monazite and Xenotime account for the total REE production. From an economic point of view, pegmatites, carbonatites and granites are the most important sources.

Monazite

Monazite has been the principal rare earth containing mineral in India. In fact India possesses the largest deposits of monazite in the world. Monazite is found in the coastal tracts of Cuttack and Ganjam districts of Orissa. In Andhra Pradesh, thick ilmenite and monazite placers are found around Vishakapatnam and Bhimunipatnam.

The beach sands in Kerala and Tamil Nadu are also very rich in monazite. The monazite content of placers is rarely more than 3%. However, this mineral contains radioactive uranium and thorium with maximum concentrations varying between 70 and 3000 ppm respectively.

Xenotime

Occurrence of xenotime, an yttrium and heavy rare earth phosphatic mineral is being explored by the AMD. It has located sizeable deposits in the fluvial placers (Siri River in Chhatisgarh and Deo River in Jharkhand) and in the soils of Kanyaluka in Jharkhand. Other xenotime occurrences have been in fluvial placers of Raigarh and Surguja districts in Madhya Pradesh, Gumla and Singbhum districts of Jharkhand,

Xenotime is also reported to occur in South Arcot district in Tamil Nadu, Baroda and Panchmal in Gujarat, Koraput in Orissa, Mehboobnagar in AP and Raichur in Karnataka. AMD has estimated about 3500 tonnes of poly-mineralic concentrate containing 3 to 8 % REs in the pre-concentrate.

Bastnasite

Bastnasite has been reported in association with carbonatites in Purulia district of West Bengal and Barmer district of Rajasthan.

Carbonate Complex

Gujarat

A number of carbonatite and carbonatite-breccia bodies and dykes of alkaline rocks are found in Baroda district. They appear as dykes and sills in the infratrappean sandstone and Deccan Trap basalt (4). These show enrichment of LREE over HREE, with total RE content ranging from 0.0016 to 0.59%.

Meghalaya

Sung Valley Complex contains mainly sovite with minor beforsite types rich in magnetite and apatite. The sovite variety analyzes 50-100 ppm of yttrium, 244-471 ppm of cerium, 50-100 ppm of lanthanum and 3355-3509 ppm of strontium. It also contains uranium and thorium, but to a much lesser extent than that in monazite. The beforsite variety analyzes 10 to 50 ppm of yttrium, 149 ppm of cerium, 30-50 ppm lanthanum and 1399 ppm strontium.

Assam

Samchampi carbonatite complex has been studied in detail by AMD. It has estimated that 2520 tonnes of yttrium are available spread over an area of 10.94 sq.km.

Tamil Nadu

Sevattur carbonatite is of sovite and beforsite variety (5). This carbonatite analyses 6427 ppm of strontium. Samalpatti is also credited with carbonatite occurrence, but the concentration of REs is around 1.8% only. Similar carbonatites are found in a few other places in Tamil Nadu.

Karnataka

Hogenakkal Carbonatite Complex shows three types of geochemical signatures: Mica-Apatite-Calcite (MAC), Mica-Pyroxene-Apatite-Calcite (MPAC) and Carbonate-Mica Pyroxinite (CMP). The total RE content is very high in MAC compared to MPAC carbonatite and CMP pyroxenite. The total RE content of MAC carbonatite is around 4700 ppm and is higher than the sovite carbonatites reported elsewhere in the world (753-2569ppm) (6).

West Bengal

Alkaline-Carbonatite Complex contains REE ranging from 231 to 1046 ppm. This has higher HREE content.

Rajasthan

The tertiary Alkaline suite comprising synetite, phonolite and carbonotite have been reported in Barmer district. These mainly possess LREE content (La + Ce upto 2.58%).

Granites and Pegmatites

Though some granites and pegmatites containing rare earths are identified in the country, they are not economically workable. Hence these are not specially addressed in this report. However, GSI has all the relevant information on these minerals.

RE Production

Indian Rare Earths Limited (IREL) has been the sole producer of rare earth compounds in the country. IREL produced only 35 tonnes of RE's in 2007-08 against 1800 tpy installed plant capacity (7). Imports of REE from China at competitive rates made production of REE in India economically unviable. However IREL has planned to restart production of RE in 2012 by processing monazite at the Monazite Processing Plant (MoPP) which is being set up in Orissa Sands Complex, Chatrapur at Odisha. The above plant will have an installed capacity to produce about 5000 tpy of rare earths oxide equivalent rare earths chemicals. It is expected to produce 2250 tonnes by the last qtr of 2012 from its plant at Odisha and Kerala.

Energy Critical Elements

Many of the ECEs are by-products of the production of base metals. The supply of these is critically dependent on the production of base metals. The important ECEs, their production and application are given in Table 5.

Table 5: Important Energy Critical Elements

Element	Source	Application
Gallium	Al, Zn processing	solar cells
Germanium	Zn, Cu, Pb refining	substrate in Ga-As solar cells, fiber optics
Selenium	Cu refining	solar cells
Indium	Zn, Cu, Tin refining	LED, Solar cells, Battery
Tellurium	Cu refining	solar panels

Gallium

Gallium is the sixteenth most common element in the lithosphere, but it is currently only extracted as a by-product of Al- and Zn-metal production. During Al production, Ga is extracted from the Bayer-liquor (containing 100 to 125 ppm Ga) during the processing of bauxite to alumina. Gallium extraction from Zn ore uses residues that accumulate during metallurgical processing of Zn. The essential disadvantage of these technologies is the poor recovery rate of only 5-10% of the Gallium contained in bauxite or Zn ore.

The USGS has estimated that in 2010 about 182 tonnes of global primary production came from alumina processing. This accounts for about 10% of alumina producers extracting Ga.

The extraction of gallium from NALCO's Bayer liquor containing 120 ppm of Ga has been successfully completed both in laboratory and pilot plant scales. A 950 kg/annum 5N purity Gallium Extraction Plant at Damanjodi based on indigenous technology and financial assistance coming from associated Government of India agencies, viz., DSIR, DST, DRDO and NRDC was set up. The process know-how is from Central Electrochemical Research Institute (CECRI), Karaikudi and Nuclear Fuel Complex (NFC), Hyderabad, licensed through NRDC, New Delhi and consultancy services rendered by Engineers India Ltd (EIL). But, it appears that the plant has not gone operational and no gallium has been produced.

HINDALCO seems to have set up a facility for gallium production, but production figures are not available. HZL has not yet carried out any extraction of gallium from its plants.

A gallium plant with 30kg/year capacity by MALCO (Madras Aluminium Company Ltd.) can produce 99.9% gallium but is currently not in operation.

There is a need to re-look at the efforts made for gallium production in the country and establish the techno-economic viability of gallium extraction. It may be worthwhile to look at alternate Ga bearing resources including coal, red mud etc.

Indium

Indium does not occur in any concentrated mineral form. It is essentially obtained as a byproduct of refining zinc. The primary global production of indium in 2010 was 480 tonnes. Hindustan Zinc Limited has not made any significant efforts to recover this metal, possibly because of easy availability of this metal from China.

Tellurium

Tellurium is rarely found naturally occurring in the Earth's crust. Its abundance in earth's crust is one part per billion by weight (7). However, it is a by-product in the electrolytic refining and smelting of copper. 500 tonnes of copper yields about 0.45 kg of Te (8). With the quality of copper ore declining, there is a possibility of electrolytic processing giving way to other processes. Then, this may lead to a shortage of this metal. In 2010, according to USGS global Te production was about 630 tonnes.

Present production figures in India are not significant. However, it is to be noted that Sterlite Industries India Ltd made an unsuccessful attempt in the bid to acquire ASARCO LLC of USA, a major tellurium producer.

Selenium

Selenium (Se) occurs naturally in only "0.05 to 0.09" ppm and is primarily obtained as a by-product from copper, lead and iron ores. Worldwide, the major producers of selenium are Japan (754 t), Germany (250 t) and Belgium (200 t).

Selenium (Se) is currently produced only in small quantities in India. Hindustan Copper Limited (HCL) has a capacity to produce 14,600 kg of selenium of 99.95 % purity at the Ghatsila Copper Smelter in Jharkand, India (2008).

Lithium

Lithium is essentially used in batteries that are required for several uses such as electric vehicles, energy storage during intermittent generation from renewable energy sources etc.

Saline brine is the major source for Li. Chile is the largest producer of this metal. U.S.A., Australia, China and Argentina are the other major producers. The 2010 production in terms of lithium carbonate equivalent was about 150,000 tonnes.

In India there has been no significant activity for lithium production. Central Salt Marine Chemicals Research Institute has established an experimental salt farm and has carried out analysis for lithium content in some sea brine and subsoil bitterns. Li concentration in sea brine is usually lower (0.1 to 0.4 mg/l) than what is in the subsoil bitterns (2.2 to 3.3 mg/l) by an order of magnitude. The concentration goes up with further removal of Mg and K salts from the bitterns (10.5 mg/l).

Uranium

Jaduguda mine of the Department of Atomic Energy has been operating since 1968 and in 2010-11; it has processed 58% of the installed capacity of 1000 tpd of ore. In the same year, Narwapahar mine has processed 134% of its rated capacity of 1000 tpd. Turamdih plant has also reported a higher turnover.

India nearly doubled its production of uranium from 230 tonnes (2003) to 400 (2010), yet was ranked only 13th in worldwide production totaling 53,663 tons.

Niobium

Niobium is an alloying addition to zirconium which is used in nuclear power reactors. This mineral is often found in conjunction with tantalum, which is a poison for neutrons, in the sense it absorbs neutrons. Methods to separate Ta from Nb have been developed at BARC.

Because of its nuclear applications, the AMD has been carrying out exploratory studies on occurrence of niobium bearing minerals. It is heartening to note that AMD has recovered about 200 tonnes of columbite-tantalite analyzing 40 to 65% Nb_2O_5 from primary pegmatites and weathered gravel zones. AMD has also reported the occurrence of Nb-REE-Li enriched alkaline carbonatite rocks in Purulia district of West Bengal.

Exploration Strategies and Constraints

Realizing the importance of REE and ECE elements which are relevant to country's energy security and use in high tech and futuristic application like wind energy, hybrid car batteries etc., GSI should give high priority for exploring these minerals in XII Plan. In India, concentration of REE in hard rock has been recorded in association with carbonatites, syenites, albitites, granites pegmatite, apatite and phosphorites and carbonaceous schists. In addition GSI needs to examine all the data generated from the Proterozoic and younger granites and also their supergene/laterite profiles, examine the chemical and other data generated in the past mapping and investigation reports for locating suitable target areas for further search of REE.

REE and ECE occur usually in very low content (<1%) in rocks. Hence, they are difficult to locate and get identified by normal megascopic and microscopic techniques., There is a need for pursuing exploration efforts with modern concepts and tools for possible breakthrough requiring high investments in sophisticated survey and spatial data management technologies including remote sensing, hyper spectral mapping and complex computerization capabilities to produce more detailed and accurate data and information of unexplored areas.

In 1975, GSI explored the Tso-Kar lake basin (Jammu & Kashmir) to access the resources of Potash. Usually, the surface evaporated encrustations from such lakes contain lithium. However, the encrustations were not analysed for lithium at that time. A new investigation may be worthwhile.

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Chapter 3: Secondary Sources

Recycling

Recycling of rare earth containing products needs a careful analysis of several factors such as availability of adequate waste material and appropriate technologies for economical recovery. Scale of operation linked with economic aspects is another important factor to be taken into account. Recycling also leads to a reduction in environmental impact due to a possible reduced mining activity. More importantly, it prevents valuable resources ending up as landfills. Worldwide, only 1% of the total rare earths in used and obsolete components are being recycled today [1].

International Developments in Recycling Rare Earths: Recycling from Permanent Magnets

Permanent magnets are a potential source for recycling. Nd-Fe-B magnets are an integral part of wind turbines. Apart from end of life magnets available for recycling, a major possible source is during manufacture of magnets. A good percentage (20-30%) of magnetic material is lost in the machining process. This scrap could be recycled [2]. Obviously, the methodology for recovering RE oxides needs to be developed. Whether one should try to get the material in metallic or oxide form is also to be decided. Metallic form will have greater monetary value.

Alternately, can one use the scrap in the compound form itself? This would depend on whether the magnetic properties have deteriorated or not. Shirayama & Okabe have tried to selectively extract Nd and Dy from scrap using magnesium chloride as an extracting agent [3]. Chinese researchers are also active in this area [4 - 6]. Zhang's method [6] of electric reduction has yielded a recovery as high as 96.1%. Japanese workers are concentrating on pyro and hydrometallurgical approaches to recover REE as metals [7, 8]. Hitachi has even developed a machine for dismantling neodymium magnets from hard disks and compressors at a rate of 100 magnets/hour.

Recycling of Rare Earth Elements from Batteries

Ni-MH batteries used in hybrid electric vehicles contain lanthanum and cerium. The Japanese Metals, Mining Technology Group (JOGMEG) is working in this area. German researchers are also active in this area and have developed a hydrometallurgical process to recover REs from the slag of pyro-metallurgical treatment of used Ni-MH batteries [9]. Umicore of Belgium and Rhodia of France have jointly developed a process for recovery of rare earths from rechargeable NiMH batteries. After separation of nickel and iron, the rare earths are to be processed at the Rhodia's plant in France.

Recycling of Rare Earth Elements from Phosphors

Phosphors in fluorescent lamps and flat panel displays contain a good amount of RE oxides. Recycling end of life products would yield considerable quantities of Y and Eu. Osram has a patent on recycling from discharge lamps and fluorescent lamps [10]. Mei et al. have given an overview of recycling phosphors [11].

Rare Earths from Slags

Alex Finlay of Durham University states that it is essential to take a more careful look at REE extraction from previously uncared for waste products [12]. According to him, extracting the desired base metal in an industrial process should lead to concentration of other elements in the waste stream. He has looked at several wastes from processes such as shale-oil extraction, coal mining and steel production. The major observation of his Geochemical Reclamation of Industrial Minerals and Elements (GRIME) group is that the wastes contain similar proportions of light and heavy REEs, which is not the case in RE minerals.

It is known that yttrium and heavier RE elements are predominant in xenotime, whereas La, Ce and lighter rare earths are found to a greater degree in monazite. Leachates from shale contains Ce and La in concentrations slightly below that in bastnasite ore, but REs like Eu, Gd and Tb are found in concentrations similar to or even greater than that found in normal ores. Blast furnace slag contains Yb and Lu in levels similar that in bastnasite. With large scale availability of such wastes, a good amount of valuable REEs can be recovered. This is a very commendable observation and needs a critical look.

Ban on Export of Wastes

Following the Basel convention on exporting hazardous electronic wastes to developing countries, several countries setup their own reclamation and recycling facilities. Belgium had taken a big lead in this connection. Realising the vast potential for recovery of valuable and critical elements from such wastes, countries have started banning export of end of life products that contain these elements. The US has recently tabled a 'Responsible Electronics Recycling Act' with a view to recycling RE material from them.

Recycling of RE in India: Potential Sources for Recycling

a) Phosphors

In India, fluorescent bulbs are a good source of rare earths that should be processed. Annually, over 180 million fluorescent tubes are manufactured in the country (See Table 6). Production of CFL is steadily increasing [13].

Table 6: Annual Manufacturing Trends in India by Lamps Category

Category	2005	2006	2007	2008	2009	2010
Fluorescent Tube Lights	180	186	190	186	179	182
Compact Fluorescent Lamps	67	100	140	199	255	304

It is well known that spent fluorescent bulbs are recycled to remove mercury, though not in our country. Effort should be made to recover RE oxides such as Tb, Eu and Y in them, apart from recovering toxic mercury. At present, the technology for recovery of rare earths from spent phosphors does not exist in India and this needs to be developed. A typical 4' fluorescent tube light (FTL) with a diameter of 1.5'' has about 4.3 g of RE oxides. From the table above, it is obvious that the number of spent FTLs should be in considerable quantities and recycling them would contribute to increased availability of rare earth oxides, particularly Tb, Eu and Y.

b) Permanent Magnets

The next big chunk of material for recycling could come from permanent magnets and hard disc drives. Nd-Fe-B magnets are an integral part of wind turbines. At present, it is not known what is being done with end of life magnets, but the quantity available for recycling may not be adequate at present. This is because the life of these permanent magnets exceeds 20 years. Wind power generation in India has only commenced now in an accelerated manner. But, another possible source is in the area of manufacture of magnets. While magnets are manufactured, a good percentage (20-30%) of magnetic material is lost in the machining process [14]. This scrap could be recycled. In addition magnets from scraped motors and hard disc devices should be available in sufficient quantities for recycling. Obviously, the process for recovering Nd and Dy needs to be developed.

c) Electronic Waste

The estimated electronic waste generation in India is expected be around 1 million tonne per year. This contains about 0.1 to 0.2 % of magnetic material including rare earths. Typical composition of secondary sources containing rare earths is given in Table 7.

Table 7: Typical Composition of Different Wastes/Secondary Resources Containing Rare Earths

Waste / secondary resource	Composition of REs and ECEs	Remarks	Reference
Personal computers	In-0.0016%, Nb-0.0002% Y- 0.0002%, Eu-0.0002%	Rare metal analysis of PCs as a whole containing 23% plastics, 20% Fe, 7% Cu, 6% Pb, 25% SiO_2, etc.	http://www.seminarprojects.com/Thread-e-waste-anagement#ixzz1cMQxaNI4
Computer monitor scrap-powder	Y-17%, In-0.49%, Ce-0.02%, Nd-0.01%, Sm-0.02%, Eu-0.76%	Powder from inner surface of monitor (1kg powder from 300 monitors)	Resende & Morais, Miner. Eng., 23, 2010, p.277.
Spent catalysts	RE_2O_3- 1.8-4% (La, Ce etc.)	As a part of alumina and silica matrix to improve catalytic properties.	Sadeghbeigi, R., 1995. Fluid Catalytic Cracking Handbook, Gulf Publ. Co., Houston, TX, p. 103.
Ni-MH rechargeable batteries	i) REs- 15.4%, ii) REs- 1.7% (Nd, Pm, Ce, La) in AAA battery & 2 kg REs in hybrid EV iii) NiMH[a], NiMH[b], NiMH[b] (AB5): (%) Ce - 3.4, 6.1, 0.4–5.5 La - 11.5, 5.4, 1.4–6.6 Nd - 10.9, 3.0, 1.0–4.1 Pr - 3.2 , 0.8, 0.3–1.3 Ni - 52.8, 49.8, 25–46 Co – 5.1, 5.5 , 2.3-4.5 iv) -ve & +ve electrode (%): Ce -23.06, –La- 20.33, 0.78 Nd -9.09,–Pr - 0.96, –	Cell weighing 28.9 g contains 19.5 g mixed electrode material (~ 70% of weight). 7.0% of NiMH batteries contains REs with such composition a - Excluding metallic case. b - Including metallic case. Other metals (%): Ti - 1.4, -, 2.2–3.9 V - 2.2–4.7 Zn - 2.8, 1.0 , 0.1–1.6 Zr - 3.9–8.7 Fe - 0.9, 0.3, 20–25 X-ray fluorescence analysis of the negative and positive electrodes	Li, Xu & Wu, Hydromet., 100, 2009, p. 41. Info: Umicore of Belgium and Rhodia of France, 2011 Rodrigues, M.B. Mansur / J. Power Sourc.e, 195, 2010, p. 3735. Bertuol et al. / J. Power Sourc.es, 193, 2009, p. 914.
RE magnets	i) $RE_2TM_{14}B$, RE- Nd, Pr, Dy, TM = Fe, Co. ii) RE_2TM_{17}: RE-Sm, TM- Fe, Co, Ni, Zr. Hf. iii) RE Co5 : RE- Sm, Pr	$Nd_2Fe_{14}B$ referred to as 2:14:1 (as atomic wt. %). Sm_1Co_5-SmCo as 1:5. Sm_2Co_{17}-SmCo as 2:17	www.magnetsales.com/Design/DesignG.

d) Rare Earths from Slags

Following Finlay's suggestion, National Metallurgical Laboratory had carried out an analysis of blast furnace slags from two different sources. It is gratifying to note that about 500ppm of Rare earths are present in these as given in Table 8.

Table 8: Rare Earth Elements in BF Slag

Element	Tata Steel BF slag Concn. (%)	Jindal steel BF slag Concn. (%)
Ce	0.016	0.001
La	0.013	0.008
Er	0.033	0.03
Nd	0.013	0.009
Y	0.004	0.004

Recycling of Energy Critical Elements: International Scenario

Lithium

At present, there is no threat to the supply of lithium. While the South American countries have a major share in the production of Li, Australia, China and the US also have considerable resources. But the demand is likely to increase further, as discussed in the next chapter. Thus recycling would become critical to conserve resources and ensure a sustainable supply over the years. It is estimated that recycling small size batteries would reduce the world reduce the demand considerably.

Toxco in USA is one of the first companies to patent a process for recycling lithium from spent primary batteries (15). But, the process is cumbersome in that the processing material needs to be cooled to a considerably low temperature to avoid Li explosion. Umicore in Belgium is also carrying out recycling of Li ion batteries.

Earlier, recycling was economical because one could get cobalt and nickel along with lithium. But, these days Li- ion batteries have opted for cheaper metals like iron and magnesium.

Indium

According to Indium Corporation, 865 tonnes of In were recovered by recycling in 2010. Most of it came from scrap recovery of Indium Tin Oxide (ITO) processing. Flat panel displays also use ITO. It appears that no economically viable process has been developed for recovering In from these FPDs. It is worth developing a suitable technology for this.

Tellurium

Unicore in Belgium has set up recycling capacities for Te from electronic scrap. Dowa in Japan has also established some facilities. First Solar, world's largest producer of CdTe has its own recycling system for both pre and post-consumer scraps.

ECE recycling in India

Recycling technologies for recovery of REs and ECEs are yet to be developed. There are no serious thoughts given to this area by the agencies concerned. CMET, Hyderabad has initiated studies for recovering REs from spent Ni-MH batteries.

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Chapter 4: Demand and Supply

This chapter discusses the demand and supply of rare earths and energy critical elements. It is reiterated that if one were to adopt clean energy technologies, then it may place a great strain on the supply chain of several of these elements. For a fuller appreciation, it is necessary to know about the major uses of these elements and their present consumption. It is equally important to understand how the present demands are met.

Major Uses of Rare Earths

Yttrium, a non-lanthanide group rare earth, is an important phosphorescent material for the fluorescent tube lights and compact fluorescent lamps. It is also used as a red phosphor in television screens. Oxide of yttrium is one of the components in coatings for jet engine blades. Yttrium metal and oxides are used as alloying additions in metallurgical industries.

Lanthanum finds use as a NiMH battery material and also as a phosphor in fluorescent tubes. Lanthanum is also used in petroleum industry in fluid catalytic cracking (FCC). It helps in increasing the speed of cracking and also in producing a valuable mix of high value products such as propylene, butylenes, petrol and diesel.

Cerium applications are similar to that of lanthanum. Cerium in FCC is mainly to reduce sulphur oxide emissions. Cerium oxides are used in glass polishing industries.

Praseodymium is not a primary element for any specific use, but finds its use as a substitute for neodymium in magnets and mischmetal in NiMH batteries.

Neodymium's major use is in high power permanent magnets along with iron and boron. Nd-Fe-B magnets are the workhorse for wind turbines and electric vehicles.

Samarium is used essentially for the production of Sm-Co magnets. While they have a slightly better high temperature capability, indications are that these may not find much use in clean energy technologies.

Europium is a primary component of phosphors and is responsible for white light in compact fluorescent lamps when used with terbium compounds.

Terbium finds use as mentioned above in phosphors. It is also used as an additive in Nd-Fe-B magnets.
Dysprosium is added to the Nd-Fe-B magnets essentially to raise the Curie temperature. Thus, it is useful in clean energy technologies.
As one can see, the main uses of REEs are in energy efficient lighting, permanent magnets for use in electric vehicles and wind turbines, and fluid catalytic cracking in petroleum refining.

Uses of Energy Critical Elements

Gallium is the preferred material for optoelectronics and integrated circuits. But, its use in solar photovoltaics along with copper, indium and selenium would be far more in the coming decades.

Selenium is proving to be a useful solar PV material in increasing the efficiency of absorption of light.

Tellurium as CdTe is used in solar PV panels world over. Major use of Te is as an addition to steel and copper alloys to improve machinability.

Lithium has become synonymous with batteries in that it is a major electrode material for applications in clean energy technologies as well as in electric vehicles.

Uranium, niobium and gadolinium are used in nuclear power reactors.

Worldwide Demand

Rare Earths

To arrive at a strategy to meet the global demand of rare earths, it is necessary to know the current level of production and also the projected augmentation of resources worldwide. The total production of RE oxides was 118,500 tonnes in 2010. Several companies have started processing existing tailings stockpile to meet the additional demand.

Energy Critical Elements

The USGS has estimated that in 2010 about 182 tonnes of global primary production of Gallium came from alumina processing. Only 10% of alumina producers extracted gallium as a by-product. As per estimates in case of a stronger development of the Photo Voltaic sector, the gross consumption of Gallium is likely to more than double by 2015 to 470 tonnes. The global demand in 2009 was about 170 tonnes.

Lithium production is in sizeable quantity now and is expected to increase further. The world production of lithium carbonate equivalent was reported (US Geological Survey) to be around 180,000 tonnes in 2011at the price of around $4300 per ton. The USGS estimates the current global end-use markets for lithium as follows: batteries, 25%; ceramics and glass, 18%; lubricating greases, 12%; pharmaceuticals and polymers, 7%; air conditioning, 6%; primary aluminium production, 4%; continuous casting, 3%; chemical processing 3%; and other uses, 22%. Currently lithium production supply and demand are relatively in balance, however there is a lithium supply deficit looming.

Reliable production data are not available for tellurium. Thin films of Cd-Te photovoltaic cells are replacing Si cells. It is estimated that 80-100 t of Te is required per GW of PV power. The production in 2009 was estimated to be around 450 t versus a total demand of 600 t. The demand is expected to exceed the theoretical production capacity in next few years.

Indium Corporation estimated the virgin production of indium to be 480 tonnes, while the reclaimed metal amounted to 865 tonnes. China controls about 60% of world's refined in production. There is a considerable supply-demand imbalance.

Demand in India

Rare Earths

Uses of rare earths have already been listed. Table 9 gives the data on import of rare earths over the last few years. While the table shows the import of individual REs in compound form, it is not clear whether finished products using rare earth elements are being imported.

Table 9: Data (in kg) on Import of Rare Earths in Last 5 Years by India

Element		2010	2009	2008	2007	2006
Lanthanum	Lanthanum Oxide	0	9100	250	0	0
	Lanthanum Acetate	2400	1250	1750	2000	1000
	Lanthanum Nitrate	2400	750	1325	200	0
	Total	4800	11100	3325	2200	1000
Cerium	Cerium Oxide	240000	202000	564000	99700	407500
	Cerium Acetate	10700	8200	2900	3200	0
	Cerium Nitrate	3600	385	2960	930	265
	Cerium Zirconium Oxide	95200	99250	84500	27400	33200
	Cerium Chloride	11275	12400	555	31100	0
	Cerium Carbonate	0	10000	0	40000	0
	Total	360775	332235	654915	202330	440965
Ytterbium	Ytterbium Oxide	500	800	500	0	2
Neodymium	Neodymium Nitrate	5500	2750	4150	1450	150
Yttrium	Yttrium Oxide	50	400	1960	0	1000
Prasodmium	Prasodymium Oxide	0	1750	5300	7140	3500
Erbium	Erbium Oxide	300	200	200	85	0
	Total	**371925**	**376775**	**670350**	**213205**	**446617**

Whether the phosphors used in the lighting industry and flat panel displays are imported or they are being made locally, is not clear. Same ambiguity exists with respect to RE permanent magnets used in wind power mills and hard disc drives. It has been difficult to get any information on these aspects. The reduction in import from 667 tonnes in 2008 to 367 tonnes in 2010 suggests that readymade items are being imported, in preference to getting individual elements and making the finished products.

Major uses of rare earths in India are likely to be as phosphors in the lighting industry, catalysts in automobiles, permanent magnets in disc drives, electric vehicles and wind mills for electrical energy production, and alloying additions in steel making. Let us see the likely demands in these sectors.

High Efficiency Lighting

Fluorescent bulbs use phosphors made of Tb, Eu and Y. Light emitting diodes (LEDs) use lesser quantity of REEs compared to FTLs. The total RE phosphor in each CFL is about 1.5 g. Fluorescent tube lights (FTL) is manufactured in various diameters and lengths. A 5mm diameter FTL of 4ft length has 1.8 g of REO as compared to a 12 mm diameter FTL which has 4.3 g.

CFL production in the country was about 200 million in mid 2009 and is projected to grow to about 700 million by 2015. CFL has also a longer life – about 6 to 12 times greater than that of incandescent bulbs. To that extent, further growth of CFL industry may be a little slower in the later part of the decade. But, ELCOMA (Electric Lamps and Components Manufacturers Association) states that CFL production may reach a figure of 1700 million by 2020. CFL growth at present has stabilized around 24% per annum. Triband phosphor is an important component of CFL. The present requirement of triband phosphor for the lighting industry in India is given below:

Table 10: Present Quantity of Triband for Lighting Industry in India

Product	Average quantity of Triband per unit	Units produced in 2010 in millions	Total quantity of phosphor in tonnes
CFL	600 mg	304 M	182.4
T5 Tube Light	3 g	3.5 M	10.5
T8 Tube Light	4.5 g	15 M	67.5

On the basis of the above, the requirement of triband phosphor may go up from 180 tonnes to over 1000 tonnes by 2020. The cost increase due to throttling of exports by China would be considerable. It is thus necessary to develop indigenous availability of materials.

Permanent Magnets

Wind power generation requires compact light weight generators as these are mounted at the heights of 80 to 100 metres. Rare earth based Nd-Fe-B magnets are the best available choice at present. Typical weight of the permanent magnets in these generators is about 600kg, out of which is Nd is around 25%. It also contains dysprosium to the extent of 2- 3%.

India has an ambitious wind power development programme. It has already established windmills in sufficient numbers in the states of Tamil Nadu, Karnataka and Gujarat. Recent studies have shown that wind energy potential may be of the order of 100,000 MW. If the magnets required for generating at least half of this 100 GW is to be met with indigenous supply of REs, it would require about 7500 tonnes of Nd. This is without taking into account the losses occurring in production and manufacturing of magnets. Thus, the progressive demand over the final goal would be about 10000 t of Nd (for 50 GW).

Electric vehicles also require permanent magnets. A Toyota Prius requires a magnet in which the Nd content is about 1kg. RE permanent magnets in electric vehicles operate at a temperature slightly above the Curie temperature of the Nd-Fe-B magnet materials. Hence, dysprosium is added to the extent of 2 to 3 % to raise its Curie temperature.

Present production of electric vehicles in India is very little and as such not much thought has been given to battery requirements or on materials needed for batteries. Society of Automobile Manufacturers, India has brought out a report on 'National; Hybrid/electric Mobility Study' in which it has projected that the demand for 4 wheelers would go up to about 1.5 million units by 2020. Electric two wheeler demands may be around 4.8 million units. Neodymium requirement for 4 wheelers alone would be of the order of 1500 tonnes, while that of dysprosium would be one tenth of that of Nd. Thus Nd demand in the coming decade would be much more than demands of other rare earth elements.

Fluid Catalytic Cracking

The price of La was $5/kg in the beginning of 2010 and rose to about $140/kg by mid 2011. This has driven the refiners to look for alternate catalysts for fluid catalytic cracking with low RE content or no RE content catalysts. Grace Davison and Albemarle have already developed some alternates with considerable lower REEs, but these are yet to be proven, particularly with respect to yield fractions.

Energy Critical Elements

Selenium import in the country was of the order of 164 tonnes in 2008-09. Major strategic application of Se is in the solar photovoltaic industry. In July 2009, India unveiled a plan to produce 20GW of solar power by 2020. Half of this capacity is to be met with PV, while the other half is expected to be based on CSP technology. Most of the PV plants in India operate on crystalline silicon or amorphous silicon technologies with low efficiencies. Cd-Te is a better PV material, but it is reported that some problems exists in its use in hot tropical climates. CIGS is still better in its efficiency but its present status of application in the country is relatively little. Tellurium is sought after by the metallurgical industry as an alloying addition to steels and copper base alloys for easy machinability.

Lithium is the major battery material that is sought after for several applications. Demand for lithium may grow to a sizable quantity.

As far as nuclear materials are concerned, the Department of Atomic Energy has taken considerable steps to augment its availability. The recent Indo-US agreement would further ease the situation.

Summarizing, the Energy Critical Elements are by-products in the production of base metals, with the exception of REE as a group and Lithium. The supply of these is critically dependent on the production of base metals. In case of REE the key issue is the complex metallurgy of separation of individual rare earth.

The global demand of ECE has grown at a higher rate than the demand of major metals such as steel. The growing demand comes from clean energy technology as well as consumer products *(Critical Materials Strategy, U. S. Department of Energy, December 2011).*

Since India has ambitious plans for generating solar power of 30,000 MW and wind energy of 50,000 MW by 2030, the demand of REE and ECE is likely to increase manifold. It may be stated that a few REEs like Nd and Dy may pose a problem in the near future as compared to others such as Ce. In the rare metals category, attention needs to be paid to gallium, indium, tellurium and selenium, the demands for these would be more critical after 5/6 years.

To secure the supply of raw materials for both the short term and long term, there is need for entering into bilateral agreements with countries with whom we have MOU in exploration and sharing of data and have set up Joint Working Groups (JWG). Countries like Afghanistan, Mozambique and Ukraine hold potential for rare earths and ECE and Bolivia for Lithium.

Chapter 5: Way Forward

Materials supply chain may be affected due to several factors, but, there is always an indication well in advance about such an occurrence. Manufacturers' first reaction is to conserve the existing stock as much as possible. Alternatively, depending on cash flow, one would try to stockpile the material in sufficient quantities till an alternate solution is found. While these are short term options, it is necessary to look for long term solutions.

The recent imposition of restrictions on export of rare earths by China has created a scare in the developed countries to look for alternatives. Along with REs, these countries have also focused their attention on other energy critical elements, particularly in the context of clean energy technologies. Several avenues for amelioration are being thought of. We shall briefly touch upon some of these below.

The first thing that one looks for is availability of additional mineral resources. Are the existing methods of exploration adequate or is it necessary to look for better or novel methods of exploration? Then, extraction of metals from these minerals comes into play. In case of lanthanides, if one requires lutetium, the 15th element in the series, then one would have to extract the first 14 elements prior to Lu. This may lead to unwanted stock piling of some of the intermediate elements. Do we have a process that can separate the requisite element preferentially? The answer is no at present. Thus, it becomes necessary to draw the attention of process metallurgists to solve this pressing problem.

There is a similar problem with respect to extraction of rare elements also. Elements like gallium, tellurium and indium are extracted as byproducts in the recovery of base metals like aluminium, zinc and copper. These are not economically viable processes and as such most of these elements end up in tailings and go unnoticed. At the same time, is there any thought given to preferentially extract these minor quantities from the ores without extracting the base metals? The answer is possibly no.

As has been described in Chapter 3, it is necessary to carry out recycling and reuse these scarce resources. Again, the necessary recycling technologies have to be developed such that the processes become economically viable. This also necessitates the availability of waste/end of life material in sufficient quantities. It is gratifying to note that the Ministry of Environment and Forests, GOI, has already promulgated an order in this connection. (Annexure II). But, how these are to be implemented is not yet clear. Some follow up actions are required.

Conservation of rare resources is another aspect that needs to be looked into. Nanotechnology has come in handy in this area. It has been possible to conserve rare metals to a considerable extent by making a composite of nano and conventional materials in proper proportions, as is described later in this chapter.

Partial substitution of scarce materials is a promising area of research in Materials Science, There are several groups working in this area and a few salient results are reported here.

A radically different approach is to look for alternative technologies that do not depend on these rare resources. One such area of active research is in replacing RE permanent magnets with induction motors. A brief description of such efforts is also given here.

However, it should be emphasized that the present labelling of some elements as 'critical' is simply based on the present level of technologies and developments. With newer and alternate technologies becoming available, one may need to take a relook at the scenario.

Exploration

Conventional explorers are looking for known resources of REs like monazite and bastnasite. However, it is necessary to look for alternate resources in unexplored locations. In this context, Boeing's remote sensing technology has come in handy (1). By this aerial imaging, existence of light and heavy rare earth deposits in Idaho and Montana has been confirmed. Aerial photographs are converted into digital databases and desired features are highlighted by simple manipulation of digital codes. By carrying out corresponding ground based sampling, huge areas can be scanned for rare earth ores.

Lithium is usually extracted from brine by an evaporation process, but it may be worthwhile to look for spodumene and other hard rock deposits that would contain Li. Likewise, reclaiming indium from indium tin oxide scrap seems to be a major source of supply of this element. Though, it is nowadays claimed that ITO coating losses are reduced to a considerable extent.

Extraction

The chemical behaviour of rare earths is very similar. The differences in ionic radii between adjacent REs are also small. The differences in ionization potentials are also small. Thus, separation of adjacent rare earths is difficult. Individual rare earth elements are separated based on the differences in their basicity. This difference in basicity is enhanced by chelating agents. Fractional crystallization, ion exchange and solvent extraction are some of the techniques developed for separation of individual elements. But, it is necessary to examine alternate routes for extraction that are environmentally friendly and sustainable.

Uda, Jacob and Hirasawa have developed a method for enhanced rare earth separation using the differences in redox potentials and vapour pressures of the rare earth di and tri-halides (2). By effectively combining selective reduction and vacuum distillation, order of magnitude increased separation efficiency for Sm from Nd was obtained. Derek Fray of Cambridge UK had stated that as the above technique involves less number of steps, REs should become cheaper (3) It is not known whether this process has been commercialized or not.

Central Electro Chemical Research Institute has carried out an electrochemical process for the separation of Ce from rare earths (4). They have carried out lab scale and bench scale studies and reported a current efficiency of 60%. The purity of the product was > 95%. It may be necessary to set up some central incubation facilities for scaling up studies.

Electrowinning of metals is an established technique but its application to extracting REs from ores has been attracting the attention of researchers only in the recent past. Pilot scale production of Ce, La and Nd from purified chlorides has been carried out (5). Electrochemical extraction of europium from molten salt fluoride media has been carried out in France (6).

Based on the work of Gomez and Taylor for the separation of boron from boric oxide, Colorado School of Mines has developed an electrolyte that contains a salt more readily reducible than RE (7). But, this should be less noble than the REE desired.

Dry milling and recovery circuits with dry concentration and pyro-metallurgical extraction are being tried to replace wet grinding, flotation and acid leaching by the same school. Carbo-chlorination followed by separation into chloride products is the route being followed, eliminating water quality issues.

Pacific Northwest National Laboratories are working on increasing separation factors between adjacent lanthanides by designing selective extractants using molecular recognition principles (7). They are also exploring separations using surface functionalized nanoporous sorbents. Separations using physical and chemical reactivity differences are also useful for lanthanide separation.

Spent nuclear fuel contains a significant amount of REs. It is reported that the concentrations of Nd, Ce, Pr and Sm are much greater than other REs in spent fuels. The processes developed for extraction of actinides from spent fuel could be used to recover REs also. BARC and IGCAR are well versed in this technology and possibly would be of great help in this work (8).

Supercritical Fluid Extraction (SFE) with CO_2 is also being tried seriously. Idaho National Laboratory has carried out considerable studies in this area. REs are dissolved in conc. nitric acid, followed by contact with supercritical CO_2 containing an extractant like tri-butyl-phosphate (TBP). The metal nitrate TBP complex is soluble in supercritical CO_2. This is water soluble. SFE of rare earth elements from luminescent materials in waste fluorescent lamps have been tried out by Shimizu et al. at the Nagoya University (9). Extraction efficiencies of the order of 99% could be achieved by them for Y and Eu recoveries.

It is also worth noting that CYTEC has developed a novel magnetic separation technique using nanotechnology to remove impurities at a much higher scale (7).

Bacterial leaching of RE elements with *bacillus subtilis* and *E-coli* has been tried out by Yoshio Takahashi et al. (10). They had reported that adsorption of heavier rare earths on the cell walls of these bacteria. Sm and Eu were the most preferred adsorped species.

Thus, newer attempts are being tried out by several researchers all over the world. Unfortunately, we do not seem to be pursuing any such activity in India. This is because extractive metallurgy as a branch of metallurgical curriculum is getting ignored in several materials engineering departments in Indian Universities, including the IITs. Improved extraction technologies are necessary to push fresh ore up the supply chain. In addition, such technologies also help in recycling waste materials.

Conservation

Phosphors

Phosphors and flat panel displays use rare earth elements in considerable amounts. The annual number of fluorescent lamps required is also large as mentioned earlier. The US DOE report on ‘Critical Materials strategy’ shows the extent of utilization of phosphors in fluorescent lamps as a function of diameter of the tube (Table 11). We are all familiar with fat fluorescent tubes and when Philips introduced the sleek thinner diameter tubes, we all felt that it looks good without realizing that it also saves some amount of phosphors used in the tube. May be there is a case to look at energy efficient lighting.

Table 11: Rare Earth content in LFLS

Lamp Length	Lamp Type	Surface Area (cm^2	REO Content (g)
4 feet	T12	1459	4.3
	T8	972	2.9
	T5	608	1.8

Substitution

PV panels

Solar photo voltaic industry has focused on high efficiency converters such as CdTe and CIGS. Cyrus Wadia suggests looking at more abundant materials such as FeS_2 and BiS which have only slightly lower efficiencies (11). However, development of practical PVs depends on detailed studies of electron-hole recombination rates, diffusion lengths, stability etc.

Phosphors

Another possible substitution is in LED phosphors. Erdem and Demir have come up with some alternatives for phosphors containing Eu, Tb and Ce (12). According to them, fluorescent colloidal Nanocrystal Quantum Dots (NQDs) formed from semiconductor nanocrystals synthesised in solution could be a viable alternative.

Permanent Magnets

Iver Anderson of Iowa State University has hit upon a novel approach of hardening soft iron alloys by altering the crystal structure of these alloys. According to him the cubic lattices is what makes these alloys soft and if that could be modified to tetragonal or hexagonal structure, then the magnetic strength of these soft materials could be increased considerably. He is looking at tungsten and nitrogen to do this trick (13). Migaku Takahashi of Tohoku University is also trying out combinations of Fe-N alloys as these are the most magnetizable material known.

Nanocomposites are perhaps the key to conserving the requirement of rare earths in permanent magnets. Hadjipanayis and co-workers have made composites of soft (Fe-Co) and hard (Nd-Fe-B) magnetic materials to achieve high strength. Ralph Skomski and Michael Coey of Trinity College Dublin had predicted strength levels of 120 MGOe in the composites. Frank Johnson of General Electric has also been trying to cut down RE content in permanent magnets by about 80%, while aiming to improve the strength by about 40%. If such efforts were to fructify, the demand for Nd and Dy would go down considerably.

Radical Changes

Induction Motors

Anticipating a possible squeeze in Nd required for the permanent magnets (PM) used in electric vehicles, many companies like Tesla (for Roadster), BMW (for Mini-E) etc. have switched over to induction motors, developed by Nikola Tesla way back in 1888. The main disadvantage of asynchronous induction motors with varying speeds has now been eliminated thanks to modern day semiconductor control mechanisms. But, the major advantage of induction motors is its capacity to withstand a wide range of operating temperatures, in addition to its ruggedness. It should be mentioned that Tesla Roadster uses just a single gear and there is no problem of quick acceleration or in climbing steep hills, a problem associated with PM motor driven vehicles. There are sceptics who say that the induction motor size required for all electric vehicles would be very large. That may have to be addressed.

Switched Reluctance Motors (SRM)

These motors work on the principle of electronically switching the electromagnetic stator field to drive an iron stator. Toyota is working on a 4-phase 22kW SRM that has a peak torque of 150Nm at a current of 210A. The diameter and stack length have been optimised to give a high specific power and a high torque.

Wind Turbines

Emphasis of wind turbine manufacturers is slowly shifting to gear driven, hybrid and direct drive systems, thereby reducing the amount of REE requirements.

Next Generation Photovoltaics

The Sunshot programme of US is to utilize the earth abundant materials in PV technologies. In this area, Purdue University is working on producing an ink based on copper, zinc, tin and sulphur for low cost PVs. NREL is committed to developing copper-nitride PV cell layers. Iron pyrite's use as a solar PV material is also being explored.

Phosphors

Lawrence Berkeley National Laboratories is working on manganese with its varying valence states as a possible replacement for REE activation. Argonne National Lab is involved in using more readily available Ce as base without Eu, Tb and Y to create the photoluminescence (14).

Summary

Things do and can get rare. As has been stated above, stockpiling the rare commodity to the extent possible to tide over the immediate concerns is one possible option. But that is a short term solution and that too applicable in adequate cash flow scenario. But, the next best option is to reduce its consumption. This can be realized by mixing with alternate materials with similar properties to arrive at the same result. In this context, nano technology has come in handy to a certain extent with regards to magnetic materials. Nano technology has a great potential and it is not fully used, more so in our country. We have a National Nano Technology Programme, but it appears to be sub-optimal. What little is being done in this area in more towards publications of research papers than applied aspects that need greater attention. Recycling normally is a cheaper and quicker way to get more out of less, than going in for exploration activities that are time consuming too. One realises the benefit after 16 years or so. A techno-economic analysis is needed to prioritise which elements are worthy of recycling. For example, recycling lithium under the present conditions does not merit consideration. Radical approaches to replace such rare elements totally as is being attempted in the case of replacing permanent magnet motors with induction motors are necessary and may prove beneficial if one were to use abundantly available and least expensive elements. Integrated computational materials science coupled with artificial neural network studies should be promoted and strengthened in all academic institutions.

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Chapter 6: Recommendations

The work of the Steering Committee has led to several recommendations for exploration and extraction, recycling, substitution and policy measures for ensuring an uninterrupted supply chain for REEs and ECEs for meeting the requirements of clean energy and strategic sectors.

Exploration

In India, monazite has been the principal source of rare earths. It also contains thorium and uranium. It occurs in association with other heavy minerals, such as ilmenite, rutile, zircon, etc. in the beach and inland placer deposit in the coastal areas. India possesses large deposits of monazite; however heavier rare earths are not present in sufficient quantities in monazite. Concentration of REEs in hard rock has been recorded in association with carbonatites, syenites, albitites, granites pegmatite, apatite and phosphorites and carbonaceous schists in various parts of the country.

The following recommendations are made with respect to exploration:

- There is a need for pursuing exploration efforts with modern concepts and tools including remote sensing and computerization capabilities to produce more detailed and accurate data and information of unexplored areas both by GSI and AMD during the XII five year Plan for locating suitable target areas for further search of economically exploitable deposits of REEs.
- ECEs have not been a primary target of domestic mineral exploration so far and hence, there is limited knowledge of what geological characteristics to indicate their deposits. A detailed study needs to be conducted on this subject.
- Lithium deserves special attention in view of its application in energy storage devices. It is usually extracted from brine. It also occurs in spodumene associated with granites and pegmatite in crystalline terrains. The occurrence of needs to be explored. The evaporite sequence of Tso-kar Ladakh (J&K) needs to be reassessed.
- It is necessary to look for bastnasite as a source, so that radioactive contamination does not come into the picture. This would enable the entry of private entrepreneurs in RE technology.

Extraction

Energy Critical Elements (ECEs) such as germanium, gallium, indium, selenium, tellurium etc. are not found in concentrations high enough to warrant extraction as a primary product. Most of these metals are produced as by-products during the production process and smelting of base metals like lead, zinc, copper, aluminium, and tin. They exist in very low percentages in ore deposits with where they occur. Their production is technology intensive.

- **Gallium** is extracted as a by-product from the Bayer-liquor during the processing of bauxite to alumina. Though laboratory and pilot scale studies for extraction of gallium have been carried out, no gallium is produced by NALCO. NALCO should revive its gallium extraction plant at Damanjodi (Orissa).
- **Indium** is essentially obtained as a by-product of refining zinc. Hindustan Zinc Limited (HZL) should make efforts to recover this metal during the processing of Zinc.
- **Selenium and tellurium** are by-products of the electrolytic refining and smelting of copper. Selenium (Se) is currently produced only in small quantities in India.

Hindustan Copper Limited (HCL) should step up its production of Se from the Ghatsila Copper Smelter in Jharkand. HCL has produced 36.81 tons of selenium in 2008-09 from copper smelting.

500 tonnes of copper ore yields about 0.45 kg of Te. Efforts should also be made to recover tellurium during the processing of copper.

Depending on the requirements, mainly in solar photovoltaics, accelerated efforts must be put in to recover these two elements.

In case of **REEs** the key issue is the separation of the individual elements Current practice requires all previous REEs in the series to be extracted first while attempting recovery of a particular element. This poses an inventory problem for the producers. Thus there is an urgent need to develop a technology for selective extraction of the requisite elements. A consortium approach involving academic institutions and R&D establishments is essential.

- Process research and development has remained dormant for the past few decades. There is a compelling need to reactivate this area of technology by encouraging process metallurgists to solve the pressing problems. DAE, IREL and CSIR laboratories - NML, IMMT and Central Electrochemical Research Institute (CECRI) should be incentivized to take up such programmes jointly.

- Recovery of REEs from wastes such as blast furnace slags and leachates from processing of materials in other sectors such as ilmenite etc. should be looked into. NML has already carried out analyses of blast furnace slags indicating the significant presence of rare earths. This activity needs to be seriously pursued.

- The process developed for extraction of actinides from spent nuclear fuel could be used to recover RE also. BARC and IGCAR might want to explore this domain.

Recycling and Substitution

As REEs and ECEs are scarce, it is natural to reduce their consumption and look for their substitutes and also recycling of end of life components. Realizing the vast potential for recovery of valuable and critical elements from wastes, a few countries have started banning export of end of life products that contain these elements. In India, recycling technologies for recovery of REEs and ECEs from e-waste are yet to be developed. There are no serious thoughts given to this area by the agencies concerned. CMET, Hyderabad has initiated studies for recovering REs from spent Ni-MH batteries. These efforts need to be systematically pursued taking techno-economic aspects into consideration.

- The Government has already promulgated an ordnance regarding disposal of e-wastes. Suitable methodologies have to be put in place to isolate different kinds of wastes and extraction plants have to be built for effective recovery of critical elements. The above should be preceded by identifying processes to be adopted for such recoveries.
- A techno-economic analysis is needed to prioritize which elements are worthy of recycling.

Partial substitution of scarce materials is a promising area of research in materials science. Radical approaches are needed to substitute or replace rare earth elements totally as is being attempted in the case of replacing permanent magnet motors with induction motors. In this context, nanotechnology has critical role to play.

- Nanotechnology has a great potential and it is not fully used, especially in our country.
- Materials science coupled with artificial neural network studies should be promoted and strengthened in all academic institutions. This approach helps in predicting new materials with reduced or no REE in their composition.

Policy Initiatives

- The stockpiling of required REEs and ECEs to the extent possible to tide over the immediate concerns in the next five years is to be considered.
- To secure the supply of raw material for both the midterm and long term, there is need for entering into bilateral agreements with countries which have these resources and with whom we have MOUs in exploration and sharing of data.
- Countries like Afghanistan, Mozambique and Ukraine hold potential for rare earths and ECE and Bolivia for lithium. India should use the Joint Working Group (JWG) route to acquire assets in these countries. Government needs to take an aggressive

role for negotiating on the acquisition of assets abroad by Indian entities. Government- backed wealth fund can be created to support acquisitions abroad.

- There is an urgent need for a thrust for cooperative research in geological modeling of the mineral deposits, ore forming systems, basic geochemistry and development of indigenous extraction and processing technologies of these elements. The option of collaborating with foreign laboratories should also be kept open. The academic community in India must be energized to work actively in these areas.

The issues surrounding the REEs and other ECEs need serious and sustained attention and we need a national level programme to integrate the suggestions made in this study. It is desirable to have an Apex Board for REEs and ECEs under the Department of Mines and several working groups for specific activities. It goes without saying that there is a need for the Government to allocate sufficient funds, even though the processes and plants to be established may not be economically very viable at the moment, but criticality of these materials justifies such a step.

Annexure 1

F.No.10/73/2011/MV
Government of India
Ministry of Mines

New Delhi, the 9th August, 2011

OFFICE MEMORANDUM

Subject:- **Constitution of a Steering Committee to Develop a Strategy Paper on Status and Availability of Rare Earth Element (REE) and Energy Critical Element (ECE)**.

Rare Earths (RE) and Energy Critical Minerals (ECE) are extensively used in high technology and futuristic applications like wind energy turbines, solar energy collectors and thin film technologies. There is need for development of a focused strategy for their indigenous production, based on analysis of availability, stepping up of exploration for discovery of economically extractable deposits and identification and development of processes for their recovery in usable forms and quantities in order to ensure long term national raw materials security.

2. A Steering Committee has accordingly been constituted for a coordinated research and development effort. The Composition and Terms of Reference of the Steering Committee are as follows:-

I Composition:

1	Secretary, Ministry of Mines, Government of India	Chairman
2	Chairman, Centre for Study of Science Technology and Policy (C-STEP	Co-chairman
3	Nominee of Department of Science & Technology	Member

4	Director General, Geological Survey of India	Member
5	Director, (Materials Group), BARC	Member
6	CMD, India Rare Earth Limited	Member
7	Director, (Materials,) Defence Research & Development Organization	Member
8	Director, (Atomic Minerals Division), Department of Atomic Energy	Member
9	Director, IMMT, Bhubaneswar	Member
10	Director, NML, Jamshedpur	Member
11	Director, Centre for Techno-Economic Mineral Policy Options (C-TEMPO)	Secretary

Terms of Reference

1. Prepare a position paper on current status of Rare Earths (REE) and Energy Critical Elements (ECE) like gallium, indium, germanium, selenium, lithium etc.

2. Identify high value REE and ECE for industrial and strategic applications, including lasers, magnets, energy and power generation and storage and other applications of widespread potential use and the status of Indian industrial sector to utilize these materials for the required applications.

3. To review Sources of supply, economics, supply chain etc. with a view to improving raw materials security for the long term in the national interest.

4. Make recommendations on restarting domestic REE/ECE production, examining extraction processes and making recommendations on the creation of process R&D

facilities to develop extraction and recovery processes on an ongoing basis to meet actual needs in specific situations.

5. Develop strategies for intensifying exploration beyond Monazites, for Xenotime, Bastnaesite and other primary sources of REE.

6. Identifying all the techno-economic issues for long term national raw materials strategy and preparing a strategy paper for the Government providing short, medium & long term options along with proposals for specific policy & legislative interventions.

7. **The Committee may submit the report preferably within six months.**

(Anil Subramaniam)
Under Secretary to the Government of India
Telefax: 011-23383946

To

All Members of the Committee

Copy to:-

1.PS to Hon'ble MoS (IC) of Mines

2.PPS to Secretary (Mines)

3.PPS to Addl. Secretary (Mines)

4.PS to JS(MR)

5.Director (CS)

6.Director (C-TEMPO)

Annexure 2

MINISTRY OF ENVIRONMENTAND FORESTS
NOTIFICATION
New Delhi, the 12th May, **2011**

S. O. 1035 (E) – Whereas, the draft rules, namely the e-waste (Management and Handling) Rules, 2010 were published by the Government of India in the Ministry of Environment and Forests vide) number S.O.1125 (E), dated 14th May,2010 in the Gazette of India, Extraordinary Part II, Section 3, Sub-section (ii) dated14th May; 2010 inviting objections and suggestions from all persons likely to be affected thereby, before the expiry of the period of, sixty days from the date on which copies of the Gazette containing the said notification were made available to the public;

AND WHEREAS the copies of the said Gazette were made, available to the public on the 14th day of May, 2010;

AND WHEREAS the objections and suggestions received within the said period from the public in respect of the said draft rules have been duly considered by the Central Government;

NOW, THEREFORE, in exercise of the powers conferred by sections 6, 8 and 25 of the Environment (Protection) Act, 1986 (29 of 1986), the Central Government hereby makes the following rules, 'namely:-

CHAPTER I

PRELIMINARY

1. Short title and commencement. —

(1) These rules may be called the e-waste (Management and Handling) Rules, 2011.
(2) They shall come into effect from 1st May, 2012.

2. Application. — These rules shall apply to every producer, consumer or bulk consumer involved in the manufacture, sale, purchase and processing of electrical and electronic equipment or components as specified in Schedule-I, collection centre, dismantler and recycler of e-waste and shall not apply to-

CHAPTER III

PROCEDURE FOR SEEKING AUTHORIZATION AND REGISTRATION FOR HANDLING E-WASTES

9 Procedure for grant of authorization.-

(1) Every producer of electrical and electronic equipment listed in Schedule I, collection centre, dismantler and recycler of ‘e-waste "shall obtain an authorization from the State Pollution Control Board or Pollution Control Committee of Union territories concerned as the case 'may be.

(2)' Every producer of electrical and electronic equipment listed in Schedule I, collection centre, dismantler and recycler of e-waste shall make an application, within a period of three months starting from the date of commencement of these rules in Form 1 to the State Pollution Control Boardor the Pollution Control Committee for grant of authorization:

Provided that any person authorized under the provisions of theHazardous Wastes (Management, Handling and Transboundary Movement)Rules, 2008, prior to the date of coming intoiforce of these ru_les shall not berequired to make an application for authorization till the period of expiry of such authorization:

Provided further that a recycler of e-waste who has not been authorized under the provisions of the Hazardous Waste (Management, Handling ‘and Transboundary /Movements) Rules, 2008, shall require authorization following the procedure mentioned in sub-rule‘ (1) above.

(3) On receipt of the application complete in all respects for the authorization, the State Pollution Control Board or Pollution -Control Committee of Union territories may, after such enquiry as it considers necessary and on being satisfied that the applicant possesses appropriate facilities, technical capabilities and equipment to handle e-waste safely, grant within a period of ninety days an authorization in Form-1(a)_ to the applicant to carry out safe operations in the authorized place only, which shall be valid for a period of five -years.

(4) The State Pollution Control Board or Pollution Control Committee of the Union territories after giving reasonable opportunity of being heard to the applicant shall refuse to grant any authorization.

(5) Every person authorized under these rules shall maintain the record of e- waste handled by them in Form-2 and prepare and submit to the State Pollution Control Board or Pollution Control/Committee, an annual return containing the details specified in Form 3 on or before 30th day of June following the financial year to which that return relates.

(6) An application for the renewal of an authorization shall be made in Form-1 before sixty days of its expiry and the State Pollution Control Board or Pollution Control Committee may

renew the authorization after examining each case on merit and subject to the condition that there is no report of violation of the provisions of the Actor the rules made there under or the conditions specified in the -authorization.

(7) Every producer of electrical and electronic equipment listed in Schedule I, collection centre, dismantler and recycler of e-waste shall take all steps, wherever required, to comply with the conditions specified in the authorization.

(8) The State Pollution Control Board in case of a respective State or the Pollution Control Committee in case of Union territories shall maintain a register containing particulars of the conditions imposed under these rules for environmentally sound management of e-waste, and it shall be open for inspection during office hours to any person interested or affected or a person authorized by him on his behalf.

10 Power to suspend or cancel an authorization.-

(1) The State Pollution Control Board or Pollution Control Committee of the, Union territories may, if in its opinion, the holders of the authorization has failed to comply with any of the conditions of the authorization or with any provisions of the Act or these rules and after ‘giving a reasonable opportunity of being heard and after recording reasons thereof in writing cancel or suspend the authorization issued under these rules for such period as it considers necessary in the public interest.

(2) Upon suspension or cancellation of the authorization, the State Pollution Control Board or Pollution Control Committee of the Union territories may give directions to the persons whose authorization has been suspended or cancelled for the safe storage of the e-waste and such person shall comply with such directions.

PROCEDURE FOR REGISTRATION WITH STATE POLLUTION CONTROL BOARD

11. Procedure for grant of registration. —

(1) Every dismantler or recycler of e-waste shall make an application, within a period of three months starting from the date of commencement of these rules, in Form-4 in triplicate to the State Pollution Control Board accompanied with a copy of the following documents for the grant or renewal of registration:-

(i) consent to establish granted by the State Pollution Control Board underwater (Prevention and Control of Pollution) Act, 1974, (25 of 1974) and Air (Prevention and Control .of Pollution) Act; 1981(21 of 1981)

(ii) certificate of registration issued by the District Industries Centre or any other government agency authorized in this regard

(iii) proof of installed capacity of plant and machinery issued by the District' Industries Centre or any other government agency authorized in this behalf

(iv) in case of renewal, a certificate of compliance of effluent and emission standards, treatment and disposal of hazardous wastes as applicable from the State Pollution Control Board or Committee of the Union territories or any other agency designated for this purpose.

FORM 1

[See rule 9(2)]

APPLICATION FOR OBTAINING AUTHORIZATION FOR GENERATION/ COLLECTION/ STORAGE/DISMANTLING/RECYCLINGI OF E-WASTE

From: ....

To

The Member Secretary,

.... Pollution Control Board or…………………… Pollution Control Committee

…………………………………………..

…………………………………………..

Sir,

We hereby apply for authorization/renewal of authorization under rule 11(2) and 11(6) of the E-wastes (Management and Handling) Rules; 2011 for collection storage transport/treatment/disposal of e-wastes

For Office Use Only

Code No.:

Whether the unit is situated in a critically polluted area as identified by Ministry of Environment and Forests (yes/no);

To be filled in by Applicant

Part - A: General

1. (a) Name and full address, telephone nos. e-mail and other contact details of the unit:

. (b) Authorization required for (Please tick mark appropriate activities*)

(i) Generation
(ii) Collection
(iii) Dismantling
(iv) Recycling

(C) In case of renewal of authorization previous authorization no. and date

2. (a) Whether the unit is generating or processing e-waste as defined in the E-wastes (Management and Handling) Rules, 2011

(i) generating
(ii) processing

3. (a) Total capital invested on the project:
   (b) Year of commencement of production:
   (c) Date of grant of the Consent to Establish:
   (d) Date of grant of the Consent to Operate:

Part - B: e-waste

4. E-waste details:

(a)	Type of e-wastes generated as defined under the e-wastes (Management and Handling) Rules, 2011:	
(b)	Total Quantity e-waste handled generated/collected/dismantled/recycled:	
(c)	Mode of storage within the plant :	
(d)	Method of treatment and disposal:	
(e)	Installed capacity of the plant:	

Part - C: Dismantling and Recycling Facility

5. Detailed proposal of the facility (to be attached) to include:'
(i) Location of site (provide map).
(ii) Details of processing technology
(iii) Type and Quantity of waste to be processed per day
(iv) Site clearance (from local authority, if any)
(v) Utilization of the e.-waste processed
(vi) Method of disposal of residues (details to be given)
(vii) Quantity of waste to be processed or disposed per day
(viii) Details of categories of e-waste to be dismantled/processed
(ix) Methodology and operational details'
(x) Measures to be taken for prevention and control of environmental pollution including treatment of leachates
(xii) Investment on Project and expected returns
(xiii) Measures to be taken for safety of workers working in the plant

Place________ Signature_________
Name (__________)
Date________ Designation_______

FORM 1(a)

[See rule 9(3)]

FORM FOR GRANTING AUTHORIZATION FOR GENERATION/COLLECTION/ /STORAGE/DISMANTLING/ RECYCLING/ OF E·WASTE*

1. (a) Authorization and (b) date of issue ....

2. '" .... of. .... is hereby granted an authorization for generation, collection, storage, dismantling and recycling of e-waste
on the premises situated at.. ....

3. The authorization granted for generation, collection, storage, dismantling, and recycling of e-wastes.

4. The authorization shall be in force for a period from .... to. , .. , ...

5. The authorization is subject to the conditions stated below andjsuch conditions as may be specified in the rules for the time being in force under the Environment (Protection) Act, 1986. "

Signature__________
Designation________ Date____________

Terms and conditions of authorization

1. The authorization shall comply with the provisions of the Environment (Protection) Act, 1986, and the rules made there under.
2. The authorization or its renewal shall be produced for "inspection at the request of an officer authorized by the State Pollution Control' Board or Committee of Union territories.
3. The person authorized shall not rent, lend, sell, transfer or otherwise transport the e-wastes without obtaining prior permission of the State Pollution Control Board or Committee of Union territories.
4. Any unauthorized change in personnel, equipment as working conditions as mentioned in the application by the person authorized shall constitute a breach of his authorization.
5. It is the duty of the authorized person to take prior permission of the State Pollution Control Board or Committee of Union territories to close down the operations.
6. An application for the renewal of an authorization shall be made as laid down in sub-rule (6) of rule 9. "

FORM-2

[See rules 4(8), 5(5) and 9(5)]

FORM FOR MAINTAINING RECORDS OF E-WASTE HANDLEDI GENERATED

Quantity in Metric Tonnes (MT) or Kilograms (Kg) per year

1.	Name & Address: Producer /Collection Centre/ Dismantler/ Recycler/ Bulk consumer *	
2.	Date .of Issue of · Authorization* Registration	
3.	Validity of Authorization* /Registration'	
4.	Types & Quantity of e-waste handled/generated	Category I Quantity Item Description
5.	Types & Quantity of e-waste stored	Category I Quantity Item Description
6.	Types & Quantity of e-waste sent to authorized Item Description collection centre/ registered. dismantled or recycled	Category I Quantity Item Description
7.	Types & Quantity of e-waste transported' Name, address and contact details of the destination	Category I Quantity Item Description
8.	Types & Quantity of e-waste refurbished* Name, address and contact details of the destination of refurbished materials	Category I Quantity Item Description
9.	Types & Quantity e-waste dismantled' Name and address and contact details of the destination	Category I Quantity Item Description
10.	Types and quantity of e-waste recycled Types and quantity of e-waste recovered Name, address and contact details of the destination	Category I Quantity Item Description Quantity
11.	Types & Quantity of waste treated & disposed	Category I Quantity Item Description

*Strike off whichever is not applicable

5. A Summary Statel1]ent on Category wise :Please attach as Annexure-II
and product wise quantity of e-waste collected :Please attach as Annexure-III
6. Mode of treatment with details
7. Brief details of collection, dismantling and :Please attach as Annexure-IV
recycling facilities
8. Any other information

9. Certified that the above report is for the period from______________
____

Date___________
Place___________

Chairman or the Member Secretary
State Pollution Control Board
Pollution Control Committee

[F. No. 23-7li2009-HSMD]
RAJIV GAUBA, Jt. Secy.

About CSTEP

CSTEP is a ‘not for profit’ research organization incorporated in 2005, under Section 25 of The Companies Act, 1956. Its vision is to enrich the nation with technology-enabled policy options for equitable growth. CSTEP provides comprehensive and objective analyses of the complex problems facing the country to decision makers as well as the public. Its research work is in the areas of Energy, Infrastructure, New Materials and National Security.

The organization is recognized as a Scientific and Industrial Research Organization by the Department of Scientific and Industrial Research. It is registered under the Foreign Contribution (Regulation) Act, 1976. Grants and donations made to CSTEP are eligible for exemptions u/s 80(G) of the Income Tax Act, 1961.

About C-TEMPO

The Centre for Techno Economic Mineral policy Options (C-TEMPO) has been set up under the aegis of Ministry of Mines, as a think tank to evolve policy options and help address the technology and management gap for nonferrous minerals.

The objective of C-TEMPO is primarily to prepare and present attributable and non-binding techno-economic advice on various issues related to the mineral and mining sector. The aim of the Centre is to facilitate effective interaction between the investors, entrepreneurs, mining industry and the Central and State Governments and evolve policy options for stakeholders of the mineral sector. It is also preparing and presenting Position Papers and studies on various techno-economic issues for the consideration of the Government, industry and other stake holders. It also undertakes networking with Industry and Government for coordinated research in the mineral sector.

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