Azadi Ka Amrit Mahotsav

FICCI





New Age Energy Minerals









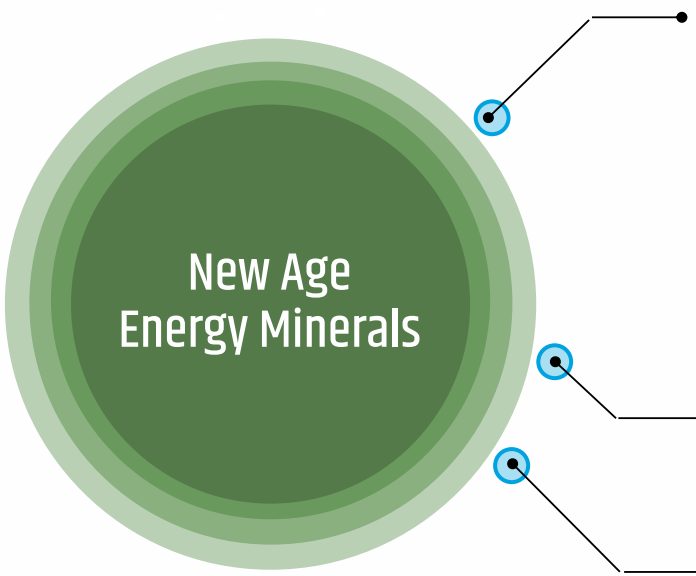




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Report Structure



Market Outlook
- Global Overview
- Indian Overview
- Importance in Indian Economy
- Value Chain
- Trade & Future Demand

Key Challenges and Opportunities

Strategic recommendations

This report has been segregated into two broad categories
- *Rare Earth Elements*
- *Battery Minerals*

Foreword



Subhrakant Panda
President, FICCI and
Managing Director, Indian Metals & Ferro Alloys Ltd

India's pursuit of sustainable, resilient and inclusive growth during *Amrit Kaal*, the celebration of 100 years of independence, entails a transformation of the economy. The aim is not just a higher growth trajectory, but a transition to green energy technologies and an environment friendly approach. Advanced industrial applications, electric vehicles, battery storage, decarbonisation, etc will drive demand for new age minerals, classified into battery minerals and rare earth elements. The occurrence of such minerals is limited and, increasingly, countries endowed with resources are looking to conserve it for their own requirement or that of friendly nations.

Given India's import dependence for most of these minerals, it is imperative to formulate a long term plan which will ensure uninterrupted supply. This involves ongoing exploration to identify occurrence of these minerals, enhanced technology adoption and increased efficiencies to augment production within the country, and tie-ups with friendly nations to access resources. India's strategic relationships and the expertise of its mining sector must be leveraged to access and extract resources.

The **FICCI Report on New Age Energy Minerals** was conceptualised to supplement the Government's efforts in this regard. It encompasses geographical and geological information, details of the value chain including end-use sectors and applications, market outlook, and the importance of such strategic minerals for the Indian economy along with long term demand forecast. The report contains key recommendations to ensure uninterrupted availability which is critical for the country's growth and development. I am sure stakeholders will find the data contained herein useful, and it will enable policy unlocks which protect India's strategic interests.

Subhrakant Panda

Acknowledgments

At the outset, FICCI would like to thank all the stakeholders involved with the development of the report. Our special thanks to FICCI President Subhrakant Panda for conceptualizing the idea of the report on this very important subject of new age energy minerals and guiding us throughout the development of the report. A word of thanks to the team from Mahindra and Mahindra for providing valuable inputs. Also, a special mention to Shailesh Pathak, Secretary General FICCI for his support and guidance.

FICCI would also like to extend its thanks to Deloitte for the preparation of this report in consultation with Industry and other stakeholders in this field. Deloitte team conducted qualitative survey alongside the secondary research to come out with rich output and holistic perspective, giving 360-degree coverage across the entire gamut of new age energy minerals segment.

FICCI would like to thank its Mining Committee for reviewing and supporting it in the process of preparing the report. An attempt has been made to comprehensively cover the issues, opportunities, challenges and recommendations pertaining to the subject. The focus has been on augmenting exploration and production of new age minerals to ensure their uninterrupted supply moving forward with the transition towards new age technologies, green industries, electric vehicles, among others.

FICCI would also like to convey its sincere thanks to various organizations, associations and individual experts in the sector for sharing their insights and contributing to the report. Their views have contributed immensely to finalizing the recommendations of the report.

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Abbreviations

Abbreviation	Description
AMRUT	Atal Mission for Rejuvenation and Urban Transformation
amu	Atomic Mass Unit
ASEAN	Association of Southeast Asian Nations
ASM	Artisanal small-scale Mining
BESS	Battery Energy Storage System
CAGR	Compound Annual Growth rate
CD	Compact Disc
COP21	Conference of the Parties
CRZ	Coastal Regulation Zone
DVD	Digital Video Disc
EAF	Electric Arc Furnace
ESG	Environmental, social and governance
ESS	Energy storage system
EV	Electric Vehicle
GW	Gigawatt
HREE	Heavy Rare Earth Elements
ICE	Internal Combustion Engines
IEA	International Energy Agency
ILO	The International Labor Organization
ISRO	Indian Space Research Organization
IUPAC	International Union of Pure and Applied Chemistry
kT	Kiloton

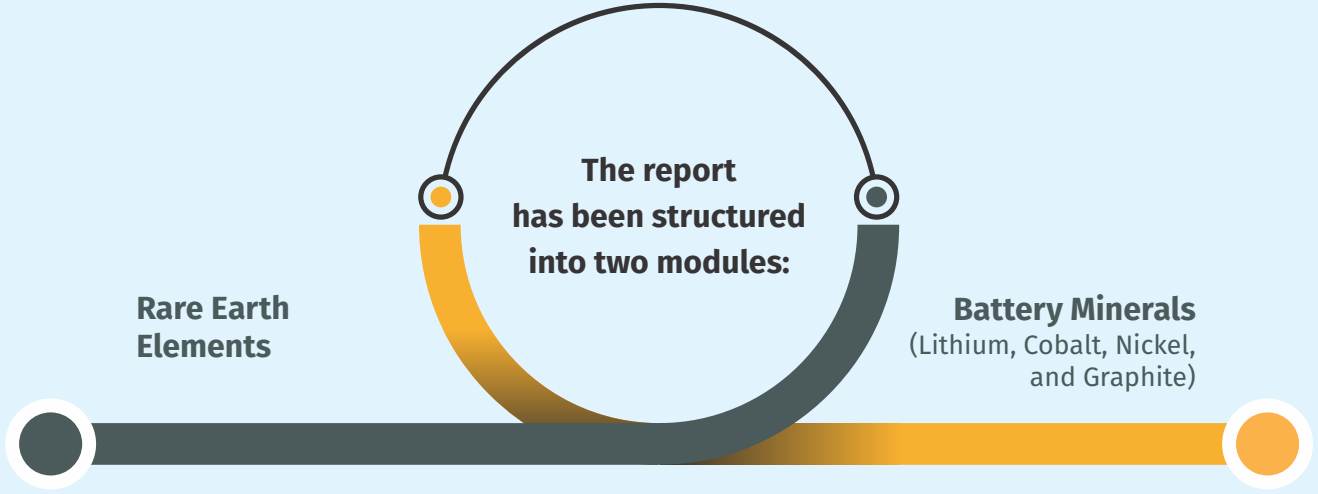
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LiB	Lithium-ion battery
LREE	Light Rare Earth Elements
LSM	Large scale Mining
MnT	Million Tonnes
MoEF	Ministry of Environment and Forests
MTPA	Metric Tonnes per annum
MWh	Megawatt-hour
NdFeB	Neodymium Iron Boron
NdPr	Neodymium and Praseodymium
NiMH	Nickel Metal Hydride
NMI	National Mineral Inventory
NPI	New Product Introduction
PDP	Plasma Display Panel
PMAY	Pradhan Mantri Awas Yojana
ppm	Parts Per Million
PPP	Public-Private Partnership
R&R	Resettlement & Rehabilitation
RE	Renewable Energy
REO	Rare Earth Oxide
SS	Stainless Steel
UAE	United Arab Emirates
UNDRIP	The United Nations Declaration on the Rights of Indigenous Peoples
UNFC	United Nations Framework Classification for Resources

Introduction



Introduction

- Rare earth elements as well as battery minerals such as lithium, cobalt, nickel, and graphite form the core for new age energy minerals. The demand for these minerals is going to witness a rising trend as India moves towards 2047, enabled by rising demand from traditional sectors such as steel, alloys, electrical applications, as well as from emerging applications such as e-mobility, renewable energy, nuclear & defence.
- Therefore, it becomes imperative for stakeholders to identify opportunities and challenges to meet the forecasted demand, augment production with enhanced technology adoption & increased efficiencies and ensure uninterrupted supply of new age energy minerals without supply chain & price fluctuations.
- Acknowledging the above and the importance of exploration and production of these minerals for the Indian Mining Industry, this report has been prepared to identify the opportunities, challenges and recommend the way forward to make India self-reliant in such minerals.



- **Rare earth elements** represent a group of seventeen elements that are found in varying combinations in earth's crust. REEs are divided into Light Rare Earth Elements (LREE) and Heavy Rare Earth Elements (HREE) based on their atomic weight and electronic configuration.
- The combinations of LREEs & HREEs are usually consumed together in varying concentrations, depending on their application.
- There is significant emphasis on exploration of REE across the globe. Despite exploration & production in the last two decades, the reserves of REE has increased from 100 MnT in 2000 to 130 MnT in 2022 only.
- As a country with one of the highest concentrations of rare earth mineral reserves and massive processing capabilities, China has a dominant control in REE value chain. China is the largest REE producer with ~70% market share with ~34% reported REE resources. India ranks 6th in terms of global production with market share of ~1% (~2.5 kT).
- Rare earth elements are very critical for the development of futuristic technologies in India. Out of 25 sectors identified, the top priority sectors are electric vehicle, hi-tech electronics, renewable and nuclear energy, defence and hydrogen powered mobility.
- REE will act as an enabler for India to become a global manufacturing hub. India has recently been taking several initiatives recognizing the importance of rare earth elements.

- **Battery Minerals,** namely lithium, cobalt, nickel and graphite are the most critical minerals in making high performance batteries and energy storage system (ESS). With increased focus on renewable energy storage and electric mobility around the world and in India, the demand for these minerals would increase immensely moving forward.
- However, despite producing around a 100 different types and being amongst the top producers for some of the bulk minerals, India is highly import dependent in case of the battery minerals.
- With significant focus on processing technology, China controls the global supply chain of these minerals; 75% of graphite, 65% of Cobalt, 58% of Lithium and 35% of Nickel is processed there.
- The economic importance of battery minerals along with risks to stable supply, make them strategically valuable for the country.
- In India's quest for self-reliance, energy security is critical, therefore, the shift to non-fossil-fuel based energy generation will need energy storage solutions for automobiles as well as renewable power generation - EV batteries and ESS.
- The report also highlights the opportunities and challenges in developing these New Age Minerals, along with the key recommendations to achieve the objective of making India self-reliant in these Minerals.

Based on the findings of this report, some of the key recommendations for new age energy minerals are

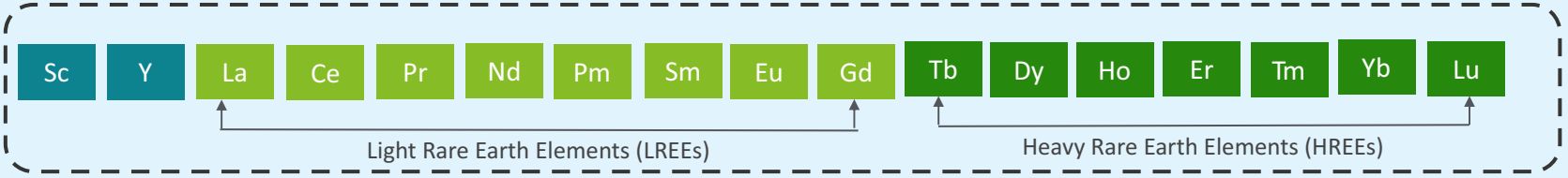
- **Focus on exploration must be increased as India's current exploration status is less than 10% of Obvious Geological Potential and New Age Minerals related exploration has not taken off.**
- **Exploration should not be limited to land & deposits along the coast but sea-bed mining must also be considered (for REE).**
- **Promoting R&D like global peers such as China, USA, who have been pushing R&D for New Age Minerals Ecosystem Development to evolve as a market leader.**
- **Financial assistance & incentivization for units focusing on exploration & production of new age energy minerals.**
- **Collaboration for technological expertise and joint exploration activities to secure New Age Mineral assets outside India.**
- **Adoption of conducive policies and strong initiatives to make India an REE hub like leading nations who have used forward integration to not only produce RE concentrates but intermediate (e.g., magnets) and end products (e.g., batteries, motors).**
- **Focus on R&D to promote recycling and material recovery from end products and secondary sources, second life applications and cost optimization.**
- **Adoption of forward-looking policies to enable the development of battery minerals ecosystem in India.**

Executive Summary



Executive Summary: REE Introduction

Rare Earth Elements (REEs) represent a group of 17 elements found in varying combinations in the earth's crust. A substantial push toward green technologies and advancement in electronics, technology, and lifestyle have substantially increased the demand for REEs.



01

Grouped Natural Occurrence
REEs are ***not found individually*** in deposits, rather occur in minerals (in groups) as either minor or major constituents

02

LREEs Vs. HREEs
REEs are divided into Light and Heavy based on their ***atomic weight*** and ***electronic configuration.***

03

Low Mineable Concentrations
Though crustal abundance of REEs is relatively high (~250 ppm) but unlike other metals, they ***do not occur in enough local concentration*** for economical extraction

04

Sequential Value Chain
Grouped occurrence of REEs makes their exploration, mining & processing (till individual metal oxide production) a ***sequential exercise,*** thus ***requiring a wholesome sectoral view***

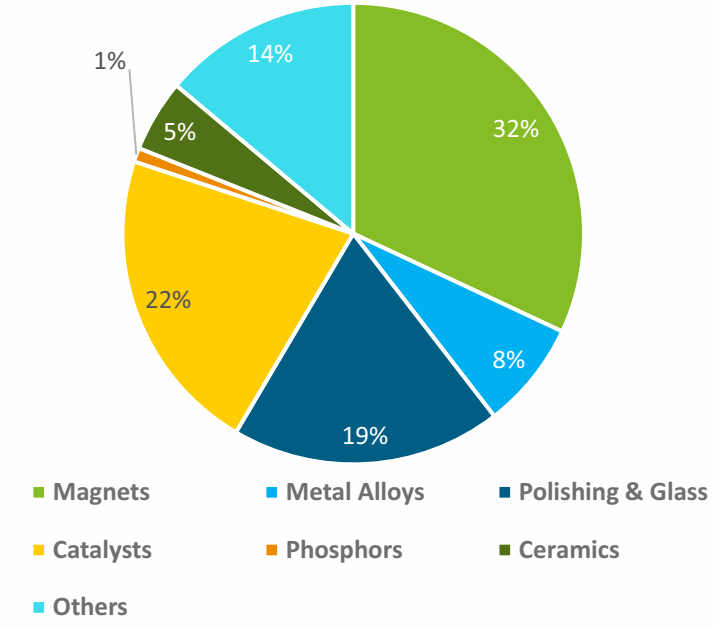
05

Geological Sources
Generally found in igneous rocks such as ***carbonatites*** and ***alkaline.*** They can also be found (as parts of mineral compounds) in placer & residual deposits. Key sources are ***Bastnaesite & Monazite***

Executive Summary – End use sector and Outlook

REEs are utilized in a wide range of critical products enabling many emerging green energy technologies, defence systems, and other high-tech applications. The ***combinations of LREEs & HREEs are usually consumed together*** *in varying concentrations, depending upon application.* ***Major elements are – La, Ce, NdPr, Tb, Dy, Sc & Y***

REE Consumption across Key Sectors



REEs usage across sectors

End-use Sectors	Major REEs used
Magnets	Neodymium, Praseodymium, Terbium, Dysprosium
Metal Alloys	Lanthanum, Cerium, Yttrium, Neodymium, Praseodymium
Polishing & Glass	Lanthanum, Cerium, Neodymium, Praseodymium, Gadolinium, Europium, Holmium
Catalysts	Lanthanum, Cerium, Neodymium, Praseodymium
Phosphors	Cerium, Neodymium, Praseodymium, Terbium, Yttrium, Gadolinium, Europium, Erbium
Ceramics	Lanthanum, Cerium, Neodymium, Praseodymium, Terbium, Yttrium, Gadolinium, Europium, Lutetium
Others	Lanthanum, Neodymium, Praseodymium, Dysprosium, Terbium, Yttrium, Europium, Lutetium, Samarium

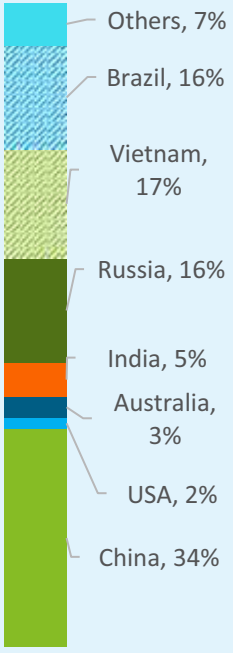
Growth Outlook Very High High Moderate

Source: USGS Minerals Yearbook, Mordor Intelligence, India EXIM Bank, Deloitte Analysis

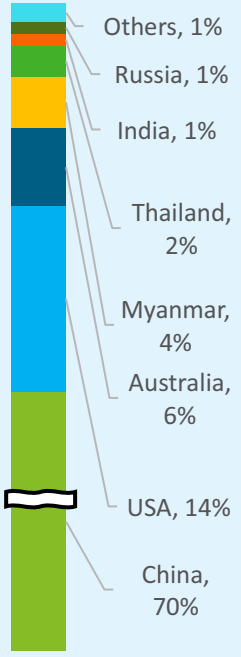
Executive Summary: Global REE Resources, Production, and Trade

China is the largest REE producer with ~70% market share with ~34% reported REE resources. India ranks 6th in terms of global production with market share of ~1% (~2.5 kT)

Country-wise REE Resources (2022)

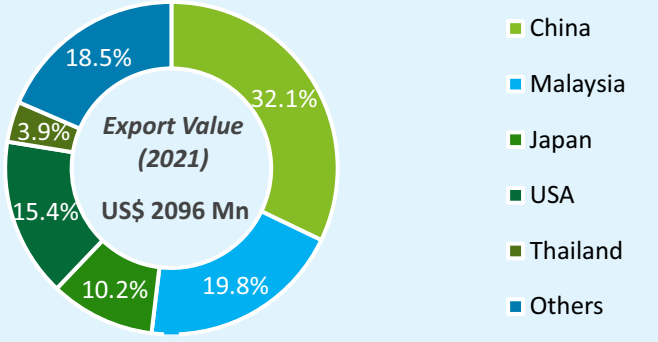


Country-wise REE Production (2022)



Note: Myanmar and Thailand's resources data is not available in public domain
Source: USGS Minerals Yearbook, Mordor Intelligence, India EXIM Bank, UN Comtrade, Deloitte Analysis

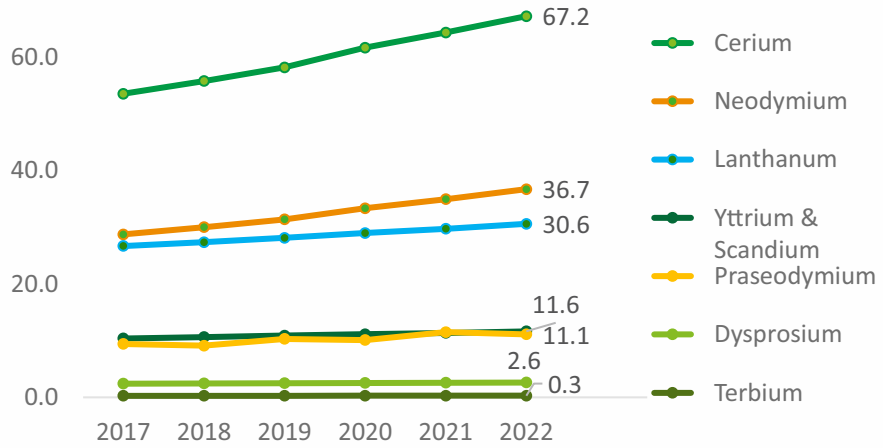
Global Trade Snapshot



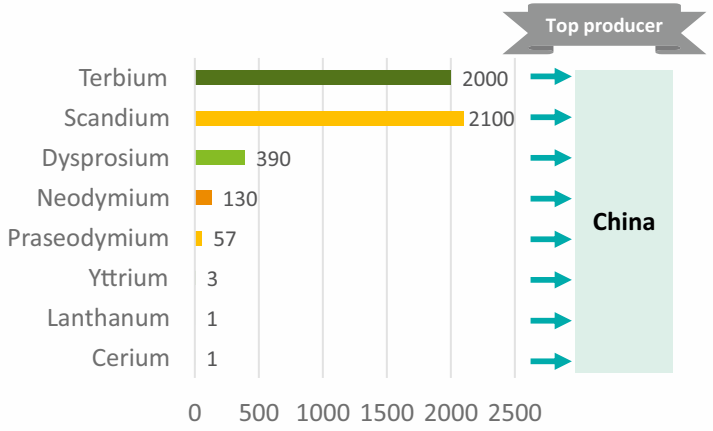
- REE trade is majorly covered under 2 HS codes (280530 & 2846) which is inclusive of REE metals, oxides, compounds, mixtures & alloys.
- China, Japan, USA, Malaysia, Thailand also accounts for ~74% of total import due to downstream ecosystem (manufacturing of intermediate products like magnets, phosphors, polishing powders; and finished products such as electric motors, batteries, and LCDs) availability in these countries.
- China has shifted its focus from exporting REEs in their raw form, to forward integration. As a result, the share of China in the world exports, which was 52.4% in 2004, declined to 48.9% in 2009 and 32.1% in 2021.

Executive Summary: Global Snapshot of Key REEs

Global production volume (in kT)



RE Oxides price USD/kg in 2022



Abundance (high to low) →

Ce	Nd	La	Y	Sc	Pr	Dy	Tb

As a country with one of the **highest concentration of rare earth mineral reserves** and **massive processing capabilities,** China has a lot of control in REE value chain

- **Reasons for high price of Tb & Sc**
- Scarcity and limited production
- Renewed stockpiling demand from downstream magnet manufacturers for Terbium
- Higher oxide feedstock costs
- Shortfall of spot supplies

The increase in use of green technology required to stabilize atmospheric carbon dioxide at 450 ppm **would increase demand of dysprosium** by **2600% over the next 25 years** (assuming current demands for wind and electric motor applications are representative of future needs).

Source: USGS Mineral Yearbook, IBM Mineral Yearbook, Mordor Intelligence, Deloitte Analysis

Executive Summary: Emerging and High Growth Sectors

Automotive

- Li-ion batteries
- Polymeric matrix brake composites
- Permanent magnets in motors
- Batteries

Ce Nd La Dy Y Sc Pr Tb

Defence

- Radar
- Surveillance aid
- Navigational aid
- Laser weapon
- Missile guidance system
- Control system
- Sonar transducer
- Ranging systems

Ce Nd La Dy **Y** **Sc** Pr Tb

Green Energy

- Photovoltaic cell
- Electrolyte for energy from hydrogen and other fuels
- Wind turbines
- Generators

Ce **Nd** **La** **Dy** **Y** **Sc** **Pr** **Tb**

Aerospace

- Aircraft components (reduces aircraft weight)
- Actuators
- Sensors

Ce **Nd** La Dy Y **Sc** **Pr** Tb

Electronics

- Phosphors for screens
- Gadgets
- Superconductors
- Lens for equipment
- Bulbs & Lamps
- Storage devices
- Speakers
- Satellite components

Ce **Nd** La **Dy** **Y** Sc **Pr** **Tb**

Nuclear

- Ultra high strength components
- Control rods in nuclear reactor

Ce Nd La **Dy** Y **Sc** Pr Tb

Biotechnology

- Lasers for surgery
- Radiation therapy
- MRI machines
- Diagnostics like X - Ray

Ce **Nd** La **Dy** **Y** **Sc** **Pr** **Tb**

Others

- Catalysts in chemical industry
- Glass polishing
- Shipbuilding
- Sporting goods
- Lighting
- Metallurgy
- Medicine
- Elevators etc.

Ce **Nd** **La** **Dy** **Y** **Sc** **Pr** **Tb**

All these rare earth elements are used in small quantities but have qualities that make them very essential in all these sectors

Note: Apart from these eight rare earth elements taken for deep-dive, other rare elements might also be used in different industries for different purposes

Executive Summary: REE Importance in the Indian Economy

Demand Forecast

REE	FY30 Estimated Demand in India (tons)
Sc & Y	360 – 420
La*	25 – 35
Ce*	600 – 700
NdPr	8000 – 16000
Dy	140 – 270
Tb	400 – 800

**Compounds of La & Ce*

REEs are critical for the development of futuristic technologies. Out of the 25 sectors identified, these are among the top priority sectors:

- Electric vehicle
- Hi-Tech electronics
- Renewable and nuclear energy
- Defence
- Hydrogen powered mobility

REE as Enabler

Industries in the intermediate value chain will use REEs in the manufacturing process.

Make in India initiative is aiming to **make India a global manufacturing hub** for which **critical and strategic minerals are essential**

Highlights of a few initiatives taken in India recognizing the importance of REE

*Indian hospitals are bringing latest technology for liver cancer treatment using an innovative procedure using **Yttrium-90.***

*A leading automobile manufacturer has developed the world's first magnet with 50 percent less **Neodymium** (replacing it with lanthanum and cerium).*

*Government has granted a domestic giant, the monopoly over primary mineral- monazite beach sand, which is mainly a source of **NdPr** and other LREEs.*

***Dysprosium** is procured by a leading domestic research center for use as control-rod material*

*Researchers discovered a novel material called single crystalline **Scandium** nitride that can emit, detect, and modulate infrared light and can convert infrared light to renewable energy.*

*Multiple projects to substitute Nd & Pr **with La & Ce** in NdFeB magnets are currently underway. Some **La & Ce** mischmetal may soon be added to reduce the neodymium content.*

*Research on **Tb** has gained a momentum in India owing to its four short-lived radioisotopes, all of which can be considered in one or another field of nuclear medicine.*

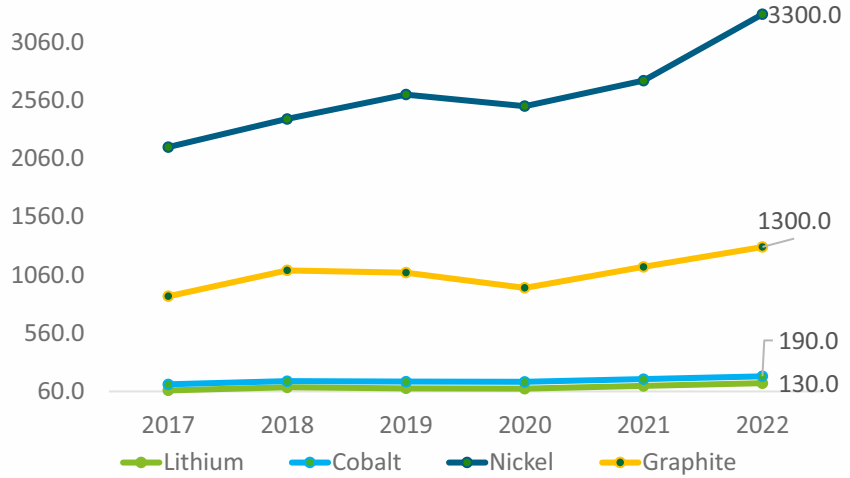
*These four radioisotopes of **Terbium**, 149Tb,152Tb,155Tb, and 161Tb have been revealed as some of the most powerful tools for both therapy and diagnosis in the near future.*

Executive Summary: Battery Minerals Introduction

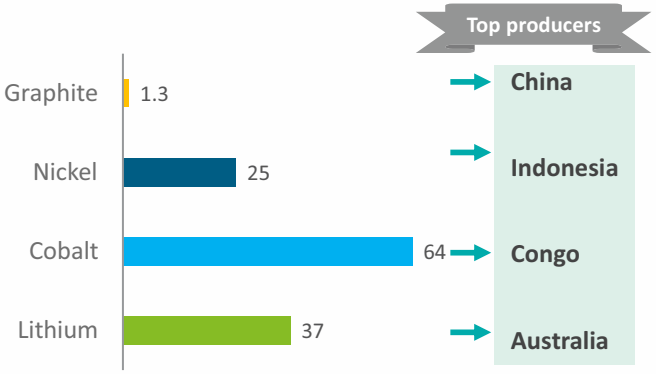
	LITHIUM	COBALT	NICKEL	GRAPHITE
	Global reserves 26 MnT	Global reserves 8.3 MnT	Global reserves 102 MnT	Global reserves 330 MnT
Countries with reserves *(Total ~70% of the world reserves)*	*Chile (36%)* *Australia (24%)* *Argentina (10%)*	*Congo (48%)* *Australia (18%)* *Cuba (7%)*	*Australia (21%)* *Indonesia (21%)* *Brazil (16%)* *Russia (7%)* *New Caledonia (7%)*	*Turkey (27%)* *Brazil (22%)* *China (16%)* *Madagascar (8%)*
Indian states with reserves/resources	*Karnataka* *Jammu*	*Jharkhand* *Nagaland* *Odisha*	*Jharkhand* *Karnataka* *Nagaland* *Odisha*	*Jharkhand* *Tamil Nadu* *Odisha* *Chattisgarh*
Deposit Types	*Brines* *Pegmatite* *Clays* *Zeolites*	*Stratiform sediment-hosted Cu-Co* *Ni-Co laterite* *Magmatic Ni-Cu(-Co-PGE)*	*Magmatic sulfides* *Laterites*	*Amorphous* *Flake* *Vein*

Executive Summary: Battery Minerals Global Snapshot

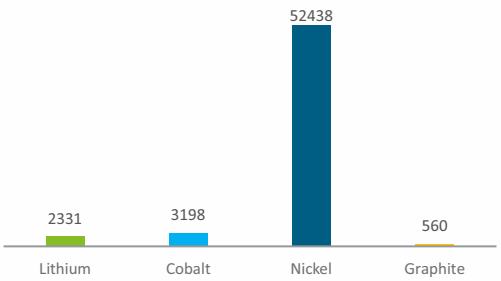
Global production volume (in kT)



Price trends USD/kg in 2022



Global Exports by Value (USD Mn)



Major Exporters (2021)

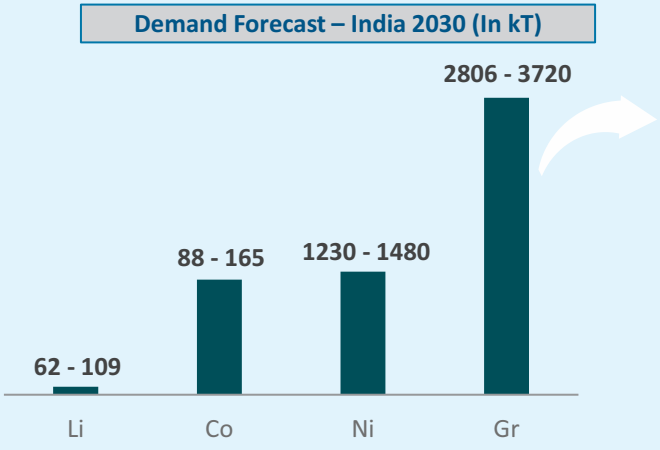
Lithium	→	**Chile**
Cobalt	→	**Canada**
Nickel	→	**Philippines**
Graphite	→	**China**

Major Importers (2021)

Lithium	→	**Rep. Of Korea**
Cobalt	→	**China**
Nickel	→	**China**
Graphite	→	**Rep. of Korea**

Source: USGS Mineral Yearbook, IBM Mineral Yearbook, Mordor Intelligence, Deloitte Analysis

Executive Summary: Battery Minerals Importance in Indian Economy



Lithium	Graphite	Cobalt	Nickel

End use sectors

Electric vehicle battery
Importance of all these four elements in EV batteries will increase their demand significantly in near future

Other batteries
All these elements are used in batteries in electronics, power tools, energy storage systems, small and large appliances etc.

Glass ceramics	Metallurgy	Industrial metals	Engineering
Grease	Automotive	Superalloys	Metal goods

Highlights of a few initiatives taken in India recognizing the importance these elements

Companies in India are planning to manufacture 1-10 GWh per year of lithium-ion battery components.

Leading graphite players manufacturing graphite electrodes in India are planning to expand for solar-wind hybrid projects.

Government of India enterprise is looking for Cobalt mining options abroad. It intends to begin mining with help of Legacy Iron Ore Ltd, Australia in which it has 90.02% stake.

India's first facility to recycle nickel, has been launched by a leading domestic Copper manufacturer at its Indian Copper Complex (ICC) at Ghatsila in Jharkhand.

A leading power company has planned for production of all components of their energy ecosystem, including batteries for energy storage.

The Kerala government has established an India's first innovation centre for graphene in co-operation with a leading steel company and the ministry of electronics and information technology.

A leading chemical company launched InsperiCo, world's first branded recycled Cobalt, by recycling Li-Ion batteries.

The Department of Mines and Geology of the Government of Jharkhand received a proposal from a domestic minerals giant to reserve a 16.70 square km area in the Saraikela-Kharswan district for the prospecting and mining of nickel.

Rare Earth Elements

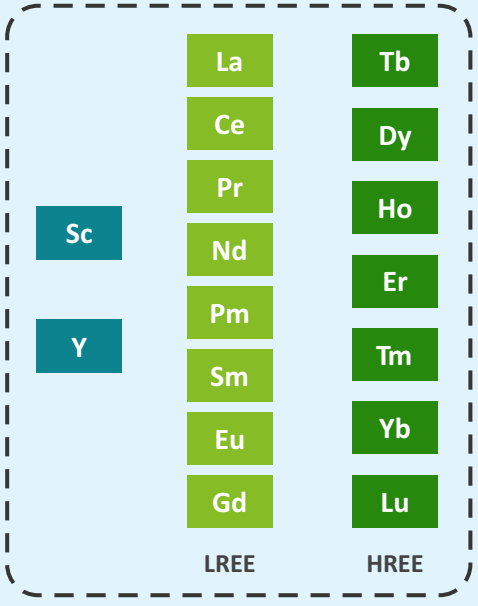
Key Questions Answered:

- What constitutes Rare Earth Elements? What is the basis of classification into Light Vs Heavy REEs?
- What are the key attributes of Rare Earth Elements?
- What are the mineral resources (source rocks) hosting Rare Earth Elements globally and in India?
- What is the quantum of global REE resources? Where are these resources located? How is India positioned?
- What are the REE minerals present in India? What are the major states with REE bearing minerals?
- Who are the major REE producers? What has been the production trend? How is India positioned?
- How much is the REE trade value globally? What has been the trend in recent years? Who are the major exporters?
- What are the key activities across REE value chain?
- Who are the global players present at different value chain positions? How is India positioned?
- What are key end-use sectors for REE? What are the rare earth elements used in the respective sectors? What is the growth outlook for end-use sectors?
- What are the specific applications in respective sectors? What is the percentage of REE consumption across end-use sectors?
- What is the importance of REEs in Indian Economy? What initiatives are being undertaken by other countries to secure their REE supply chain?

Rare Earth Elements: Introduction & Classification

The 17 REEs are found in varying combinations in the earth's crust in relatively higher crustal concentrations; however, their abysmally low local concentration renders them difficult to mine.

- Traditionally, the REEs are divided into 2 groups (Light & Heavy REEs) **based on atomic wt.**
- Another basis of REE classification is **based on the electronic configuration.**



REE Name	Crustal Abundance (ppm)	Atomic Wt (amu)
★ Scandium	22	45
★ Yttrium	33	89
★ Lanthanum	39	139
★ Cerium	66.5	140
★ Praseodymium	9.2	141
★ Neodymium	41.5	144
Promethium	(NA - unstable)	145
Samarium	7.05	150
Europium	2	152
Gadolinium	6.2	157
★ Terbium	1.2	159
★ Dysprosium	5.2	162.5
Holmium	1.3	165
Erbium	3.5	167
Thulium	0.52	169
Ytterbium	3.2	173
Lutetium	0.8	175

★ *Elements in focus based on their usage and outlook*

Key Attributes of REEs

- *REEs tend to occur together. This makes their **exploration, mining, processing activities a sequential exercise.***
- *REEs are found in relatively high concentrations in the earth's crust (~250ppm combined), but **not locally concentrated enough to mine economically***
  - *For comparison, average crustal abundances for gold, silver, lead, and copper are 0.004, 0.075, 14, and 60 ppm, respectively*

Note:

- *In few instances europium and gadolinium are included within the group of heavy REEs.*
- *Although light (atomic number 39), yttrium is sometimes included in the heavy REE group because of its similar chemical and physical properties.*

Source: IBM Mineral Yearbook, USGS, IUPAC, Deloitte Analysis

REE: Geological Occurrence

*The REEs are commonly found together in the Earth's crust because they **share a trivalent charge ($^{+3}$)** and **similar ionic radii. Naturally, REEs do not exist individually**, like gold or copper often do, but instead occur in minerals as either **minor or major constituents. Monazite** is the key REE-bearing rock found in India.*

Principal Sources of REEs

- *Economically exploitable REE concentrations are generally found in uncommon igneous rocks, such as **carbonatites** and **alkaline rocks**. They can also be found (as **parts of mineral compounds**) in **placer deposits, residual deposits** due to weathering, pegmatites, **iron-oxides, copper-gold deposits,** and even in **marine phosphates***
- *The principal sources of REE are **bastnaesite** (a fluorocarbonate that which occurs in carbonatites and related igneous rocks), **xenotime** (Yttrium phosphate) commonly found in mineral sand deposits, **loparite** which occurs in alkaline igneous rocks and **monazite** (a phosphate).*



Bastnaesite



Monazite (powder)

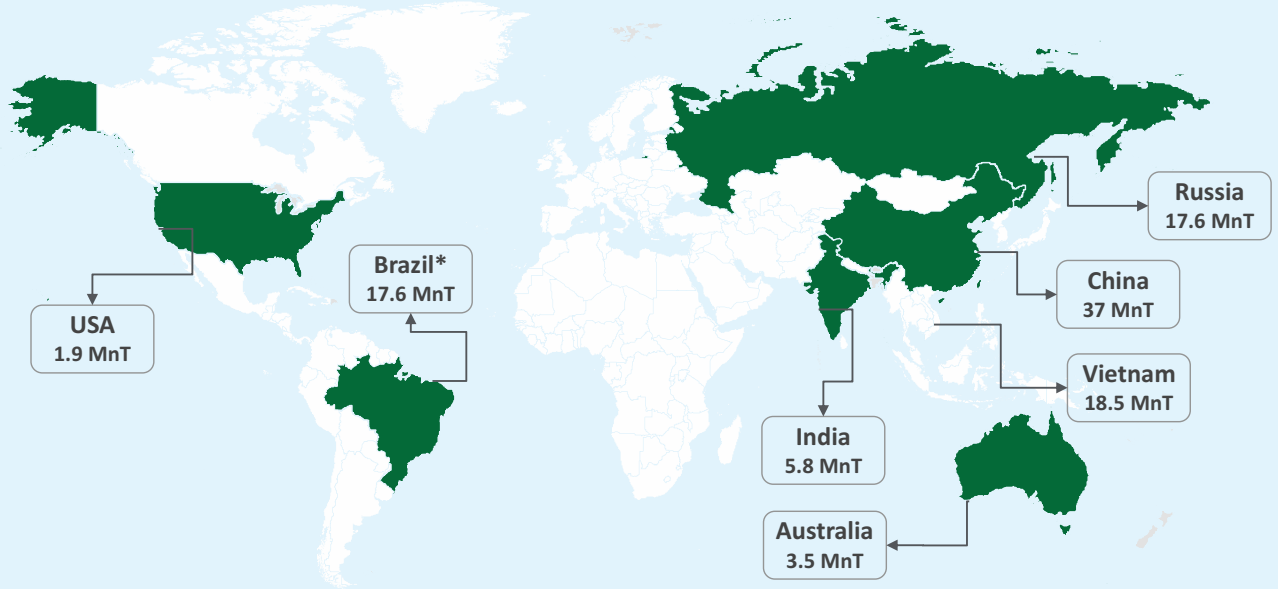
List of REE Bearing Minerals

S No	Mineral Name	S No	Mineral Name	S No	Mineral Name
1	Cerianite	11	Gadolinite	21	Florencite
2	Bastnasite	12	Synchisite	22	Allanrte (orthlle)
3	Hydroxylbast-nasite	13	Fergusonite	23	Yttrotantalite
4	Monazite	14	Ancylite	24	Apatite
5	Mosandrite	15	Churchite	25	Samarskite
6	Parisite	16	Euxenite	26	Eudialite
7	Thalenite	17	Huanghoite	27	Brannerite
8	Britholite	18	Kainosite	28	Cheralite
9	Xenotime	19	Aeschynite	29	Zircon
10	Cerite	20	Loparite	30	Anatase

Source: USGS, IBM, Asian Metal, Deloitte Analysis

REE: Geographical Occurrence

Global REE reserves (metal content) stood at ~109 MnT by CY22. While China holds ~34% of the global reserves, India ranks 5th with 5% of total global reserves.



*Though Brazil has high reserves, majority of these reserves have low-level deposits (~10%) and thus require new techniques for extraction and making their mining financially feasible.

**REE reserves are also located in geographies such as South Africa, Tanzania, and Canada. The ongoing explorations are expected to lead to further resource discovery worldwide.

Source: USGS Mineral Commodity Summaries, IBM Mineral Yearbook, Mordor Intelligence, Deloitte Analysis

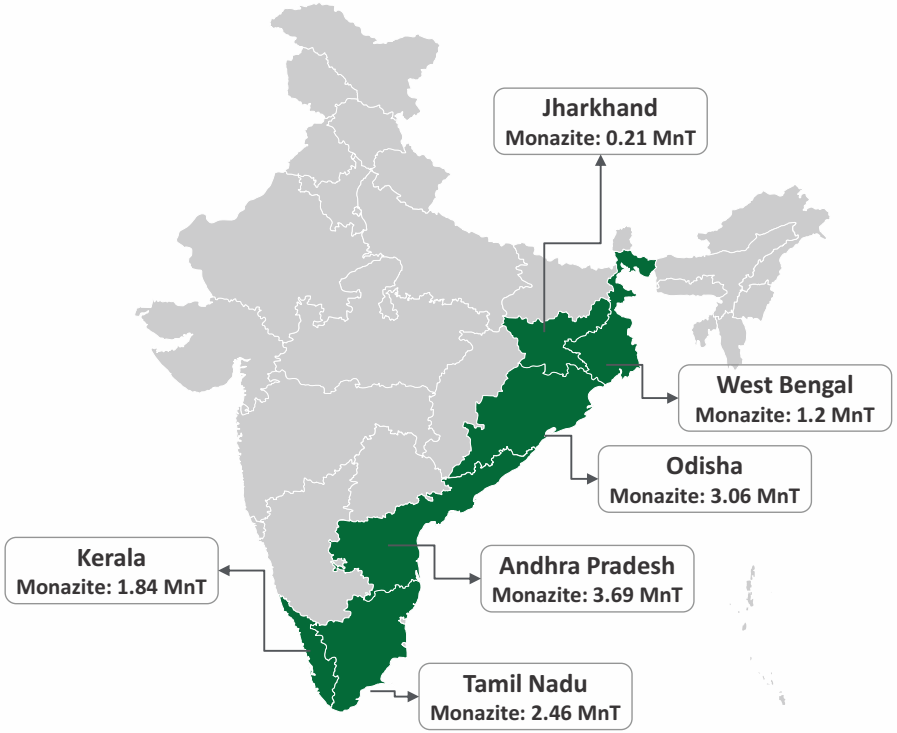
Key Insights

- *Worldwide **exploration** for economic deposits of REEs and efforts to bring them into production have **increased substantially since 2000.***
- *REE reserves were **100 MnT** in **2000**. Despite production in the last 22 years, the reserves of REE were **130 MnT** in 2022 owing to an increased focus on exploration.*
- *Exploration for additional REE deposits is ongoing; therefore, the **world's known in-the-ground resources (endowment) of REEs are likely to increase***
- *Despite many known REE deposits, the global supply of REEs is **limited by the cost and complexity of exploring REE deposits and developing REE mines, including REE extraction and separation facilities***

REE: Occurrence in India

Monazite is the primary source of REEs in India. It is found in beach sand and inland placer deposits.

Major states with monazite resources



Key Insights

- Monazite is a complex phosphate of thorium and REEs [(Ce,La,Nd,Th,Y)PO^4]; it is radioactive in nature.
- The mineral monazite is a prescribed substance as per the Notification under the Atomic Energy Act of 1962.
- AMD performs Monazite resource evaluation in India.
- Monazite occurs in association with other heavy minerals, such as ilmenite, rutile, and zircon, in concentrations of 0.4%–4.3% of total heavy minerals in the beach and inland placer deposits of the country.

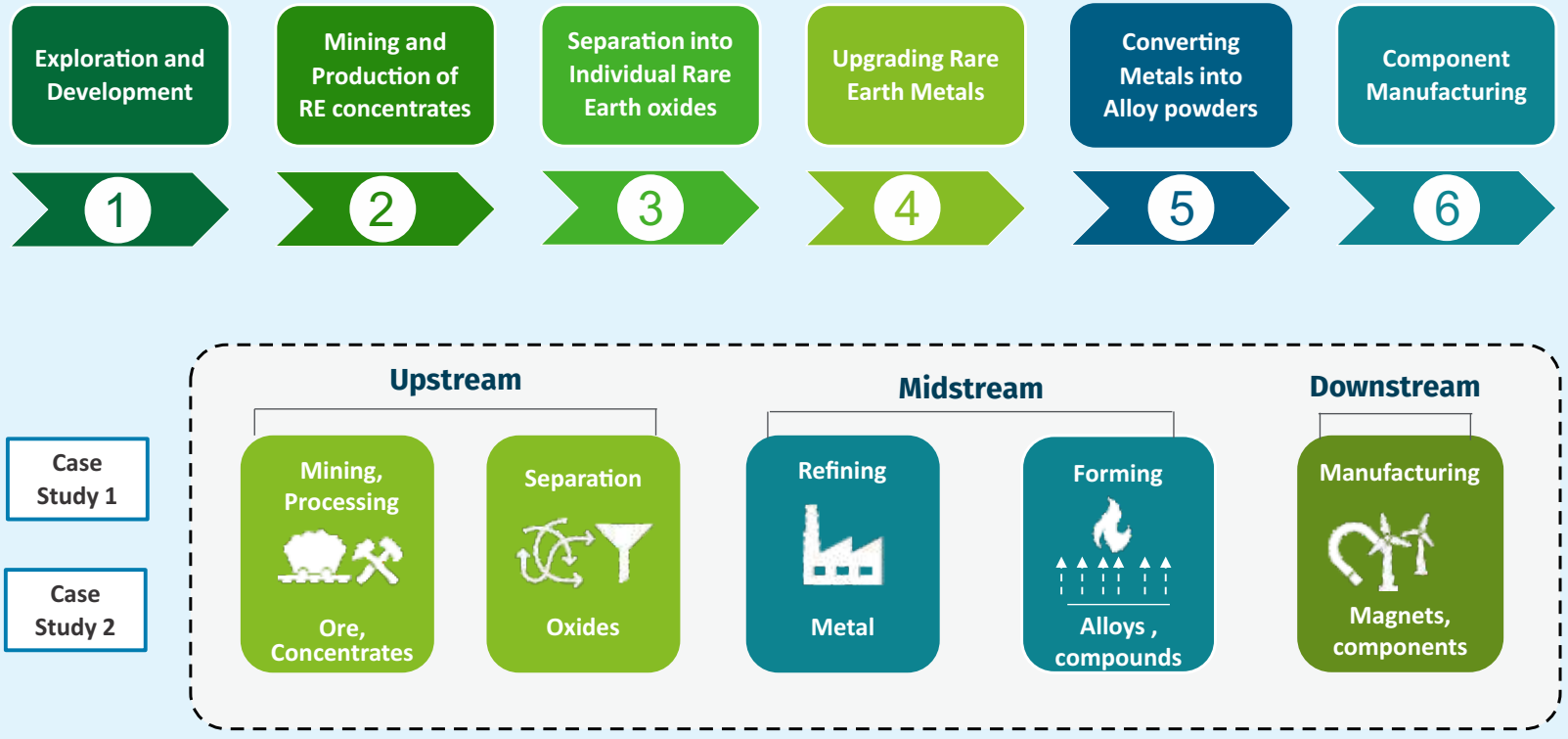
Other states with REE-bearing minerals:

- ***Gujarat:*** *Monazite, Carbonatite Alkaline complex*
- ***Maharashtra:*** *Monazite*
- ***Rajasthan:*** *Alkaline complex (Polymetallic mineralization)*
- ***Madhya Pradesh:*** *Xenotime*

Source: IBM Mineral Yearbook, Atomic Minerals Directorate, Indian Nuclear Society, Deloitte Analysis

REE: Value Chain

REEs are not found individually in deposits but in minerals as minor or major constituents, making their exploration, mining, and processing activities a sequential exercise until individual RE oxide/compounds are separated.



Source: USGS, BloombergNEF, India EXIM bank

REE Value Chain and Presence of Global and Indian Players



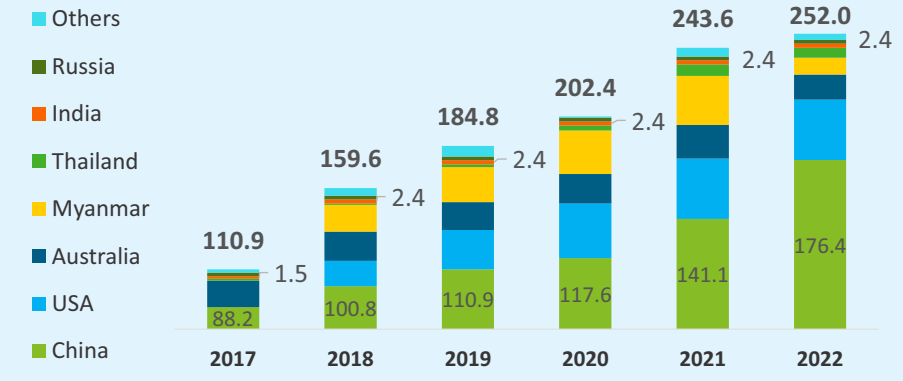
Player	Mining	MSP	Upgrade Product	VAP
Baotau	✓	✓	✓	✓
IREL	✓	✓	✓	✓
Lynas	✓	✓	✓	×
Iluka	✓	✓	×	×
Canada Rare Earth	✓	✓	✓	×
ASM Rare Earth	✓	✓	✓	×
NINGBO NGYC	×	×	×	✓
Hangzhou Group	×	×	×	✓
Hitachi Metals	×	×	×	✓
Innuovo Metals	×	×	×	✓

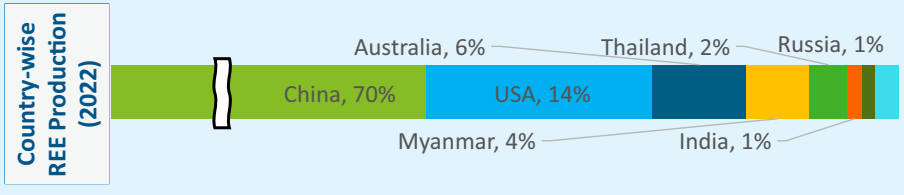
Source: IBM Yearbook, Investor Reports, Company Presentations, TZMI, Iluka, Grandview Research Reports, USGS<, GII Research, EMIS, Mordor Intelligence, Adamas Intelligence, NITI Aayog, SIAM, Deloitte Analysis

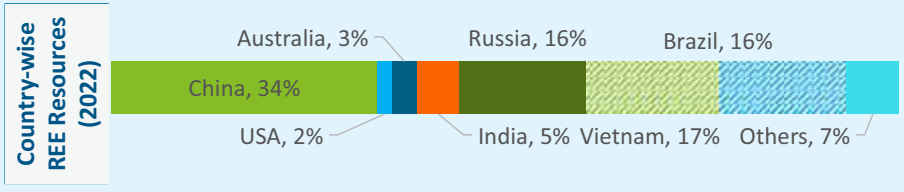
REE: Key Global Producers and Trends

China is the largest REE producer, with a 70% market share. India ranks 6th in global production, with an ~1% market share.

Country-wise REE (metal content) production trend (kT)







Note: REE resources quantification of Myanmar and Thailand not available

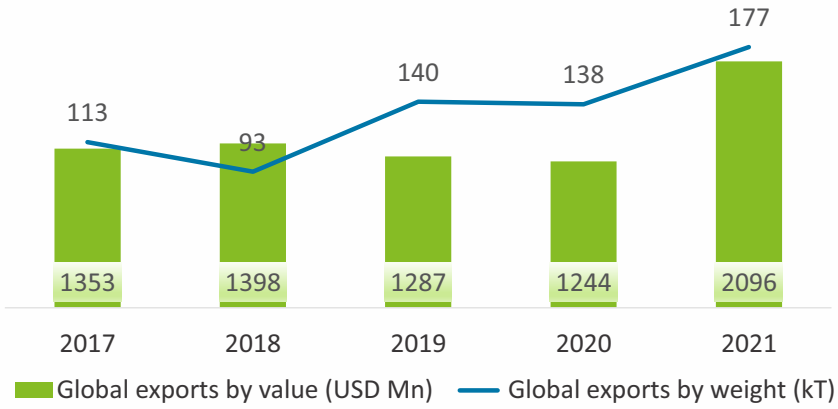
Source: USGS Minerals Yearbook, Mordor Intelligence, India EXIM Bank, Deloitte Analysis

Key Insights

- Historically, REE production (metal content) in 1994 stood at ~54 kT. It reached ~111 kT in 2017, exhibiting a compound annual growth rate **(CAGR) of ~3.2%** during this period
- The heavy push towards green technologies and advancement in electronics, technology, and lifestyle has substantially increased the demand of REEs. This is evident from the high **CAGR of ~17.8% observed in the last 5 years** REE production.
- China started REE production in the 1980s
- China's share in global REE production increased from 47.4% in 1994 to as high as 97.7% in 2010. It stood at ~70% of the global production in 2022. This is expected to moderate further in the future, given the push to secure domestic supply globally.
- Apart from China's ~15% annual growth in production, Thailand has also increased tis production from 1 kT to 6 kT (CAGR of ~40%).
- Countries such as China and the USA have increased their production levels due to strong demand from their domestic downstream industries.
- Rare earth mining had rapidly expanded in northern Myanmar, fueling human rights abuses, deforestation and environmental contamination. Social opposition and challenges led to decline in its production levels in 2022.
- Indian production levels have remained at a moderate levels of~2.5 kT since 2018 onwards.

REE: International Trade (1/2)

Global REE Exports

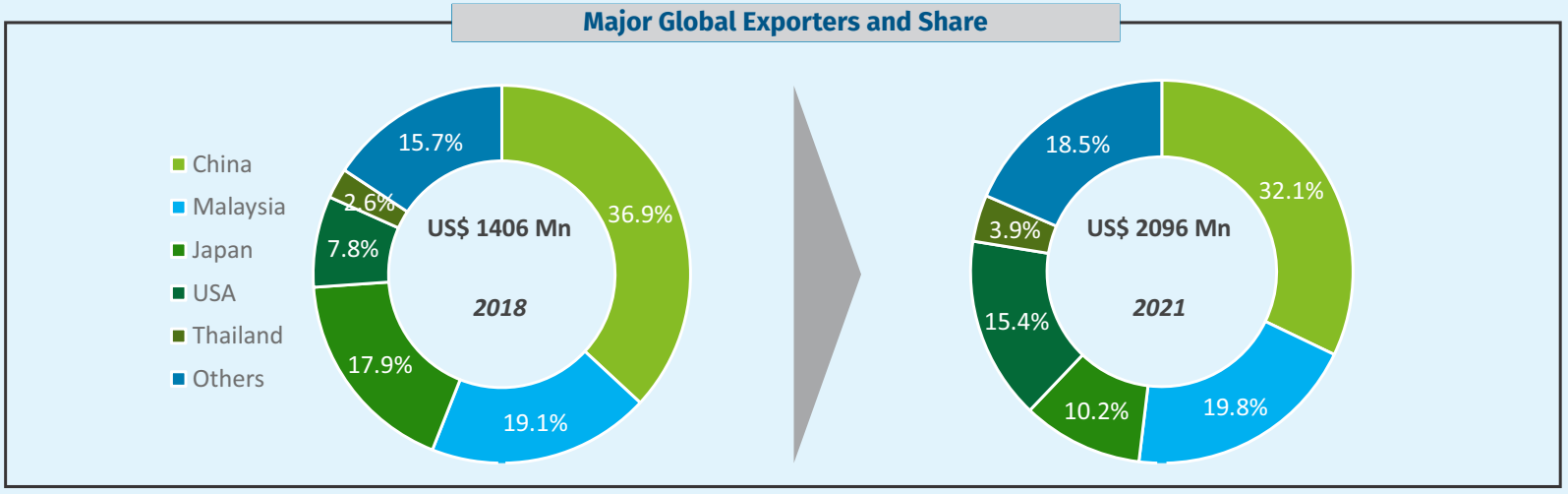


Key Insights

- REEs are typically traded in terms of their metal oxide equivalent content
- Major REE trade occurs under 2 HS Codes:
  - **HS 280530** - Earth-metals, rare; Scandium and Yttrium, whether or not intermixed or inter-alloyed
  - **HS 2846** - Compounds, inorganic or organic, of rare-earth metals yttrium or scandium or mixtures of these metals

- The global exports of REEs by value were registered at 2,096 million USD in 2021, up from 1,352.9 million USD in 2017, recording a CAGR of 11.57% during this period.
- Further, by volume, the global exports were recorded at 177.4 ('000 metric tons) in 2021, up from 112.7 ('000 metric tons) in 2017, growing at an average rate of 12% during this period.
- Until 2010, there was less interest in REEs, as companies outside China could not compete with China in terms of price; however, with the prices rising, because of high demand and low exports from China, many new mining projects were operationalized across various countries.

REE: International Trade (2/2)



- While REEs have been produced for almost a century, the countries supplying them have changed. In the mid-twentieth century, almost all REE mining was conducted at Mountain Pass, California, and by 1990, only eight countries reported exporting these minerals either in concentrated or refined form.
- China, which once focused on exporting REEs in their raw forms, has used forward integration to its benefit. In the 1970s, China exported only rare earth concentrates. By the end of the 1990s, China began producing magnets, phosphors, and polishing powders. Now, China produces finished products such as electric motors, batteries, and LCDs. Consequently, China's share in global REE exports, which was 52.4% in 2004, declined to 48.9% in 2009 and 32.1% in 2021.
- China, Japan, USA, Malaysia, and Thailand together account for ~74% of total imports due to the developed downstream ecosystem (manufacturing of intermediate products such as magnets, phosphors, and polishing powders as well as finished products, such as electric motors, batteries, and LCDs) in these countries.

Source : UN Comtrade, India EXIM Bank, Deloitte Analysis

REE: Key Elements Usage across End-use Sectors

REEs are utilized in a wide range of critical products enabling many emerging green energy technologies, defence systems, and other high-tech applications. Depending upon the application, ***the combinations of LREEs and HREEs are usually consumed together*** *in varying concentrations.* ***Major elements are La, Ce, NdPr, Tb, Dy, Sc, and Y.***

Key Insights

Due to their unusual physical and chemical properties, such as unique magnetic and optical properties, REEs have diverse applications that touch many aspects of modern life and culture

- Magnets that employ REEs are rapidly growing in application. These are especially useful when space and weight are limiting factors
- Specific REEs are used individually or in combination to make phosphors—substances that emit luminescence
- The glass industry is one of the largest consumer of REE raw materials, using them for glass polishing and as additives that provide color and special optical properties.
- Lanthanum-based catalysts are used to refine petroleum. Cerium-based catalysts are used in automotive catalytic converters
- Mischmetal, a combination of various REE oxides, is used in steel making to remove impurities and produce special alloys.

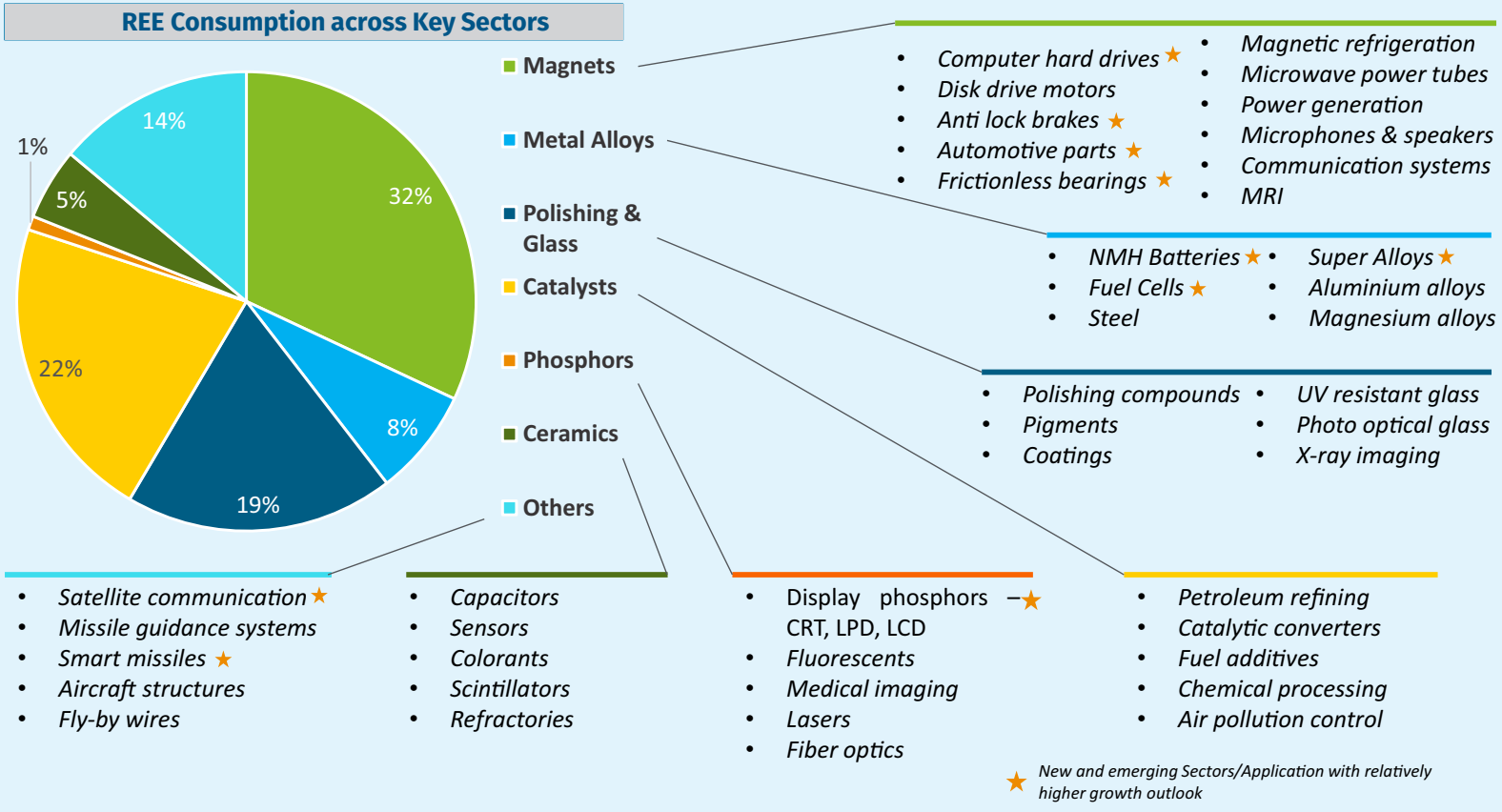
REEs usage across sectors

End-use Sectors	Major REEs used
Magnets	Neodymium, Praseodymium, Terbium, Dysprosium
Metal Alloys	Lanthanum, Cerium, Yttrium, Neodymium, Praseodymium
Polishing & Glass	Lanthanum, Cerium, Neodymium, Praseodymium, Gadolinium, Europium, Holmium
Catalysts	Lanthanum, Cerium, Neodymium, Praseodymium
Phosphors	Cerium, Neodymium, Praseodymium, Terbium, Yttrium, Gadolinium, Europium, Erbium
Ceramics	Lanthanum, Cerium, Neodymium, Praseodymium, Terbium, Yttrium, Gadolinium, Europium, Lutetium
Others	Lanthanum, Neodymium, Praseodymium, Dysprosium, Terbium, Yttrium, Europium, Lutetium, Samarium

Growth Outlook — Very High | High | Moderate

Source :USGS, EXIM Bank, Mordor Intelligence, Deloitte Analysis

REE: End Use Sectors and Applications

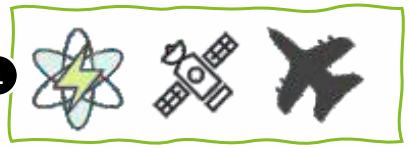


Source: USGS, India EXIM Bank, Mordor Intelligence, Deloitte Analysis

REE: A strategic sector for India

The REE sector is key to making India self-reliant across critical strategic industries for a sustainable future.

Four Strategic Sectors In India

1. 
   Atomic Energy, Space & Defence

2. 
   Transport & Telecom

3. 
   Power, Petroleum, Coal & Other Minerals

4. 
   Banking, Insurance & Financial Services

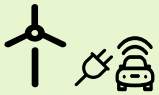
Why should the REE sector be considered a strategic sector?

- Considering the low volume of RE consumption, it is difficult to attract private sector investments given the high initial setup costs of processing plants, including downstream industry, making it an unattractive business case for the private sector.
- However, the end-use of RE minerals is strategic and important for achieving the country's vision of "Atmanirbhar Bharat" or self-reliance through technical superiority.



Atmanirbhar Bharat and Make In India

- Develop downstream industries and support upstream, midstream, and downstream value chain for strategic industries such as aerospace and defense.
- Self-reliance—Reduce dependence on imports of high-value RE products (e.g., EV magnets).



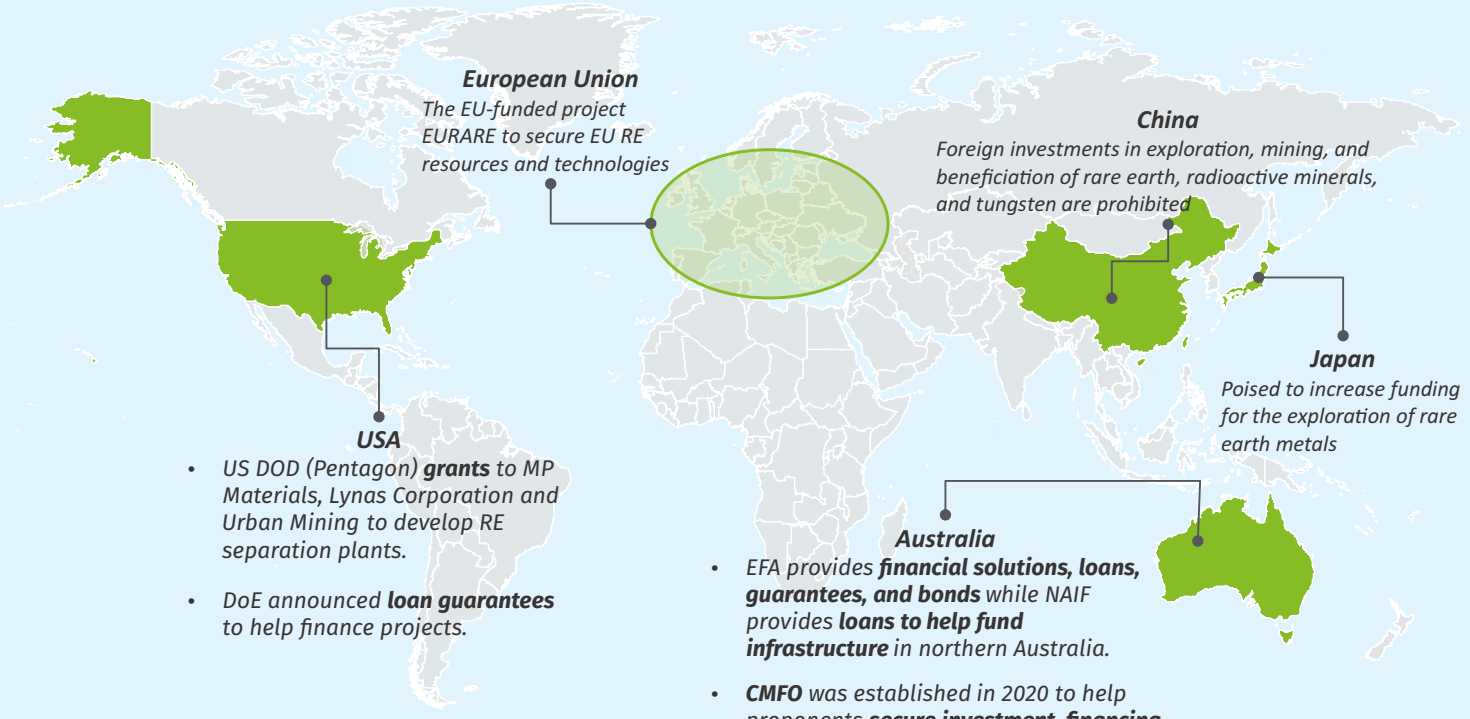
Investment & Growth in Renewables & e-mobility

- **GOI's commitment for installation of renewable energy sources ahead of COP21**
- Shift towards **alternate sources of energy** like Solar will push **demand for RE** materials
- Development of **e-mobility infrastructure and enabling manufacturing ecosystem**

Low volumes in REE sector currently make it investment averse for the private sector; however, to meet India's vision of self-reliance and its strategic applications, positioning it as a "strategic sector" will be the key enabler for development.

REE: Major Steps Taken by Countries Worldwide

Recently countries have seen fast-paced development of the rare-earth sector and building resilient supply chains.



European Union

The EU-funded project EURARE to secure EU RE resources and technologies

China

Foreign investments in exploration, mining, and beneficiation of rare earth, radioactive minerals, and tungsten are prohibited

Japan

Poised to increase funding for the exploration of rare earth metals

USA

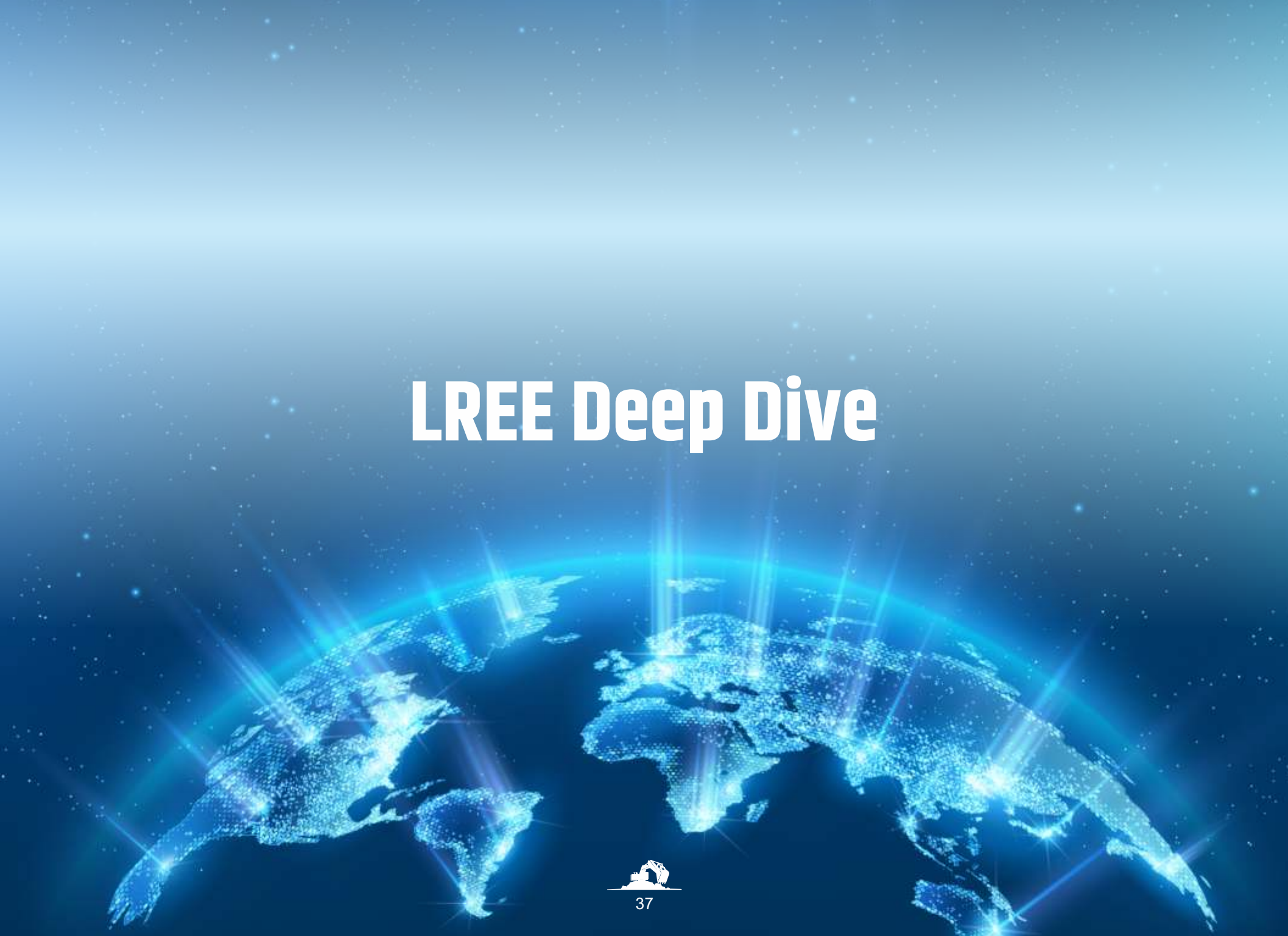
- *US DOD (Pentagon) **grants** to MP Materials, Lynas Corporation and Urban Mining to develop RE separation plants.*
- *DoE announced **loan guarantees** to help finance projects.*

Australia

- *EFA provides **financial solutions, loans, guarantees, and bonds** while NAIF provides **loans to help fund infrastructure** in northern Australia.*
- ***CMFO** was established in 2020 to help proponents **secure investment, financing and market access.***

DOD – Department of Defence|| DoE – The Department of Energy|| EFA - Export Finance Australia|| NAIF – The Northern Australia Infrastructure Facility || CMFO - Critical Minerals Facilitation Office || GoI – Government of India

LREE Deep Dive



Lanthanum and Cerium

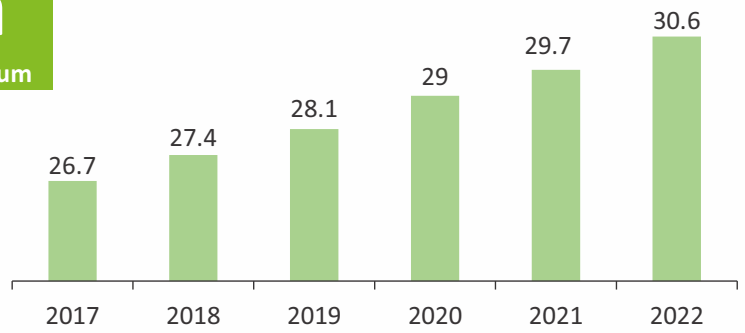
Key Questions Answered:

- *What is the Global Production of La and Ce? How are La and Ce extracted, and what are the key mining areas?*
- *What is the price trend of La and Ce-Oxide?*
- *What are the major applications of La and Ce globally?*
- *What is the importance of La and Ce in the Indian Economy? What does the future outlook look like, and what are the challenges?*
- *What is the current Production capacity and Demand of La and Ce in India?*
- *What does the demand scenario of La and Ce look like in India in 2030 and 2047?*

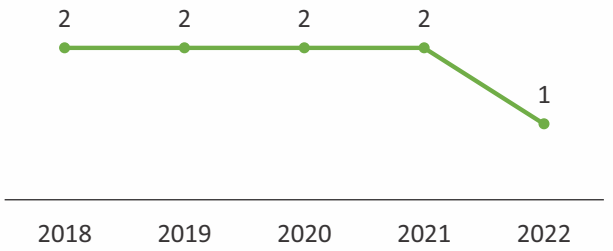
Lanthanum: Production and Price Trends

57 139
La
Lanthanum

Global Lanthanum (metal) Production (in kT)



Lanthanum Oxide (Price trends – USD/kg)



Note: REEs are typically traded in terms of their metal oxide equivalent content

Key Insights

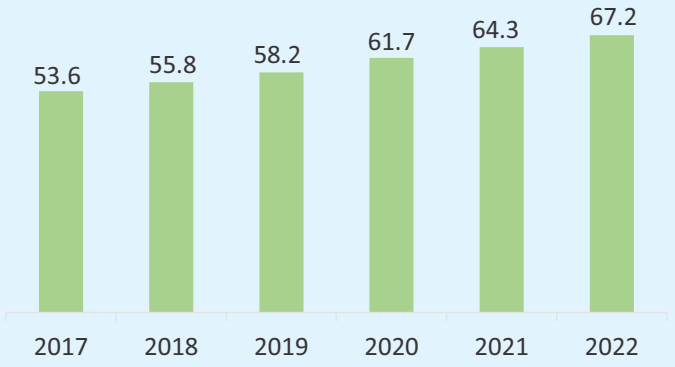
- Lanthanum is a silvery-white, soft, ductile metal that tarnishes slowly when exposed to air and has traditionally been classified as a **rare earth element.** The most common **oxidation state is +3.**
- Major mineral types for La include **Monazite and Bastnasite,** where La makes up **25%** and **38%** of these minerals, respectively. **Allanite and Cerite** also contain Lanthanum, but these ores are not mined for their Lanthanum content in particular.
- The main mining regions for La are the **USA, Brazil, India, Sri Lanka, and Australia.** Its reserves (oxide equivalent) are estimated to be 6 MnT.
- Global Lanthanum Production witnessed a subtle growth at a **CAGR of 2.98 %** throughout FY-17 to FY-22. The production volume is expected to reach **38.7 kT in FY-2030** and **63.8 kT by FY-2047.**
- Lanthanum is a key application in catalytic convertors for IC engines. The **global shift from IC engines to electric motors has subdued demand for Lanthanum oxide.** Furthermore, the preference for Neodymium magnets in electric vehicles and wind turbines over Lanthanum-containing magnets has further **reduced its demand.** Such factors have resulted in the price of Lanthanum oxide dropping in 2022.

Source : Deloitte Analysis , USGS Mineral Commodity Summaries 2018,2019,2020, 2021 and 2022, EMIS, Mordor Intelligence, India Exim Bank

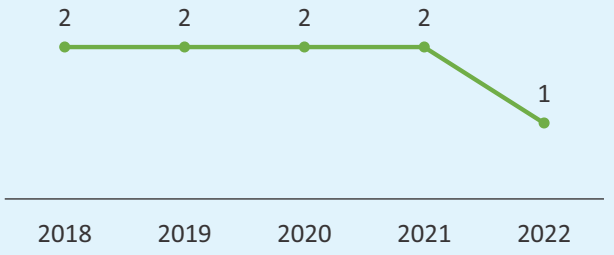
Cerium: Production and Price Trends

58 140
Ce
Cerium

Global Cerium (metal) Production (in kT)



Cerium Oxide (Price trends – USD/kg)



Note: REEs are typically traded in terms of their metal oxide equivalent content

Key Insights

- Cerium is the **most abundant of the REEs.** It is a reactive, grey metal and a member of the Lanthanoid Group of the Periodic Table. It is the **25th** most abundant element within the Earth's crust. Due to its reactivity, it is stored in light mineral oil to protect it against oxidation.
- Cerium is extracted from the ores **bastnasite and monazite.**
- The main **mining areas** are in the **USA, Brazil, India, Sri Lanka, Australia, and China.** The characteristics and uses of Cerium are also very similar to all lanthanides; however, Cerium is one of the most reactive REEs.
- Global Cerium Production witnessed a moderate growth at a **CAGR of 4.78 %** from FY-17 to FY-22.
- Global Cerium Production is expected to reach 97.6 kT in 2030 and 215.9 kT by the end of 2047.
- The price trend Cerium Oxide has seen a fall in FY-22 as there is a global switch from **combustion engines to electric motors.**
- As we are witnessing a shift from **IC engines to electric motors,** the **price of Cerium,** which is majorly used in **catalytic converters,** is likely to remain **low**.

Source : Deloitte Analysis , USGS Mineral Commodity Summaries 2018,2019,2020, 2021 and 2022, EMIS, Mordor Intelligence, IndiaEximbank

La & Ce: End Use Sectors and Applications



Glass Additives and Polishing - The commercial grade Cerium Oxide is widely used in the industry for polishing glass. Cerium oxide is used in glass to produce a harder, more resistant surface. It lowers the surface energy of the glass and makes it easier to clean. Cerium oxide also acts as an anti-reflective material, meaning it works like a mirror inside windshields and windows. Lanthanum makes up as much as 50 % of digital camera lenses, including cell phone cameras and telescope lenses.



Catalyst - Lanthanum is one of the main REEs used in catalytic applications along with cerium; these two metals are considerably more abundant and available at considerably lower prices. REEs play an important role as catalysts in petroleum refining. Lanthanum and cerium are used as additives for fluid catalytic cracking (FCC), a key process in gasoline production. These REEs increase gasoline yield and reduce air emissions from the oil refining process. Cerium oxide is a catalyst component in catalytic converters, which are used to clean exhaust from vehicles.



Metallurgy - Mischmetal (usually 50% cerium, 25% lanthanum, 18% neodymium, 5% praseodymium, and 2% other REEs) is largely used in lighter flints, alloying additives to remove impurities during steelmaking, and production of special alloys.

Cerium metal in a highly pure form is used in casting alloys, e.g., as an additive to aluminum, magnesium, iron, and battery and vacuum alloys. It is also used to impart resistance to stainless steel, tool steel, and lamps and can refine the grains in some alloys.

Lanthanum is added to ferrous alloys (to scavenge oxygen, sulfur, and other impurities) and to nonferrous alloys, such as superalloys, magnesium alloys, or aluminum alloys.



Others - Cerium is also used in flat-screen televisions, low-energy light bulbs, magnetic–optic compact discs, and chromium plating. The metal is a core for arc lamp carbon electrodes and incandescent mantles for gas illumination.

Lanthanum carbonate is used in medication to incorporate excessive amounts of phosphate in medical conditions like renal failure.

Some scientific developments suggest that adding rare earth Lanthanum into Strontium oxide and Niobium oxide can produce a special ceramic film that exhibits superconductivity at 255 K.

Source : Deloitte Analysis , Mordor Intelligence,

Cerium: Importance in Indian economy (1/2)

Application	Industry	Outlook	Remarks
Micro-alloy Agent in Hydrogen Storage	Hydrogen Storage		Cerium addition to the LaNi5 alloy causes structural changes such as lattice shrinkage andchanges enthalpies of formation and decomposition and increases the absorption properties.
Bio-antioxidants	Medicine		CeO2 nanozymes possess enzyme mimetic activities with outstanding free radical scavenging activity, facile synthesis conditions, and excellent biocompatibility. CeO2 nanozymes have been demonstrated to be a highly versatile therapeutic method for many diseases, such as as inflammation,, rheumatoid arthritis, hepatic ischemia-reperfusion injury, and Alzheimer's disease. Furthermore, CeO2 nanozymes have been widely used in the diagnosis and treatment of cancer.
Coagulant in wastewater treatment	Biological Wastewater Treatment		Cerium Chloride as a coagulant gave good results when it was tested based on the capacity to remove dissolved phosphorus and other impurities while maintaining alkalinity, sludge production, and operation cost.
Polishing	Electronics and Precision Equipment		Nanoparticulate ceria is used in various ultra-fine polishing applications including semiconductor wafers, computer hard - disk drives, and optics.
Polishing of Glass	Electronics Automotive Home decor		Cerium oxide (CeO2) – Ceria powder is used to polish glass for tableware, LCD screens, car windows, mirrors, and optical lenses.
Decolouration of glass	Many (Automotive)		Usage is normalizing because of the replacement of fluorescent lamps with LEDs.
Catalytic Convertors	Automotive		Car exhaust catalyst can contain up to 20 wt% of CeO2. Consumption of exhaust catalysts will be moderate if there is a global switch from combustion engines to electric motors.

Emerging Markets

Growth Outlook Very High High Moderate

Source: IBM Yearbook, Investor Reports, Company Presentations, Research papers, IndiaEximBank, USGS, GII Research, EMIS, Mordor Intelligence, Deloitte Analysis

Lanthanum: Importance in Indian economy (2/2)

Application	Industry	Outlook	Remarks
Electrolyte material in Solid Oxide Fuel Cells	Electricity		As an electrolyte material in solid oxide fuel cells, Lanthanum is a promising material for generating clean electricity from Hydrogen and other fuels.
Electric Vehicle Batteries	Automotive		Lanthanum is used in the production of Lithium - ion batteries.
Magnetic Refrigeration	HVAC		Lanthanum is used in the development of magnetic refrigeration, a new type of cooling technology that does not rely on refrigerants or compressors. This technology has the potential to be more energy efficient and environmentally friendly.
Optical Glasses	Electronics Appliances		Its main usage is in lenses of cameras, microscopes, binoculars, or telescopes (can contain up to 40 wt% of La2O3), security, and mobile - phone cameras.
Stabilizer in PVC	Polymer		A large market exists for Lanthanum compounds as stabilizers for PVC.
Brake Composites	Automotive		Lanthanum Oxide is used in polymeric matrix brake composites to replace copper.
Mischmetal in NdFeB Magnets	Automotive, Wind Turbine and Electronics		Mischmetal (i.e., La + Ce mixture) replaces part of the Neodymium. Up to 20 wt% of Neodymium can be replaced without substantially compromising on the magnetic properties.
Hydrogen Storage in NiMH Batteries	Automotive		LaNi5 has a high hydrogen storage capacity; however, its price is high. Therefore, mischmetal use is growing. Additionally, lithium-ion batteries are replacing NiMH batteries in the market.

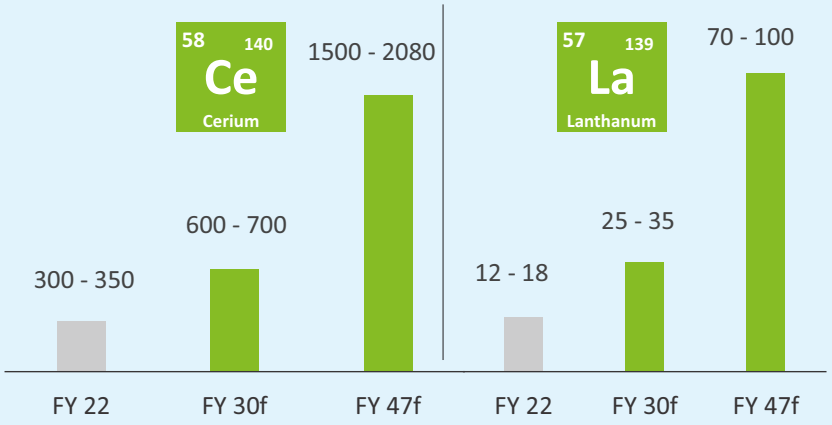
Emerging Markets

Growth Outlook Very High High Moderate

Source: IBM Yearbook, Investor Reports, Company Presentations, International Journal of ChemE, Nanografi, Baotou rare earth r esearch paper, IndiaEximBank, USGS, GII Research, EMIS, Mordor Intelligence, Deloitte Analysis

La and Ce: Indian Demand Scenario

Cerium and Lanthanum compound* Demand Forecast: India (T)



Highlights

- A leading automobile manufacturer has developed the world's first magnet with 50% less Neodymium (replacing it with lanthanum and cerium) while retaining heat resistance properties.
- As per in-house R&D conducted by a domestic player, the production of Lanthanum zirconate using Lanthanum carbonate and zirconyl nitrate is suitable for thermal barrier coatings on metal substrates and graphite for the prevention of oxidation.
- Multiple projects to substitute neodymium and praseodymium with lanthanum and cerium in NdFeB magnets are underway. Some lanthanum and cerium mischmetal may soon be added to magnets to reduce the neodymium content without changing the magnets' properties and performance.

- The current domestic production capacity is 900–950 tons and that of cerium compounds is 1,900–2,000 tons.
- Cerium compound demand in India stands at 300–350 tons in FY-22; it is forecasted to increase at a CAGR of 9.1 % to reach 600–700 tons by FY-30. Lanthanum compound demand in India stands at 12–18 tons in FY-22; it is forecasted to increase at a CAGR of 9.1% to reach the cumulative demand potential of 25–35 tons by FY-30.
- Innovative metal chemistry (to replace other REEs, particularly HREEs, with cerium) may help India utilize its high cerium production capacity.
- There is a growing demand for Lanthanum in the energy storage sector where it is used in producing NiMH batteries, commonly used in hybrid EVs.
- Adoption of cerium- and lanthanum-bearing NdFeB magnets is expected to accelerate, partially helping to offset the market's increasing undersupply of Neodymium oxide.

*Cerium and lanthanum together represent ~68% of REE content of Indian monazite. Owing to their relatively high production volume and abundance, the data in India is reported in terms of their compounds (such as oxides, chlorides, nitrides, and carbonates) rather than metal content.

Source : Deloitte Analysis, USGS Mineral Commodity Summaries, EMIS, Mordor Intelligence, IndiaEximBank, The Future of strategic natural resources, IREL, Australia Trade and Investment Commission

La and Ce: Opportunities & Challenges

Challenges

- Lanthanum and Cerium's abundance (wrt domestic demand) has led to stockpiling of these oxides at the producer's end, leading to significant oversupply in the market.
- Prices for Lanthanum and Cerium oxide are significantly lower and have declined vis-à-vis other RE oxides in recent past
- One major application of Lanthanum & Cerium has been in catalytic convertors in IC engines. As the EVs are gaining momentum, a complementary growth slowdown can be expected in IC based automobiles, thereby impacting Lanthanum and Cerium demand from such end-use; thus, it is imperative to promote their new applications

Opportunities

- Indian Monazite resource contains high Lanthanum (22%) and Cerium (46%) content
- India has the technological and commercial capability to produce high-purity La and Ce carbonate compounds.
- There are emerging and new markets for Lanthanum and Cerium
    - Substitute of Neodymium and Praseodymium in mischmetal and NdFeb magnets
    - Application in Hydrogen storage fuel cell material Coagulant
    - Coagulant/phosphor capturing component in wastewater treatment
    - Additives in austenitic steel

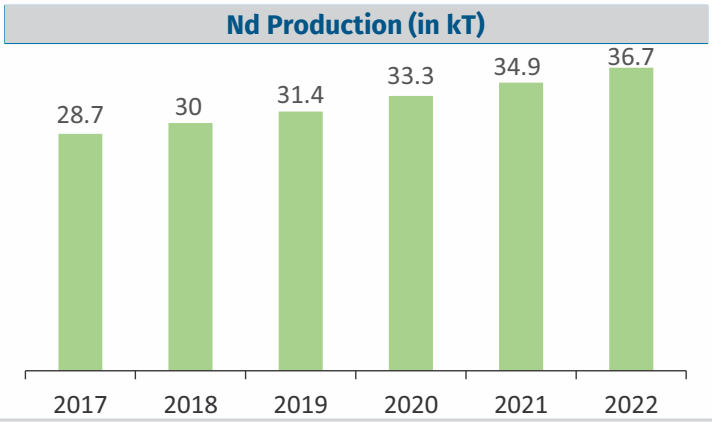
Neodymium and Praseodymium

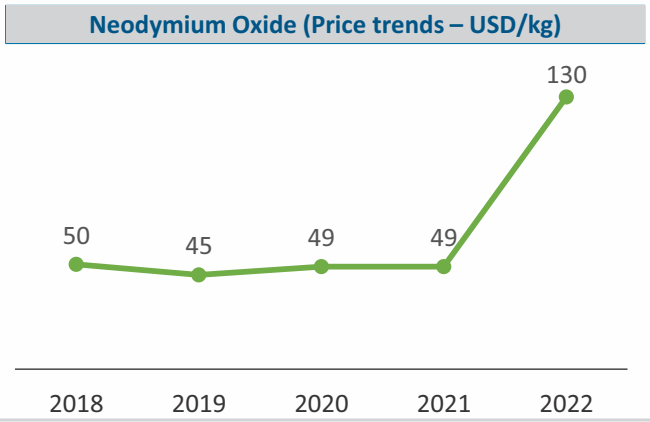
Key Questions Answered:

- *What is the Global Production of Nd and Pr? How are Nd and Pr extracted, and what are the key mining areas?*
- *What is the price trend of Nd and Pr Oxide?*
- *What are the major applications of Nd and Pr globally?*
- *What is the importance of Nd and Pr in the Indian Economy? What does the future outlook look like, and what are the challenges?*
- *What is the current Production capacity and Demand of Nd and Pr in India?*
- *What does the demand scenario of Nd and Pr look like in India in 2030 and 2047?*

Neodymium: Production and Price trends (1/2)

60 144
Nd
Neodymium





Key Insights

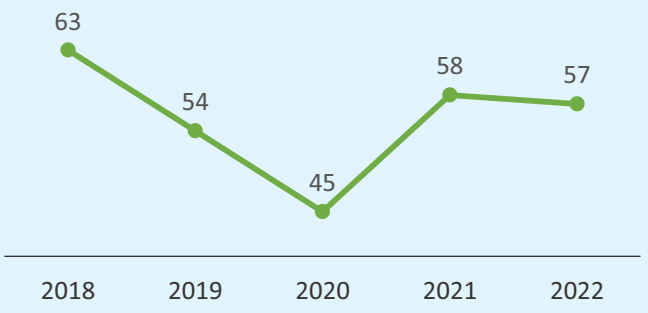
- Neodymium is a bright silvery-white metal belonging to the Lanthanoid group in the Periodic Table. It is the 26th most abundant element within the Earth's crust.
- Neodymium can be extracted from all minerals and ores containing lanthanides; however, monazite and certain bastnasite deposits are the most important
- China, the USA, Brazil, India, Sri Lanka, and Australia are the primary sources of these ores, with China dominating production; however, Neodymium reserves are expected to be 8 million tons.
- Very pure Neodymium metal is produced by reacting Neodymium fluoride with calcium, however, little is produced due to the high costs involved.
- Global Neodymium production witnessed moderate growth at a **CAGR of 4.85 %** over the period of FY-17 to FY-22.
- Global Neodymium Production is forecasted to reach 53.6 kT in 2030 and 119.9 kT by the end of 2047.

Source : Deloitte Analysis , USGS Mineral Commodity Summaries 2018,2019,2020, 2021 and 2022, EMIS, Mordor Intelligence, Journal of Brazilian Chemical Society

Praseodymium: Production and Price trends (2/2)

59 141
Pr
Praseodymium





Key Insights

- Praseodymium is a soft, malleable, silvery, and ductile metal. It is a member of the Lanthanide group of metals and is the 39th most abundant element within the Earth's crust.
- Praseodymium reacts slowly, with oxygen forming a flaky, green oxide layer. This oxide layer does not protect the element from further oxidation; therefore, it is often stored in a sealed plastic container or covered with oil, although it is less readily oxidized than other REEs. Praseodymium also reacts rapidly with water.
- Praseodymium can only be found in two types of ores: monazite and bastnasite.
- The main mining areas are China, the USA, Brazil, India, Sri Lanka, and Australia.
- Reserves of Praseodymium are estimated to be around 2 million tons.
- Global Praseodymium production witnessed moderate growth at a CAGR of 3.38 % from FY-17 to FY-22.
- Global Praseodymium production is forecasted to reach 14.5 kT in 2030 and 25.48 kT by the end of 2047.

Source : Deloitte Analysis , USGS Mineral Commodity Summaries 2018,2019,2020, 2021 and 2022, EMIS, Mordor Intelligence, Journal of Brazilian Chemical Society

NdPr: End Use Sectors and Applications

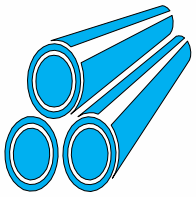


Permanent Magnets – NdPr is primarily used to produce high-strength permanent magnets. These magnets have unique magnetic properties, such as high magnetic strength, coercivity, and resistance to demagnetization, making them ideal for various applications in several industries.



Glass Additives and Polishing - The coloring of glass with Neodymium or Praseodymium is based on their selective absorption in the visible range. In the decolorizing of glass, the oxidation effect of 4-valent cerium is combined with the absorption of small quantities of Neodymium/Praseodymium.

Neodymium, along with Praseodymium, is a component of didymium glass. This is a unique goggle glass used for glass blowing and welding. The glass element hues are delicate violet, wine-red, and grey tones.



Metallurgy – Cerium (50%), lanthanum (25%), neodymium (18%), praseodymium(5%), and 2% other REEs, commonly in the form of a mixed oxide known as mischmetal, are used in steel making to remove impurities and in the production of special alloys. Mischmetal is largely used in lighter flints and alloying additives.

Source : Deloitte Analysis , Mordor Intelligence, IndiaEximBank

NdPr: Importance in the Indian Economy

Application	Industry	Outlook	Remarks
Electric Vehicles	Automotive	●	The demand for electric vehicles (EVs) is rapidly increasing, and NdPr magnets are used in EVs to increase the efficiency and performance of motors. Emerging technologies in the EV sector include the development of more powerful and energy-efficient motors and batteries, which require more NdPr magnets.
Wind Turbines	Electricity	●	The wind energy industry is growing rapidly, and NdPr magnets are used in the generators of wind turbines to convert kinetic energy into electrical energy. Emerging technologies in the wind energy sector include the development of larger and more powerful wind turbines, which require more NdPr magnets.
Magnets in Lightweight Electronics	Consumer Electronics	●	NdPr magnets are used in small, lightweight electronics, such as smartphones, laptops, and hard disk drives.
Industrial Equipment	Compressors, Pumps, and Elevators	●	NdPr magnets are used in industrial equipment, such as compressors, pumps, and elevators, to increase efficiency and reduce energy consumption.
Strong Magnetic Fields in MRI Machines	Medical	●	NdPr magnets are used in medical equipment, such as MRI machines, to produce strong magnetic fields for imaging and diagnostics
Aerospace Industry	Automotive	●	NdPr magnets are used in various aerospace applications, such as actuators, sensors, and electric propulsion systems.

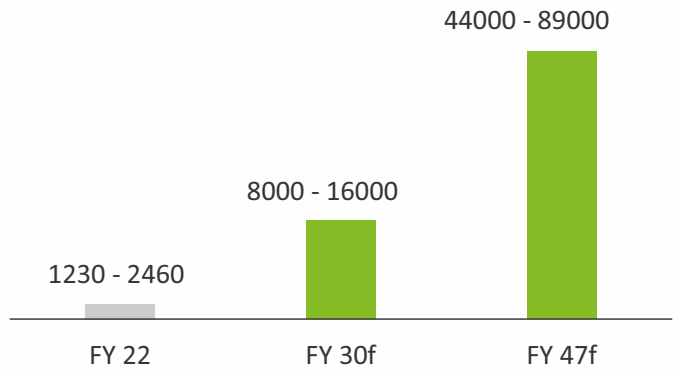
Emerging Markets

Growth Outlook ● Very High ● High ● Moderate

Source: IBM Yearbook, Investor Reports, Company Presentations, TZMI, Iluka, Grandview Research Reports, USGS<, GII Research, EMIS, Mordor Intelligence, Adamas Intelligence, NITI Aayog, SIAM, Deloitte Analysis

NdPr: Indian Demand Scenario and Insights

NdPr Demand Forecast: India (T)



Highlights

- Lab analysis highlights that Nd metal produced at a leading Indian research institute is at par or even better than that imported in India. Efforts should be put in to promote domestic commercial scalability.
- With public–private partnerships, explorations and mining of LREEs such as NdPr can be improved, impacting the trade scenario for these minerals.

- NdPr demand ranged from 1,230 to 2,460 in FY-22 and is forecasted to increase at a CAGR of 26.49 %, reaching 8,000–16,000 tons by FY-30.
- India's installed wind energy capacity is estimated to increase from its current 40GW to 140GW (both onshore and offshore) by 2030. Wind energy to facilitate the government in achieving "net zero" emissions target by 2070. NdPr demand for Wind turbines currently stands at 4.4 kT and is expected to reach 15.1 kT by FY-2030 and 32.8 kT by FY-2047.
- India's government has planned to complete the electrification of vehicles by 2047; central and state governments offer subsidies to boost EV penetration.
- NdFeB magnets are also used in other applications, including electronics and industrial magnetic equipment. Demand for NdPr for these applications was estimated to be 0.9 kT in 2022 and is expected to reach 5 kt by 2047.

Source : Deloitte Analysis , USGS Mineral Commodity Summaries 2018,2019,2020, 2021 and 2022, EMIS, Mordor Intelligence, IREL, Austrade

NdPr: Opportunities and Challenges

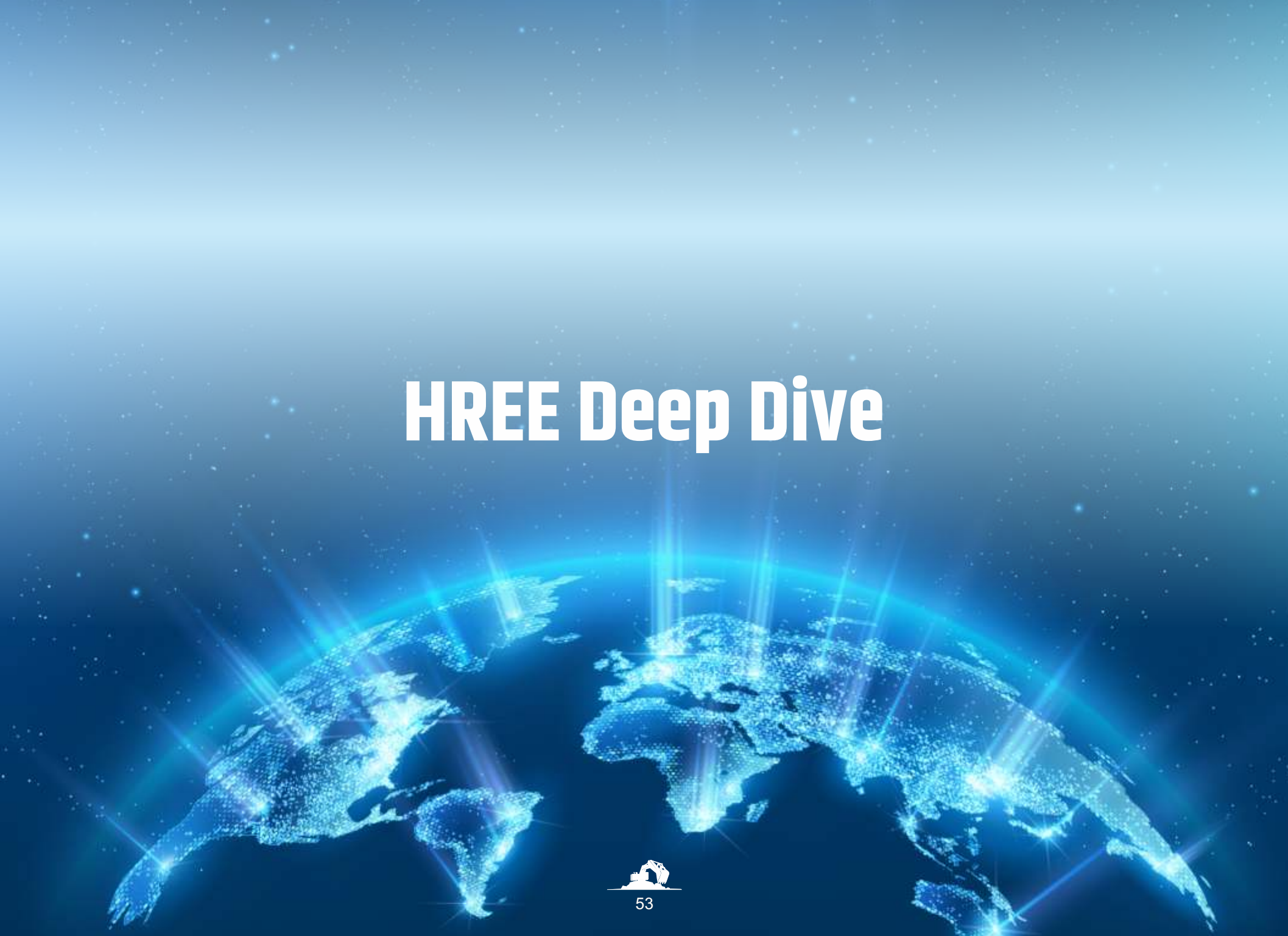
Challenges

- Low oxide concentration in Monazite (Nd – 20%, Pr – 5.5%) resources
- NdPr oxides are expensive and exhibit price volatility (Neodymium Oxide prices ranged 50–130 USD/kg and Praseodymium prices ranged 45–53 USD/kg from FY-18 to FY-22).
- India does not have domestic NdFeb magnet production facilities, which is the emerging and growing application of NdPr oxide

Opportunities

- Demand for NdPr magnets will be driven by increasing wind power capacity and demand for EVs in India
- The usage of Praseodymium oxide in ceramic tiles is increasing. Ceramics is a significant market for India, and increasing urbanization will increase demand for Pr.
- Neodymium and Praseodymium, commonly in the form of a mixed oxide known as mischmetal, are used in steel making to remove impurities and in the production of special alloys. PLI for steel sector would drive demand for specialty steel.
- As India has technological and commercial capability of producing high purity NdPr oxide, there exists an opportunity to scale up production

HREE Deep Dive



Dysprosium

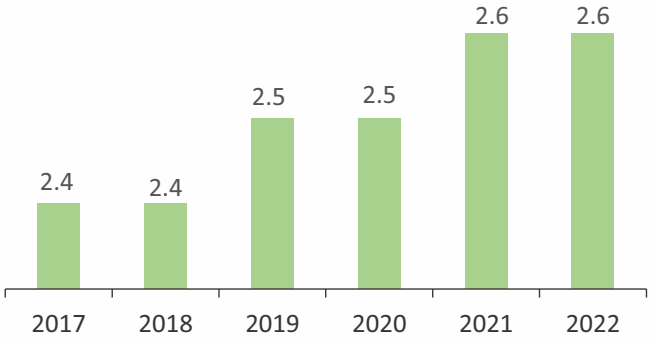
Key Questions Answered:

- *What is the Global Production of Dysprosium?*
- *What is the price trend of Dysprosium Oxide?*
- *What are the major applications of Dysprosium globally?*
- *What is the importance of dysprosium in the Indian economy? What does the future outlook look like, and what are the challenges?*
- *What does the demand scenario for dysprosium look like in India?*

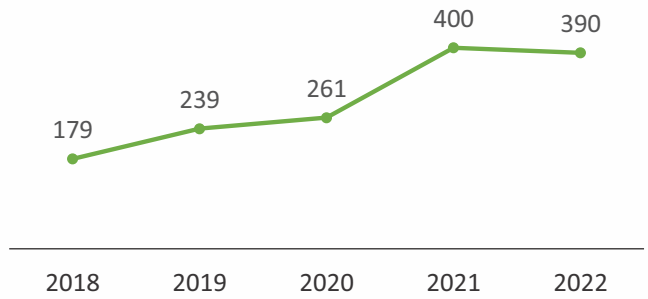
Dysprosium: Production and Price Trends

66 162.5
Dy
Dysprosium

Global Dysprosium (metal) Production (in kT)



Dysprosium Oxide (Price Trends - USD/kg)



Key Insights

- Dysprosium is a **critical heavy REE;** it is lustrous, soft, and silvery. As a pure metal, it is little used because it reacts readily with water and air. Dysprosium is mainly used in alloys for neodymium-based magnets.
- Projections indicate that the increase in the use of green technology required to stabilize atmospheric carbon dioxide at 450 ppm **would increase demand for dysprosium** by 2,600% over the next 25 years (assuming current demands for wind and electric motor applications are representative of future needs).
- **China produces 98% of the world's dysprosium;** thus, changes in China's export policy could severely reduce global dysprosium supply. Dysprosium is currently almost exclusively supplied by ion-adsorption clays (IACs) located in seven provinces in southern China.
- Elements such as dysprosium and neodymium are experiencing major shortages. Dysprosium **supply is only 15%–18% of demand.**
- Dysprosium **increased in price by almost 800% from 2006 to 2011,** a considerably large increase for a five-year period. In late 2011 and early 2012, its price dropped substantially owing to a decrease in demand. The decrease in demand was mainly due to **cost-saving substitutions** of Nd–Dy magnets with more traditional non-REE magnets.

Source : Deloitte Analysis , USGS Mineral Commodity Summaries 2018,2019,2020, 2021 and 2022, EMIS, Mordor Intelligence, US Department of Energy

Dysprosium: End Use Sectors and Applications

Future Dysprosium demand growth will be driven by global megatrends linked to electric mobility, clean energy, energy efficiency, and automation. As per the reports, China's production alone will be insufficient to support global demand growth.

	**Permanent magnets:** Dysprosium allows such permanent magnets to maintain their properties at high temperatures. These magnets are used in **EV traction motors** and, by 2025, are expected to become the single largest end-use of dysprosium oxide globally. Nearly **95% of the total dysprosium demand accounts for the use in permanent magnets.**
	**Renewable energy:** Owing to high temperatures inside turbines, the main demands for dysprosium-doped magnets originate from the production of **wind turbines.**
	**Nuclear applications:** It can absorb extra neutrons; therefore, it is used in fission reactions. This property of dysprosium is attributed to its high neutron capture cross-section. It is also used in the cermet of **nuclear reactor to make control rods.**
	**Electronics:** An alloy of vanadium and dysprosium can be used in making **laser devices. Data storage devices** such as hard disks, floppy disks, compact disks, and flash drives can also be produced using dysprosium alloys. Dysprosium is used in semiconductor deposition, chemical vapor deposition (CVD), and physical vapor deposition (PVD) .
	**Ships -** Dysprosium alloys can be used in **ships' sound navigation and ranging systems** due to their magnetic property. Hence, Dysprosium is relevant in the marine industry
	**Corrosion resistance:** Magnets made using dysprosium are **more corrosion-resistant** than most of their counterparts; therefore, Dysprosium is sometimes used instead of neodymium for producing magnets.
	**Reinforcement:** When Dysprosium is used to **manufacture nanofibers,** these nanofibers are very strong. These nanofibers can, in turn, be used to reinforce other products.

Source : Deloitte Analysis , USGS Mineral Commodity Summaries 2018,2019,2020, 2021 and 2022, EMIS, Mordor Intelligence

Dysprosium: Importance in the Indian Economy

Application	Industry	Outlook	Remarks
Radiation Monitoring	Medical Diagnostics		Among the thermoluminescence phosphors, dysprosium-doped calcium sulfate is useful for certain diagnostic and therapeutic dosimetric applications in medical physics.
Biomedical Applications	Biomedical		Dysprosium doping on the evolution of structural and magnetic properties of magnetite nanoparticles can be used as catalysts and for biomedical applications because the effect of functional materials attached to them will be over a large area compared with spherical particles.
Halogen Lamps	Electronics		Dysprosium oxide improves the emission spectrum of high performance halogen lamps
EV Motors	Automobile		High-performance **permanent magnets** are indispensable in the production of high-efficiency EV motors. As India is committed to an aspirational goal of having at least **30% of private automobiles as EVs by 2030,** the EV market is anticipated to reach 10 Mn annual sales, growing at a compound annual **growth rate (CAGR) of 49% between 2022 and 2030.** It will substantially accelerate the demand for dysprosium in the coming years.
Turbines	Renewable Energy		India has aimed to become **front-line nation in clean energy generation and an investment flow of over INR 800 billion with respect to wind energy has been envisioned** over the next few years. The need for dysprosium will increase as it is used in high-performance permanent magnets for producing high-efficiency turbines.
Nuclear Applications	Nuclear Power		India plans to construct **10 indigenously developed pressurized heavy-water reactors** at INR 1.05 lac Cr., which will increase demand for dysprosium as a control-rod material for the reactors.
Laser and Data Storage Device	Electronics		India's focus on domestically producing electronics will drastically increase the demand for critical elements such as dysprosium, which can be used in making laser devices and data storage devices such as hard disks, floppy disks, compact disks, and flash drives.

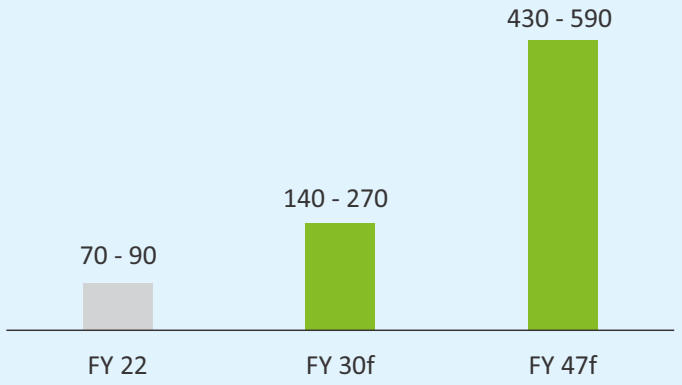
Emerging Markets

Growth Outlook Very High High Moderate

Source: USGS' Mordor Intelligence, Deloitte Analysis, Invest India, Economic times, Indian express

Dysprosium: Indian Demand Scenario and Insights

Dysprosium Demand Forecast: India (T)



Highlights

- A process flowsheet has been developed for **extracting dysprosium** from Monazite by leading domestic research institutes in India, which is available in **the BSM ore in traces.**
- A leading research institute in India is conducting research on **dysprosium application in control rods for nuclear reactors.**

- Dysprosium demand in India stands at 70–90 tons as of FY-22 and is forecasted to increase at a CAGR of 10.7% to a cumulative demand potential of 140–270 tons by FY-30.
- The content of REE in Indian resources is approximately 0.05%–0.06%, of which the content of **dysprosium is approximately 0.00009%**
- **Indian Monazite** is rich in light Rare Earths; heavy Rare Earths are found in traces and are difficult to extract.
- Dysprosium is **not present in India in extractable quantities.** India is almost 100% import-dependent.
- Dysprosium is critical for clean energy technologies but has a small market owing to **limited supply.**
- In-house R&D is being conducted for laboratory scale production of 99.5% pure Dysprosium.

Source : Deloitte Analysis , USGS Mineral Commodity Summaries 2018,2019,2020, 2021 and 2022, EMIS, Mordor Intelligence, IREL

Dysprosium: Opportunities and Challenges

Challenges

- Players operating in application industries are investing in R&D for the development of products that can potentially replace Dysprosium. For instance, CeCo5 could be used in place of the strongest rare earth magnets that contain Neodymium (Nd) and Dysprosium (Dy)
- Low Dysprosium oxide concentration (~0.18%) in domestic monazite resources
- Dysprosium prices have been consistently rising (amid volatility throughout the year due to illiquid market). It reached about ~USD 390/kg in 2022 and is expected to remain in upward trajectory due to demand-supply gap

Opportunities

- Dysprosium elements are used to manufacture bonded and sintered NdFeB magnets for EV traction motors and wind turbine generators to improve magnet performance.
- Demand for dysprosium is largely derived from demand in the clean energy sectors, such as wind turbines (in magnets) and nuclear energy (in control rods), which will be pursued aggressively to reach India's net-zero targets.

Terbium

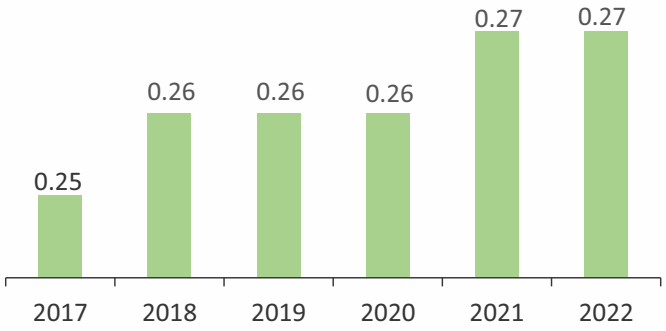
Key Questions Answered:

- *What is the Global Production of terbium?*
- *What is the price trend of terbium oxide?*
- *What are the major applications of terbium globally?*
- *What is the importance of terbium in the Indian Economy? What does the future outlook look like, and what are the challenges?*
- *What does the demand scenario of terbium look like in India?*

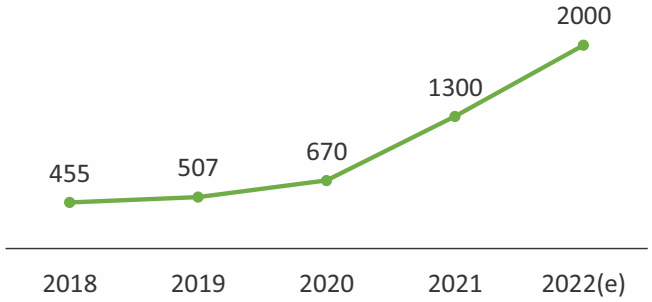
Terbium: Production and Price Trends

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Tb
Terbium

Global Terbium (metal) Production (in kT)



Terbium Oxide (Price Trends - USD/kg)



Key Insights

- Terbium is a soft, malleable, ductile, silver-gray metal member of the lanthanide group of the periodic table. Terbium is twice as common in the Earth's crust as silver.
- The most important ores are **monazite, bastnasite, and cerite.** The main mining areas are China, the United States, India, Sri Lanka, Brazil, and Australia, and terbium reserves are estimated to be around 300,000 metric tons.
- Terbium, like dysprosium, is considered a **critical element** in the HREE metals group, as supply levels are low.
- **China is the largest global producer** of terbium. In 2019, the country exported approximately 115 tons of terbium, of which nearly 94% was exported to Japan (87.3%) and the US (6.4%).
- **Renewed stockpiling demand from downstream magnet manufacturers, higher oxide feedstock costs, and a shortfall of spot supplies** prompted suppliers to increase terbium metal prices.

Source : Deloitte Analysis , USGS Mineral Commodity Summaries 2018,2019,2020, 2021 and 2022, EMIS, Mordor Intelligence, Journal of Brazilian Chemical Society

Terbium: End-use Sectors and Applications

	**Phosphors:** Terbium is used to manufacture LCD and plasma screens. Terbium and europium are needed to manufacture phosphors used in LEDs: **terbium in green phosphors** and europium in red phosphors. Phosphor substances emit luminescence for many types of ray tubes and flat-panel displays and screens ranging from smartphone displays to stadium scoreboards.
	**Permanent magnets:** Terbium can be added to Neodymium–iron–boron (NdFeB) to improve the coercivity of permanent magnets. In particular, the performance of terbium is better than that of dysprosium in increasing the maximum working. Similarly, terbium is also a key component of terbium–dysprosium–iron (TbDyFe) magnetostrictive materials, an alloy that expands or contracts to a high degree in the presence of a magnetic field.
	**Loudspeakers:** An alloy of Terbium, Dysprosium and iron lengthens and shortens in a magnetic field, forming the basis of loudspeakers that sit on a flat surface, such as a windowpane, which then act as the speaker.
	**Light bulbs and lamps:** Terbium is used in solid-state electronics to dope calcium fluoride, calcium tungstate, and strontium molybdate. It's also **in low-energy light bulbs and mercury lamps.** It has been used to **increase the safety of medical X-rays** by producing the same quality image with a significantly shorter exposure period. **Lasers** make use of Terbium salts.
	**Clean energy:** While each REE is used in different applications, neodymium, dysprosium, praseodymium, and terbium are particularly important to the clean energy sector.
	**X-ray:** X-rays are generated using terbium oxide, which also acts as activator of fluorescent powder, which is a fluorophore of an X-ray intensifying screen.

Source : Deloitte Analysis , USGS Mineral Commodity Summaries 2018,2019,2020, 2021 and 2022, EMIS, Mordor Intelligence, Journal of Brazilian Chemical Society

Terbium: Importance in the Indian Economy

Application	Industry	Outlook	Remarks
Bone Repair	Biomedical		Terbium has been widely applied in the biomedical field owing to its excellent physicochemical properties, and Tb–Cys NPs (terbium–cysteine nanoparticles) efficiently promote bone repair.
Photocatalysis	Chemical		Terbium doping with SnO2 improved photocatalytic dye degradation efficiency, enabling them to be used in the chemical industry. The high photocatalytic performance, excellent reusability, and low toxicity of Tb-doped TiO2 indicated that it is a promising candidate material for dye wastewater treatment.
Detection	Biotechnology		Terbium is used to detect endospores. Endospores are tough, dormant, and non-reproductive structure produced by some bacteria in the phylum firmicutes.
Phosphors	Electronic		Overall, 48% of terbium is used to produce phosphors used in making screens. Displays constitute a considerable portion of the total bill of materials in electronic products. Government plans to develop an ecosystem of display fabrication units in the country that will increase demand for phosphors. Phosphors are also used in X-ray imaging.
Permanent Magnets	Automobile, Clean Energy		Overall, 22% of terbium production is used to manufacture permanent magnets, which are used in EV motors and wind turbines. Terbium could be used as an alternative to dysprosium in magnet production; however, the annual supply of terbium is far more limited than that of dysprosium.
Laser	Electronic		Terbium is a promising element for the theranostic approach in nuclear medicine. It is used to produce medical radioisotopes to support related R&D projects in biomedicine.
Loudspeakers	Electronic		Terbium is a vital ingredient of magnetostrictive alloys that change length when exposed to a magnetic field. Such alloys are used in loudspeakers designed to push against solids rather than against air.

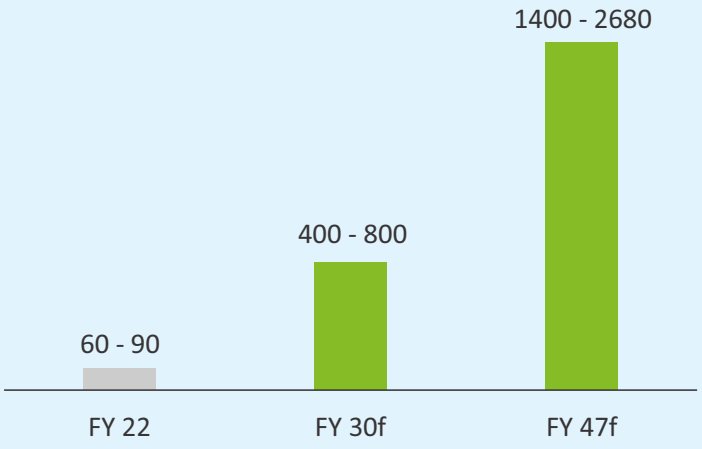
Emerging Markets

Growth Outlook Very High High Moderate

Source: IBM Yearbook, Investor Reports, Company Presentations, Research papers, IndiaEximBank, USGS, GII Research, EMIS, Mordor Intelligence, Deloitte Analysis

Terbium: Indian Demand Scenario and Insights

Terbium Demand Forecast: India (T)



Highlights

- Currently, research on Terbium has gained a momentum in India owing to its four short-lived radioisotopes, all of which can be considered in one or another field of nuclear medicine
- The four radioisotopes of Terbium, 149Tb, 152Tb, 155Tb, and 161Tb have been revealed as some of the most powerful tools for both therapy and diagnosis in the near future.

- India's cumulative demand potential for terbium for NdFeB magnets is expected to be 549 tons by 2030.
- The country currently has small terbium traces in its monazite supply (consisting of 0.06 percent terbium).
- Terbium could be used as an alternative to dysprosium in magnet production. However, the annual supply of terbium is far more limited than that of dysprosium, typically at a supply ratio of 1:4.
- Despite its small presence, terbium is still economically viable to extract. The main areas of mining and production of terbium are in China (in the ion-absorption clays found in the southern region), the USA, and Brazil.
- India mostly sources its dysprosium and terbium from China and Myanmar. Import duties on NdFeB magnets requiring terbium are high. Total duties on importing permanent magnets to India are 27.74%.

Source : Deloitte Analysis , USGS Mineral Commodity Summaries 2018,2019,2020, 2021 and 2022, EMIS, Mordor Intelligence, India EXIM bank, Austrade

Terbium: Opportunities and Challenges

Challenges

- Terbium could be used as an alternative to Dysprosium in magnet production. However, the annual supply of Terbium is far more limited than that of Dysprosium (at a supply ratio of 1:4)
- The domestic monazite resources have very small Terbium traces (containing 0.06 % Terbium oxide)
- Terbium is a very costly element (reached levels of USD 2000/kg in 2022) and prices have increased with ~45% CAGR in last 5 years

Opportunities

- In India, the value of mobile phone production in the country accounted for INR 2,200 billion for FY2021, which in turn is likely to enhance the demand for Terbium (for screen manufacturing application)
- Terbium is used to manufacture LCD and plasma screens, missile guidance systems, permanent magnets, solid-state electronics, and sonar systems. PLI in electronics, IT hardware, and defense corridors provides opportunity for domestic Terbium value chain development.
- Terbium usage in permanent magnets manufacturing has increased from 11% in 2010 to 22% in 2020. This provides additional growth opportunity for Terbium in magnet segment

Other REEs: Yttrium and Scandium

Key Questions Answered:

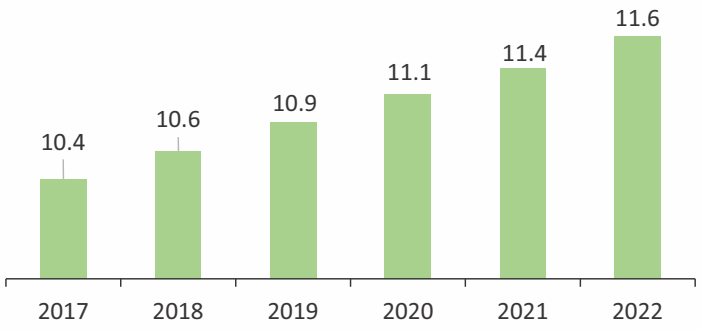
- *What is the global production of yttrium and scandium?*
- *What is the price trend of yttrium oxide and scandium oxide?*
- *What are the major applications of yttrium and scandium globally?*
- *What is the importance of yttrium and scandium in the Indian economy? What does the future outlook look like, and what are the challenges?*
- *What does the demand scenario of yttrium and scandium look like in India?*

Yttrium and Scandium: Production and Price Trends

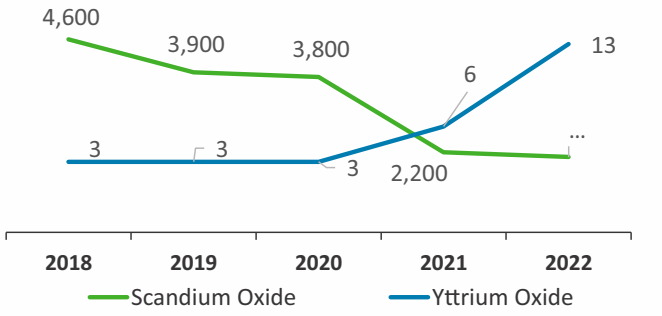
39 89 Y Yttrium

21 45 Sc Scandium

Global Yttrium & Scandium (metal) Production (in kT)



(Price Trends - USD/kg)



Note: REEs are typically traded in terms of their metal oxide equivalent content

Key Insights

Yttrium

- It is a rare-earth metal with a highly crystalline iron-gray crystal structure. It is the 28th most abundant element within the Earth's crust
- China, Russia, India, Malaysia, and Australia are the top Yttrium producers
- Substitutes for Yttrium are available for some applications but generally are much less effective. In most uses, especially in electronics, lasers, and phosphors, Yttrium is generally not subject to direct substitution by other elements
- Large resources of Yttrium in monazite and xenotime are available worldwide in placer deposits, carbonatites, uranium ores, and weathered clay deposits (ion-adsorption ore)

Scandium

- The top producers were China, the Philippines, and Russia. Scandium oxide prices in the United States have declined marginally compared to those in 2019, this is due to its growing production and availability
- The global supply and consumption of Scandium oxide was estimated to be about 20 to 30 tons per year with a global capacity estimate of 80 tons per year

Source : Deloitte Analysis , USGS Mineral Commodity Summaries 2018,2019,2020, 2021 and 2022, Mordor Intelligence

Yttrium: End-use Sectors and Applications

	Yttrium is used to make **microwave filters** for radar and as a catalyst in ethene polymerization
	Yttrium is also used to produce **phosphors,** which are used in **cell phones, larger display screens,** and general lighting; however, in the 1960s and 1970s, Yttrium in red phosphors in color television tubes led to widespread adoption. Fluorescent tubes (both linear and compact) consume far more Yttrium per watt than LED bulbs.
	Yttrium is used to make ferrites for high frequencies and to stabilize zirconia in **oxygen sensors** for automotive fuel control.
	Yttrium-aluminum-garnet (YAG) is a common medium for **solid-state lasers.** When doped with erbium, YAG lasers produce wavelengths of focused light useful for **oral surgery and dentistry.** Yttrium-aluminum garnet (YAG) is used in metal-cutting lasers. However, The radioactive isotope Yttrium-90 has medical use. It can be used to treat some tumors, such as liver cancer.
	It is also used for making superconductors, resonators in frequency meters, and magnetic recording.
	Yttrium oxide is added to the glass used to produce **camera lenses** to make them heat and stress resistant
	The radioactive isotope Yttrium-90 has medical use. Yttrium-90 internal **radiation therapy** is a treatment for some **inoperable cancers.** Doctors deliver this radiation by using special glass or resin beads, known as microspheres, that have Yttrium-90 embedded in them
	Yttrium-stabilized zirconia **ceramic** containing the rare earth oxide Y2O3 exhibits good thermal and chemical stability at high temperatures . As a good oxygen-ion conductor, this ceramic plays an important role in ion**-conductive ceramics.**

Source : Deloitte Analysis , USGS Mineral Commodity Summaries 2018,2019,2020, 2021 and 2022, EMIS, Mordor Intelligence, Journal of Brazilian Chemical Society

Scandium: End-use Sectors and Applications

	Scandium–aluminum alloy has many applications in **high-tech and new technology sectors,** such as **shipbuilding, rocket missiles,** and **nuclear energy.** Based on the existing aluminum alloy, a series of new-generation high-performance aluminum alloy materials, such as ultrahigh-strength and high-toughness aluminum alloy and high-strength corrosion-resistant aluminum alloy, should be produced by adding a small amount of scandium.
	Several scandium-containing aluminum alloys are used in **aerospace applications.** Aircraft manufacturing companies are mainly interested in scandium-alloyed aluminum materials as their application **can help reduce aircraft weight by approximately** 15%–20%. It is also employed in the aircraft industry to make welded gas tanks, dashboard panel and compartment structures, and huge stamped and welded structures. When added to aluminum, scandium **affords the largest increase in tensile strength per atomic % of any other alloying element.** Scandium is not yet recognized for large commercial applications and has a considerably low global annual demand, mainly owing to its low concentration and difficulties separating it from the ore, which drives up costs and makes its commercial use difficult. Consequently, despite increased demand from the automobile industry, Al–Sc master alloys remain highly expensive for most commercial uses.
	Solid-oxide fuel cells (SOFCs) are a major application of scandium. These fuel cells can produce energy cheaply and efficiently through continuous heat-producing internal reactions. SOFCs can be powered with cheap natural gas, and overall electricity from these cells costs only cents per kilowatt hour.
	Scandium is used mainly in aluminum alloys for sporting goods. Aluminum–scandium alloys are used in sports equipment such as bicycle frames, fishing rods, golf iron shafts, and baseball bats.
	Scandium, in minor amounts, is used in semiconductors and special lighting, including halogen bulbs. It is useful for creating high-intensity lights that mimic natural light because it has a broad emission spectrum close to the sunlight. This technology is used in camera lighting and in movie and television studio lights. Scandium oxide (scandia) is used to make high-intensity “stadium” lights.

Source : Deloitte Analysis , USGS Mineral Commodity Summaries 2018,2019,2020, 2021 and 2022, EMIS, Mordor Intelligence, Journal of Brazilian Chemical Society

Yttrium and Scandium: Importance in the Indian Economy

Application	Industry	Outlook	Remarks
Host material	Biotechnology		Yttrium oxide (Y2O3) nanoparticle is widely used as a host material for various rare earth dopants, biological imaging, and photodynamic therapies. Y2O3 has also been used in the optoelectronic fields for cancer therapy, biosensor, and bioimaging. Y2O3 nanoparticles have attractive antibacterial and antioxidant properties.
Defence equipment	Defence		Yttrium is increasingly used in defense radar for surveillance and navigational aids. It is also used in laser targeting, air-based lasers, FCS vehicle with laser weapons, sonar transducers, and satellite components. They are also used in fin actuators in missile guidance and control systems; disk drive motors installed in aircraft and tanks.
Energy harvesting	Clean energy		Scandium nitride can emit, detect, and modulate infrared light, making it useful for solar and thermal energy harvesting and optical communication devices.
Aerospace components, Sporting goods	Aerospace, Sports		Scandium is used mainly in aluminum alloys for sporting goods; consumption is in the order of 5,000 kg/year, and it is typically employed in aluminum alloys as a grain refiner.
Lighting	Electronic		Small amounts of scandium are also used in high-intensity lights and fuel cells.
Solar cells	Clean energy		Yttrium enhances the efficiency of the zinc oxide (ZnO) materials that further enhance the conductivity of solar cells.
Cancer treatment	Biotechnology		Yttrium is used to treat cancer by targeting cancer cells, and yttrium-90 is used as radiation therapy to provide antibodies to arteries.

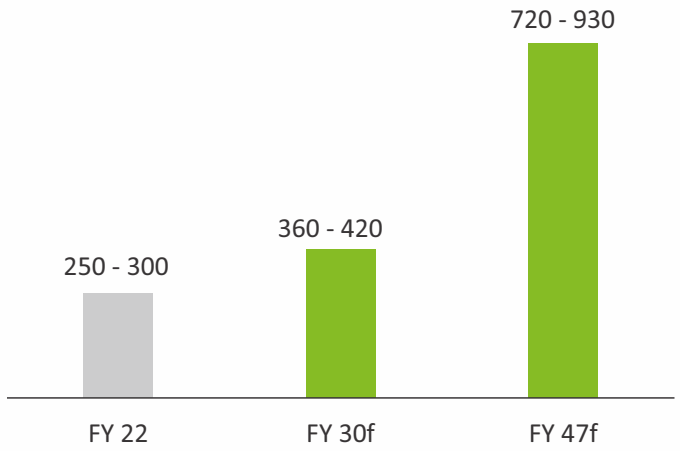
Emerging Markets

Growth Outlook Very High High Moderate

Source: Mordor Intelligence, Center for Airpower Studies

Yttrium & Scandium: Indian Demand Scenario

Yttrium & Scandium Demand Forecast: India (T)



Case Study

- Indian hospitals are procuring the latest technology for liver cancer treatment, and this technology involves innovative procedures that utilize special gadgets and microcatheters to access the tumor in order to deliver precise radiotherapy using yttrium-90.
- In July 2022, researchers from an autonomous research institute discovered a novel material called single-crystalline scandium nitride (ScN) that can emit, detect, and modulate infrared light and convert infrared light to renewable energy.
- A leading aerospace player in India plans to invest 5 billion INR over the next 3.5 years in a new mega manufacturing unit outside Mumbai. Similar facilities will eventually be making components for commercial aerospace. The company plans to make modules for civilian aircraft in the future, increasing the demand for scandium.

- Yttrium and scandium demand in India is estimated to be 250–300 tons in FY-22, and it is forecasted to increase at a CAGR of 4%–5% to reach a cumulative demand potential of 360–420 tons by FY-30.
- Yttrium oxide, along with the CaO, MgO, and BN, is considered an aspirant material for insulator coating owing to its considerably high temperature stability of up to 2,200°C.
- Yttrium oxide is used in many applications in the refractory field as it provides stability at high temperatures. With the increasing demand for iron and steel, power generation, and refining capacities, along with the increased consumption of various chemicals, the demand for various refractory materials is likely to grow in the country during the forecasted period.

Source : Deloitte Analysis , USGS Mineral Commodity Summaries 2018,2019,2020, 2021 and 2022, EMIS, Mordor Intelligence, IREL, IBM minerals yearbook

Yttrium and Scandium: Opportunities and Challenges

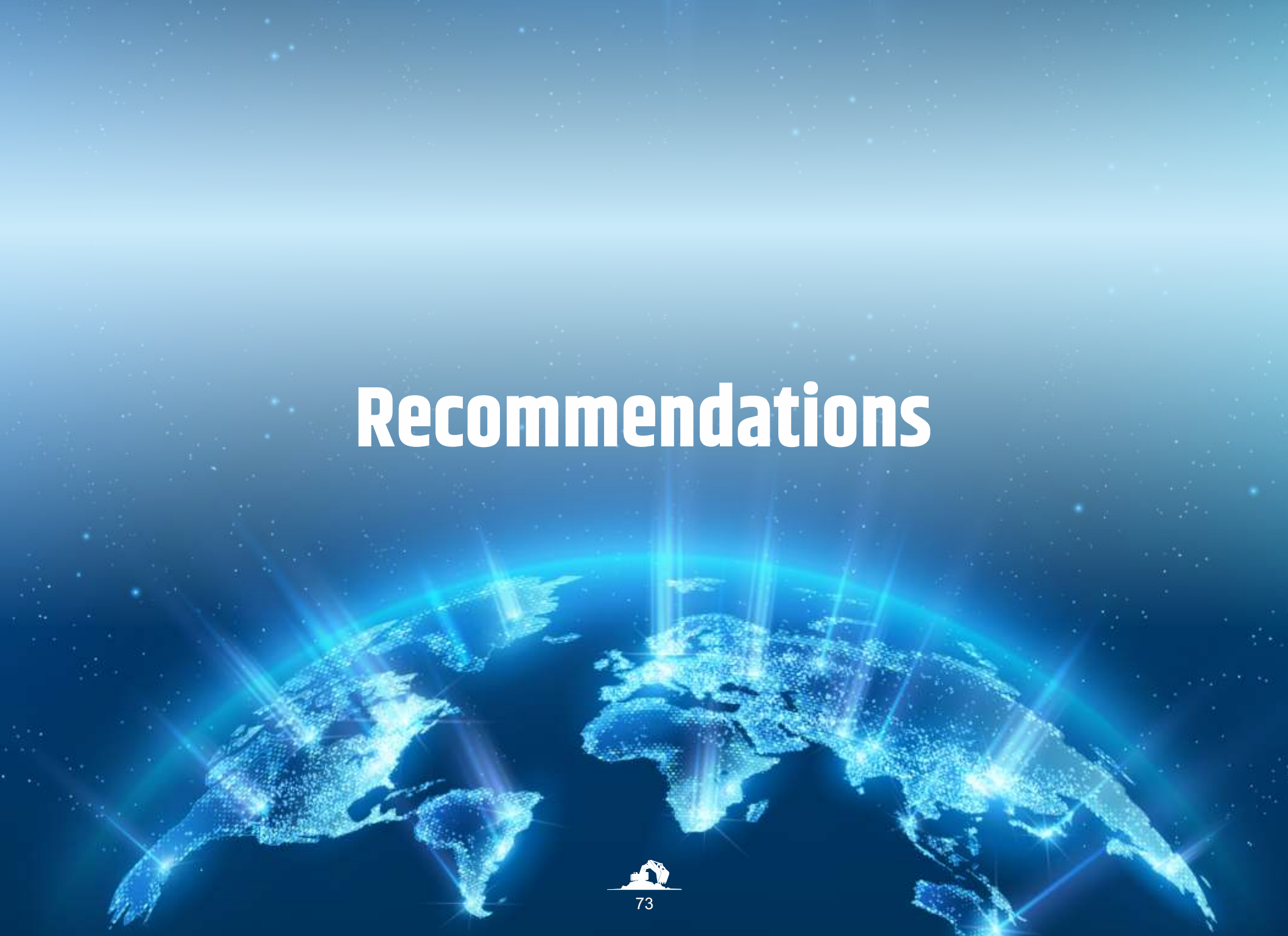
Challenges

- Although Yttrium is comparatively less costly, the prices of scandium are considerably high (scandium oxide price was 2,100 USD/kg in FY-2022).
- Yttrium and scandium have high price volatility (scandium oxide was in the range of 4,600 USD/kg to 2,100 USD/kg from FY-18 to FY-22; yttrium oxide was in the range of 3–13 USD/kg from FY-18 to FY-22).
- Low Yttrium oxide concentration (~0.45%) and almost NIL concentration of Scandium in Monazite resources

Opportunities

- India's aviation industry is expected to witness INR 350 billion (USD 4.99 billion) investment in the next four years; thereby, it is likely to create potential opportunity for aluminum–scandium alloys in the aerospace manufacturing sector.
- R&D is being is conducted to develop a cost-effective process for the recovery of one of the most strategic REEs: scandium oxide from bauxite residues.
- Electronic screens are another area where Yttrium plays a crucial role, apart from being used in catalysts, ceramics, lasers, metallurgy, and domestic electronic manufacturing initiatives (PLI, electronics manufacturing clusters, etc.).

Recommendations



REE: Recommendations (1/3)

01

Increase Focus on Exploration

While India's current exploration status is less than 10% of obvious geological potential, REE-related exploration has been limited.

- **Incentives:** Provide right of first refusal to the exploration agency involved in REE exploration to promote private investment
- Dedicated **REE exploration budget**
- **NMET Utilization:** Set REE specific (or allied minerals) targets for annual exploration expenditure
- Investment in Exploration **Technology, Equipment**
- Exploration of **other REE containing minerals**

Agents of Change



02

Exploration beyond land

Minerals eroded from the land may be concentrated in placer deposits along the coast and even further. Recent studies suggest a significant presence of REEs in oceanic beds.

- Dedicated program for **sea-bed mineral exploration**
- **Separate funds** for REE-focused exploration amongst sea-bed exploration
- Sea exploration strategy to be holistic from sustainability and ecological conservation point of view

Agents of Change



Regulatory Bodies

Govt (via Ministries, PSUs)

Private Enterprises

Research Institutions

REE: Recommendations (2/3)

03 Domestic R&D promotion

India must learn from global peers such as China, the USA, and Australia, who have been promoting R&D for REE ecosystem development to evolve as a market leader.

- Incentives: **Incentives** to private enterprises(similar to PLI); **Prolonged Patent** rights; **Milestone** based incentive (lab success, commercial viability)
- Mandate: Establish **dedicated REE research institute** with specific **mandate to support entire REE value chain** – from exploration technology, processing, till market making and downstream ecosystem integration
- R&D Focus areas: REE **exploration technology; Refining technology;** Extraction from secondary sources (like Red mud from bauxite processing, fly ash etc.) REE substitution (with relatively abundant materials); **Recycling** and material recovery from End Products/e-wastes

Agents of Change

- Regulatory Bodies
- Govt (via Ministries, PSUs)

04 Dedicated policy framework for REEs

A conducive policy which can make more room for REEs within Atomic Mineral definition, is need of the hour, along with dedicated financial assistance

- Review of existing concession regulations to promote private participation: Granting **lease to private players** in partnership with govt controlled entity
- **Dedicated Financing Institution/Financing program for REE investments:** Lower interest rate; extended moratorium and payback period; REE investment bonds; Foreign currency loans for overseas asset investment
- Declare Rare Earth Minerals as a strategic sector to promote investment in REEs in India.

Agents of Change

- Private Enterprises
- Research Institutions

REE: Recommendations (3/3)

05 Collaboration

Potential to explore diplomatic associations in other countries for collaboration in joint exploration activities, thereby securing REE assets within the country and abroad.

- **Raw material sourcing:** Investment in ongoing/upcoming REE projects in countries such as Australia, USA, Vietnam, and Russia.
- **Exploration technology/equipment sourcing**
- **Processing Technology transfer:** Countries like France, Japan
- **Industry-Academia partnership:** Tie up with industries and academic institutions for REE specific courses and R&D

Agents of Change

06 Groundwork to make India a REE hub

Leading nations have used forward integration to not only produce RE concentrates but intermediate (e.g. magnets) & end products as well (e.g. batteries, motors). This initiative is pertinent to achieve goal of Atmanirbhar Bharat

- Development of **REE industry ecosystem –** Mining till Intermediate and Finished goods production, Marketing and Financing centers
- Development of **downstream industries (like Ceramics, Glass, Metallurgy, Automobile, Electronics, Renewable Energy etc.)**
- **Dedicated SEZs** for REE in resource rich states like AP, Odisha and upcoming regions like Gujarat

Agents of Change

Regulatory Bodies | Govt (via Ministries, PSUs) | Private Enterprises | Research Institutions

Imagining India as REE hub

	Critical Success Factors	Description
	**Major manufacturing inputs**	• Major manufacturing inputs like **Chemicals** (Hydrochloric acid, Sulfuric acid, caustic soda etc.), **Energy** (Power generation facilities), **Equipment** (Crushers, Grinding Mills, Magnetic separators, etc.), **Water** (1250 – 1300 kl/tonne REO required for washing, leaching, and in extraction of rare earth concentrates), and **Labor (Process specific** Engineers, technicians and Operators) is required.
	**Infrastructure**	• Development and access to key infrastructure is necessary for the hub set-up including **land area (≈ 2 sq. km.), an efficient transportation network, storage facilities** (for Chemicals and other materials), **R&D centers,** etc.
	**Raw material Availability**	• Lanthanum, Cerium, Neodymium, Praseodymium and Samarium are available in India, but HREEs such as **Dysprosium, Terbium, and Europium,** are **not available** in Indian deposits in extractable quantities and is **primarily dependent on China. Exploration opportunities** are to be looked upon for these minerals. • Rare earth elements associated with carbonatite–alkaline complexes in **Western Rajasthan** has been discovered.
	**Investment promotion and facilitation**	• Need for dedicated resources responsible for **Marketing, Promotion, Relationship building, Policy advocacy,** and **Investment readiness** for rare earth value chain in India.
	**Policy**	• Need to develop **policies** and **regulations** that supports the REE industry in India, including **incentives for investment and value addition,** and R&D in the sector.
	**Skill development**	• The development of an REE hub would require a **skilled workforce trained** in the relevant areas such as **mining, processing and refining. Skill development programs** and **training initiatives** would be necessary to develop the required workforce.

Source : Deloitte Analysis, News Articles

Imagining India as an REE Hub: Key Actionable (1/2)

	Actionable	Description
	**Conduct a Feasibility Study**	• **Demand** for REEs in India should be analyzed, and the **availability** of these elements should be assessed. • Factors such as **infrastructure, logistics, and government policies** should be considered.
	**Identify Key Stakeholders**	• Identify and engage with key stakeholders such as **regulatory bodies, government agencies, industry associations, and potential customers (ceramics, glass, metallurgy, automobile, electronics, renewable energy etc.).** This will help to build support for the project and ensure that it meets the needs of all stakeholders.
	**Establish Partnerships**	• Establish partnerships with **mining companies** or **suppliers of raw materials in other countries like Australia, Japan, the US, Canada etc.** These partnerships can help to secure a **steady supply of raw materials** and ensure that the hub can operate efficiently.
	**Invest in Infrastructure**	• Invest in the necessary **infrastructure**, such as **processing facilities, storage facilities, and transportation networks**. This will require a substantial amount of capital investment; however, ensuring that the hub can operate effectively and efficiently will be crucial.

Source : Deloitte Analysis, News Articles

Imagining India as an REE Hub: Key Actionable (2/2)

	Actionable	Description
	**Develop a Skilled Workforce**	• Develop a skilled workforce with **expertise** in **mining**, processing, and logistics. This may require training programs or partnerships with educational institutions to ensure the necessary skills are available. **REE-specific** courses should also be included in the curriculum of the educational institutions.
	**Focus on Ssustainability**	• REEs are often associated with environmental issues, such as mining waste and pollution. To ensure the long-term viability of the hub, it is important to focus on sustainability by **implementing environment-friendly** practices (e.g., renewable energy sourcing wherever possible, and highly mechanized mining, water recycling/reuse) and **investing in clean technologies** (e.g., REE separation technologies with higher separation factors).
	**Encourage R&D**	• Encourage research and development (R&D) activities related to REEs. This could involve **funding R&D projects or establishing partnerships with educational, research institutions, and private companies** to advance knowledge in this field.
	**Provide Incentives for Investors**	• The government of India can **incentivize investors** to set up **REE-related businesses** in the hub. This could include **tax breaks, subsidies,** and other forms of **financial support.** Furthermore, it can leverage the **production linked incentive (PLI)** scheme to encourage domestic production of rare earths and attract investors to the hub.

Source : Deloitte Analysis, News Articles

Battery Minerals



Battery Minerals: Setting the Context

In India's quest for self-reliance and energy security is critical. The shift to nonfossil fuel–based energy generation will need energy storage solutions for automobiles and renewable power generation: EV batteries and ESS.



Lithium

Lithium is a key ingredient for the anode material in modern batteries. Lithium's application in batteries has grown from ~30-35% in 2014 to **~80% in 2023.**



Cobalt

Cobalt is used in superalloys, hard metals, and catalysts. Cobalt is another key metal for anode application in batteries. Cobalt application in batteries was ~40% in 2011. With the advent of EVs, it has grown to **~65%.**



Nickel

Battery application is the new and emerging segment for Nickel application. Nickel sulfate is used in Li-ion, NMH (Nickel Metal Hydride), and Ni–Cd batteries. EVs and other battery applications (such as battery storage) are expected to account for **20%–25% by FY30.**

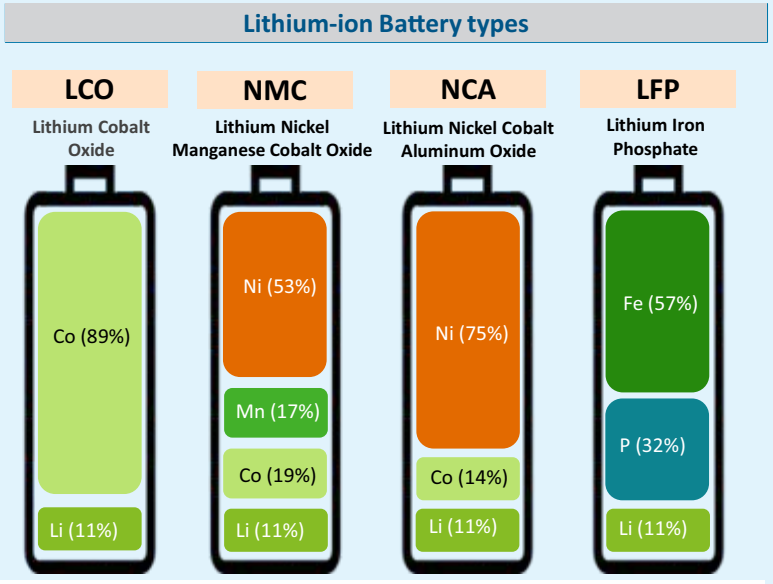


Graphite

Graphite's traditional usage has been prominent in electrodes and refractory applications; however, its usage in EV batteries is expected to grow substantially. **By FY30, 20% of the total graphite demand** is expected to be driven by its consumption in EV batteries.

Battery Minerals: Types of Batteries in EVs

Lithium-Ion batteries are the most promising alternative for EVs considering the limitations of the other options, and are expected to capture a market size of USD 70 Billion by 2025. The EV revolution and, thereby, the Li-ion batteries shape the FOUR important commodities for the future: ***Lithium, Cobalt, Nickel, and Graphite.***



LIBs have four major components: **cathode (positive electrode), anode (negative electrode), electrolyte, and separator**. The electrolyte carries lithium ions back and forth between the anode and cathode via the separator. Of the four materials, lithium, cobalt, and nickel are used in the cathode, and graphite is used in the anode.

LCO

- *High energy density*
- *Limited specific power*
- *Low thermal stability*
- *Short lifespan*

Applications: Cameras, laptops, mobile phones, and tablets

LFP

- *Enhanced Safety*
- *Good thermal stability*
- *High specific power*
- *Long cycle life*
- *Low specific energy*

Applications: Mainly stationary applications with high endurance

NMC

- *Excellent specific gravity*
- *Good overall performance*
- *High specific power*
- *Lowest self-heating rate*

Applications: E-bikes, EVs, medical devices, and industrial

NCA

- *High energy density (capacity)*
- *Long lifespan*
- *Marginal safety*
- *Reasonably good specific Power & performance*

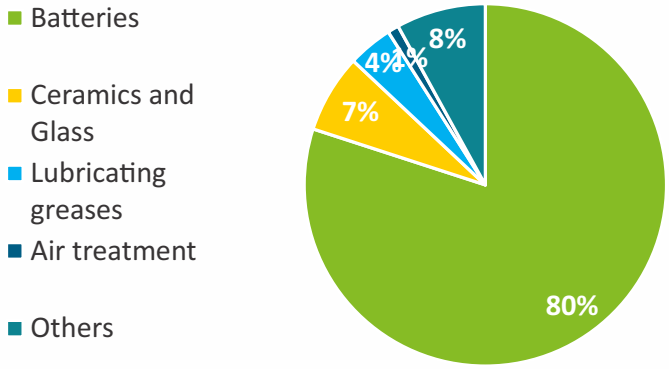
Applications: EVs and electric powertrains

Source : Blackridge

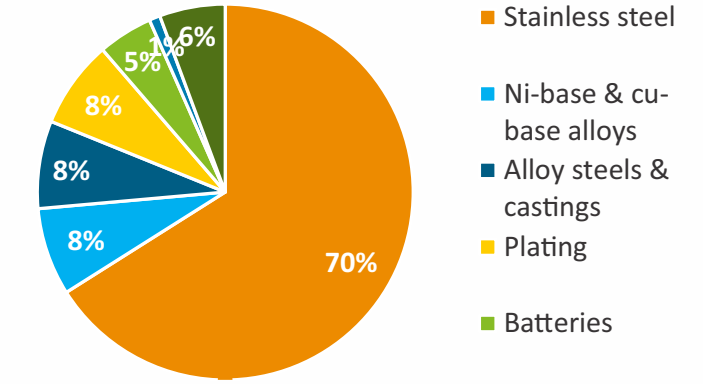
Battery Minerals: Consumption Across all End-use Sectors

Electric vehicles and energy storage technologies are the key drivers of the clean energy transition, and the four minerals, namely Lithium, Cobalt, Nickel, and Graphite, are crucial ingredients for the same.

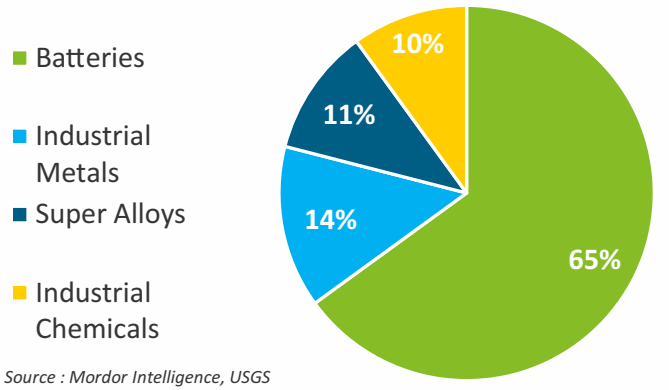
Lithium - Consumption by end-use sector



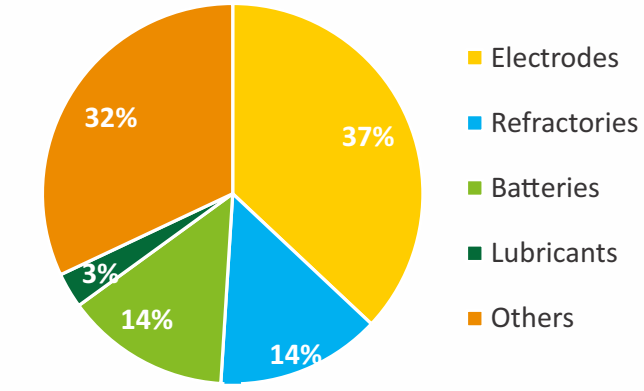
Nickel - Consumption by end-use sector



Cobalt - Consumption by end-use sector



Graphite - Consumption by end-use sector



Source : Mordor Intelligence, USGS

Lithium

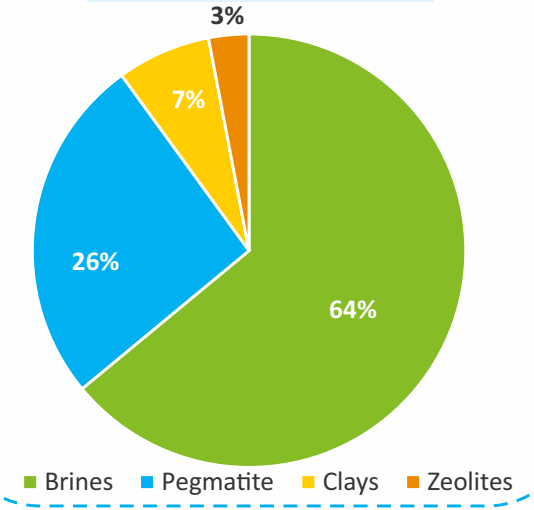
Key Questions Answered:

- *What is the global production of lithium? Where and how much are the reserves of lithium in the world?*
- *Where are the lithium reserves in India?*
- *What has been the price trend for lithium over the years?*
- *What is the global value chain for lithium?*
- *Who are the major exporters and importers of lithium?*
- *What are the major applications of lithium globally?*
- *What is the importance of lithium in the Indian Economy? What does the future outlook look like, and what are the challenges?*
- *What is the current production capacity and demand for lithium in India?*
- *What does the lithium demand scenario look like in India in 2030 and 2047?*

Lithium: Geological Occurrence

Lithium is the lightest of all metals and has been listed as a critical or near-critical element in various studies based largely on its importance in green technologies. Lithium resources are estimated to be more than 39 million metric tons worldwide.

Lithium deposit types



BRINES

Type: Closed basin brines have a maximum share of ~58%; oilfield and geothermal brines represent ~3%

Compounds obtained: Lithium carbonate, lithium chloride and lithium hydroxide

Main producers: Chile, Argentina, China, and the United States

PEGMATITE

Type: Intrusive igneous rock

Compounds obtained: Lithium minerals like spodumene, petalite, and lepidolite

Main producers: Australia, Brazil, China, Portugal, and Zimbabwe

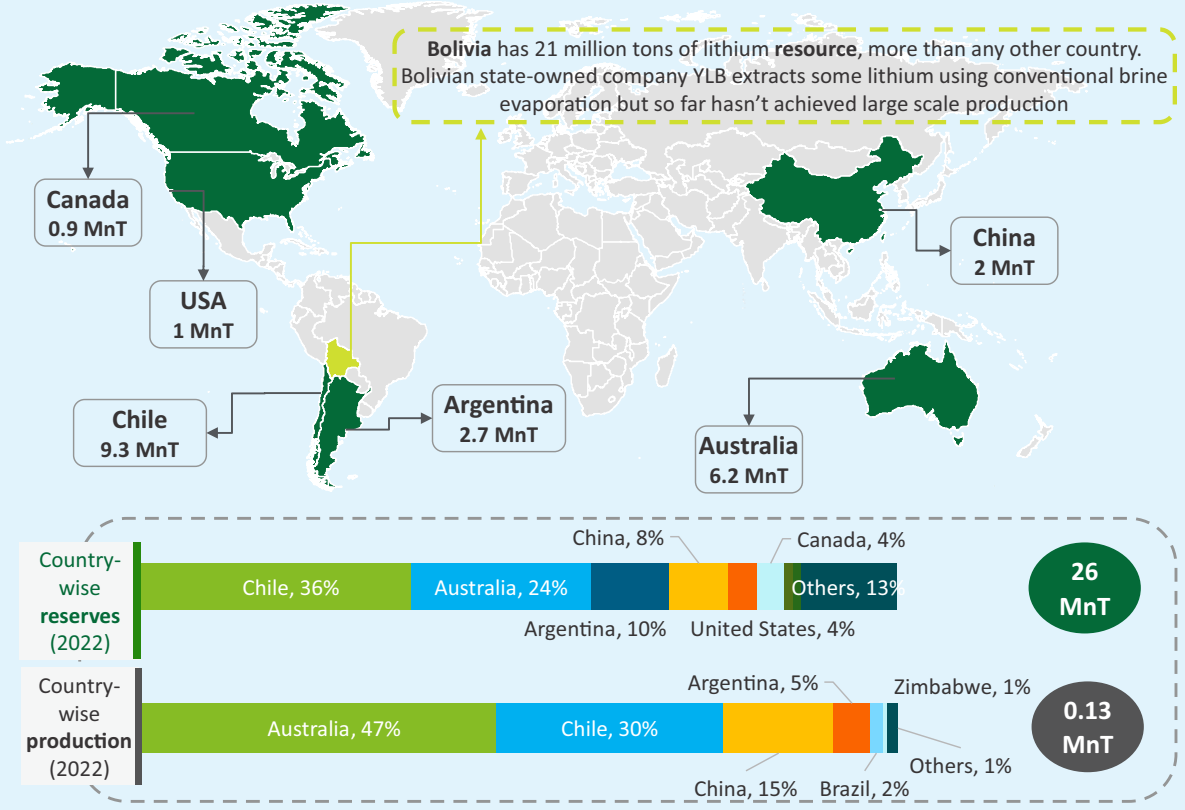
OTHERS

- *The most important lithium-clay resource so far discovered is the Kings Valley hectorite deposit, an extinct volcanic center in northern Nevada.*
- *The only documented lithium-zeolite deposit is from a Neogene basin system in the Balkan region of Eastern Europe*
- *Lithium is traded in three forms: mineral concentrates, mineral compounds and refined metal. Lithium metal is obtained by electrolysis from lithium chloride*

Source: USGS report - Critical Mineral Resources of the United States—Economic and Environmental Geology and Prospects for Future Supply

Lithium: Geographical Occurrence

Global Lithium reserves (metal content) stood at ~26 MnT by CY22. Chile holds ~36% of the global reserves, followed by Australia with 24% of the global reserves.



Source: USGS Mineral Commodities Summary 2023, Deloitte Analysis

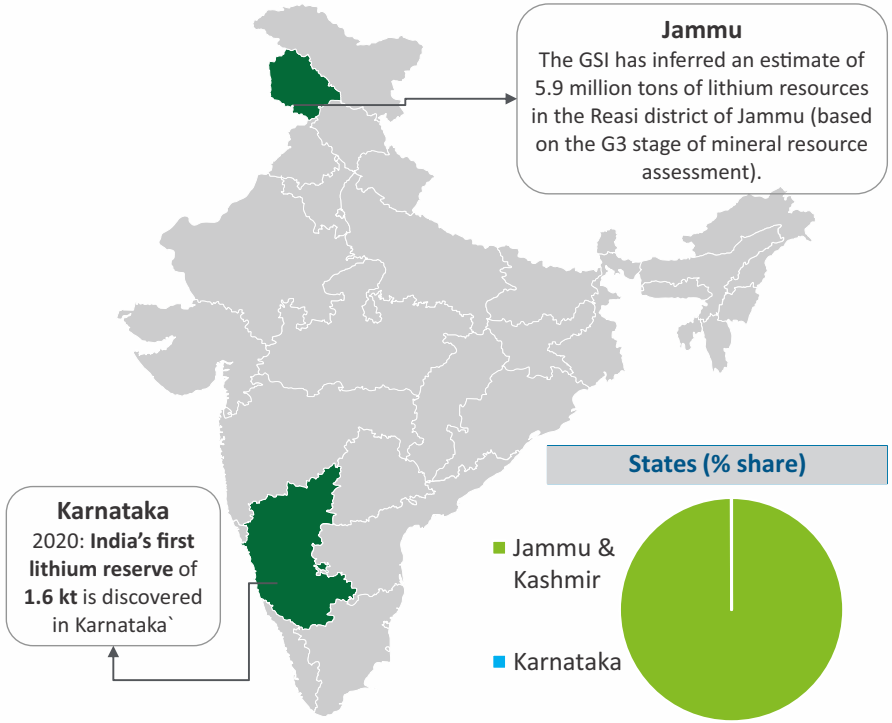
Key Insights

- Although Chile has the highest lithium reserve, its share in global production as of CY2022 was 30%.
- The majority of the lithium-producing sites in **Australia** are of **spodumene**, which is mined like any other mineral, but in case of **Chile**, it is brine salars that take considerable time to process, thus reducing the production capacity of Chile.
- The US Department of Energy funded 1.6 billion USD to support new commercial-scale domestic facilities to extract and process lithium, manufacture battery components, and recycle batteries.
- **Chinese firms have partnered with Bolivia's YLB** to build a 1 billion USD project to exploit untapped lithium resources in Bolivia.

Lithium: Occurrence in India

Owing to the lack of a lithium-processing ecosystem, India currently imports a substantial share of its lithium-ion batteries and battery materials.

Major states with lithium resources



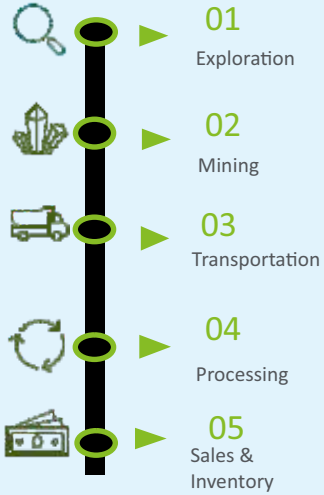
Source: Austrade, Deloitte Analysis

Key Insights

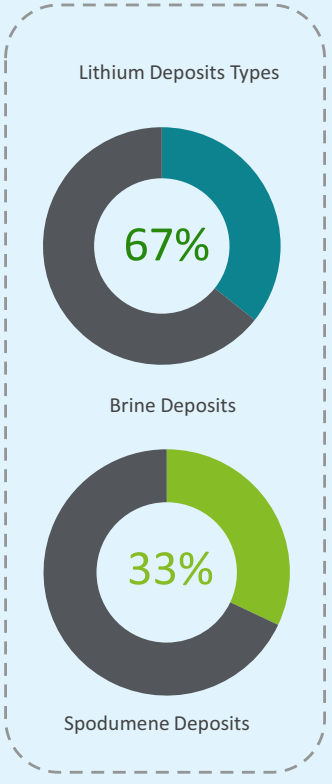
- The **current G3 exploration** in Jammu and Kashmir is preliminary in nature and does not indicate whether metal extraction is possible
- The country took two decades to move from the **G4 (reconnaissance) stage,** where the mapping of resources takes place, to the **G3 (prospecting) stage,** where quantities are inferred, based on interpretation of geological, geophysical and geochemical results and a deposit is identified which will be the target for further exploration.
- In the next stage, **G2 (general exploration),** more studies are done to estimate the minerals' shape, size and grade. And finally, the **G1 stage (detailed exploration)** is where characteristics of the deposit are established with a high degree of accuracy. A decision whether to conduct a feasibility study next, can be made from the information provided by the G1 stage.
- Preliminary surveys on surface and limited subsurface by AMD, have shown presence of **Lithium resources** of **1.6 kT (inferred category)** in the pegmatites of Marlagalla – Allapatna area, Mandya district, Karnataka. The significance and quantity of lithium resources may be established only after the completion of exploration in the entire area. Subsequently, plan for commercial exploitation of the lithium deposits can commence after the **technical, social and economic feasibility studies** in the area.

Global Value Chain for Lithium

Spodumene Deposits



- The processing route for hard-rock lithium ores follows a more conventional mining and processing approach.
- Ore is mined via conventional drill and blast methods and excavated. The ore is crushed down to below 6mm.
- Spodumene is liberated from gangue minerals via dense media separation



Brine Deposits



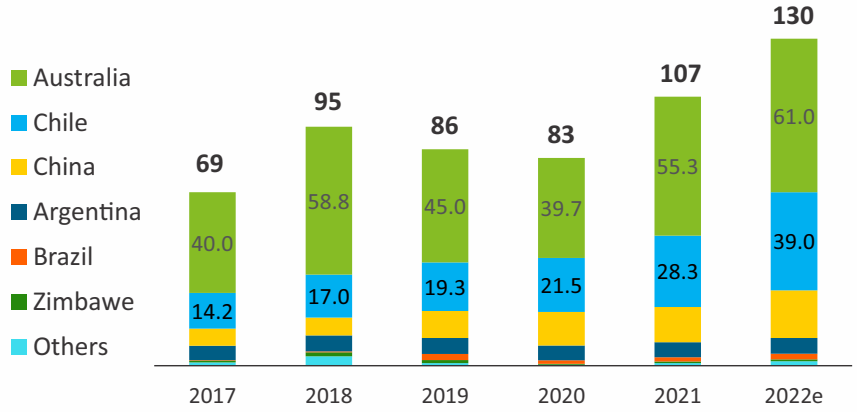
- Brine-based operations extract lithium brine from a salar (salt-lake) deposit via a series of pumping wells.
- The brine is stored in a large pond system over a 9–12 month period where lime is added (to precipitate impurities); evaporation occurs, and the brine is concentrated for processing.

Source : Mordor Intelligence

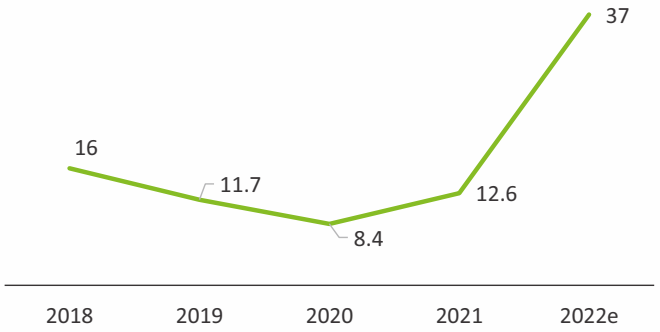
Lithium: Key Global Producers and Trends

Australia is the largest lithium producer, with a 47% market share, followed by Chile, with a 30% market share.

Country-wise Lithium (metal content) production trend (kT)



Price of lithium carbonate - battery grade (USD per kg)



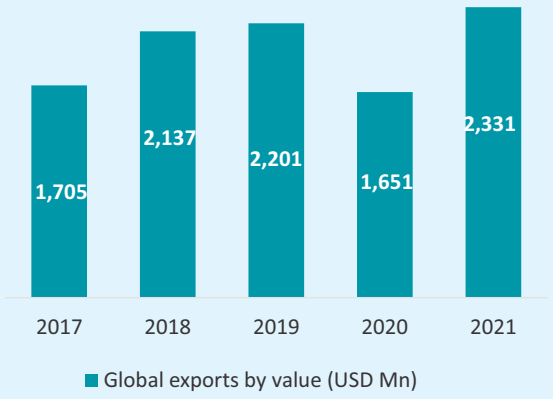
Key Insights

- The drop in production between 2018 and 2019 was because the **production outpaced the EV boom** and **mineral conversion in China,** resulting in **higher inventories** of Lithium and a **drop in price** as well, during the period
- Worldwide lithium production in 2022 **increased by 21% to approximately 130,000 tons** from 107,000 tons in 2021 in response to strong demand from the lithium-ion battery market and increased prices of lithium*
- Global **consumption** of lithium in 2022 was estimated to be 134,000 tons, a **41% increase** from 95,000 tons in 2021.
- Spot lithium carbonate prices in China (cost, insurance, and freight [c.i.f.]) increased from approximately 35,000 USD per ton in January to about 67,000 USD per ton in November. For fixed contracts, the annual average US lithium carbonate price was 37,000 USD per ton in 2022, almost three times higher than that in 2021.

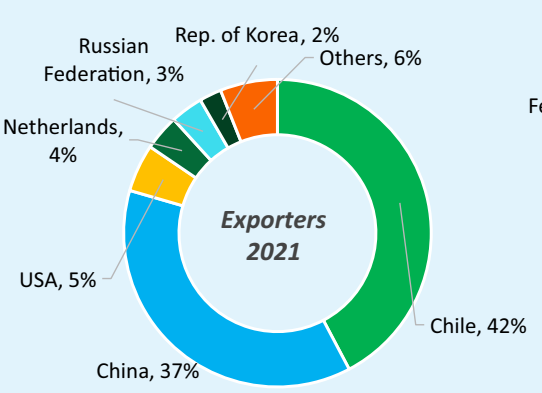
**These numbers are excluding United States as per the USGS report*
Note: All mentioned year are in CY unless specified
Source: USGS Mineral Commodity Summaries 2023, Deloitte Analysis

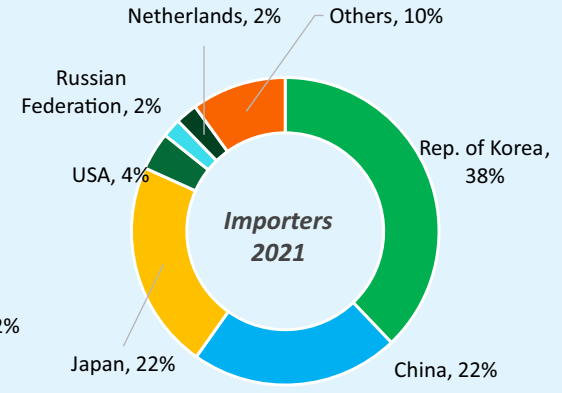
Lithium: International trade

Global Lithium Trade



Major Exporters and Importers Of Lithium Oxide, Hydroxide, and Carbonate





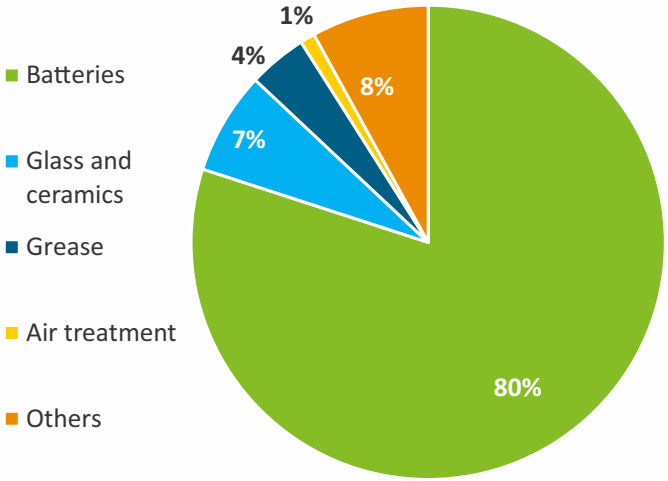
- Lithium carbonate and lithium oxide and hydroxide constitute 52% and 48% (by value), respectively, of the **total exports of 2,331 Mn USD** in **2021**.
- India imported lithium worth ~25.2 Mn USD in 2021, 66% of which was lithium oxide and hydroxide and the rest was lithium carbonate.
- Strategic alliances and joint ventures among technology and exploration companies continued to be established to ensure a reliable, diversified lithium supply for battery suppliers and vehicle manufacturers.
- The lithium contents in lithium oxide, lithium hydroxide, and lithium carbonate are 46.5%, 29%, 19%, respectively.
- **Australia is the world's biggest exporter of lithium in spodumene concentrate; however, as the global demand grows, several Australian lithium mines are commencing production of lithium hydroxide.**

Note: HS code taken for the data are: 283691 for lithium carbonate & 282520 for lithium oxide and hydroxide

Source: USGS Mineral Commodity Summaries 2023, Comtrade, Austrade

Lithium: End-use Sectors and Applications

Lithium Consumption across Key Sectors



Batteries

- Li-ion batteries are available in all shapes and sizes. And that renders them to be the perfect option for power needs irrespective of the size of the system. Some of the most common applications of lithium-ion batteries are:
  - **Lithium cobalt oxide** is manufactured from lithium carbonate and cobalt and is also known as lithium cobaltate or lithium-ion cobalt batteries. These batteries are used in cell phones, laptops, and electronic cameras because of their high specific energy.
  - **Lithium manganese oxide** is frequently found in medical equipment and devices, but it can also be used in power tools, electric motorcycles, laptops, and electric vehicles.
  - **Lithium iron phosphate** is used in electric bikes.
  - **Lithium nickel manganese cobalt oxide and lithium nickel cobalt aluminum oxide** are used in electric vehicles, energy cells, or power cells.
  - **Lithium titanate** has the potential to be used in electric buses for public transport, aerospace applications, and wind and solar energy storage.

Glass and ceramics

- *Special glass and ceramics where it is used to control thermal expansion*

Grease

- *Lubricant in wheel bearings*
- *Chassis application*
- *Displaces sodium and calcium greases*

Air treatment

- *Industrial humidity control*
- *Drying systems*

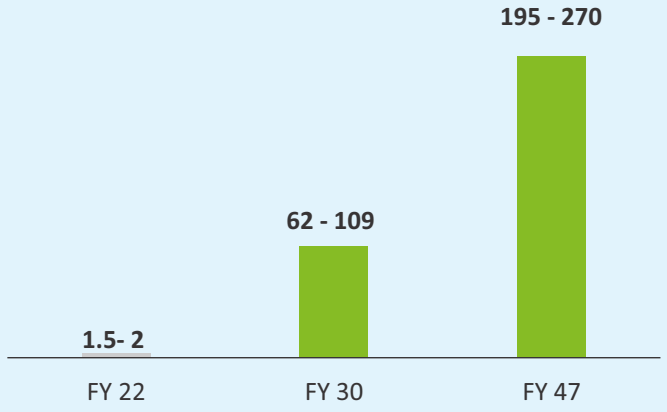
Others

- Iron casting
- *Aircraft components*
- *Bipolar disorder treatment*

Source : Deloitte Analysis , Mordor Intelligence, IndiaEximBank

Lithium: Indian demand scenario

Lithium demand forecast: India (kT)



Highlights

- **Telecomm Service providers** plan to use Li-ion batteries at communication tower sites to meet power requirements.
- **A leading Indian chemical company** has a plant in Dholera, Gujarat, and plans to manufacture up to 10 GWh per year of lithium-ion battery components.
- A JV between an **auto component giant and OEM,** is setting up a plant to produce 1 GWh batteries for an OEM's plant in Gujarat.
- **A leading power company in India** has announced a plan for four large-scale production bases to manufacture all components of their new energy ecosystem, including batteries for energy storage .

- India's lithium-ion battery manufacturing ecosystem is emerging due to electric mobility and grid storage requirements. Manufacturers may invest in establishing lithium refining, cell manufacturing and battery assembly units in India. The primary minerals used in lithium-ion batteries are cobalt, lithium, manganese, nickel, and graphite
- Lithium is classified as an atomic mineral under the first schedule of MMDR, which limits the scope of FDI in exploration, mining, and processing for lithium in India.
- Lithium exploration has gathered momentum recently - During the last five years, GSI carried out 20 projects on Lithium and associated elements in Andhra Pradesh, Arunachal Pradesh, Bihar, Chhattisgarh, Himachal Pradesh, Jharkhand, Jammu & Kashmir, Madhya Pradesh, Meghalaya, and Rajasthan.

Source : Deloitte Analysis , USGS Mineral Commodity Summaries 2018,2019,2020, 2021 and 2022, EMIS, Mordor Intelligence, IndiaEximBank, The Future of strategic natural resources, MIT

Lithium: Challenges and Opportunities

Challenges

- A mismatch exists between domestic lithium demand and supply capability. The demand for lithium is rising rapidly with EV penetration; however, mining is a time-intensive activity expected to take 5 to 8 years to operationalize the mine (and processing unit) post-exploration.
- Lithium prices could triple by the end of this decade as the supply of lithium lags the demand growth spurred by the rise of EVs
- India currently lacks infrastructure, technological expertise, experience in processing and refining mined lithium
- Lithium-Ion batteries can be a safety hazard because they contain flammable electrolytes. Damage or incorrect charging of these batteries can cause fires.

Opportunities

- India's EV market is expected to grow by 30%–35% in the coming decade, which will be a key demand driver for lithium.
- Solar and wind resources will drive India's objective of achieving 500-GW non-fossil fuel–based installed capacity; however, as these sources cannot ensure a consistent power supply, energy storage systems (ESS) will be required. This segment is also expected to grow by 20%–25% by 2030. ESS will further increase the demand for lithium.
- The rising use of portable electronics such as cell phones, portable chargers, watch and clock batteries, and cameras would also increase the demand for lithium.
- Indian Government's PLI scheme for Advanced Chemistry Cell Battery incentivizes the domestic players to develop a domestic battery ecosystem.

Cobalt

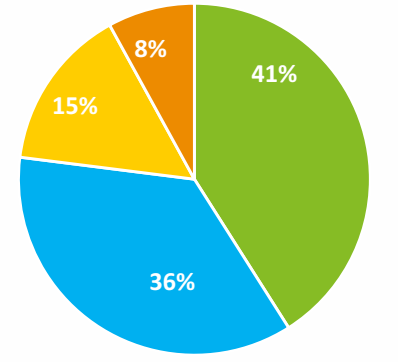
Key Questions Answered:

- *What is the global production of cobalt? Where and how much are the reserves of cobalt in the world?*
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- *What is the current production capacity and demand for cobalt in India?*
- *What does cobalt's demand scenario look like in India in 2030 and 2047?*

Cobalt: Geological Occurrence

Nearly all cobalt is mined as a byproduct of other, more abundant metals, such as nickel or copper, which means that the production is driven primarily by the markets for the principal metals, not by the need for cobalt.

Cobalt deposit types



Other terrestrial

Types of deposits that, on a global scale, have produced relatively minor amounts of cobalt include:

(a) black-shale-hosted Ni-Cu-Zn-Co
(b) Fe-Cu-Co skarn and replacement
(c) iron oxide-Cu-Au(-Ag-U-REE-Co-Ni)

Stratiform sediment hosted Cu Co

About: Most of the world's cobalt is produced as a byproduct of copper mining in sediment-hosted Cu-Co deposits that form strata-bound and commonly stratiform zones within siliciclastic or carbonate strata.

Minerals: Chalcopyrite, pyrite, and carrollite

Presence: Democratic Republic of the Congo, Zambia

Ni-Co laterite

About: Laterites are red regoliths developed on ultramafic bedrock and contain important Ni-Co deposits

Minerals: Nickeliferous serpentine, nontronite, erythrite, goethite

Presence: Western Australia, New Caledonia

Magmatic Ni-Cu(-Co-PGE) sulfide

Origin: This deposit type comprises semi massive to massive sulfides that occur within or near the basal zones of layered intrusive complexes, in discordant magmatic conduits, and within ultramafic intrusions and lava flows

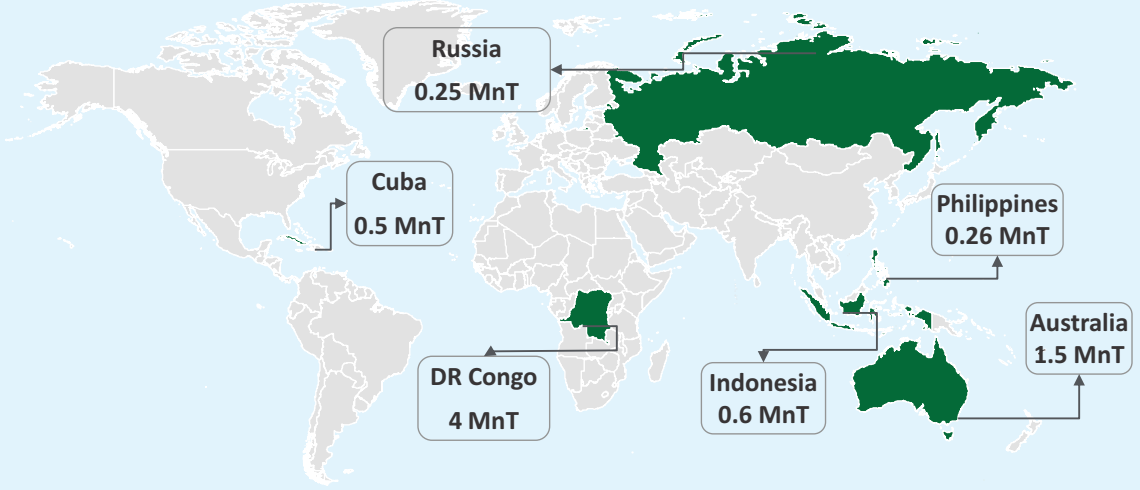
Minerals: Cobaltiferous pentlandite, linnaeite, olivine

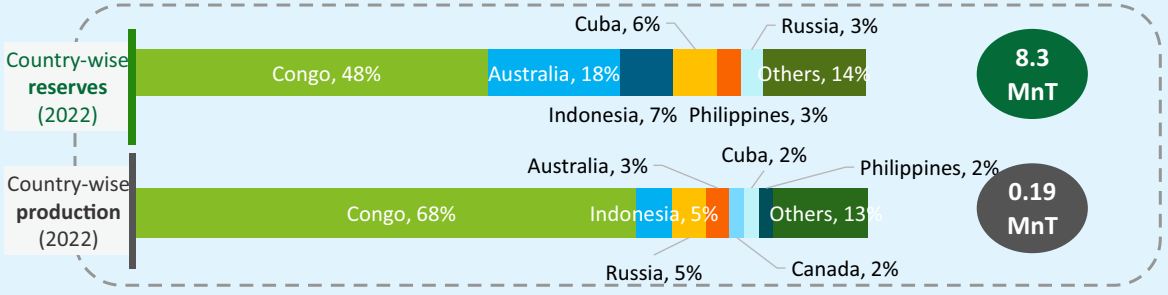
Presence: Canada, Russia

Source: USGS report - Critical Mineral Resources of the United States—Economic and Environmental Geology and Prospects for Future Supply

Cobalt: Geographical Occurrence

Global cobalt reserves (metal content) stood at ~8.3 MnT by CY22. Democratic Republic of the Congo holds ~48% of the global reserves, followed by Australia with 18% of the global reserves.





Key Insights

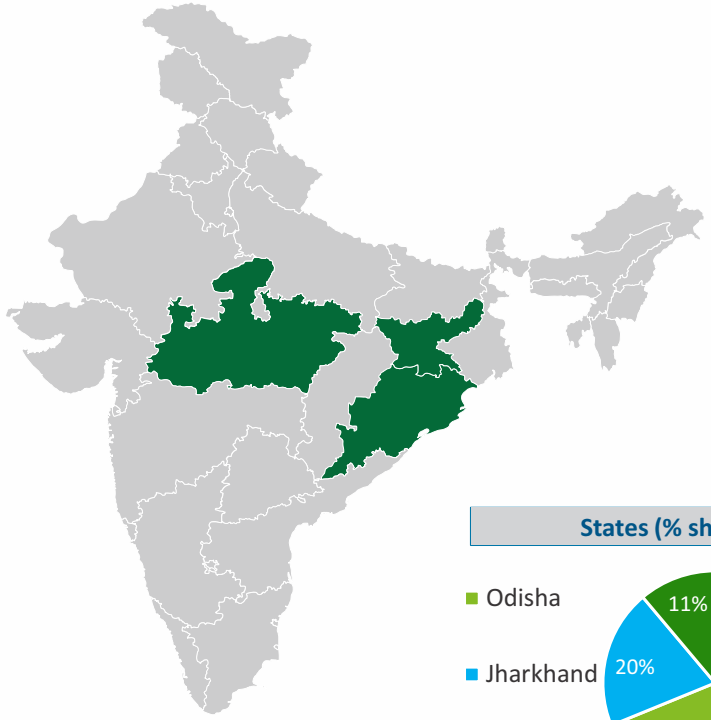
- ~70% of **Global Production** of Cobalt occurred in **Democratic Republic of the Congo** in CY2021. Most of the country's cobalt mine production was from copper–cobalt ores mined using industrial or mechanized methods; tens of thousands of artisanal miners gathered a lesser amount by handpicking cobalt-rich ores.
- **China** leads the world in **refined cobalt production at 70%** of the total global supply chain.

Source: USGS Mineral Commodity Summaries, IBM Mineral Yearbook, Mordor Intelligence, Deloitte Analysis

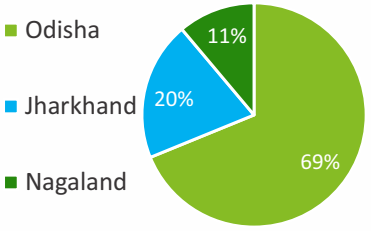
Cobalt: Occurrence in India

Cobalt is extracted as a by-product of copper, nickel, zinc or precious metals.

Major States with Cobalt Resources



States (% share)

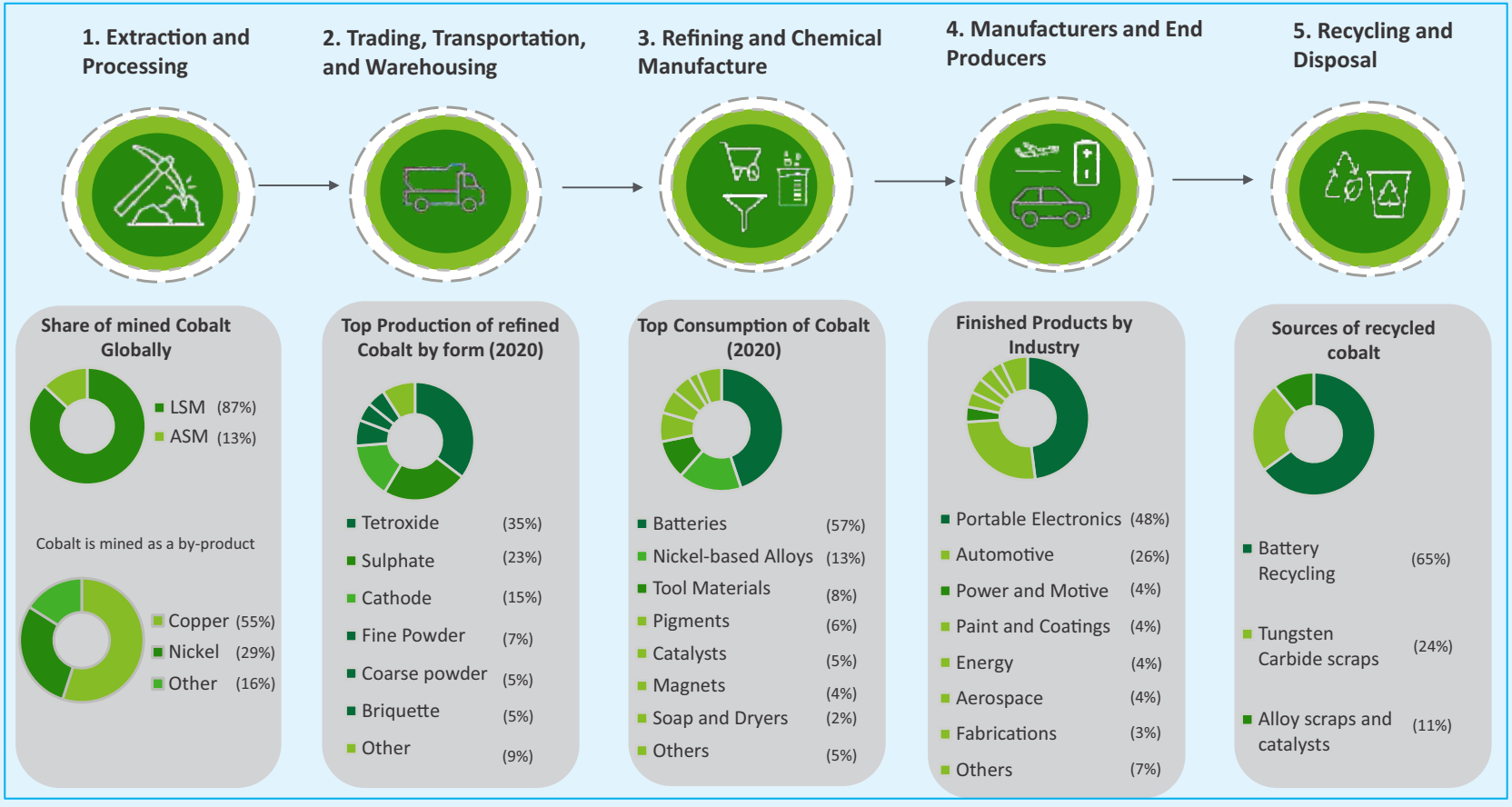


Key Insights

- As of 1.4.2015, India had 44.91 MnT of cobalt resources, according to the National Mineral Inventory based on the UNFC system.
- The refining capacity of cobalt in India is estimated to be 2,060 tons/year.
- India had detailed exploration in less than 10% of the total obvious geological potential area approximately as of 2020.
- Currently, there is no cobalt production in the country from primary cobalt resources. The demand for cobalt is usually met through imports.
- An Indian multinational mining group is also exploring approaches to produce cobalt for batteries as the group has become the latest entrant among companies that seek to capitalize on the anticipated EV boom.
- It is expected that recycled cobalt will continue to be used for domestic supply.

Source: IBM Mineral Yearbook, Atomic Minerals Directorate, Indian Nuclear Society, Deloitte Analysis

Cobalt: Global Value Chain

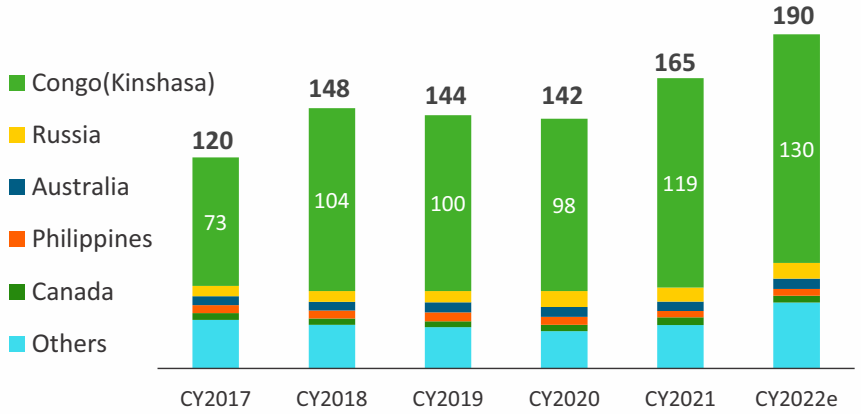


Source : Cobalt Institute's State of the Market Report, Roskill, USGS, Base Year: 2020 , Note: LSM : Large Scale Mining ,ASM : Artisanal and small-scale Mining

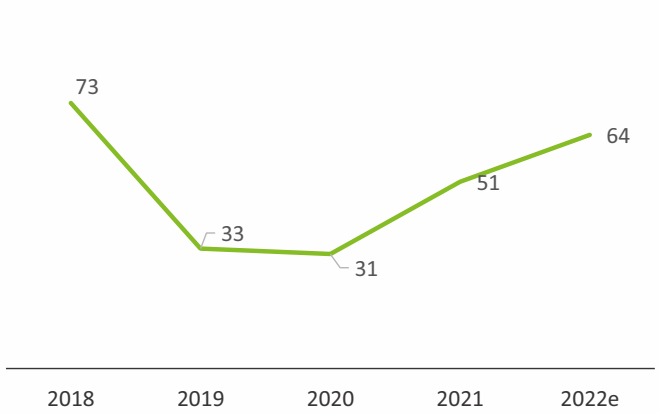
Cobalt: Key Global Producers and Trends

Congo is the largest cobalt producer, with a 68% market share, followed by Indonesia, with a 5% market share.

Country-wise Cobalt (Metal Content) Production Trend (kT)



Price of Cobalt (London Metal Exchange in USD per kg)



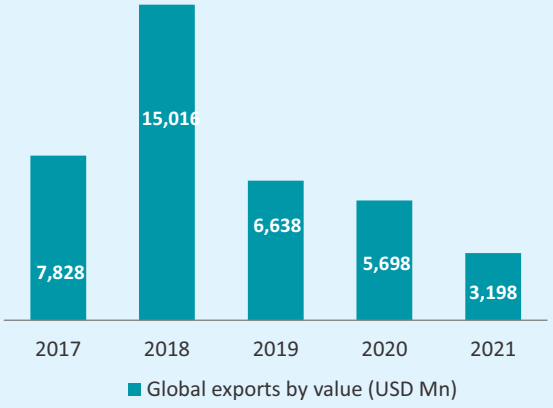
Key Insights

- The lack of processing facilities for cobalt recovery from nickel and copper as well as other technologies for setting up downstream manufacturing ecosystems has caused a lag in cobalt production domestically.
- The price of cobalt has dropped drastically to less than 50% in 2019 because of:
    1. Poor regulation on the extraction of cobalt in the Democratic Republic of Congo
    2. China has established a monopoly controlling seven of the largest DRC mines and over half of the DRC's cobalt supplies. China's demand for cobalt and the mineral's price peaked in 2018 and dipped in 2019

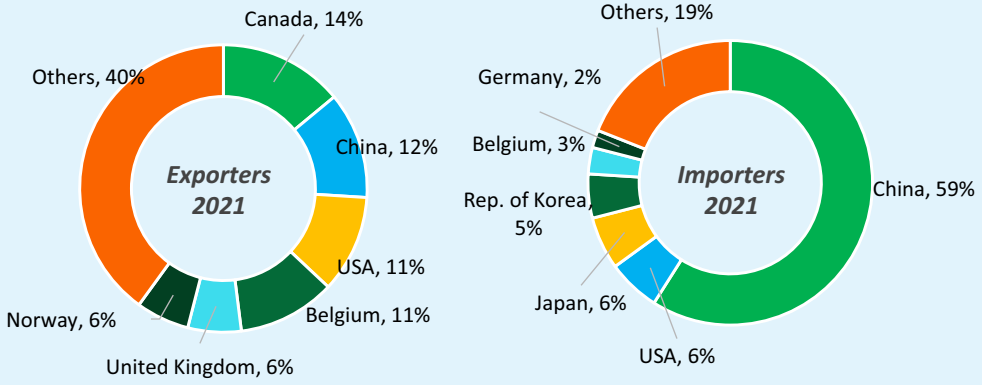
Source: USGS Mineral Commodity Summaries, IBM Mineral Yearbook, Mordor Intelligence, Deloitte Analysis

Cobalt: International Trade

Global Cobalt Trade



Major exporters and importers

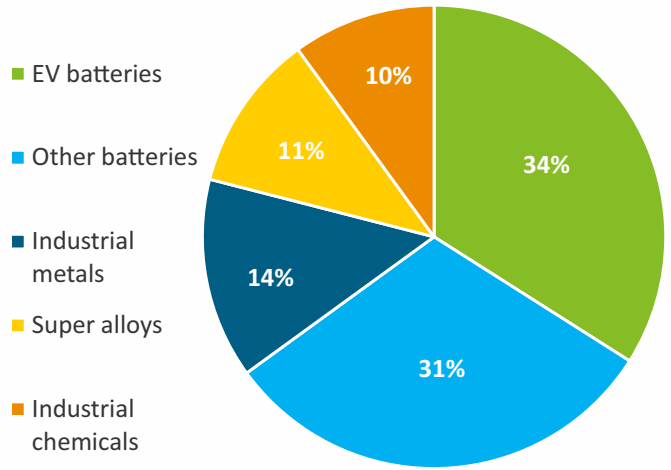


- India imported Cobalt worth ~30.8 Mn USD in 2021.
- India imports cobalt ores, oxides, and hydroxide from Belgium, China, and Finland. It imports cobalt sulfate from Finland and China.
- Cobalt content in cobalt oxide is 75%, cobalt hydroxide is 62% and intermediate products of cobalt is 99%
- Until 2020, the Democratic Republic of Congo was the biggest exporter of cobalt in the world, but it banned exports to encourage miners to process and refine the ore locally.
- There was a substantial decrease in exports value in 2019 mainly because of the price drop of cobalt to less than 50% compared with 2018.

Note: HS code taken for the data are: 2822 for Cobalt salts (oxides and hydroxides) & 8105 for Intermediate products of cobalt metallurgy, unwrought powder, articles and waste
Source: USGS Mineral Commodity Summaries, IBM Mineral Yearbook, Mordor Intelligence, Comtrade, Austrade

Cobalt: End Use Sectors and Applications

Cobalt Consumption across Key Sectors



EV batteries

*The EV sector uses a combination of lithium-ion battery chemistries, with cobalt-containing **cathodes** maintaining the largest share. Due to high energy density and performance, cobalt is particularly important for stability and safety. The best combination for many energy storage needs involves a cathode structure largely comprising cobalt (Co) ions.*

Other batteries

Cobalt has been widely used in lithium-ion batteries owing to its high capacity and good electrochemical performance. It is used in following applications:

- *Electronics*
- *Toys*
- *Wireless headphones*
- *Handheld power tools*
- *Small and large appliances*
- *Electrical energy storage systems*

Industrial metals

- *Cobalt steel as magnets*
- *Cutting tools*
- *Binding material for diamond cutting tools*

Super alloys

- *Superalloys used in gas turbines, space vehicles, rocket motors, and nuclear reactors*

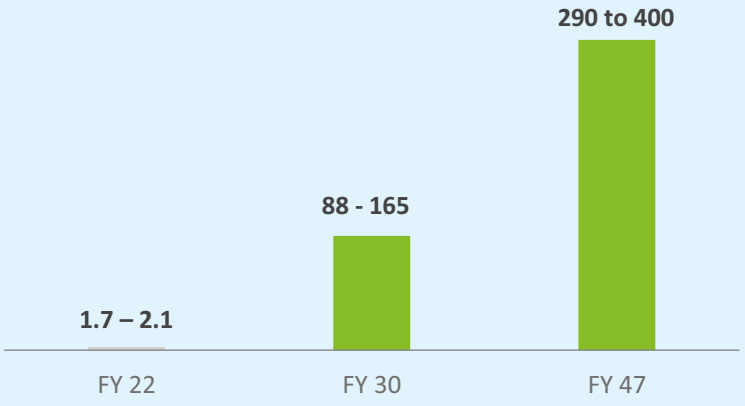
Industrial chemicals

- *Catalysts in this desulphurization process*
- *Drying agent*
- *Glass decolorizer*

Source : Deloitte Analysis , Mordor Intelligence, IndiaEximBank

Cobalt: Indian demand scenario

Cobalt Demand Forecast: India (kT)



Highlights

- ***A leading chemical company*** *launched* ***InsperiCo****, the world's first* ***branded recycled cobalt,*** *by recycling Li-Ion batteries.*
- ***A central public sector undertaking under*** *the* ***Ministry of Steel*** *is looking for* ***cobalt*** *mining options abroad. It intends to begin mining with the help of an exploration company in Australia in which it has a 90.02% stake.*
- ***A Joint Venture company created by the Ministry of Mines*** *has signed a* ***MoU*** *with Australia's Critical Minerals Facilitation Office* ***(CMFO)*** *to collaborate on Australian* ***cobalt minerals assets of battery.***
- ***National Metallurgical Laboratory*** *has developed a* ***technology*** *to recover up to 95% pure cobalt from Li-ion batteries.*

- India does not have any primary cobalt resources. Two possible secondary sources are nickel-bearing laterite deposits in Odisha and copper slag produced by a domestic minerals giant, which has been under R&D studies for commercial applications over the years.
- The cobalt refiners in India have catered to the market for chemical applications or where the cobalt metal or salt is dissolved and converted to cobalt oxide for cutting tools application.
- Owing to the specialized nature of applications and difficulty in substitution, the future demand for cobalt will likely follow an increasing trend.
- In India, cobalt will find major applications in metallurgy due to greater demand in special alloys/super alloys and cutting tools and as an alloy in permanent magnets. Cobalt powder demand will continue to grow as it is extensively used in the manufacture of bonded tools used in the diamond Industry.

Source : Deloitte Analysis , USGS Mineral Commodity Summaries 2018,2019,2020, 2021 and 2022, EMIS, Mordor Intelligence, IndiaEximBank, The Future of strategic natural resources, MIT

Cobalt: Challenges & Opportunities

Challenges

- Democratic Republic of the Congo accounts for ~70% of global production, and China accounts for ~65% of processing capacity, which poses a challenge from the perspective of securing a resilient supply chain.
- In India, cobalt consumption is showing a rising trend; however, in addition to the absence of domestic production from primary sources, recovery (recycling) from secondary sources is also commercially unavailable.
- Cobalt mining is also associated with human rights risks in the major producing geography (Democratic Republic of the Congo). This is nudging various battery users (automobiles and electronic goods) to find alternatives of cobalt in battery technologies.

Opportunities

- Cobalt's high melting point and ferromagnetic properties make it suitable for two major applications: lithium-ion battery cathodes and superalloys. Cobalt demand for lithium-ion battery cathodes (primarily used for EVs and ESS, and other batteries) shall drive ~80 percent of Cobalt demand by 2030.
- Numerous innovative cobalt development projects in countries like Australia are looking for financing and offer an opportunity for collaboration with Indian EV and battery manufacturers.
- While cobalt-free battery technologies are being explored, lithium-ion battery designs with cobalt cathodes are still likely to dominate the medium-term battery market.

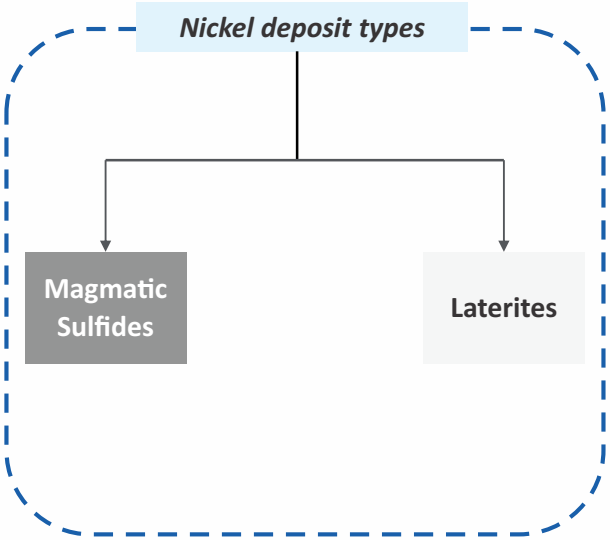
Nickel

Key Questions Answered:

- *What is the global production of nickel? Where and how much are the reserves of Nickel in the world?*
- *Where are the nickel reserves in India?*
- *What has been the price trend for nickel over the years?*
- *What is the global value chain for nickel?*
- *Who are the major exporters and importers of nickel?*
- *What are the major applications of nickel globally?*
- *What is the importance of nickel in the Indian economy? What does the future outlook look like, and what are the challenges?*
- *What is the current production capacity and demand for nickel in India?*
- *What does the demand scenario of nickel look like in India in 2030 and 2047?*

Nickel: Geological Occurrence

Nickel is a metallic element with a silver-white, shiny appearance that occurs naturally. It is the fifth most abundant element on the earth and is widely found in the crust and core of the earth.



SULFIDES

Principle Ore Mineral: *Pentlandite [(Ni,Fe)9S8].*

Origin: *Fractional crystallization within magma chambers or in ancient lava flows*

Grade: *(0.15 – 8)% Nickel; For more than 90% of identified deposits - (0.2 – 2)% Nickel*

Presence: *Canada, Russia, Australia, and Africa*

LATERITES

Principle Ore Mineral: *Nickeliferous limonite [(Fe,Ni)O(OH)] and garnierite (a hydrous nickel silicate)*

Origin: ***T****ropical and sub-tropical surface weathering*

Grade: *(1 – 1.6)% Nickel*

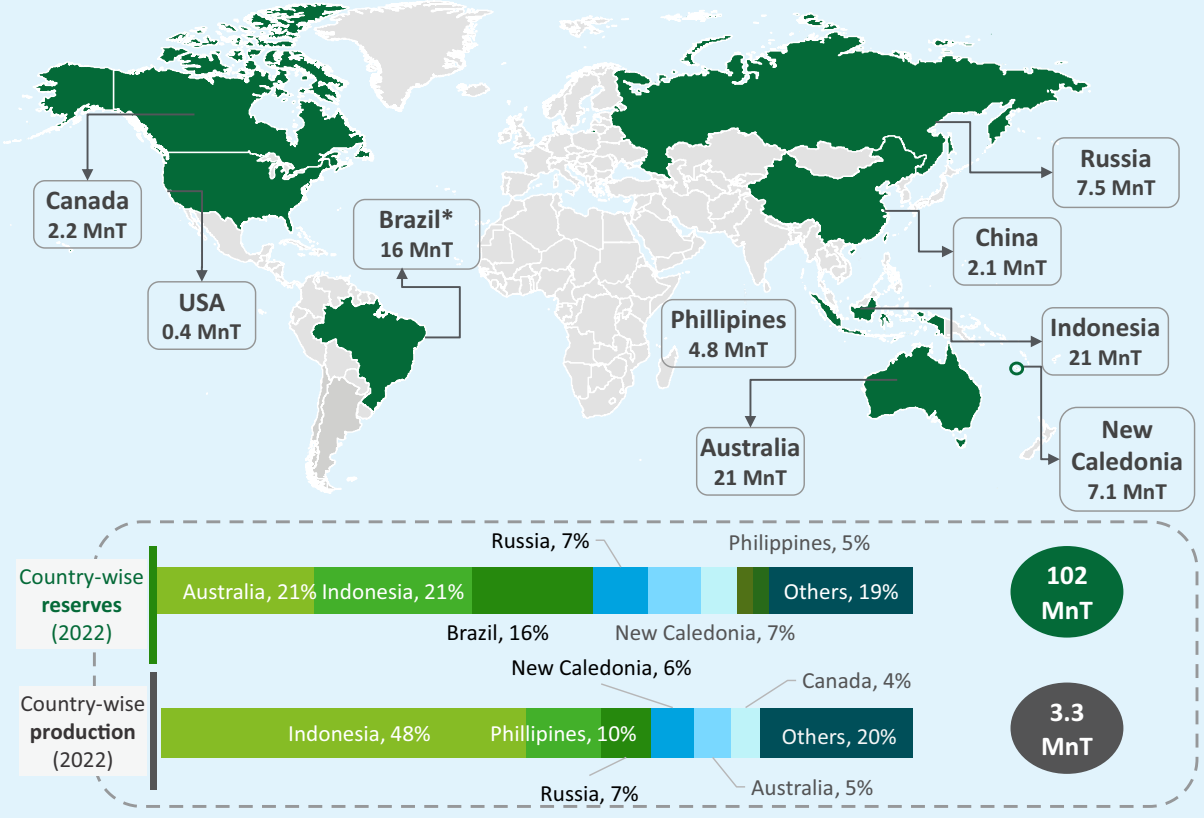
Presence: *New Caledonia, Australia, Philippines, Indonesia, and Central and South America*

- *Currently, sulfide deposits are the major source of mined nickel. Magmatic sulfide ores currently contribute* ***~60%*** *of world nickel production, and lateritic ores most of the remaining* ***40%****.*
- *Nickel-bearing lateritic ores are predominant land-based deposits (~70%), but they account only for 40% of global mine nickel production. The supply of nickel from these deposits is expected to increase with the improvement in* ***ore processing techniques*** *and* ***increasing demand*** *for nickel worldwide.*

Source: USGS report - Critical Mineral Resources of the United States—Economic and Environmental Geology and Prospects for Future Supply

Nickel: Geographical Occurrence

Global Nickel reserves (metal content) stood at ~102 MnT by CY22. Australia and Indonesia hold ~42% of the global reserves, followed by Brazil with 16% of the global reserves.



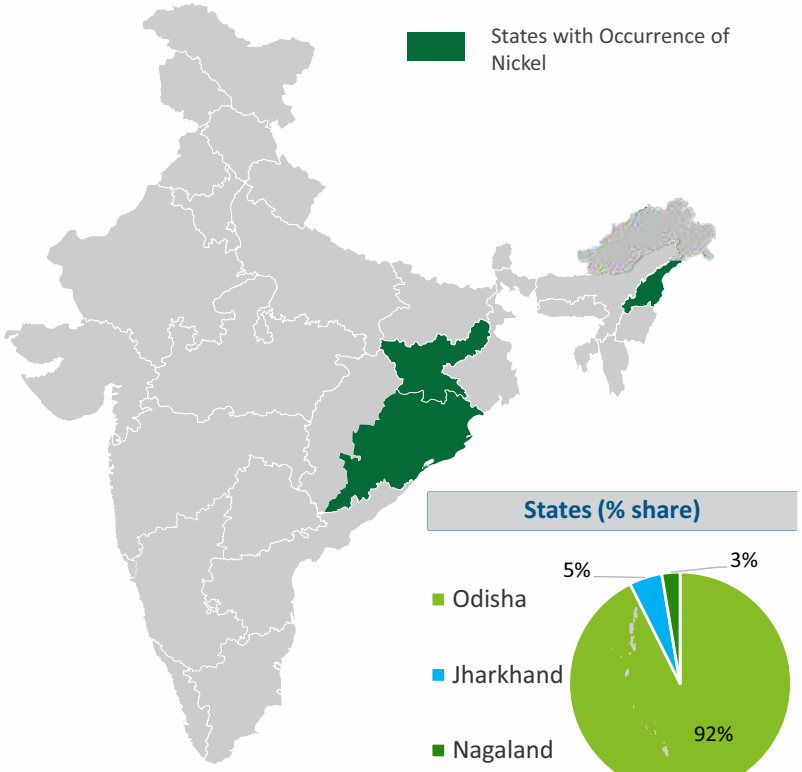
Key Insights

- Around 70% of the world's nickel reserves are found in the form of laterites, which are soils rich in mineral ores. Many of these reserves remain untapped due to the complexities of extraction from laterites.
- Australia has abundant nickel laterite reserves, but until now, extraction of nickel from these laterites has been challenging and expensive, resulting in the generation of large amounts of waste chemicals.
- Although Australia has the highest Nickel reserves, its share in global production as of CY2022 was 4.8%.
- Indonesia produced **~48%** of the **global production** of nickel (metal content) in CY2022.

Source: USGS Mineral Commodity Summaries, IBM Mineral Yearbook, Mordor Intelligence, Deloitte Analysis

Nickel: Occurrence in India

Major States with Nickel Resources

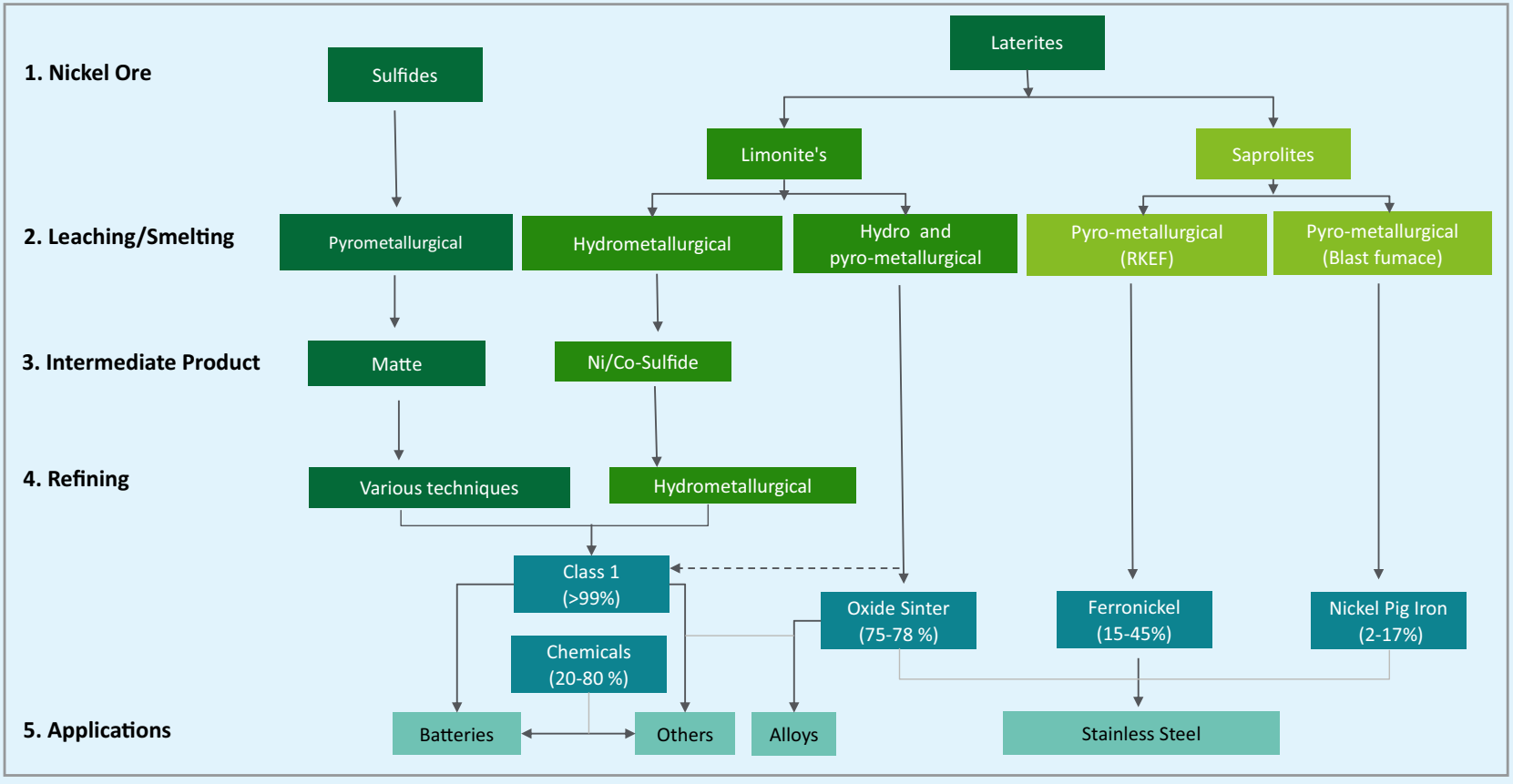


Source : Deloitte Analysis, IBM , austrade.gov -2021 ,Ministry of Mines , Company Annual Report, Note : Import Duties -2021

Key Insights

- As per the NMI database as of 1.4.2015, based on UNFC, nickel ore resources are estimated at 189 MnT.
- Nickel is mainly found in India as oxides, sulfides, and silicates. A significant occurrence is a nickeliferous limonite in Sukinda Valley, Jajpur district, Odisha. In addition, at Jaduguda (Jharkhand), nickel is found to be associated with uranium deposits, for which a recovery process is under development. Resources are distributed across the Singhbhum East district of Jharkhand and Jajpur, Keonjhar, and Mayurbhanj districts of Odisha.
- Only three states in the country have nickel resources: Odisha, Jharkhand, and Nagaland. Odisha has 93% of the total resources; the main districts with nickel resources are Jajpur, Mayurbhanj, and Keonjhar. Jharkhand houses 5% of the resources in the district Singhbhum (East), while Nagaland has 3% in the Kiphire district.
- The Department of Mines and Geology (Jharkhand) received a proposal from a domestic giant to reserve a 16.70 square km area in the Saraikela-Kharswan district for the prospecting and mining of nickel, which is being pursued with the Government of Jharkhand for reservation.
- Nickel production in India is lagging owing to the unavailability of commercial-scale technology, which can aid in recovering nickel from the overburden of chromite ore in Odisha.

Global Nickel Value Chain

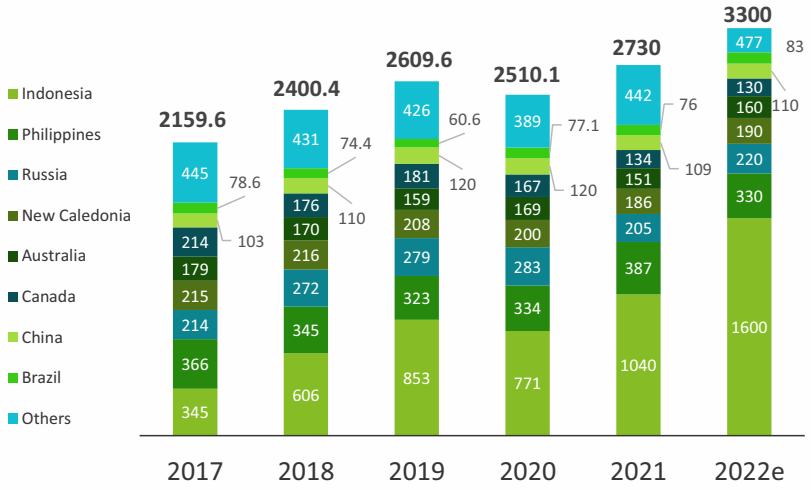


Note: Percentages mentioned represent Nickel content.
Source : nanthavictor.com

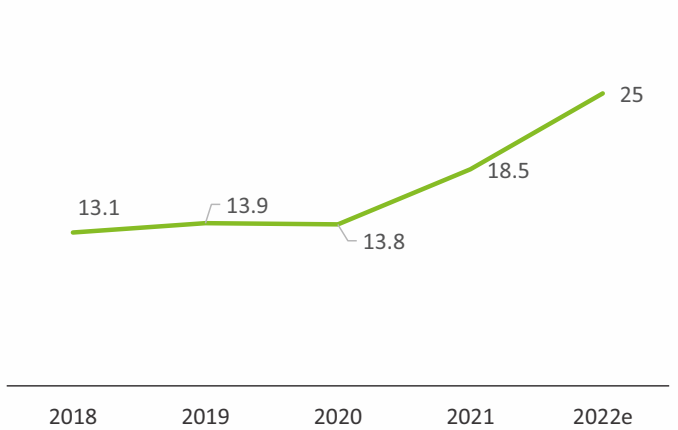
Nickel: Key Global Producers and Trends

Indonesia is the largest Nickel producer, with a 48% market share, followed by the Philippines, with a 10% market share.

Country-wise Nickel (metal content) Production Trend (kT)



Price of Nickel (metal) (USD per kg)



Key Insights

- Global Nickel production increased at a CAGR of 8.85% from CY-17 and is estimated to be 3,300 kT in CY-2022.
- In 2022, the annual average LME Nickel cash price was estimated to have increased by 35% compared with that in 2021, which was attributed to the increasing use of nickel in electric vehicle batteries and the continued strong demand for stainless steel.
- Nickel prices were particularly volatile early in 2022 owing to global geopolitical tensions. In March, the price surge disrupted nickel trading on the LME for approximately two weeks. Monthly average prices peaked in March but began to decline through July and stabilized for the remainder of the year.
- Key factors for the estimated price growth of nickel in 2022 include the rise in the alloy and stainless-steel sectors and the growth of lithium-ion battery manufacturing.

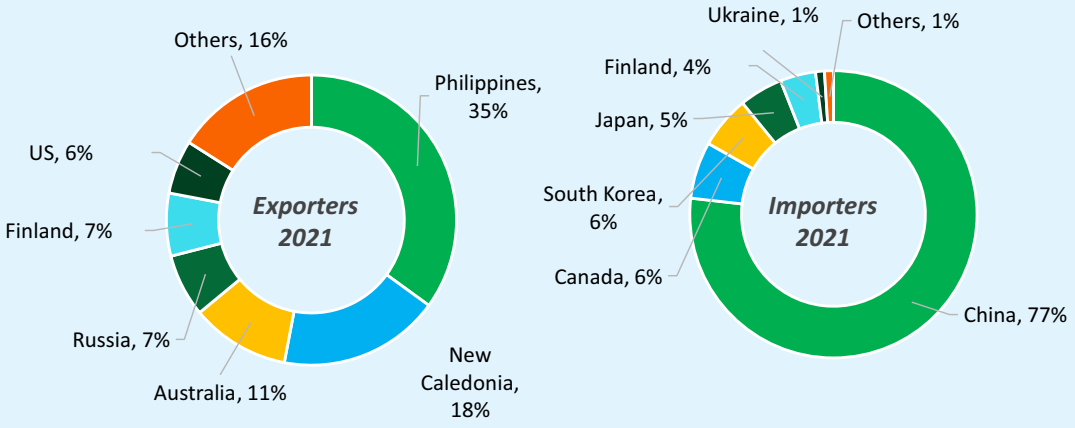
Source: USGS Mineral Commodity Summaries, IBM Mineral Yearbook, Mordor Intelligence, Deloitte Analysis

Nickel: International Trade

Global Nickel Trade



Major Exporters and Importers



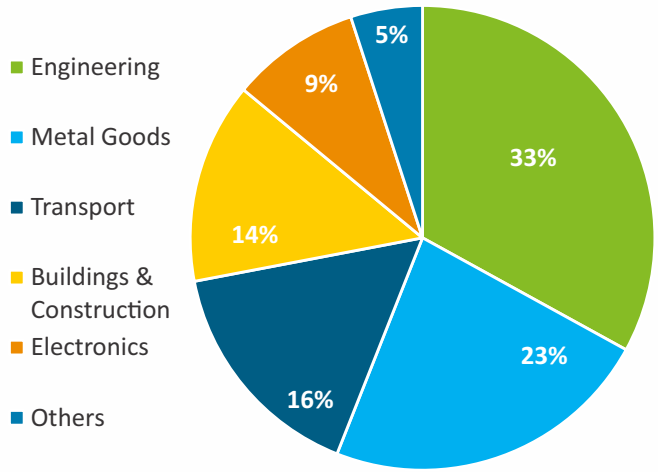
- India imported nickel worth ~230 Mn USD in 2021.
- The Philippines is the world's largest exporter of nickel, with a considerable share every year. Other major exporters include New Caledonia and Australia. The Philippines experienced a significant growth of ~22% in 2020. Exports from other countries, however, fell drastically in 2019.
- China is the largest nickel importer and imports a significant portion of the entire quantity traded globally. Its cumulative imports from 2016 to 2018 were around 80% of the total quantity. Canada, South Korea, Japan, Finland, and Ukraine follow it.
- Nickel is practically unavailable in the country, and the entire quantity of unwrought and other nickel needs to be imported.

Note: HS codes taken for the data are: 7202, 7502, 7505, 7506, and 7507 for ferronickel; nickel unwrought; nickel bars, rods, profiles, and wire; nickel plates, sheets, strips, and foil; and nickel tubes, pipes, and their fittings, respectively.

Source: USGS Mineral Commodity Summaries, IBM Mineral Yearbook, Mordor Intelligence, Comtrade, Austrade

Nickel: End Use Sectors and Applications

Nickel Consumption across Key Sectors



Engineering

Some common uses of nickel in engineering include stainless steel, the aerospace industry, the chemical industry, the automotive industry, the manufacturing industry, batteries, and electronics, amongst others.

Metal Goods

Stainless steel is the largest end-user of nickel, accounting for approximately 70% of global nickel consumption. Nickel is an essential component of stainless steel, providing corrosion resistance, strength, and durability. Furthermore, nickel is used in producing jewelry, springs, and metal coatings.

Transport

- *Aerospace (Gas Turbine Engines, Structures, Rocket Engines)*
- *Nickel Manganese Cobalt & Nickel Cobalt Aluminium batteries in EVs*
- *Li-ion batteries*

Buildings & Construction

- *Building Components (Roofing and Cladding)*
- *Architectural Hardware*
- *Stainless Steel Alloys*

Electronics

- *Computer Electromagnetic Shielding*
- *Electronic Lead Wires*
- *Sparking Electrode*

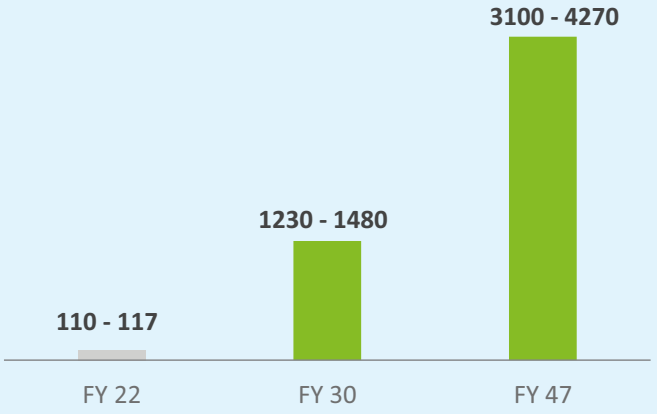
Others

- *Chemical Compounds in Biochemistry*
- *Catalysts*

Source : Deloitte Analysis , Mordor Intelligence, IndiaEximBank

Nickel: Indian Demand Scenario

Nickel demand forecast: India (kT)



Highlights

- India's first facility to recycle nickel, a metal for which the country is completely dependent on imports, has been launched by a leading domestic copper manufacturer at its Indian Copper Complex (ICC) at Ghatsila in Jharkhand.
- A specialized metals and metal alloys manufacturing facility in India, in a joint venture with HCL, would work on scaling up nickel production through its new facility at Ghatsila in Chhattisgarh.
- The Department of Mines and Geology of the government of Jharkhand received a proposal from a domestic minerals giant to reserve a 16.70 square km area in the Saraikela-Kharswan district for the prospecting and mining of nickel, which is being pursued with the government of Jharkhand for reservation.

- The demand for Nickel in India was estimated at 110–117 kT in FY22, and it is expected to reach the cumulative demand potential of 1,230–1,480 kT by FY30.
- NCA and lithium NMC oxide batteries are dominant in EVs. India’s demand for these and other new lithium-ion batteries containing nickel will likely increase.
- Nearly 50% of the nickel resources in India are of 0.5 to 0.9% Ni-grade; this is followed by (+) 0.5% Ni, unclassified (28%), and + 0.9% Ni (22%) grade.
- India imports most of its nickel ores and concentrates from Indonesia, Japan, and the UAE. Nickel oxides and hydroxides are imported from Sweden, China, the Philippines, Germany, Belgium, and Australia.

Source : Deloitte Analysis , USGS Mineral Commodity Summaries 2018,2019,2020, 2021 and 2022, EMIS, Mordor Intelligence, IndiaEximBank, The Future of strategic natural resources, MIT

Nickel: Challenges & Opportunities

Challenges

- India's nickel deposits are currently classified as Resources. A detailed exploration exercise would be required to evaluate reserves and economically extractable quantities.
- The industry does not have access to commercially viable mining and processing technologies
- Nickel prices have been rising with a CAGR of ~18% in last 5-years. Nickel prices have also been quite volatile in the past. In March 2022, after the onset of the conflict between Russia and Ukraine, prices surged to ~USD 100,000 on LME. This led to ~2-week halt on Nickel trading.

Opportunities

- Using nickel in lithium-ion batteries lends a higher energy density and more storage capacity to batteries. As a result, EV producers employ more nickel than ever, leading to rising demand. The EV segment is expected to account for ~15% of Nickel demand by FY30.
- The primary reasons propelling market expansion include rising demand for nickel in automotive batteries, energy storage systems (ESS) in wind turbines, or solar panels at a cheaper cost. ESS is expected to account for 6%–10% of Nickel consumption by FY30.
- India's commitment toward the national steel policy's objectives of steelmaking capacity enhancement and initiatives such as PLI for specialty steel will also drive the demand for nickel.

Note (source – UNFC classification of reserves)
Resources – These are the occurrence of material of economic interest which have reasonable prospect for eventual economic extraction.
Reserves – These are the economically mineable part of mineral resource.

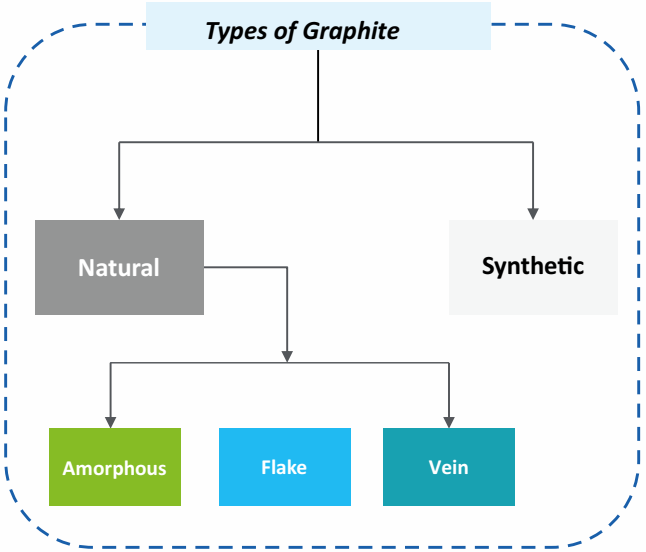
Graphite

Key Questions Answered:

- *What is the global production of graphite? Where and how much are the reserves of graphite in the world?*
- *Where are the graphite reserves in India?*
- *What has been the price trend for graphite over the years?*
- *What is the global value chain for graphite?*
- *Who are the major exporters and importers of graphite?*
- *What are the major applications of graphite globally?*
- *What is the importance of graphite in the Indian Economy? What does the future outlook look like, and what are the challenges?*
- *What is the current production capacity and demand for graphite in India?*
- *What does graphite's demand scenario look like in India in 2030 and 2047?*

Graphite: Geological Occurrence

Graphite is a form of pure carbon that normally occurs as black crystal flakes and masses.



SYNTHETIC

Origin: Produced by heat treatment (graphitization) of, or chemical deposition from, hydrocarbon materials above 2,100 °C

Crystallinity: Microcrystalline to Crystalline

Product Grade (% Graphite): 99.95

Main producers: China, Japan, United States, Germany

AMORPHOUS

Origin: Contact metamorphism, often by diabasic or granitic intrusions, and (or) regional metamorphism of carbonaceous sediments, often coal

Crystallinity: Microcrystalline

Product Grade (% Graphite): 60 to 90

Main producers: China, the Republic of Korea, Mexico, Austria

FLAKE

Origin: Regional metamorphism of carbonaceous sediments at or exceeding amphibolite facies conditions

Crystallinity: Crystalline

Product Grade (% Graphite): 75 to 97

Main producers: China, Brazil, India, Madagascar, Germany, Austria, Norway, Canada, Zimbabwe

VEIN

Origin: Epigenetic veins and lodes formed from metamorphic fluids in high-grade metamorphic rocks, usually granulites

Crystallinity: Crystalline

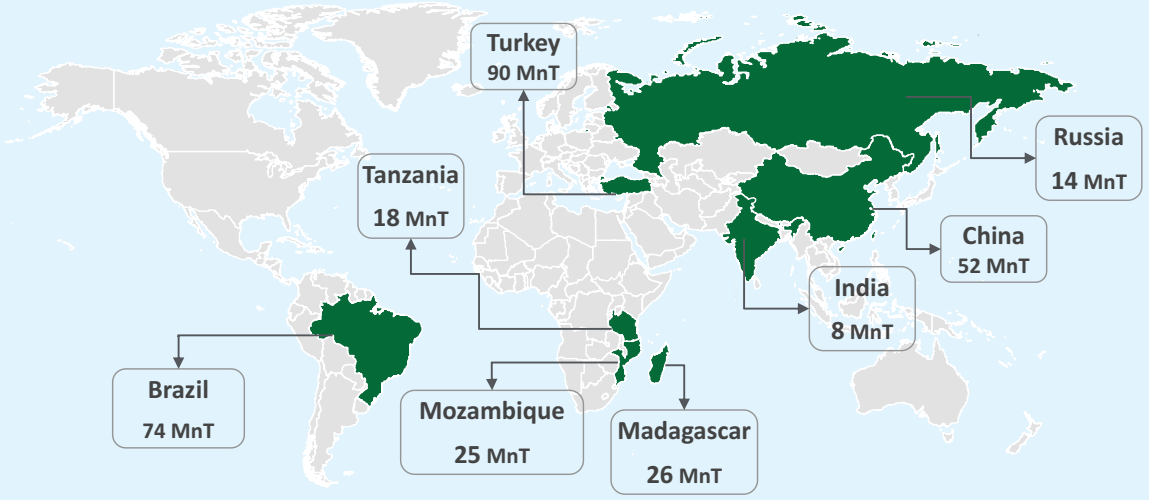
Product Grade (% Graphite): 90 TO 99.9

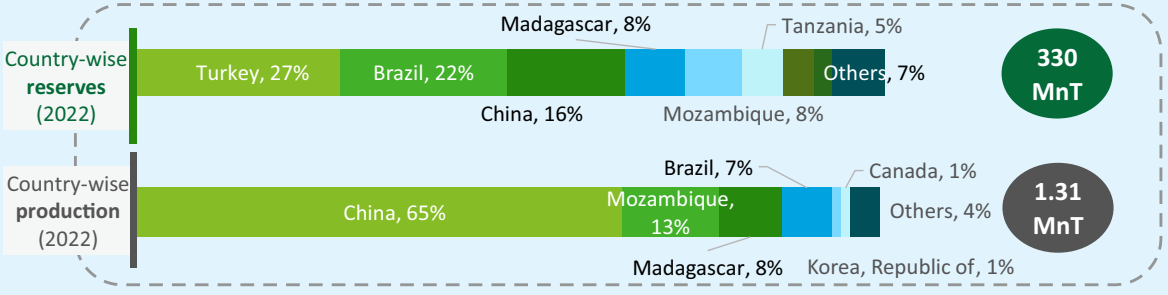
Main producers: Sri Lanka

Source: USGS report - Critical Mineral Resources of the United States—Economic and Environmental Geology and Prospects for Future Supply

Graphite: Geographical Occurrence

Graphite is a form of pure carbon that normally occurs as black crystal flakes and masses.





Key Insights

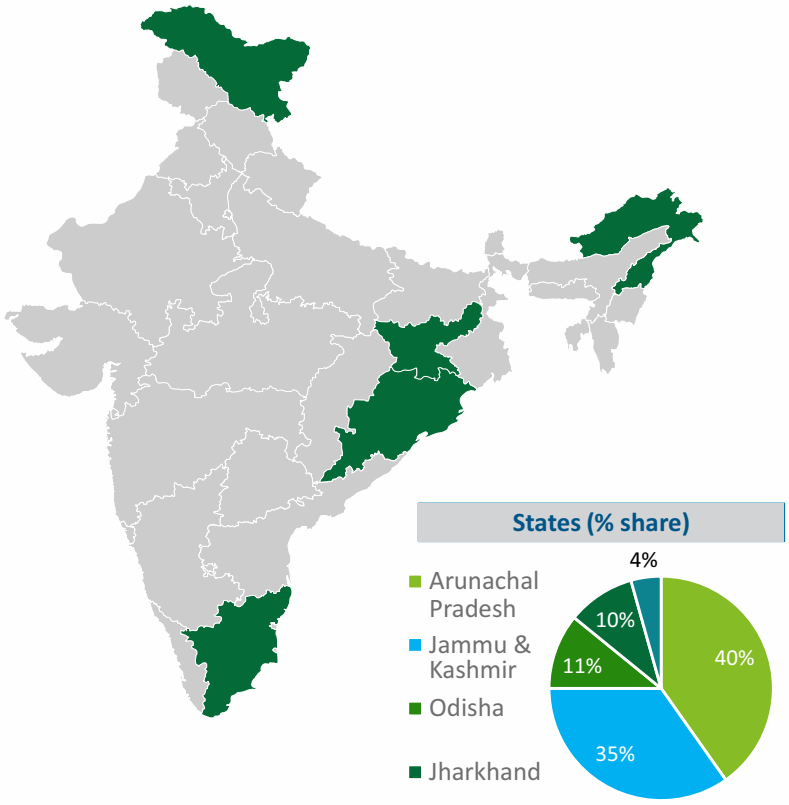
- Although Turkey has the highest reserve of natural graphite, production has stayed low owing to a lack of detailed exploration, technical know-how, and unviable economics
- A Canadian company and an Australian company continued to construct mines in Madagascar and Tanzania, respectively, with production expected to begin in 2023
- Africa has been a recent focus for graphite exploration, with projects under development in Madagascar, Mozambique, Namibia, and Tanzania. Additional projects were in advanced development stages in Australia, Canada, and Sweden.

Source: USGS Mineral Commodity Summaries 2023, IBM Mineral Yearbook, Mordor Intelligence, Deloitte Analysis

Graphite: Occurrence in India

India is estimated to have total reserves of graphite ore (as of 1.4.2015) at approximately 194.89 MnT, out of which 7.96 MnT are in the reserves category and 186.92 MnT are placed under the remaining resources category.

Major states with Graphite resources



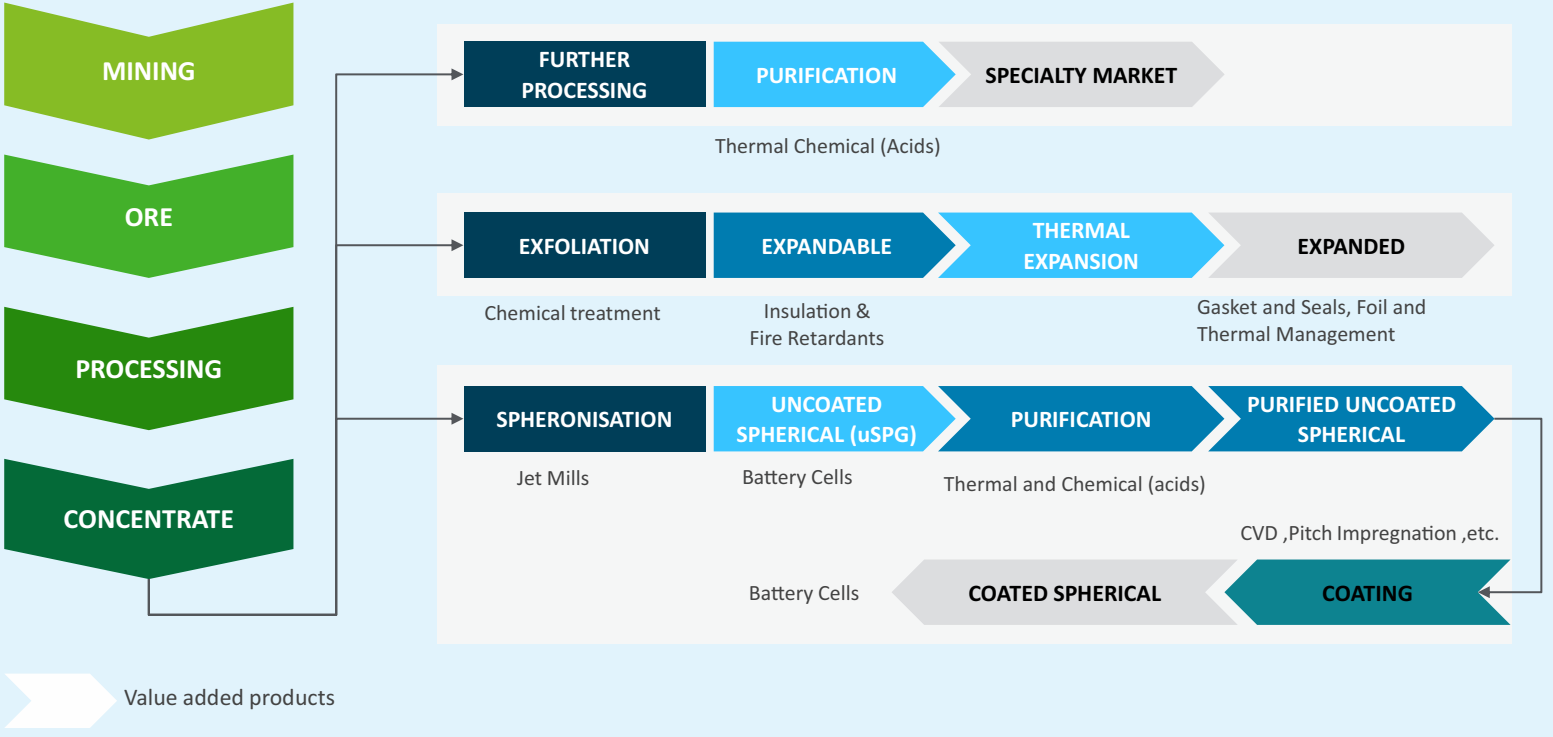
Key Insights

- The country has limited reserves of high-grade graphite. Owing to the lack of advanced mineral processing and refining technology essential to process raw materials, production lag exists.
- During FY 2022–2023, GSI has taken up 125 projects to give impetus to exploration for graphite and other strategic, critical minerals.
- Production of graphite in India was ~31.9 kT in 2019–2020
- Jharkhand was the leading producing state contributing 61% to the total output during 2019–2020, followed by Odisha.
- In 2019–2020, production was mainly reported from eleven mines.
- Five principal producers accounted for 96% of the total production during 2019–2020. About 61% of the total production in 2019–2020 was accrued from two mines, each producing more than 5,000 tons annually, while 39% was contributed by four mines in the production range of 1,000 to 5,000 tons per annum.

Source: IBM Mineral Yearbook, Atomic Minerals Directorate, Indian Nuclear Society, Deloitte Analysis

Global Value Chain for Graphite

Natural flake graphite requires processing, primarily into spherical graphite (SPG) material, particularly for manufacturing anodes.



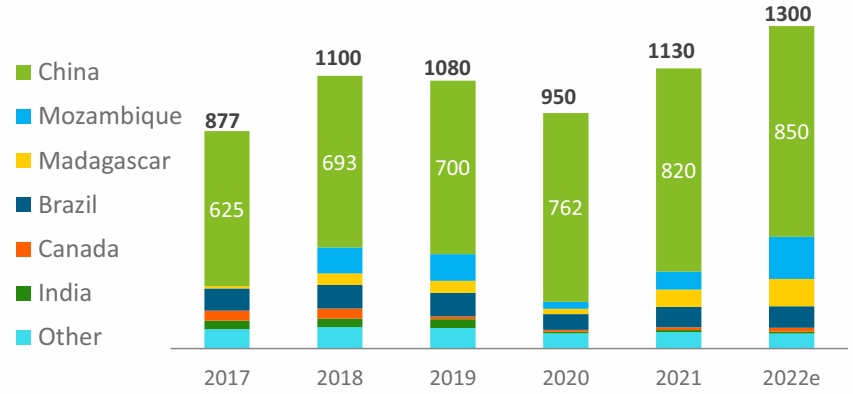
Most batteries with natural graphite are generationally prepared in the "uncoated spherical" stage. Batteries are also prepared in the "coated spherical" stage; however, the manufacturing cost at this step is substantially higher.

Source : EMIS

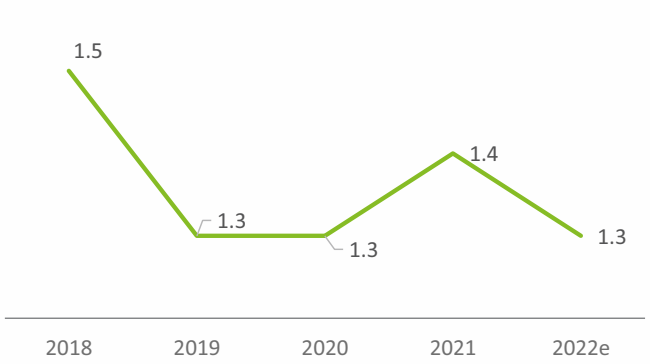
Graphite: Key global producers and trends

China is the largest graphite producer, with a 65% market share, followed by Mozambique, with a 13% market share.

Country-wise Graphite (Natural) Production Trend (kT)



Price of Graphite Flakes (USD/kg)



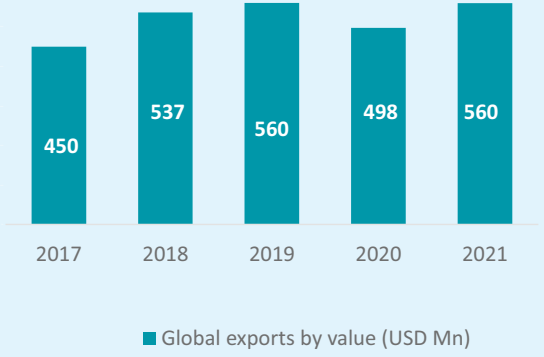
Key Insights

- In 2022, China was the world's leading graphite producer, producing an estimated 65% of total world production. Approximately 24% of graphite produced in China was amorphous, and approximately 76% was flake.
- In February, Ukraine halted graphite production, citing Russian military action. Operations recommenced in August, although future production was uncertain as the conflict continued. Additionally, many other countries have suspended normal trade relations with Russia, removing supplies of Russian graphite from much of the global market.
- Graphite consumption is expected to continue to increase, owing largely to growth from the electric-vehicle market. The battery end-use market for graphite has grown by 250% globally since 2018.

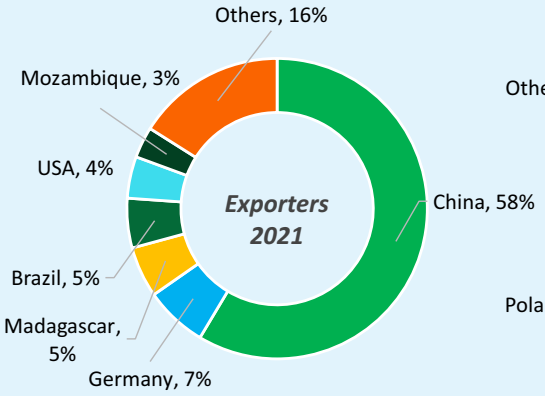
Source: USGS Mineral Commodity Summaries, IBM Mineral Yearbook, Mordor Intelligence, Deloitte Analysis

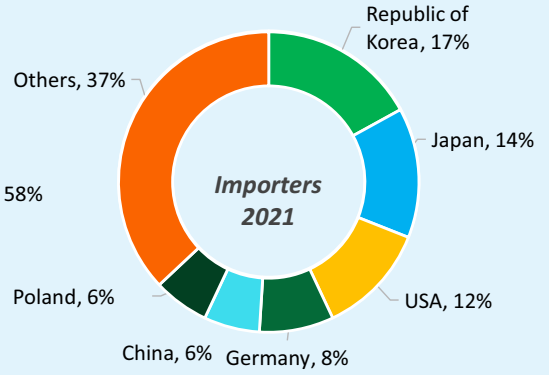
Graphite: International Trade

Global Graphite Trade



Major Exporters and Importers





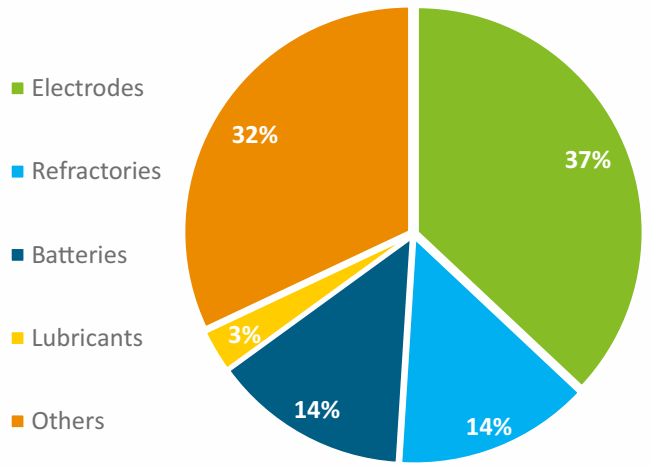
- India imported graphite worth ~24.4 Mn USD in 2021.
- In 2020–2021, graphite (natural) exports increased compared with the previous year. The increase in consumption is likely due to rising demand from the lithium-ion battery industry.
- China is the largest producer and exporter of graphite in the world
- India remains a net importer of natural graphite and depends on imports to meet its domestic demand for graphite.

Note: HS code taken for the data is 2504

Source: USGS Mineral Yearbook, IBM Mineral Yearbook, Mordor Intelligence, Comtrade, Austrade report, Ministry of Commerce

Graphite: End-use Sectors and Applications

REE Consumption across Key Sectors



Electrodes

Graphite electrodes are an essential component in the production of steel. They're the main heating component in electric arc furnaces, which are used to melt down scrap metal to create new steel.

- High-purity graphite electrodes are used to conduct electrical current to melt scrap steel.
- Synthetic graphite electrodes are employed in metallurgical applications as a source of energy for processes, including refining ceramic materials, manufacturing chemicals, such as calcium carbide, and other applications that require high temperature and clean energy.
- In most metallurgical applications, synthetic graphite is preferred to natural graphite, as it withstands considerably high electric currents owing to its high purity and conductivity.

Refractories

- *Graphite is used as a refractory material because it is resistant to oxidation, offers good thermal conductivity, and is chemically inert. It is used to make crucibles, mag-carbon bricks, molds, and other components in high-temperature applications. It is also used in continuous casting.*

Batteries

- *Anode Material in Li-ion Batteries*
- *Carbon Electrodes, Brushes, and Plates in Dry Cell Batteries*

Lubricants

- *Grease and Forging Lubricant*
- *Mining Machine Gear Lubricant*
- *Anti-seize Lubricant*

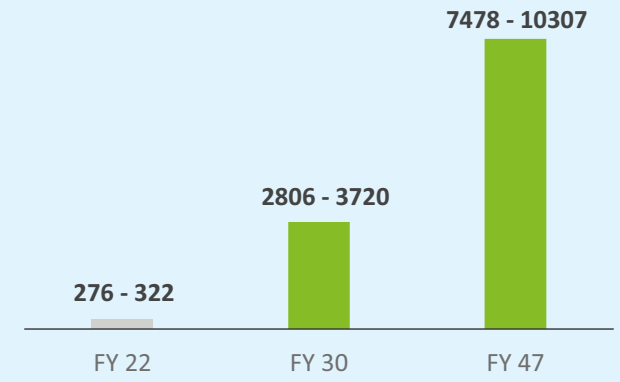
Others

- *Graphene Sheets*
- *Catalysts*
- *Paints and Coatings*
- *Pencil Lead*

Source : Deloitte Analysis , Mordor Intelligence, IndiaEximBank

Graphite: Indian Demand Scenario

Graphite demand forecast: India (kT)



Highlights

- A leading graphite producer in India will become the world's largest company in graphite production after an investment of Rs 1,200 crore in its existing facility at Mandideep near Bhopal
- A leading graphite manufacturer, pioneer in India for manufacture of graphite electrodes, plans to build a 35 MW captive solar-wind hybrid project
- The Kerala government has established India's first innovation center for graphene in cooperation with a leading steel company and the Ministry of Electronics and Information Technology.

- In India, graphite demand for use in lithium-ion battery anodes, mostly for EVs and ESS, is expected to drive aproximately25% of graphite demand in 2030. The high growth rate would result from the anticipated rapid shift from internal combustion engines to EVs over the next decade, with demand growth expected to slow.
- Graphite will remain core to the battery anode for the foreseeable future.
- Refractories use natural graphite, and the rising demand for EAF-based steel production increases the demand for graphite in refractory-based applications.
- The National Steel Policy 2017 envisaged using DRI-EAF route steelmaking to minimize GHG emissions, reduce the import of Coking Coal and subsequently increase the demand for graphite electrodes.

Source : Deloitte Analysis , USGS Mineral Commodity Summaries 2018,2019,2020, 2021 and 2022, EMIS, Mordor Intelligence, Austrade, IBM

Graphite: Challenges, Opportunities and Recommendations

Challenges

- India has limited reserves of High-grade Graphite ores. However, India's demand for graphite is expected to grow significantly, making it challenging to extract high-quality graphite for use in various industries.
- India's graphite production levels are ~30-35 kT, while the demand is 5-6 times that of the production, creating heavy dependency on imports.
- China accounts for ~65% of global production and controls ~60% of global exports. Such heavy reliance puts the global supply chain and India's raw material security at risk.
- Although anode chemistries have changed only marginally in the past few years, R&D is being conducted to replace graphite in battery anodes with silicon and silicon composites, which could dampen graphite demand in future.

Opportunities

- India's demand for graphite is likely to grow significantly due to the development of the battery electrodes and battery chemicals industry. By FY30, expected graphite demand in India is ~3,250 kT, of which 20% will be driven by consumption in EV batteries.
- The traditional downstream industries, such as refractories and electrodes, also have a bright outlook considering the strong focus on steel capacity development, particularly EAF, based on national objectives of net-zero emissions by 2070.
- An emerging technology breakthrough involving graphene-based batteries could boost natural graphite demand exponentially.

Recommendations: Battery Minerals



Battery Minerals: Recommendations (1/3)

01 Increase Focus on Exploration

India's exploration status is less than 10% of the Obvious Geological Potential. It is thus necessary to expedite the exploration activities to unlock full economic potential

R&D Focus areas:

- India's exploration expenditure needs to increase multifold (For comparison, India spends ~170 Mn USD annually on mineral exploration, while USA, Australia, and Canada spend >1 Bn USD).
- **National Mineral Exploration Trust (NMET) Utilization** – The trust is funded through a cess imposed on mining companies, and the funds are used to finance exploration projects that are deemed to be of national importance.
- Investment in Exploration **Technology, Equipment**

Agents of Change

02 International Asset Acquisition

India could look for international investment opportunities to secure these mineral assets

India may look for investment in existing/upcoming projects (mineral value chain) in the following regions for respective minerals:

- Lithium – Australia, LATAM
- Graphite – Brazil, Turkey
- Cobalt – Australia
- Nickel – Australia, Indonesia, Brazil

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Regulatory Bodies | **Govt (via Ministries, PSUs)** | **Private Enterprises** | **Research Institutions**

Battery Minerals: Recommendations (2/3)

03

R&D promotion

Domestic R&D should be promoted to enable commercialization at a cheaper rate and encourage self-reliance.

R&D Focus areas:

- Production cost optimization (e.g., for synthetic graphite)
- Recovery from secondary sources (e.g., for nickel and cobalt from domestic copper ore)
- Second-life applications (Li-ion batteries can deliver up to 70%–80% performance in their second life) in ESS
- Recycling and material recovery from end products

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04

Policy support

A forward-looking policy should be established to enable the development of a battery mineral ecosystem in India.

- **A holistic metal-wise recycling policy** is recommended to reduce dependence on primary sources and imports and harness circular economy potential.
- **A dedicated financing institution/financing program for investment in battery value chain** can lower interest rates, extend the moratorium and payback periods, and increase green investment bonds and foreign currency loans for overseas asset investment.

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Regulatory Bodies

Govt (via Ministries, PSUs)

Private Enterprises

Research Institutions

Battery Minerals: Recommendations (3/3)

05 Collaboration

India could explore through its diplomatic associations in other countries for collaboration in joint exploration activities, technological advancement amongst others

- **Exploration technology/equipment sourcing**
- **Processing Technology transfer** – Domestic players may partner with International players to get the technological expertise needed for setting up downstream industries in India
- **Industry - Academia collaboration:** Tie up with industries and academic institutions for specific courses and R&D related to battery's role in energy security

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06 Development of Battery Ecosystem

Nations such as China has used forward integration to not only produce ores but have invested in processing capabilities. This has cemented China's dominance over these minerals' market

- Multipronged approach is needed to support all parts of value chain – Invite **investments from international firms with core competency in Exploration, Processing, Battery manufacturing** and **recycling**
- Set up dedicated resources responsible for **Marketing, Promotion, Relationship building, Policy advocacy,** and **Investment readiness** for battery minerals in India.

Agents of Change



Regulatory Bodies | Govt (via Ministries, PSUs) | Private Enterprises | Research Institutions

Annexure 1: Case Studies of Global REE Projects



Case Study 1: Ngualla Rare Earth Project

Location: *Tanzania*



Organization

Peak RARE EARTHS

Mineralogy, Reserves & Grade

Bastnaesite, 195 MnT at 2.26% REO

RE elements concentrations (oxides)

Nd (46%), Pr (27%), La (7%), Ce (9%), Dy (1%), Tb (1%) & Others (9%)

Key project Details

Project Life	58 Years
Activities	Mining, Processing, Metal separation
Annual Production	10 kT
Product Quality	>99% purity RE Oxides

Project Financials**

CAPEX	*USD 367 Mn*
OPEX	*USD 11.74/kg*
NPV*	*USD 1005 Mn*
IRR*	*39%*

**Post tax and Royalties*

Comminution — *Mining, Crushing, Milling*

Beneficiation — *Magnetic separation, Milling, Floatation*

Recovery — *Sulphation, acid dissolution, caustic conversion, double sulfate precipitation*

Separation — *Solvent extraction, precipitation, calcination*

- *NdPr Oxide*
- *La oxide*
- *Ce oxide*
- *Other REO*

Disclaimer: The cost structure of some parts of the value chain is subject to changes in mineralogy, technology, and location-specific factors (such as human resources cost, equipment cost, raw material cost, etc.). Continuous exploration might also lead to the discovery of more resources, thus increasing project life and changing cost/profitability estimates. **Financials are provided per the first DFS study outcomes in 2014.

Source: Peak Resources Ltd Annual Report 2014

Case Study 2: Yangibana Project

Location: *Australia*



Organization HASTINGS Technology Metals Limited

Mineralogy, Reserves & Grade	**Monazite + Bastnaesite,** 27.42 MnT at 0.97% REO
RE elements concentrations (oxides)	*Nd (33%), Pr (8%), La (11%), Ce (41%), & Others (7%)*

Key project Details

Project Life	15 Years
Activities	Mining, Processing, Metal separation
Annual Production	15 kT MREC**
Product Quality	~56.7% RE oxide concentrate

Project Financials

CAPEX	***USD 494 Mn***
OPEX	***USD 14/kg***
NPV*	***USD 759 Mn***
IRR*	***26%***

**Post tax and Royalties*

Mining
↓
Beneficiation
↓
Crushing, Screening, Grinding, Floatation
↓
Hydro-metallurgical Plant

- *Acid Bake*
- *Off Gas Treatment*
- *Water Leach*
- *Impurity Removal*
- *Uranium Removal*
- *Mixed Rare Earths Carbonate precipitation*
- *Waste handling*

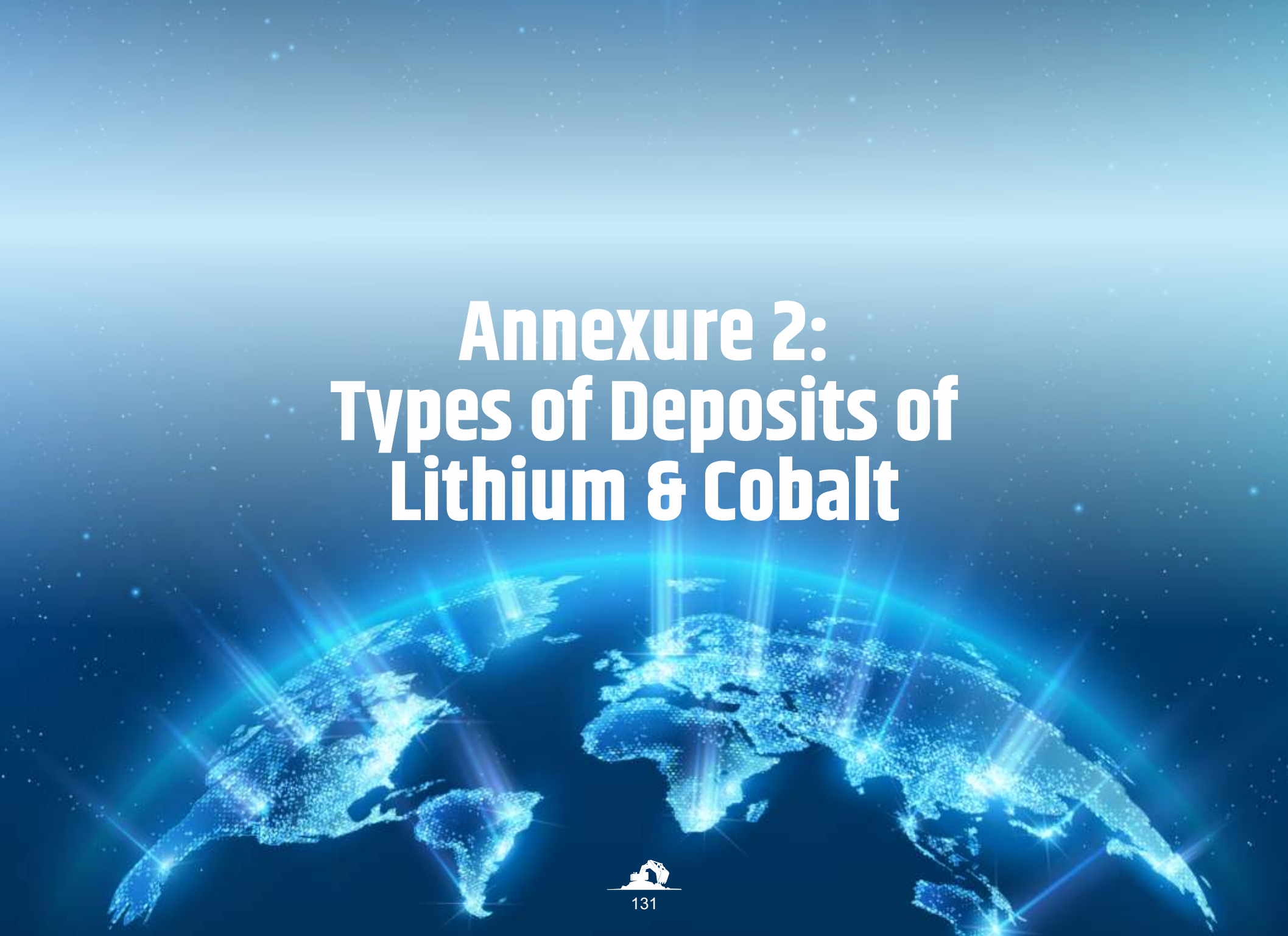
→ ***MERC - Mixed Rare Earth Concentrate*

Disclaimer: The cost structure of some parts of the value chain is subject to changes in mineralogy, technology, and location-specific factors (such as human resources cost, equipment cost, and raw material cost). Continuous exploration might also lead to the discovery of more resources, thus increasing project life and changing cost/profitability estimates.

Source: DFS Yangibana Project, Hastings Technology Metals Limited Annual Reports,

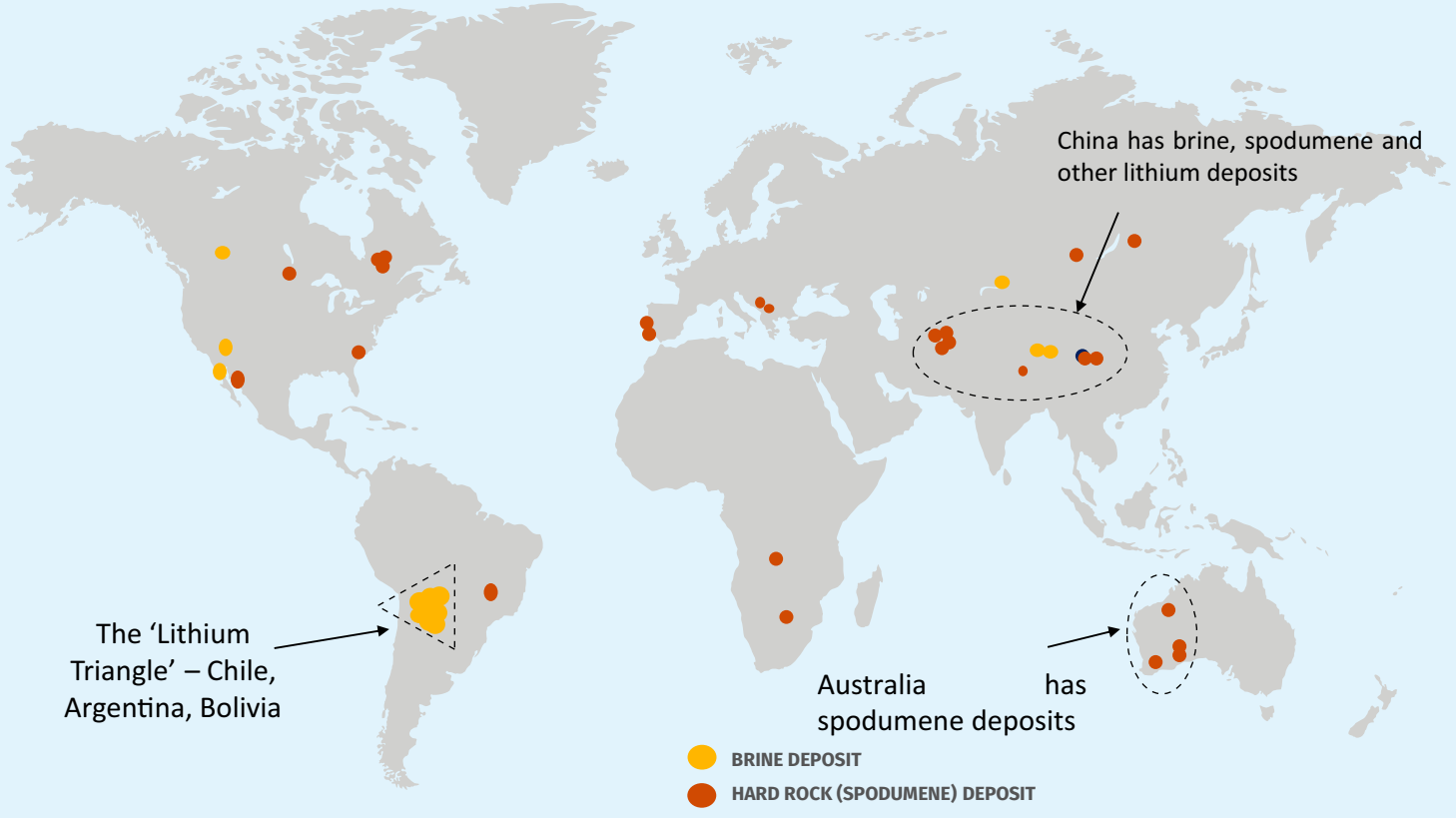
Note: Australian inflation during 2017-22: ~1.84% (World Bank), AUD/USD exchange rate: 0.75

Annexure 2: Types of Deposits of Lithium & Cobalt



Lithium: Types of Deposits

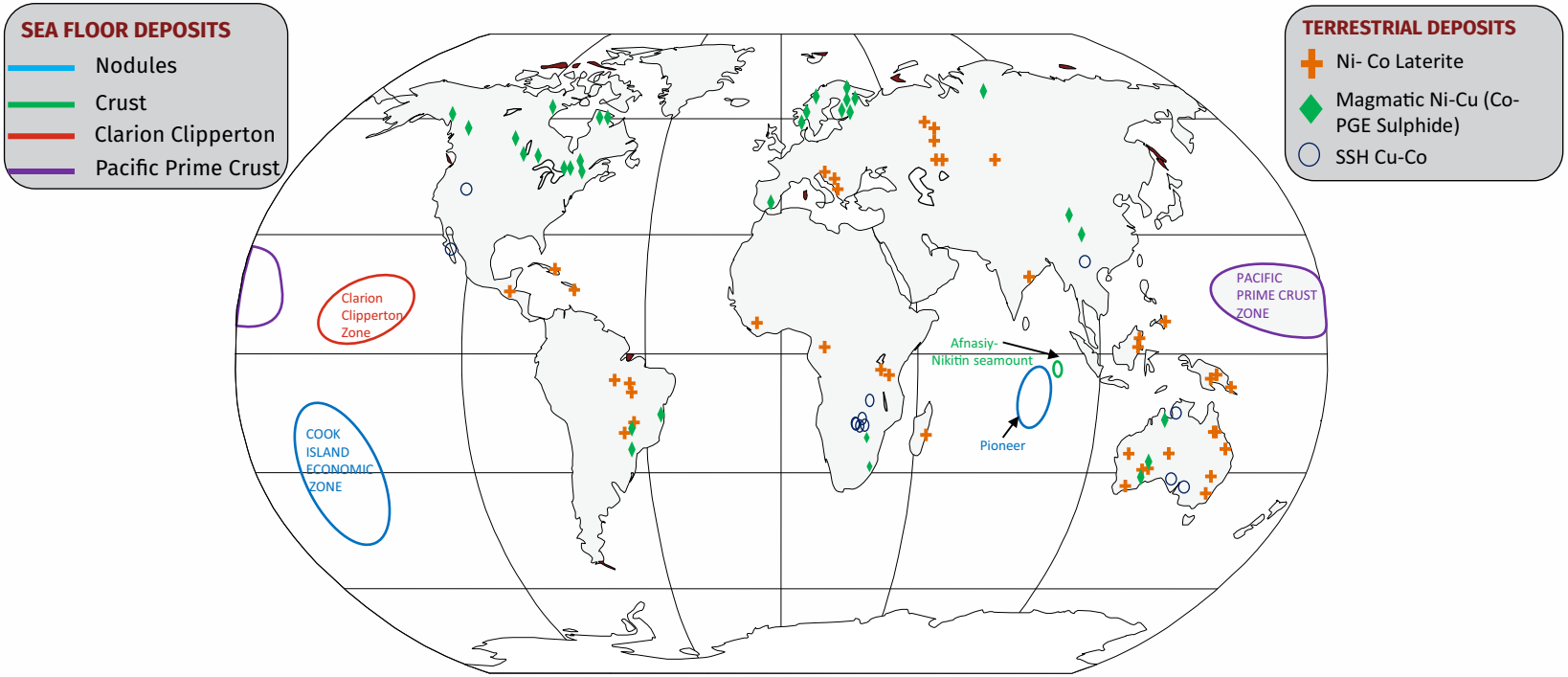
Natural resources of lithium are found in concentrations in two types of deposits – Hard rock deposits (67%) and brines (33%)



Source : USGS

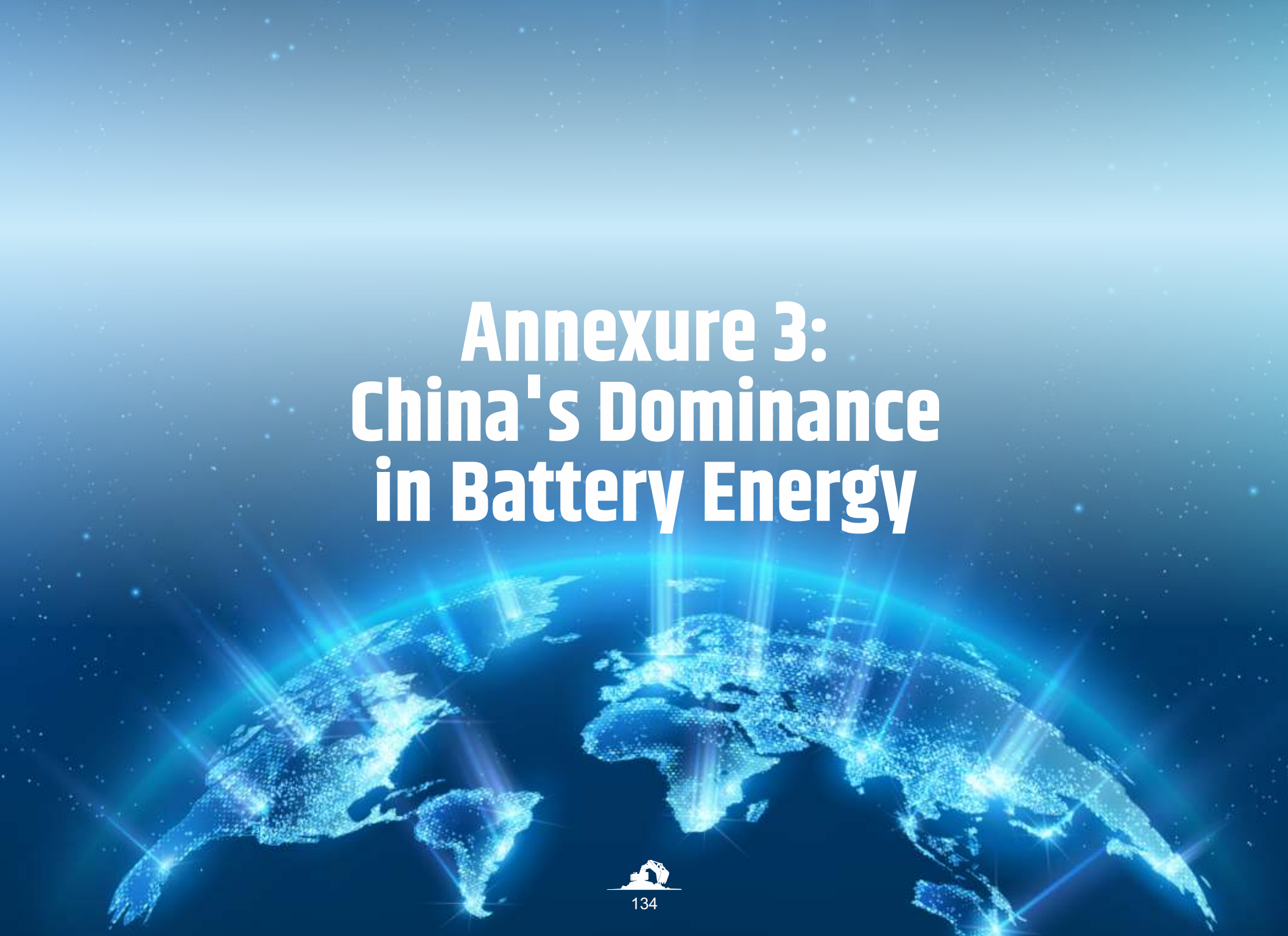
Cobalt: Types of Deposits

Significant cobalt deposits are present in DR Congo, Australia, Cuba, the Philippines, and the seafloor (PPCZ, CIEZ, and CCZ).

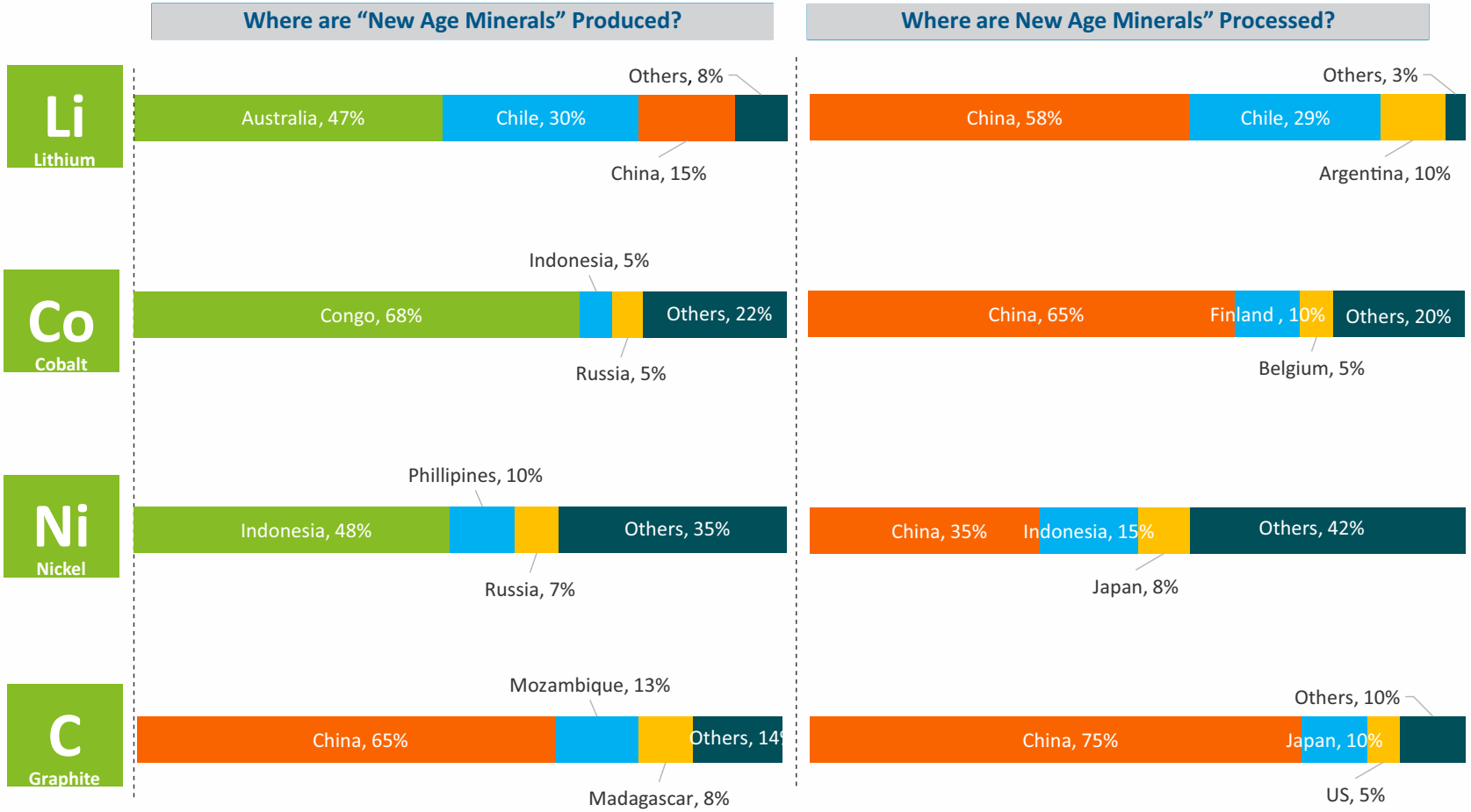


Source : USGS

Annexure 3: China's Dominance in Battery Energy



Battery Minerals: China's Dominance



Source : International Energy Agency

Notes

About FICCI

Established in 1927, FICCI is the largest and oldest apex business organisation in India. Its history is closely interwoven with India's struggle for independence, its industrialization, and its emergence as one of the most rapidly growing global economies.

A non-government, not-for-profit organisation, FICCI is the voice of India's business and industry. From influencing policy to encouraging debate, engaging with policy makers and civil society, FICCI articulates the views and concerns of industry. It serves its members from the Indian private and public corporate sectors and multinational companies, drawing its strength from diverse regional chambers of commerce and industry across states, reaching out to over 2,50,000 companies.

FICCI provides a platform for networking and consensus building within and across sectors and is the first port of call for Indian industry, policy makers and the international business community.

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