Serviço Geológico do Brasil - CPRM

Economic Viability and Global Market Competitiveness of Specific Minerals

Rare Earths Geoeconomic Profile

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Rare Earths

Outline

- Mineral Occurrences
- Mineral Rights
- Resources and Reserves
- Monazites and Monazite Sands
- Uses and Applications
- World Market
- Brazilian Production
- Enterprises in Perspective
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Rare Earths

Mineral Occurrences

Rare Earths (REs)

“The Rare Earths (REs) ... are a group of 17 chemical elements, metals with similar physical-compound properties, which are associated with other elements forming about 200 minerals that occur in nature in different ways. Of these, ... only three are important in the production of REs: monazite, bastnasite and xenothymium, all with proven existence in Brazilian lands, ... ”(Netto, O. B., 2012)

In Brazil, important carbonatite REE deposits also stand out, such as in Catalão (GO), Araxá (MG), Mato Preto (PR) and others.

Rare Earth Elements

	Elements	Symbols	Atomic Number
LIGHT	Lanthanum	La	57
	Cerium	Ce	58
	Praseodymium	Pr	59
	Neodymium	Nd	60
	Promethium*	Pm	61
	Samarium*	Sm	62
	Europium*	Eu	63
HEAVY	Gadolinium*	Gd	64
	Terbium	Tb	65
	Dysprosium	Dy	66
	Holmium	Ho	67
	Erbium	Er	68
	Thulium	Tm	69
	Ytterbium	Yb	70
	Lutetium	Lu	71
	Yttrium	Y	39
	Scandium	Sc	21

Source: Germani, 2012;
Obs.: *Also classified as Medium REs

Rare Earths

Mineral Occurrences

According to the USGS, RE are relatively abundant in the Earth's crust, although the discovery of economically usable concentrations is less frequent, compared to other mineral goods.

RE occur most frequently in carbonatite phosphates, iron formations and alluvial formations. They are mainly contained in the minerals of the groups of bastnaesite (Ce, La)CO3F, monazite (Ce, La)PO4, ionic clays and xenothymium (YPO4).

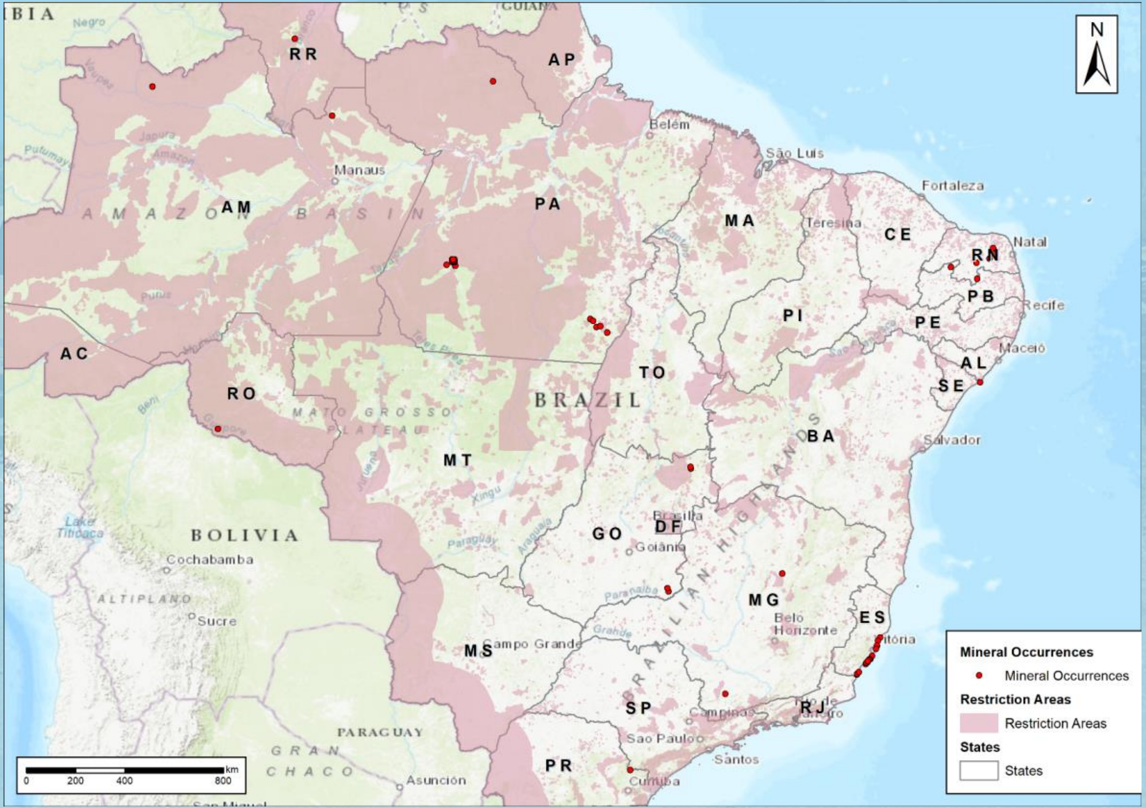
Lapido (2013) highlights the following RE minerals, in descending order of approximate contents of REO: Bastnaesite (75%), Monazite (65%), Xenothymium (61%), Parisite (61%), Gadolinite (60%) , Ytrocerita (53%), Fergusonite (53%), Huanghoita (39%), Allanita (38%), Kainosita (38%), Aechynita (32%), Britholita (32%), Florencita (32%), Cebaita (32%), Loparite (30%), Euxenite (28%), Samarskite (24%), Apatite (19%), Eudialite (9%), Brannerite (9%).

Source: ConDet, 2013

Rare Earths

Mineral Occurrences/ Restriction Areas

Occurrences, Deposits and Mineral Production Units	
States	**O, D, MPU**
Amazonas	3
Espírito Santo	15
Goiás	4
Minas Gerais	2
Pará	48
Paraíba	2
Rio Grande do Norte	6
Rondônia	1
Roraima	1
São Paulo	1
Sergipe	1
Total	**84**



Sources: Mineral Ocurrences: SGB GEOSGB – June, 2020

Restriction Areas: MMA, INCRA, ICMBio, FUNAI, CSN and CDN – 2021

Data processed by the Platform P3M

Rare Earths

Mineral Rights

Mineral Rights								
States	Available		Exploitation		Exploration		Total	
	Number	Area (ha)	Number	Area (ha)	Number	Area (ha)	Number	Area (ha)
Amazonas					2	18,101	2	18,101
Bahia	1	445			137	136,824	138	137,269
Ceará					3	3,977	3	3,977
Espírito Santo	1	3	2	19	22	9,362	25	9,385
Goiás			8	9,716	99	114,166	107	123,882
Maranhão					1	1,065	1	1,065
Mato Grosso					1	908	1	908
Minas Gerais			3	1,388	9	5,561	12	6,949
Pará					1	10,000	1	10,000
Paraná					1	1	1	1
Rio de Janeiro					9	6,235	9	6,235
Rio Grande do Norte					9	14,707	9	14,707
Rondônia	1	9,881			4	21,506	5	31,387
São Paulo					4	2,877	4	2,877
Tocantins					34	20,774	34	20,774
Total	**3**	**10,329**	**13**	**11,123**	**312**	**366,066**	**328**	**387,518**

Source: ANM Open Data – 2019; Processed by the Platform P3M

Among the resources and reserves, one should point out the placers of marine origin from the coast of the state of RJ (monazite) and those of fluvial origin, such as Pitinga (AM) and São Gonçalo do Sapucaí (MG), in which the RE minerals are, respectively, xenothymium and monazite.

Stand out too silexite from Catalão (GO) and Morro do Ferro (MG), phosphates from Araxá (MG) and Catalão (GO), niobium ore from Araxá (MG) and Catalão (GO), and fluoritic ore from Mato Preto (PR).

The Córrego do Garimpo (GO) monazite deposit is promising due to its contents, reserves (680 M tons of REO) and low radioactivity (0.46% ThO_2).

Due to its mineralogical complexity and its high thorium content (4.9% ThO_2), the ore from Morro do Ferro, in Poços de Caldas (MG), presents processing difficulties

Source: ConDet, 2013

Rare Earths

Resources and Reserves

Lapido (2013) emphasizes that the vast majority of rare earths resources are associated with only three minerals: bastnaesite and monazite, for the light REs, and xenothymium, for the heavy REs.

The resources of REs are mainly contained in bastnaesite and monazite. Bastnaesite deposits from China and the US constitute the majority of the world's RE resources, while monazite deposits rank second.

The largest reserves of bastnaesite are in China (Baotou) and in US (Mountain Pass, California). In Brazil, Australia, India, South Africa, Thailand and Sri Lanka, RE occur in monazite and sands with other heavy minerals (ilmenite, zirconite and rutile).

According to the Mineral Summary 2012 (DNPM), China has about 50% of the world's reserves of RE, followed by the The Commonwealth of Independent States (CIS) and the US.

Source: ConDet, 2013

Rare Earths

Resources and Reserves (2020)

		Reserves (in thousand tons)					
		Measured		Indicated		Inferred	
Municipality	**State**	**Ore**	**REO**	**Ore**	**REO**	**Ore**	**REO**
Alcobaça	BA	179	4	0	0	0	0
Caravelas	BA	117,321	645	41,407	228	41,407	228
Araxá	MG	750,283	19,918	67,083	1,519	10,381	522
Poços de Caldas	MG	4,658	159	366	9	75	2
Pouso Alegre	MG	1	1	0	0	0	0
São Gonçalo do Sapucaí	MG	32,849	4	1,182	1	904	1
Linhares	ES	10	2	1	0	0	0
São Mateus	ES	1	0	0	0	0	0
São Francisco de Itabapoana	RJ	365	1	0	0	0	0
Itapirapuã Paulista	SP	960	47	1,043	51	14,433	706
Minaçu	GO	204,325	292	368,633	403	230,767	263
Total		**1,110,950**	**21,072**	**479,715**	**2,211**	**297,967**	**1,721**

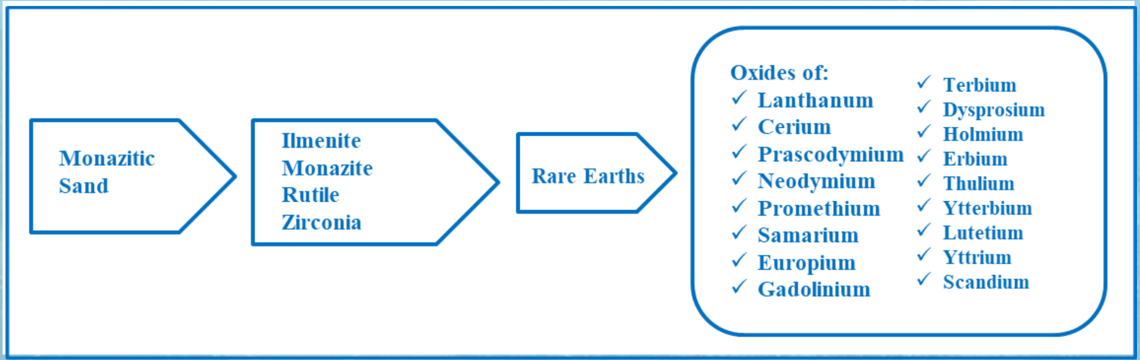
Source: ANM, June, 2021; Processed by Platform P3M

Current Brazilian reserves:

- in the order of 22 M tons of REO

Rare Earths

Uses and Applications



Monazitic sands: are found on the Brazilian coast, in the north of the state of RJ, in ES, and in the south of BA. In Brazil, the use of these sands began at the end of the 19th century, in Cumuruxatiba, Bahia, to supply the production of incandescent mantel for gas lamps.

In the 1940s, MIBRA - Mineradora Brasileira S.A. and SULBA - Sociedade Comercial de Minérios Ltda., began to carry out the mining and physical separation of monazite contained in monazite sands. MIBRA operated on the north coast of RJ, in ES; and Sulba, in BA.

REs compounds are intended for the following main basic segments of use:

- Oil cracking
- Tablets, cell phones, leisure, and wind energy turbines components,
- Catalysts for oil refining
- Automotive catalysts
- Magnetic resonance devices
- Guided missiles
- Electric cars (hybrid and pure electric)
- Color TV
- Permanent magnets
- Magnetic levitation
- Laser generating crystals
- Superconductors

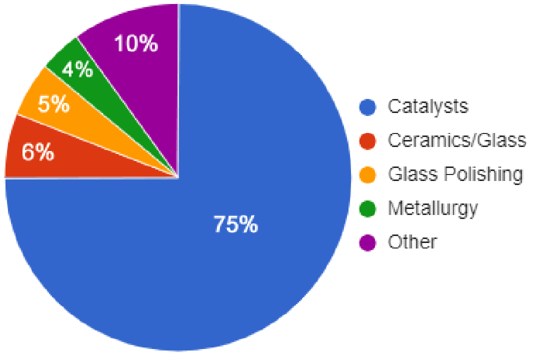
Source: ConDet,. 2013

Rare Earths

Uses and Applications/

The Use of RRE in the USA in 2020

- Vehicles use RE catalysts in their exhaust systems for air pollution control.
- Large number of alloys are made more durable by the addition of RE metals.
- Glass, granite, marble, and gemstones are polished with cerium oxide powder. Many motors and generators contain magnets made with RE elements.
- Phosphors used in digital displays, monitors, and TVs are created with REO.
- Computer, cell phone, and electric vehicle batteries are made with RE metals.
- Rare earth elements play an essential role in national defense.
- The military uses night-vision goggles, precision-guided weapons, communications equipment, GPS equipment, batteries, and other defense electronics.
- RE metals are key ingredients for making the very hard alloys used in armored vehicles and projectiles that shatter upon impact.



Uses in the United States as reported by the United States Geological Survey Mineral Commodity Summary, 2020

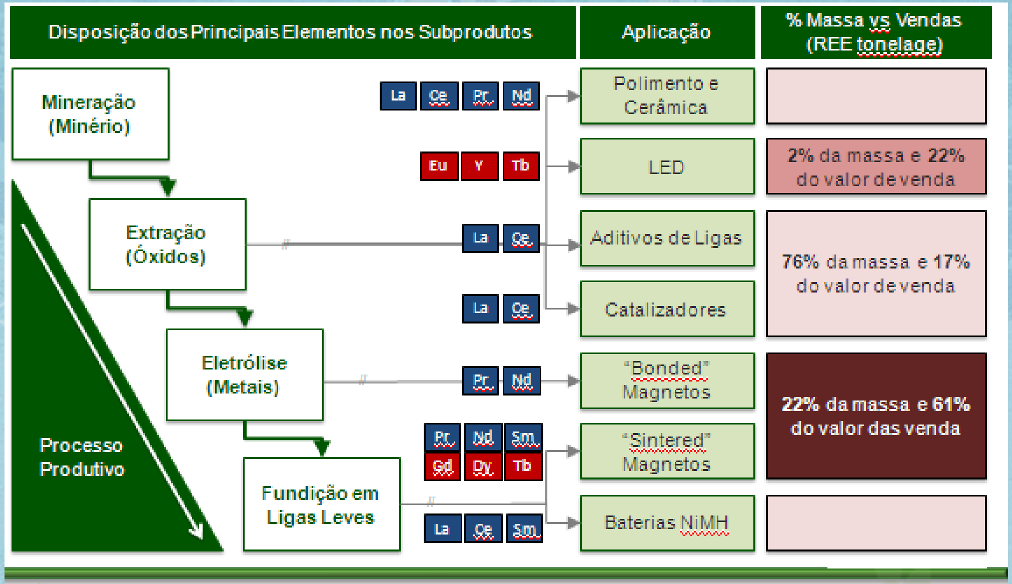
Defense Uses of Rare Earth Elements	
Lanthanum	night-vision goggles
Neodymium	laser range-finders, guidance systems, communications
Europium	fluorescents and phosphors in lamps and monitors
Erbium	amplifiers in fiber-optic data transmission
Samarium	permanent magnets that are stable at high temperatures
Samarium	precision-guided weapons
Samarium	"white noise" production in stealth technology

Source: https://geology.com/articles/rare-earth-elements/

Rare Earths

Uses and Applications/ Production Chain

Productive Chain and Applications of REEs



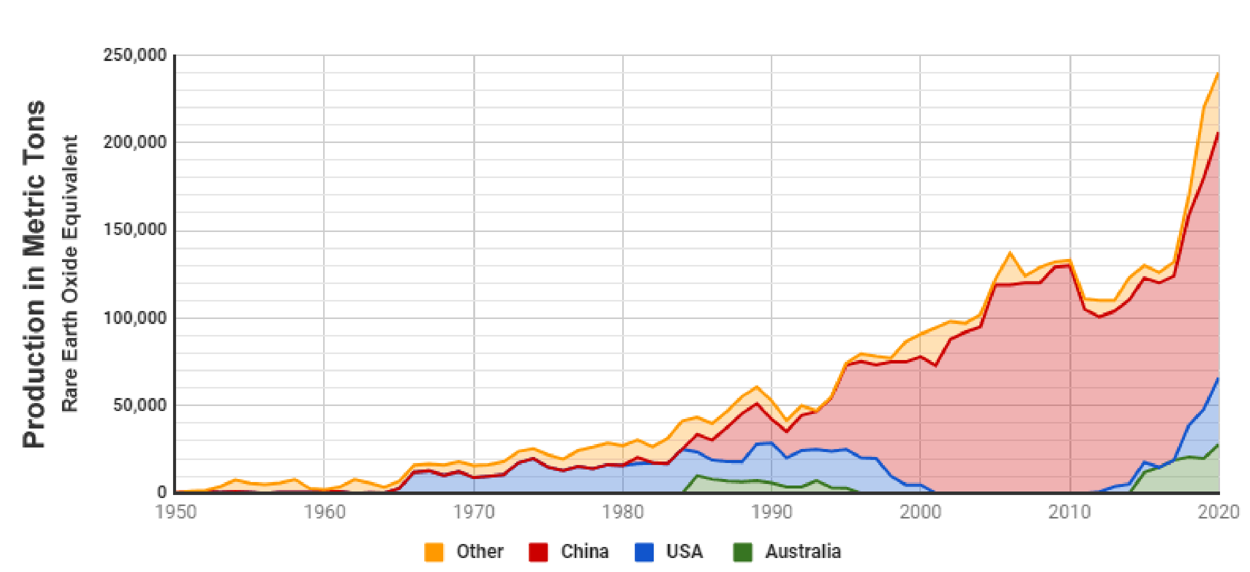
Approximately 10 years ago, special magnets participated with about 22% of the volume and 61% of the value of the global market for RE.

Source: MBAC, 2012, apud ConDet, 2015

Rare Earths

World Market

- The chart shows the REE production, in metric tons of REO equivalent, between 1950 and 2020.
- It shows the US' entry into the market in the mid-1960s when color television exploded demand.



- When China began selling RE at low prices in the late 1980s and early 1990s, mines in the US were forced to close.

- When China cut exports in 2010, RE prices skyrocketed. That motivated new production in the US, Australia, Russia, Thailand, Malaysia, and other countries.

- In 2018 production data in Burma/ Myanmar became available and boosted the "others" category.

- Prior to 2018, some production from Burma / Myanmar may have been unreported.

- The graph by Geology.com used data from USGS/ Mineral Commodity Summaries and other publications.

Source: https://geology.com/articles/rare-earth-elements/

Rare Earths

World Market

China is the leader in the world production of RE, with around 90% of the produced volume of REO. China also leads the world consumption of RE, followed by Japan, US and Germany.

Through export quotas and other barriers, China restricts the external sales of RE, in benefit of its internal consumption. However, if the Chinese producer of RE products chooses to import the raw material, the corresponding processed production escapes the limitation established by the export quotas.

China also uses dumping to inhibit competing production, in addition to having labor and environmental legislation that in a way establishes spurious competitiveness. Baotou Steel Rare Earth High-Tech Corp. and Jiangxi Copper Corp. are some of the largest Chinese producers of RE.

Chinese production is concentrated i) in the interior of Mongolia (RE as by-products of iron ore production); and ii) in southern China (RE that occur in clayey soils).

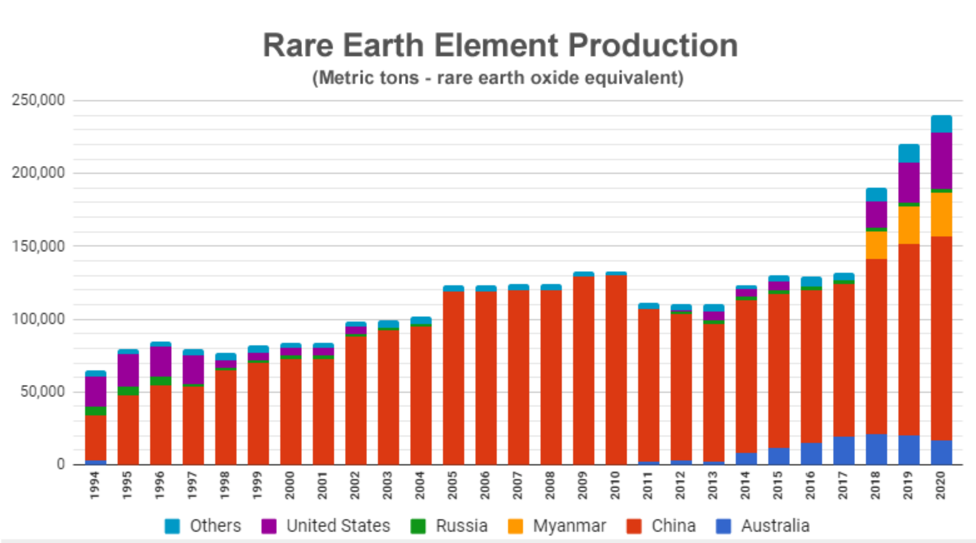
In Mongolia, the Bayan Obo mine stands out - the largest in the world. Its production started in 1927 and the corresponding mineral deposit has resources estimated at 48 to 100 M tons, with a content of 6% of REO (RE_2O_3).

Source: ConDet, 2013

Rare Earths

World Market

- The chart shows China's dominance in the production of REE between 1994 and 2020.
- The US was a significant producer through the 1990s, but low priced materials sold by China forced mines in the US and other countries out of operation.



- As China limited exports, and prices increased rapidly in 2009 and 2010, mines in Australia and the US became active again.
- In 2018, data from Burma / Myanmar became available, causing an increase in production that may have been present but unreported prior to 2020.
- Graph by Geology.com using data from the USGS.

Source: https://geology.com/articles/rare-earth-elements/

Rare Earths

World Market / Scenario View

The 21st century has been notable for its widespread replacement of non-renewable energy and the advance in the use of renewable sources. The trend towards a user-generator system is evident, through the implementation of new energy sources, associated with the use of new materials.

Renewable energy of an intermittent nature (solar and wind) and even seasonal (biomass) tends to be generated for self-supply, rather than being injected into large and expensive transmission/distribution systems. Consequently, it will require efficient accumulators that allow the generation flow to be harmonized with the consumption regime/flow.

In this context, electrical energy will progressively tend to depend less on fossil fuels, while mechanical energy will increasingly come from electrical energy generated from renewable sources. The technology for the generation, storage and use of renewable energy is a key factor in the technological revolution that emerges at the beginning of the 21st century.

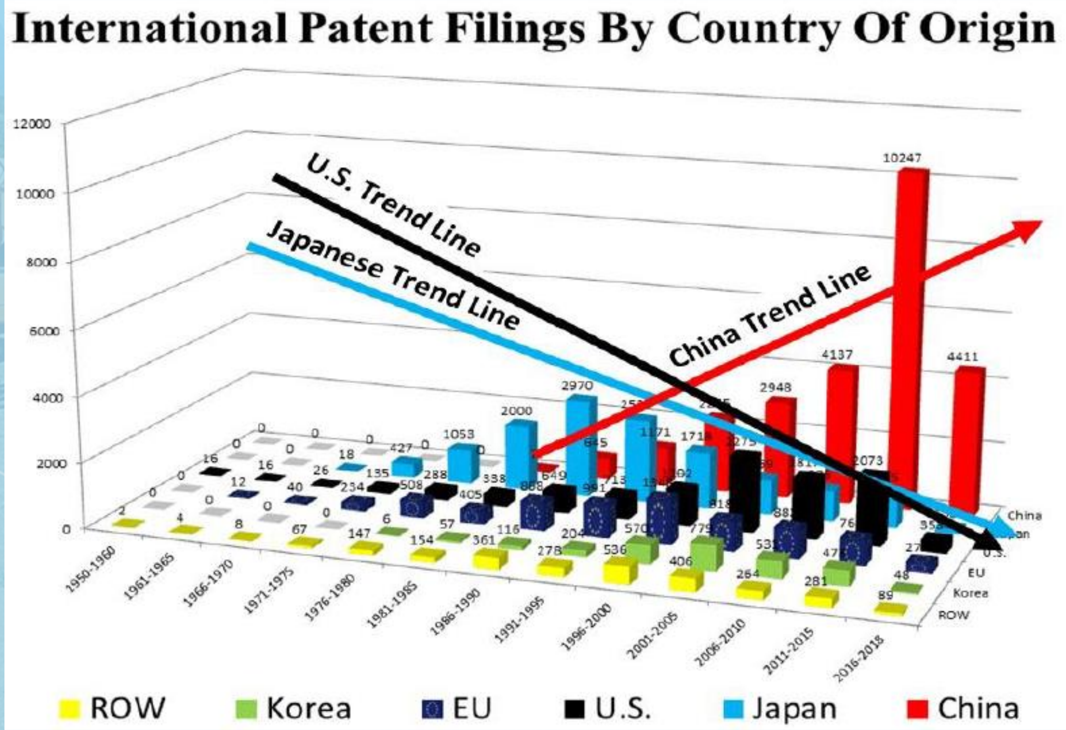
Among the mineral resources that should stand out in this new industrial revolution stand out the Rare-Earths, essential for the manufacture of high-efficiency magnets, used, for example, in wind turbines and motors of vehicles powered by electricity.

Source: ConDet, 2013

Rare Earths

World Market

- China has 5 R&D centers dedicated exclusively to RE. The Bouton Research Institute of Rare Earths is considered the largest in the world.
- China has eclipsed the rest of the world in rare earth basic science, IP and R&D research.
- China has more rare earth patents each year than the rest of the world combined.



Source: Understanding China Rare Earth Monopoly/ Congressional Briefing/ Presentation at the Capitol Building Visitor Center, 2019

Rare Earths

Brazilian Production

The production of monazite in Brazil was initiated by Orquima, which operated from 1946 to 1956, using autochthonous techniques for separating RE. In the mid-1950s, it became the first supplier of pure europium concentrate for color TV (Phillips) development.

From 1956 onwards, the extraction and processing of monazite for the recovery of RE compounds came under State control, through the following organizations:

- 1956 to 1962: Monazite Production Administration;
- 1962 to 1974: CBTN - Cia. Brasileira de Tecnologia Nuclear;
- 1974 to 1994: NUCLEMON - Nuclebrás de Monazita e Associados;
- 1992 to 2004: INB – Indústria Nuclear Brasiliera.

CBTN started the production of yttrium concentrates by solvent extraction and, at the end of the 60s, developed neodymium separation techniques with ion exchange, using chromium as the auxiliary separation retainer ion.

Source: ConDet, 2013

Rare Earths

Brazilian Production

NUCLEMON implemented a pilot unit for the production of cerium hydroxide and lanthanum carbonate and, at the beginning of the 1980s, started the production, on a pilot scale, of neodymium carbonate, with 85% purity. In 1986, it generated high purity neodymium carbonate, from which the State University of Campinas (UNICAMP) built the Laser prototype.

In 1988, the Interlagos Plant (USIN) was set up, 1st industrial installation for solvent separation of RE, obtaining concentrates of RE Light (La, Ce, Pr and Nd) and RE Medium / Heavy (Sm, Eu, Gd, Tb, Dy, Ho, Er, Yb and Y).

In 1992, INB deactivated the facilities of the Santo Amaro Plant and signed a contract with the Nuclear Energy Institute aiming at the technological development of separation of RE by solvent extraction. In 1993, INB set up the Rare Earth Separation and Demonstration Unit, in Buena, comprising 115 mixers/decanters. Between 1993 and 1996, through UDES, INB produced:

- Lanthanum carbonate with 99% purity
- Didymium Concentrate (Praseodymium and Neodymium)
- 99.9% pure neodymium carbonate
- Samarium carbonate and oxide with purity above 99.9%;
- Gadolinium and Europium Concentrate;
- Rare Earth Concentrate (Tb, Dy, Ho, Er, Yb, Y)

Source: ConDet, 2013

Rare Earths

Brazilian Production

The Industrial Unit of Caldas-MG was installed in 1997, with the aim of opening up monazite and the production of cerium hydroxide and lanthanum chloride.

- **Cerium Hydroxide:** 30 tons/month (Market: manufacture of special glasses for color TV, lenses for glasses and catalysts for automotive vehicles.
- **Lanthanum Chloride:** 130 tons/ month (Market: manufacture of catalysts for oil cracking)

In 2004, the license for experimental operation was obtained, with 300 tons of monazite being processed. After this campaign and once the economic evaluation was carried out, it was decided to close the activity.

Source: ConDet, 2013

Brazilian Production (2019)

Municipality	State	Tons	R$ thousand
São Francisco de Itabapoana	RJ	600	1,987
Total	-	**600**	**1,987**

Source: ANM Open Data – 2019; Data processed by Platform P3M

CFEM (2020)

Counties	R$ thousand
São Francisco de Itabapoana	25,5
Total	**25,5**

Source: ANM Open Data – 2020; Processed by Plataforma P3M

Rare Earths

Enterprises in Perspective

With recognized potential for producing RE, Brazil has projects in different stages of development. Part of this potential is related to the production of RE as by-products, or the reuse of tailings and waste dumps. The main recent projects are listed below:

- Serra Verde: Minaçu/ GO;
- CBMM: Araxá/ MG;
- Mineração Terras Raras: Morro do Ferro Project/ MG;
- MbAC: mineral properties in Araxá/ MG;
- Pitinga/Mineração Taboca: Presidente Figueiredo/ AM;
- VALE and Anglo American: Catalão/ GO;
- VALE: Araxá, Tapira, Salitre/ MG
- INB's waste: Caldas/ MG;
- Mineração Mata Azul: Tocantins;
- Seis Lagos: SGB/CPRM/ AM;
- Placers: monazite sand – several in Brazil.

Source: Magazine "In the Mine", 2018

Rare Earths

Enterprises in Perspective

Mineração Serra Verde (MSV): The company is controlled by the Mining Ventures Brasil group, which in turn is controlled by Denham Capital Management LP - specialized in the development of natural resource exploration projects, with minority participation by Arsago Mining Capital (BVI) Ltda., a Swiss group focused on ventures in Brazil..

MSV has 75 mining rights, covering an area of 70,363 ha, comprising 5 municipalities in the north of the state of Goiás (Minaçu, Trombas and Montividiu do Norte) and two in the south of the state of Tocantins: Palmeirópolis and Jaú do Tocantins.

MSV has resources of 911 M tons, with 0.12% REO, mainly Prazeodymium, Neodymium and Terbium. The pre-feasibility study, completed in 2014, showed reserves of 350 M tons of ore with 0.15% REO, allowing the annual production of 10,000 tons of REE contained in concentrates, with a useful life of 22 years.

According to the company's CEO, it is one of the largest deposits of "rare earths in ionic clays in the Western Hemisphere".

Source: Magazine " Brasil Mineral"

Rare Earths

Enterprises in Perspective

- **Companhia Brasileira de Metalurgia e Mineração (CBMM):** located in Araxá (MG), it is investing in the development of technology for the production of REO and final RE products. In partnership with the Technological Research Institute (IPT), it develops technology to obtain metallic neodymium, praseodymium and didymium, with a view to manufacturing supermagnets.

- **Mbac Fertilizantes:** had been investing in mineral exploration and technological development aimed at producing REO from mineral rights located in the region of Araxá-MG. Its project foresaw the production of 9,000 tons/year of REO, with expansion to 18 thousand tons/year. Installed a pilot plant for the production of REO concentrates with purity greater than 99%.

- **Mineração Terras Raras S.A.:** plans to put into operation the Morro do Ferro Project, which provides for the production of REO in the alkaline complex of Poços de Caldas (MG), in mineral rights with an area of 300 ha, known since 1934, and which contains 3.5 M tons of ore with an average content of 3.9% of REO (Prazodymium, Neodymium, Dysprosium and Europium), or the equivalent of 138,500 tons of REO.

- In the region of Plateau Mata da Corda (MG), three companies are working on the feasibility of REE projects; Vicenza Mineração, Brasil Exploration Mineral S.A. (Bemisa) and TerrAtiva Mineração

Source: ConDet, 2015; Rolim, 2014

Rare Earths

Government Policies / Some Examples

- In 2010, the PNM-2030 was launched, highlighting RE in the list of priority mineral goods for the country.
- In 2016, the government issued a public notice in partnership with the National Council for Scientific and Technological Development (CNPQ) aiming to finance R&D projects on RE.

\- **Objective:** to structure the RE production chain, from mineral exploration and mining to obtaining oxides and, from these, the production of alloys and components for various applications.

- Strategies for verticalization and value addition have been considered in planning the country's mining and industrial development. Recently, such issues have been highlighted in different Plans and Programs.

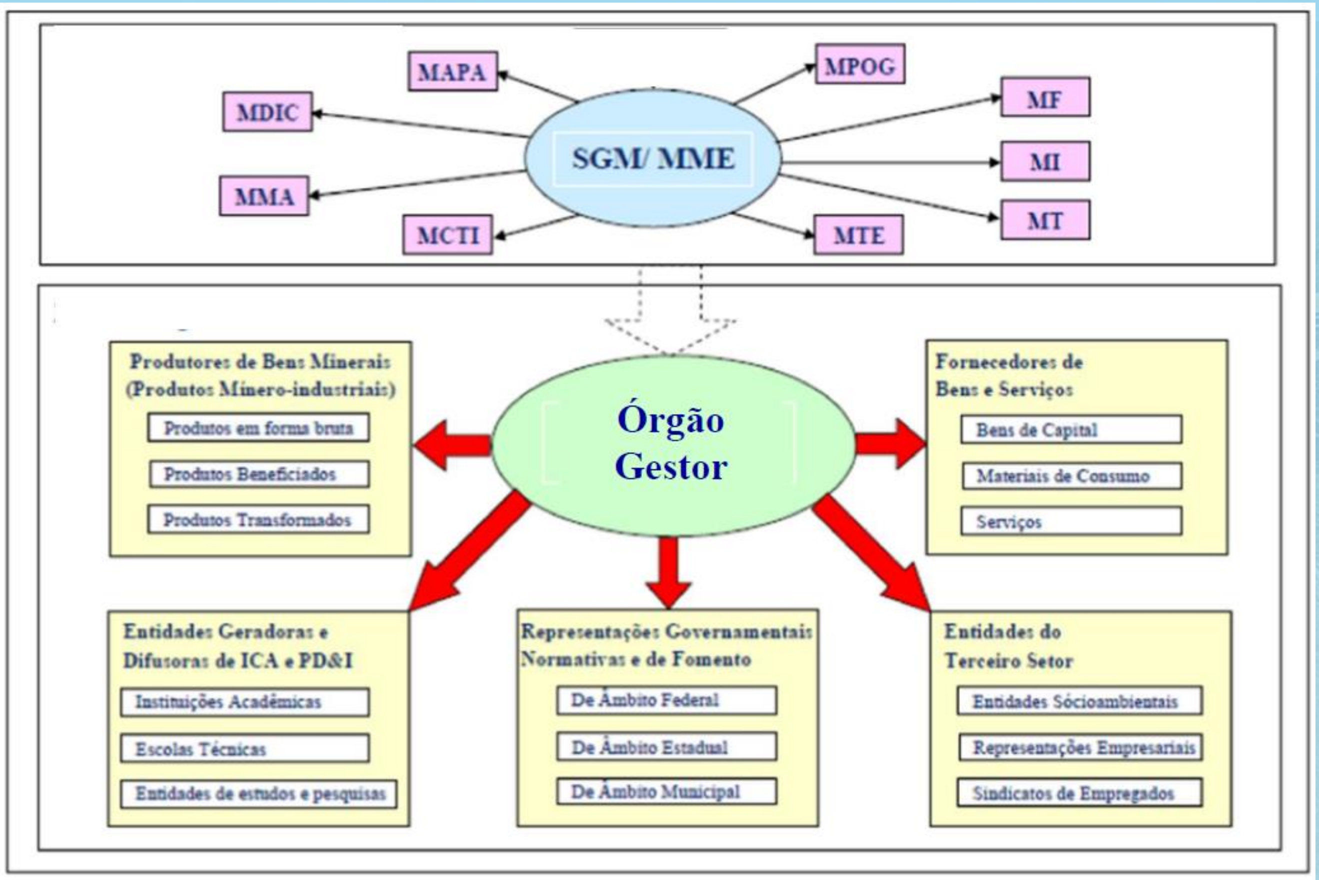
\- **Foundation:** densification of production chains downstream, with value addition, as well as upstream, with the diversification of regional economic activities

- Tax exemption on the disposal of shares of small and medium-sized companies (Law 13,043/ 2014)
- **Pro-Strategic Minerals:** Decree 10,657, of March 24th, 2021 - Institutes the Policy to Support the Environmental Licensing of Investment Projects for the Production of Strategic Minerals - Pro-Strategic Minerals, provides for its qualification under the Investment Partnership Program and creates the Interministerial Committee for the Analysis of Strategic Minerals Projects.

Source: ConDet, 2015

Rare Earths

Government Policies/ A framework previously discussed



Source: ConDet/ 2015

Rare Earths

Government Policies / A framework previously discussed

Strenghts:

- **Resources and Reserves:** Geological environments with high potential for RE reserves.
- **Tailings Use:** Production of REO from large volumes of tailings, accumulated over decades, originating from the mining of phosphate rock/ pyrochlore.
- **Technology/ Rescue:** Brazilian experience and tradition that can be rescued.
- **Technology/ R&D Centers:** Good articulation with companies and academic environment.
- **Technology/ CBMM**: CBMM's technological development program articulated with the IPT.
- **Human Resources:** Reasonable availability and training.

Weaknesses:

- **Resources and Reserves:** Low mineral exploration effort and low knowledge of already discovered deposits.
- **RD&I Network:** In the structuring phase.
- **Productive Sector:** Incipient with low linkage in the production chain.
- **Technology:** The synthesis of REE requires high cost technology.

Source: ConDet, 2015

Rare Earths

Government Policies / A framework previously discussed

Opportunities:

- **Geological Vocation:** Geological conditioning favorable to the discovery of new deposits.
- **Domestic market:** Perspectives: i) wind energy, ii) automotive industry; and iii) electronics industry.
- **External market:** Prospects for alliances with major REO importing countries, which seek to diversify their supply sources, currently concentrated in China.
- **Incentives:** prospects for new financial structuring mechanisms.

Threats:

- **Market:** Chinese competition
- **Regulatory System:** risks of aggravation of issues related to mining, environment, taxation and labor relations.
- **Energy:** risks associated with deficiencies in the electricity generation and transmission system.
- **Taxation:** high tax burden on revenue, with regressive effects.
- **Fiscal and Financial Stimuli:** - inadequacy of internal sources of financing and capitalization;
  - volatility in the venture capital market.

Source: ConDet, 2015

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