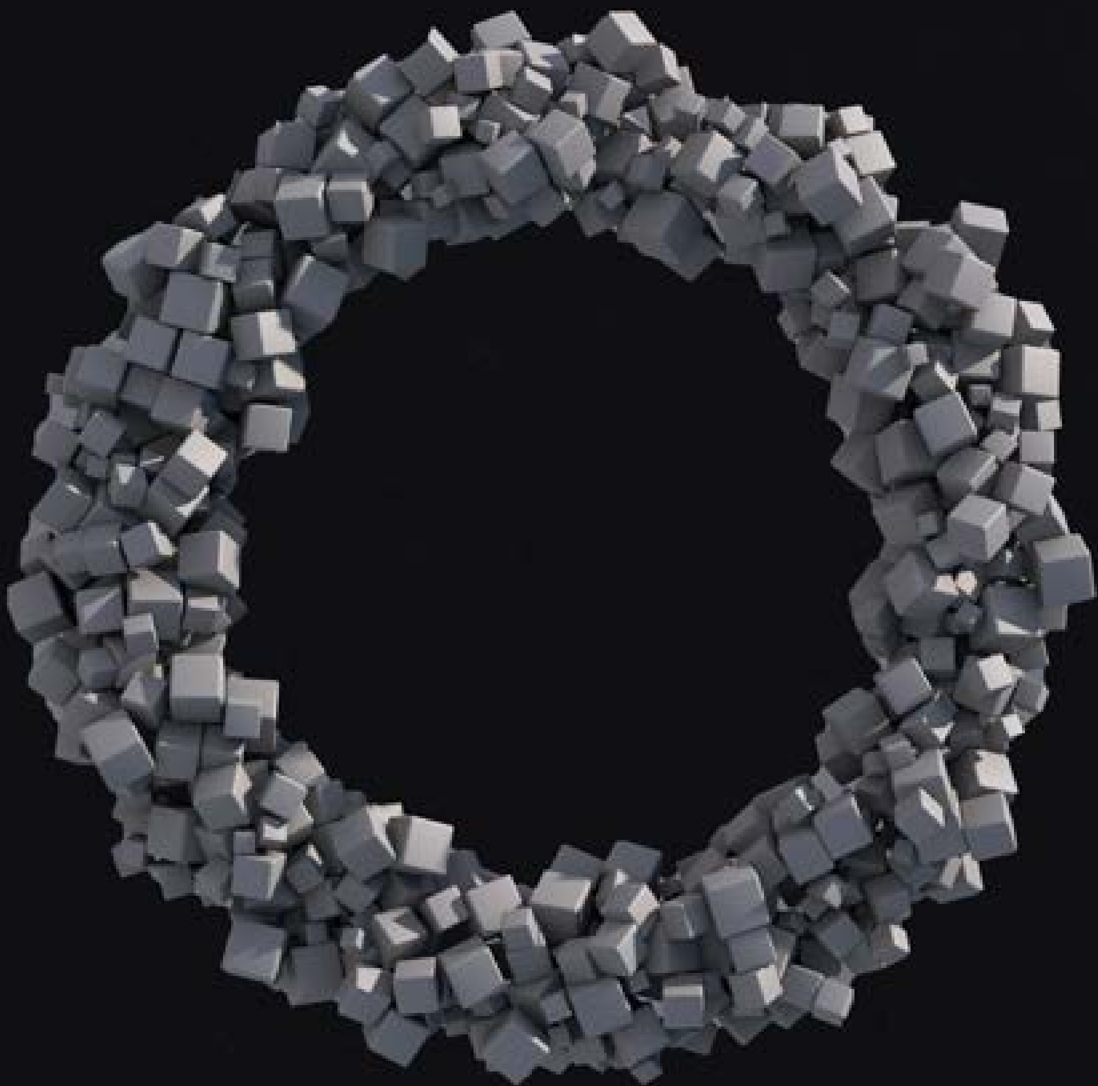
Deloitte.



REES 2024

Heavy minerals and lithium: Critical minerals for India's energy security

August 2024

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Acknowledgement

Rare Earth Association of India (REAI) and the Indian School of Mines Alumni Association (ISMAA) Kolkata chapter in association with the knowledge partner Deloitte, are pleased to present this comprehensive report on "Heavy Minerals and Lithium: Critical Minerals for India's Energy Security".

As India advances towards its vision of becoming a developed nation by 2047, the strategic importance of heavy minerals and lithium cannot be overstated. These critical minerals are fundamental to our nation's energy transition, technological advancement and economic growth during the Amrit Kaal period.

Despite India's considerable mineral wealth and the sector's immense growth potential, the country remains heavily dependent on imports for value-added products in heavy minerals and lithium. This dependency primarily arises due to limited domestic processing capabilities. The widening demand-supply gap driven by the rapidly rising demand for these minerals further underscores the urgent need for strategic interventions to tackle the challenge in the heavy and critical mineral space.

To achieve its "Make in India" goal, the government must build a robust downstream manufacturing of heavy and critical mineral industry. The industry is a key component of India's economic development due to its ability to create jobs, cater to the burgeoning needs of downstream industries, such as manufacturing and infrastructure and significantly boost fiscal growth.

Recognising this imperative, REAI ISMAA and Deloitte embarked on a mission to provide insights into what lies ahead. The "Heavy minerals and lithium – Critical minerals for India's energy security" is the culmination of this endeavour. REES and Deloitte have collaborated to understand the nuances of the heavy and critical minerals industry, unravel trends, address challenges and highlight opportunities that define the mining and metals industry narrative.

Foreword

Rajib Maitra
Partner, Deloitte India

The heavy minerals and lithium sector in India stands at critical crossroads, balancing the imperatives of sustainability and growth. As a key enabler in India's journey towards energy security and technological advancement by 2047, this sector is poised to play a pivotal role in meeting the nation's growing demand for critical minerals and supporting the clean energy transition.

The focus is on developing a robust, self-reliant industry capable of meeting domestic needs while positioning India as a global player in the heavy minerals and lithium value chain. To achieve this goal, the sector must embrace cutting-edge technologies and sustainable practices across exploration, extraction, processing and recycling.

As the industry stands on the brink of transformation, it must adopt innovative technologies to enhance efficiency, reduce environmental impact and optimise resource utilisation. The sector needs to strengthen its technological capabilities and competencies to meet these ambitious goals.

Recognising this imperative, REAI, ISMAA and Deloitte have collaborated to provide valuable insights into the future of heavy minerals and lithium in India. This report is the culmination of our partnership, offering a comprehensive analysis of industry trends, addressing key challenges and highlighting the technological opportunities that will shape the sector's transformation journey.

We hope you find this report insightful and valuable as you navigate the evolving landscape of India's heavy minerals and lithium industry, and its critical role in ensuring the nation's energy security and technological sovereignty.

Executive summary

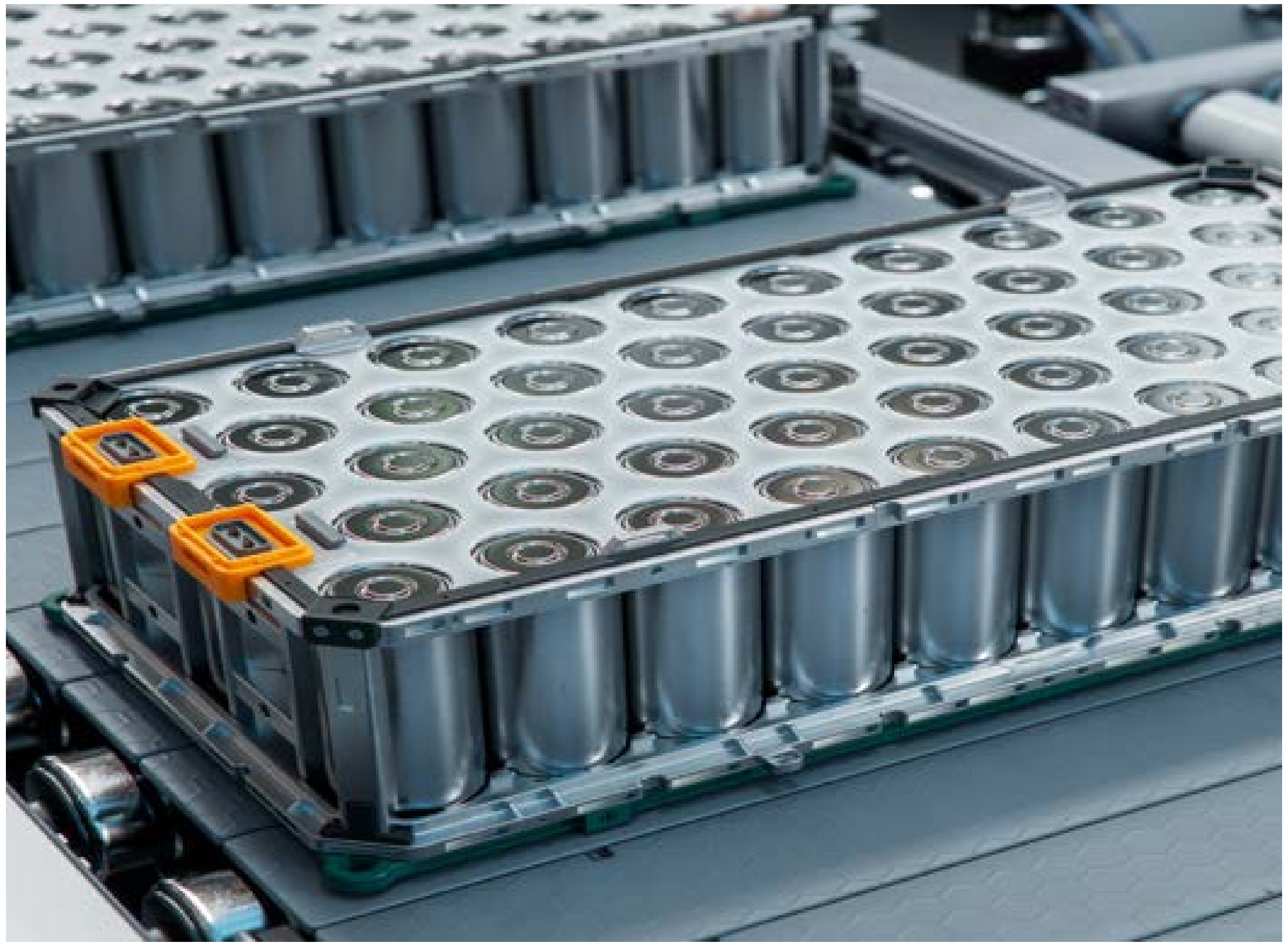
The surge in electric vehicle adoption, India's ambitious clean energy goals, and growth in infrastructure and construction have significantly increased the demand for heavy minerals and lithium. India has significant reserves of heavy minerals such as ilmenite, rutile, zircon, garnet and sillimanite but lacks adequate downstream processing facilities. This gap in processing capabilities leads to reliance on imports for these processed minerals. Recent discoveries of lithium have not reduced India's complete dependence on imports due to inadequate exploration and limited processing infrastructure. India must prioritise strategic exploration, incentivise private sector involvement, enhance supply chains, foster international partnerships and streamline regulatory processes to reduce this dependence.

The Indian government has made notable progress in the heavy mineral and lithium sectors in recent years. The National Critical Minerals Mission aims to address the entire supply chain, from domestic production to recycling, reflecting the government's commitment to reduce import dependence and achieve sustainability goals. The government has also rationalised and approved new royalty rates for mining of 24 critical and strategic minerals, including lithium, to encourage both mining and private sector participation. The auction of 38 critical mineral blocks across three tranches and the move to fully exempt 25 critical minerals from custom duties, along with reducing Basic Custom Duties (BCD) on two of them, in the Union Budget 2024–25 are expected to further boost the industry growth.

Technological advancements in the heavy minerals and lithium value chains are being driven by the strong push on sustainability and a rising demand for these minerals. Innovations such as Direct Lithium Extraction (DLE) technology are making lithium extraction more sustainable and efficient by reducing processing times. Exploration techniques have advanced with the integration of Artificial Intelligence (AI) and machine learning, improving the accuracy of mineral identification. For example, AI-integrated remote sensing technologies have been effectively used in Australia to discover new mineral deposits, significantly cutting exploration time and costs. Advancements in recycling technologies for lithium-ion batteries and the implementation of urban mining frameworks are promoting a circular and sustainable approach to mineral resource management. These technological developments could enhance the global supply of heavy minerals and lithium by bridging the demand-supply gap and supporting industry growth.

Looking towards 2047, India should focus on establishing a robust policy framework to ensure sustainable and strategic use of heavy minerals and lithium. In the short to medium term, the country should prioritise comprehensive geological surveys and strategic mineral exploration with the help of advance technologies. Encouraging private sector participation through incentives such as Production Linked Incentives (PLI) and tax breaks will be crucial for developing processing and refining units. Establishing Special Economic Zones (SEZs) and fostering international collaborations will help integrate the supply chain from mining to end-product manufacturing. For long term, India should invest in recycling technologies and urban mining frameworks to support a circular economy. Developing dedicated research institutes and promoting sustainable mining practices will strengthen the industry's growth in an environmentally responsible manner.

India has the potential to become a global leader in heavy minerals and lithium by prioritising sustainable practices, strategic investments and innovation-driven growth. Achieving a resilient and self-reliant mineral industry will allow India to meet domestic needs and contribute significantly to the global supply chain, aligning with its long-term economic and environmental objectives.



Introduction

The world is rapidly shifting towards sustainable clean energy and there is a growing focus on battery and heavy minerals. These minerals are essential for various high-tech applications, including renewable energy technologies, advanced industrial processes and defence systems. Countries such as Australia, China, South Africa, the United States, Brazil and India are leading the way and substantially contributing to the supply of these essential minerals.[1]

Global policy trends for heavy minerals and lithium have intensified in recent years, as several countries aim to introduce or update critical mineral lists to secure supply chains and support clean energy transitions. The United States expanded its critical minerals list from 35 to 50 in 2022,[2] while Australia launched its Critical Minerals Strategy in 2022.[3] Canada introduced The Canadian Critical Minerals Strategy in 2022[4] and the European Union proposed the Critical Raw Materials Act in 2023.[5] India, recognising the strategic importance of these minerals, identified a list of 30 critical minerals in 2023.[6] These initiatives aim to identify strategically important minerals, guide investment and inform policy decisions to ensure sustainable supplies for the future. Key global partnerships have emerged focusing on the responsible development of critical mineral supply chains.[7] These include the MSP led by the US, which includes 14 countries and the EU. Many countries recognise lithium, cobalt and REE as the most critical minerals. In addition, titanium, also recognised as a critical mineral is primarily produced from heavy minerals such as ilmenite and rutile.

[1]https://www.verifiedmarketreports.com/product/heavy-minerals-market/
[2]https://www.usgs.gov/news/national-news-release/us-geological-survey-releases-2022-list-critical-minerals
[3]https://www.australiaminerals.gov.au/__data/assets/pdf_file/0008/120797/2022-critical-minerals-strategy.pdf
[4]https://www.canada.ca/en/campaign/critical-minerals-in-canada/canadian-critical-minerals-strategy.html
[5]https://erma.eu/european-raw-materials-alliance-for-a-more-resilient-and-greener-europe/
[6]https://pib.gov.in/PressReleaseIframePage.aspx?PRID=2035583

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Heavy minerals and lithium are essential to India's energy security, underpinning advanced technologies and strategic applications. Minerals such as ilmenite and rutile are essential for producing TiO_2, which is widely used in aerospace, defence and renewable energy technologies. Lithium, a key component in lithium-ion batteries, is essential for powering EVs and large-scale ESS.

India's ambitious clean energy targets, which are driving the rapid growth of EVs and ESS, have significantly increased the demand for heavy minerals and lithium. Despite having resources, India is dependent on imports of lithium. In addition, there is a lack of adequate downstream facilities for heavy minerals, enhancing dependence on imports of processed products. Given the geopolitical sensitivity of lithium and its importance for energy security, India needs to develop domestic capabilities in mining, processing, extraction and refining.

The list of 30 critical minerals is important for India's national security and economic growth.[8] In addition, the recent government policies also encourage private sector participation for improved exploration, production and rationalisation of royalty rates and pricing of 24 critical and strategic minerals.

So far, the government has launched 38 critical mineral blocks across two separate tranches for auction and a third tranche which consisted of the recycled blocks from the first tranche. The first three tranches of the auction garnered significant interest from bidders.[9]

The government has introduced the National Critical Minerals Mission to address the entire supply chain of essential minerals, from domestic production to recycling. In the Union Budget 2024–25, a complete exemption on BCD of 25 critical minerals has been announced.

The government has announced the first offshore mineral block auction under the newly introduced Offshore Areas (Existence of Mineral Resources) Rules, 2024. It focuses on critical minerals such as cobalt and nickel, which are essential for manufacturing low-carbon technologies that generate, store and transmit clean energy. The identified 10 mineral blocks are located in India's EEZ.

[7]https://www.state.gov/minerals-security-partnership/
[8]https://pib.gov.in/PressReleasePage.aspx?PRID=1942027
[9]https://pib.gov.in/PressReleaseIframePage.aspx?PRID=2027954

Global perspective

The global demand for heavy minerals and lithium is increasing, driven by key industries such as aerospace, defence, construction, automotive and renewable energy.

Lithium:

Globally, lithium is found in four types of deposits namely brines, pegmatite, clay and zeolite. Lithium is traded in three forms: mineral concentrates, mineral compounds and refined metal. About 64 percent of lithium deposits are found in brine sources followed by 26 percent in pegmatite and remaining 10 percent in clay and zeolites. Worldwide lithium resources are estimated to be more than 39 Mt.[10]

More than 75 percent of the world's lithium resources , in the form of brine are concentrated in the South American region comprising Argentina, Bolivia and Chile.

Chile has the largest lithium reserves with 9.3 Mt, primarily extracted from brine in the Salar de Atacama. Australia follows with 6.2 Mt, mostly obtained from hard rock spodumene deposits.

[10]USGS report - Critical Mineral Resources of the United States—Economic and Environmental Geology and Prospects for Future Supply

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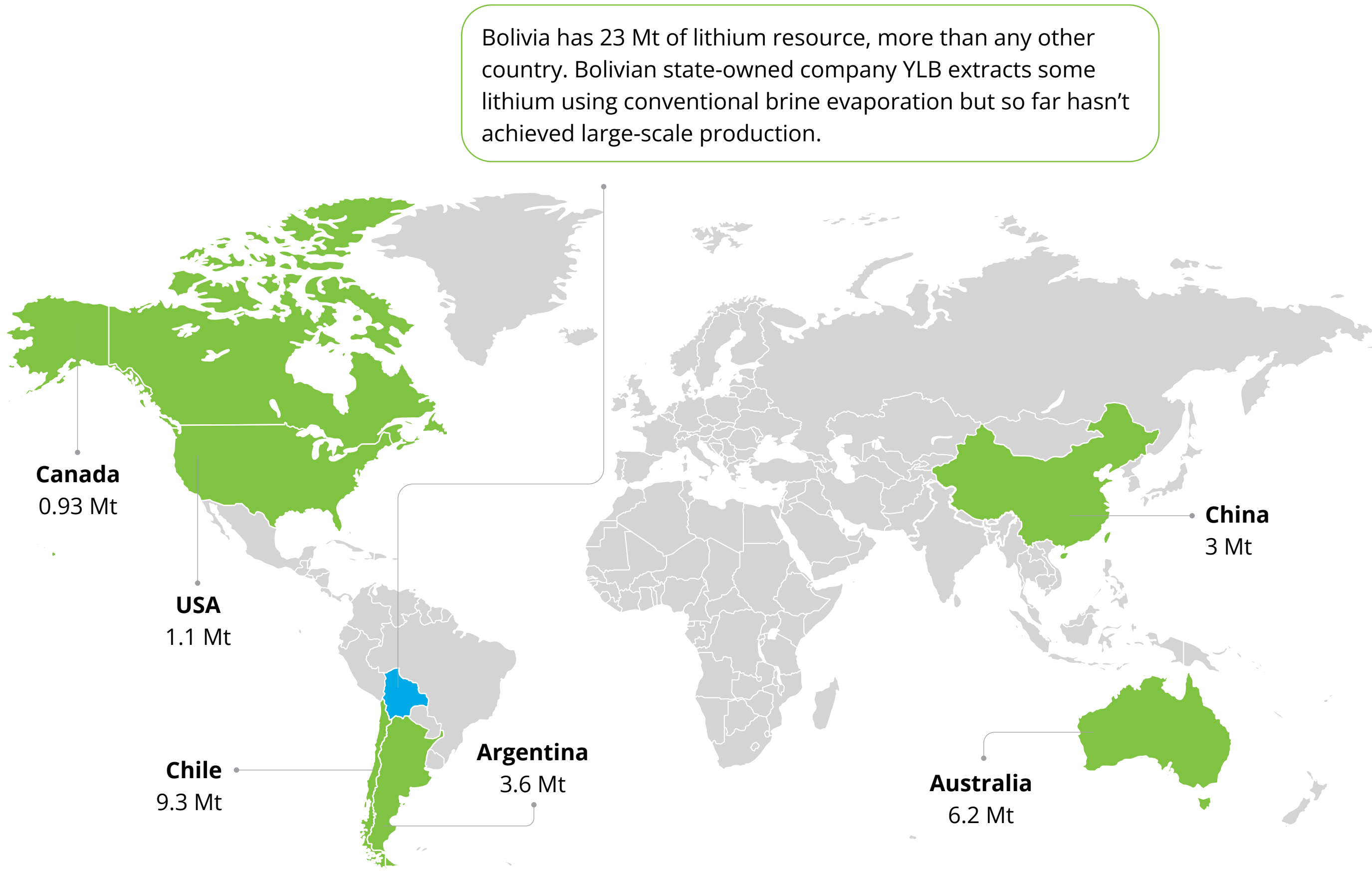
Figure 1: Worldwide lithium reserves[11]



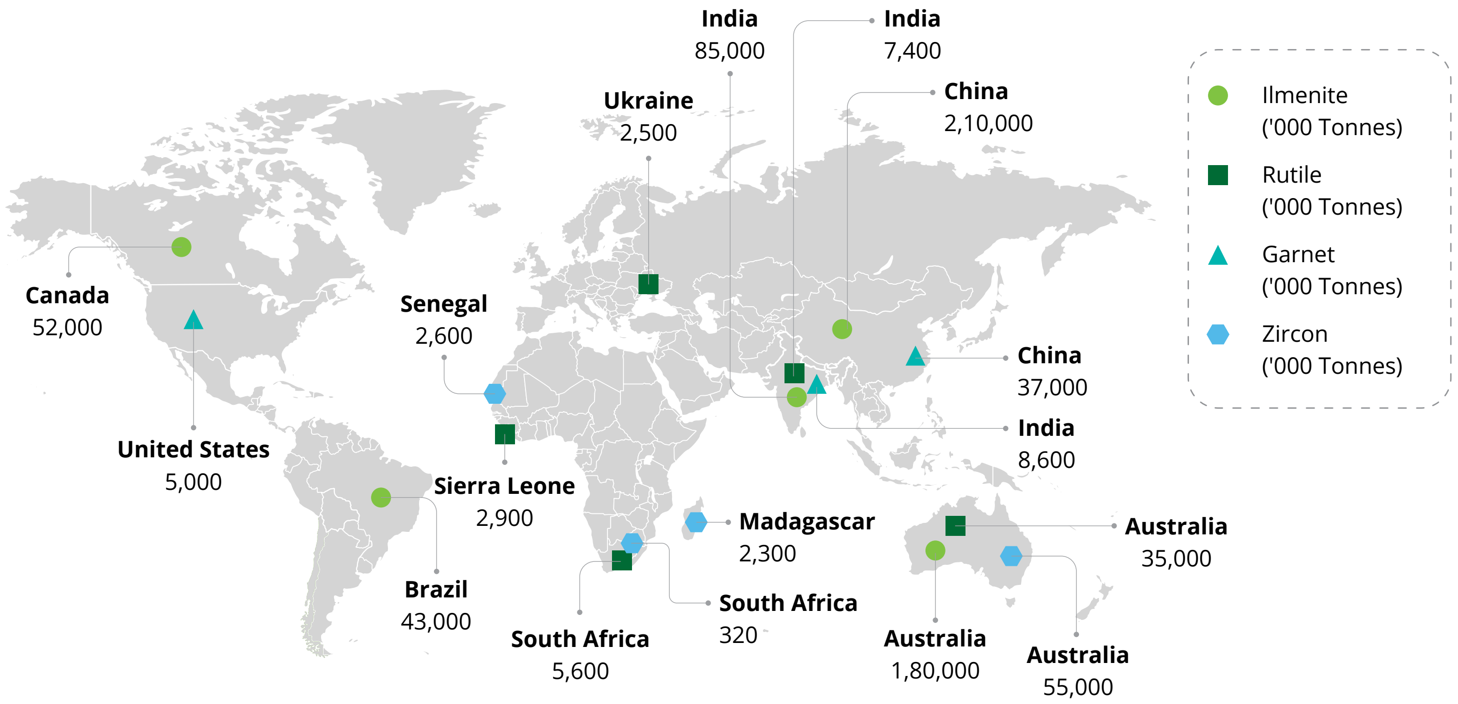
Heavy minerals:

Heavy minerals are primarily extracted from mineral sand deposits typically found in coastal environments formed by the mechanical concentration of these minerals due to their high specific gravity. These mineral sand deposits are found in more than 45 countries, with major deposits in Australia, Asia and Africa, particularly along the Indian Ocean's coastal regions.

Australia, South Africa and India host extensive heavy mineral sand deposits, which are rich in ilmenite, rutile and zircon.[12] China contains more than 200 known coastal heavy mineral sand deposits[13], especially along the eastern and southern coasts.[14] The United States and Canada have significant deposits in riverbeds and coastal areas, including rocky deposits, which contain similar key minerals.

[11]FICCI New Age Minerals
[12]https://ibm.gov.in/writereaddata/files/168319673064538b3a8794ellmenite_Rutile_2021.pdf
[13]https://www.usgs.gov/publications/heavy-mineral-sands-resources-china
[14]Heavy mineral sands and resources in China (USGS Publication)

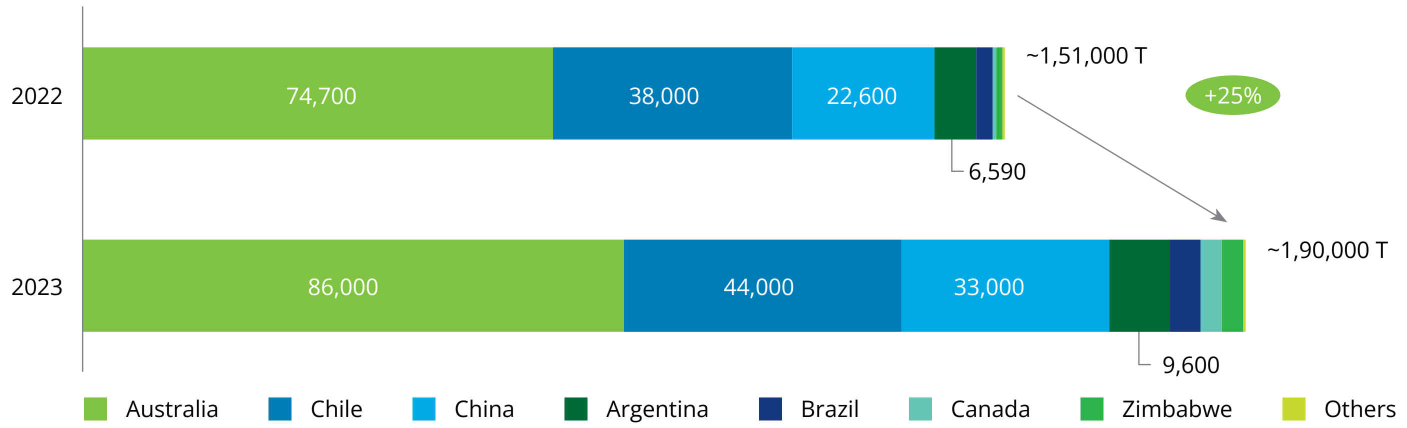
Figure 2: Country-wise heavy mineral reserves[15]



The rise and demand for heavy minerals and lithium

In 2023, global lithium consumption was estimated at 165 kt[16] and is projected to grow at a compound annual growth rate (CAGR) of 17.7 percent from 2024 to 2030. This growth is attributed to the global shift towards sustainable energy solutions and the electrification of transportation.[17] In 2023, the global production of Lithium was ~0.19 Mt, with Australia leading the production.[18]

Figure 3: Country-wise share of lithium production (in tonnes)[19]

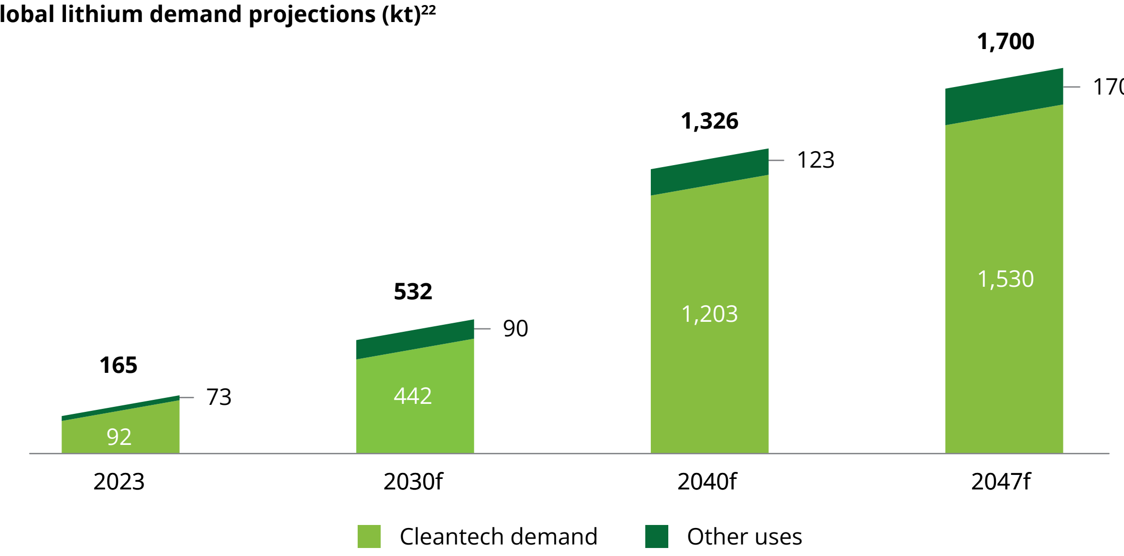


[15]USGS Mineral Commodity Summaries 2024
[16]https://www.iea.org/reports/global-critical-minerals-outlook-2024
[17]https://www.grandviewresearch.com/industry-analysis/lithium-market
[18, 19]USGS 2024: Lithium

The global production is dominated by Australia, Chile and China accounting for ~86 percent of the total lithium production in 2023.[20,21]

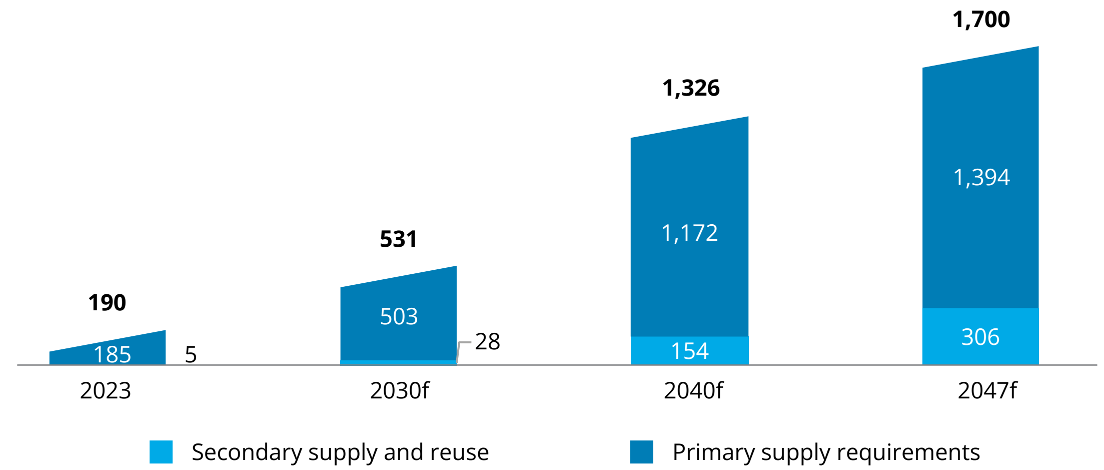
The production of lithium has been steadily increasing to meet the growing demand driven by the expansion of EVs and renewable ESS. This increase in demand is expected to increase tenfold from the current demand of 165 kt to 1,700 kt in 2047.

Figure 4: Global lithium demand projections (kt)[22]



Lithium supply is projected to grow significantly from secondary sources, including battery recycling. The supply from secondary sources is anticipated to grow from 4–6 kt in 2023 to 300–320 kt in 2047 with advancements and adoption of battery recycling technologies.

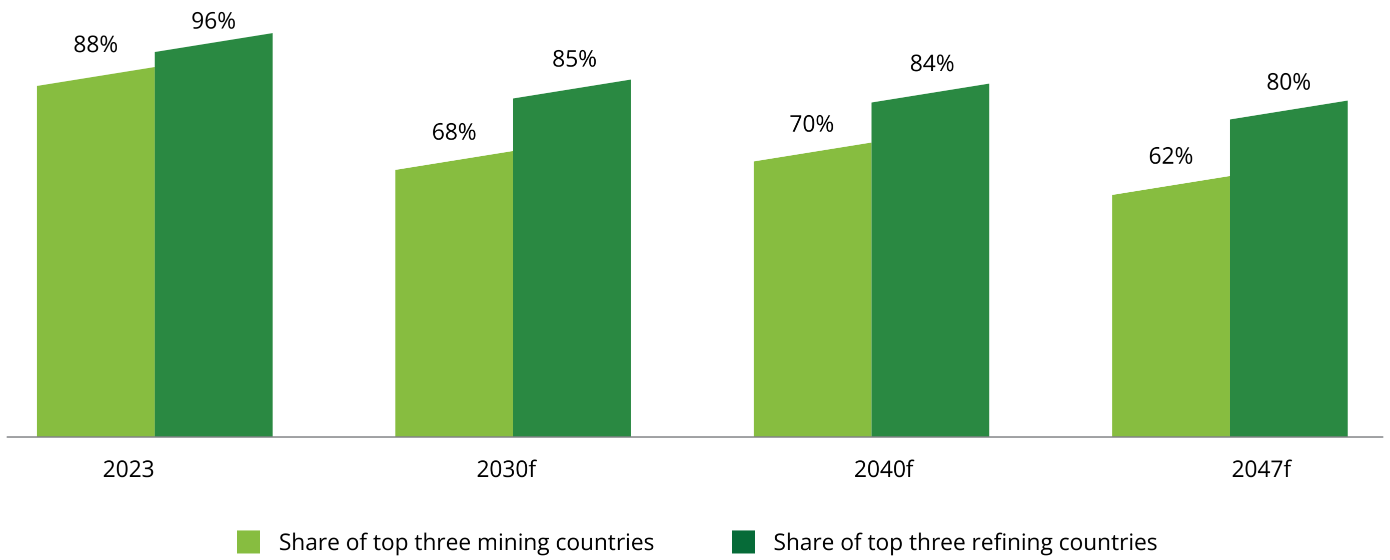
Figure 5: Global lithium supply projections (kt)[23]



The share of the top three lithium mining and refining countries is expected to reduce with the emergence of new producers, such as Bolivia. This shift will diversify the supply chain, reduce reliance on a few key players and could help stabilise global lithium prices.

[20]USGS 2024 Lithium,
[21]Lithium production of USA estimated to be 5000 t, https://www.cnbc.com/2022/10/14/lithium-for-tesla-evs-batteries-touring-silver-peak-nevada-.html
[22]https://evmarketsreports.com/lithium-demand-soars-as-electric-vehicle-industry-accelerates/
[23]https://evmarketsreports.com/lithium-demand-soars-as-electric-vehicle-industry-accelerates/

Figure 6: Projected share of top three lithium producing and refining countries[24]

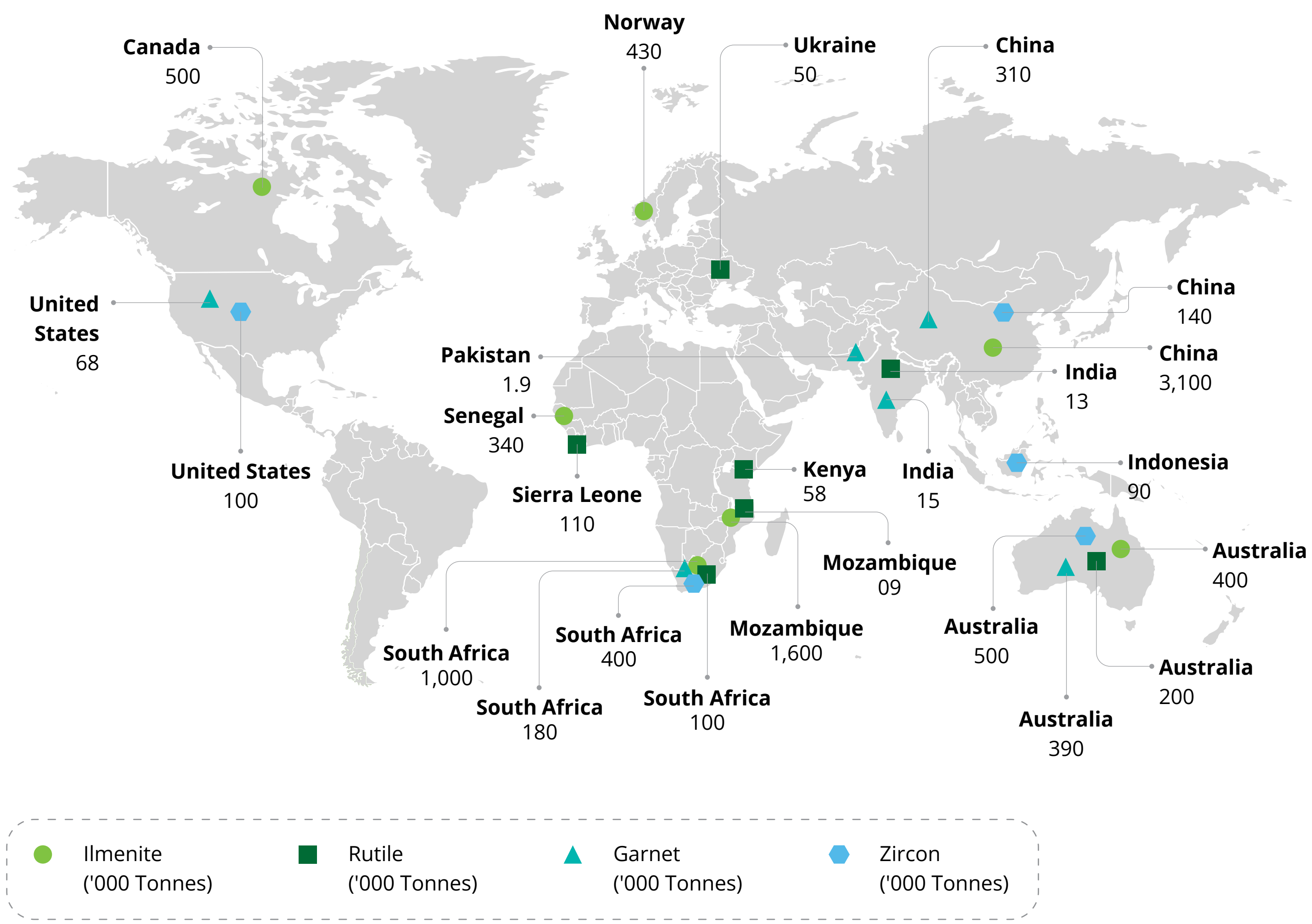


Globally, there is a short-term supply surplus of lithium. This surplus is driven by the withdrawal of China's decade-long EV subsidy programme[25] and weaker-than-anticipated global EV sales.[26] This led to a significant drop in lithium prices in 2023. However long term, projections indicate that this oversupply will be short-lived, and the demand-supply mismatch will start to stabilise from 2027 onwards.[27]

[24]https://www.iea.org/reports/lithium
[25]https://dialogue.earth/en/digest/china-ends-electric-vehicle-subsidies/
[26]https://www.goldmansachs.com/insights/articles/why-are-ev-sales-slowing
[27]https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/metals/040423-global-lithium-demand-seen-outpacing-production-in-2023-oce
[28]https://www.marketresearchintellect.com/product/global-heavy-minerals-market/

The global heavy minerals market, valued at US$35 billion in 2023, is projected to grow at a CAGR of ~7.4 percent from 2024 to 2030.[28] The Asia-Pacific region is dominating due to rapid industrialisation and infrastructure development. Australia and South Africa dominate the global heavy mineral production landscape, collectively accounting for more than 3 Mt annually.

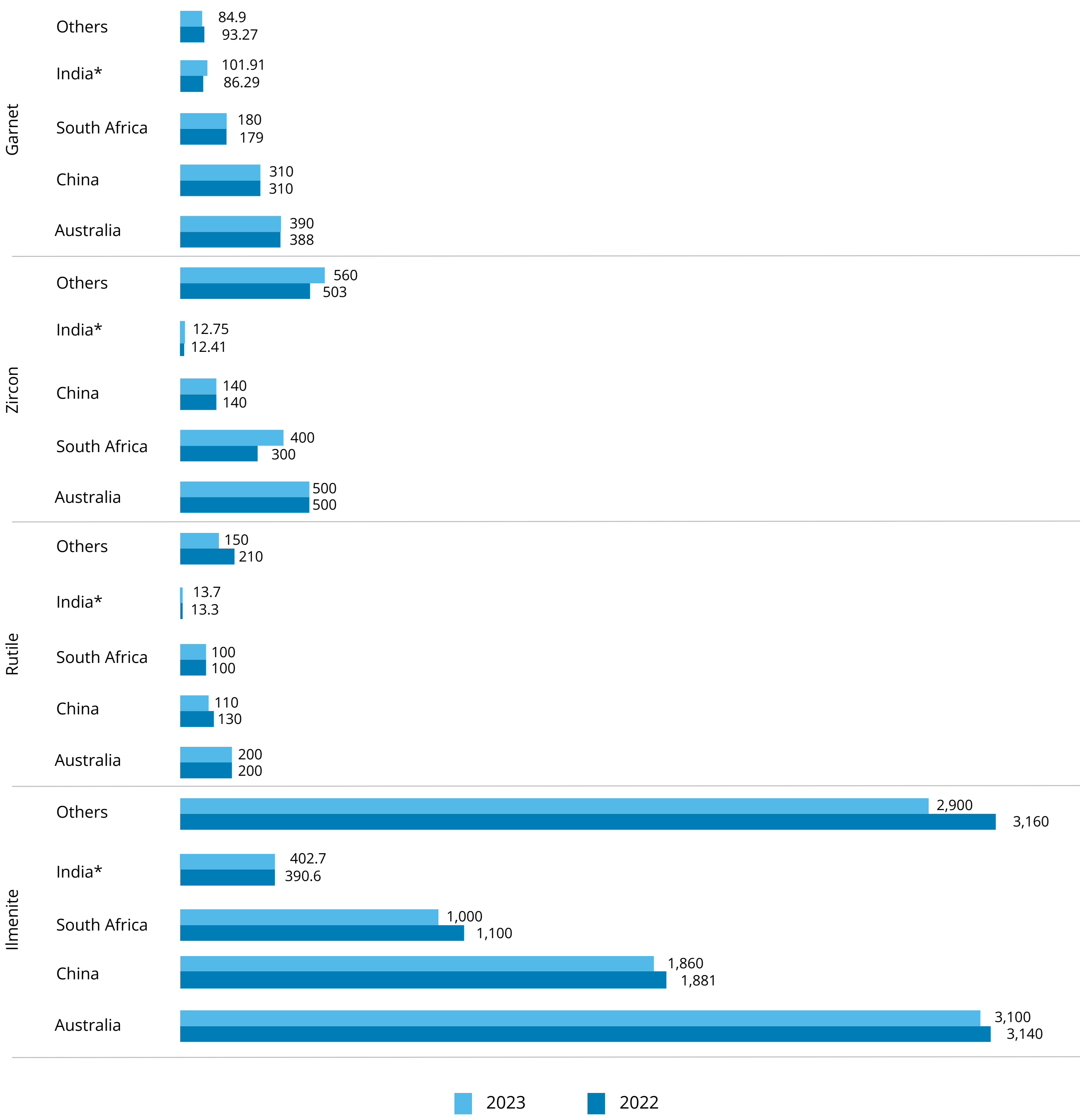
Figure 7: Country-wise heavy mineral production (2023)[29]



Emerging producers such as Mozambique have displayed good growth in heavy mineral production. Whereas major producers have not matched this pace of growth. Specifically, Australia's heavy mineral production has remained stable, while South Africa has experienced only a slight increase.

[29]USGS 2024

Figure 8: Country-wise production trend of heavy minerals[30] (kt)



*Data for India in FY

[30]USGS Mineral Commodity Reports
[31]https://finance.yahoo.com/news/titanium-reserves-country-10-biggest-155049656.html?
[32]https://sierra-rutile.com/rutile/

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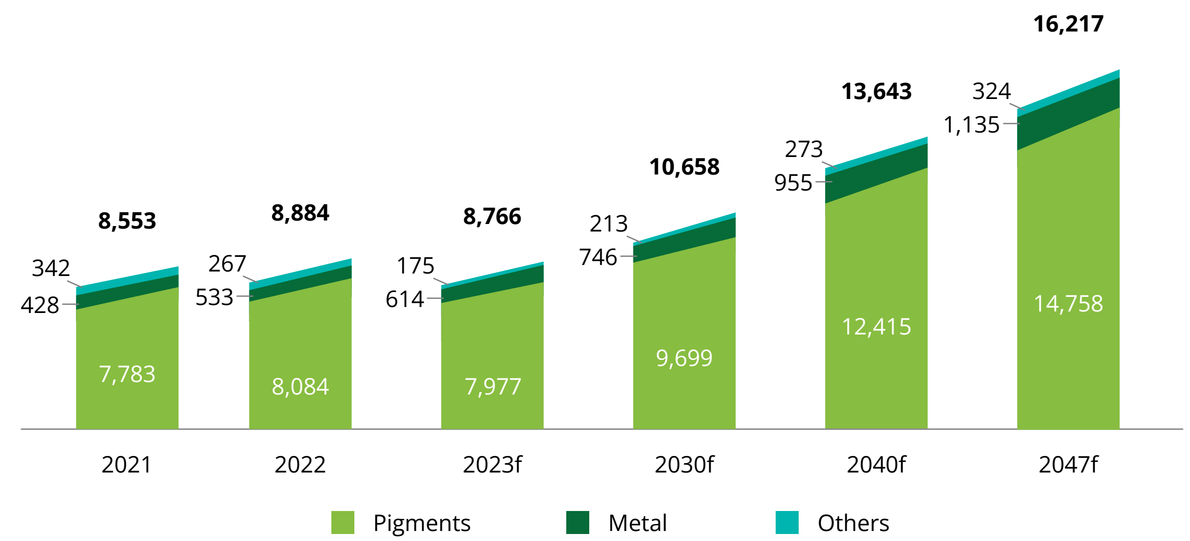
Demand outlook for heavy minerals

Ilmenite and rutile

The demand for titanium feedstocks, mainly ilmenite and rutile, is expected to increase due to their use in pigments. Ilmenite makes up about 90 percent of global titanium mineral consumption.[31] Meanwhile, rutile, with its high TiO_2 content of ~95 percent, plays a crucial role in meeting this rising demand.[32]

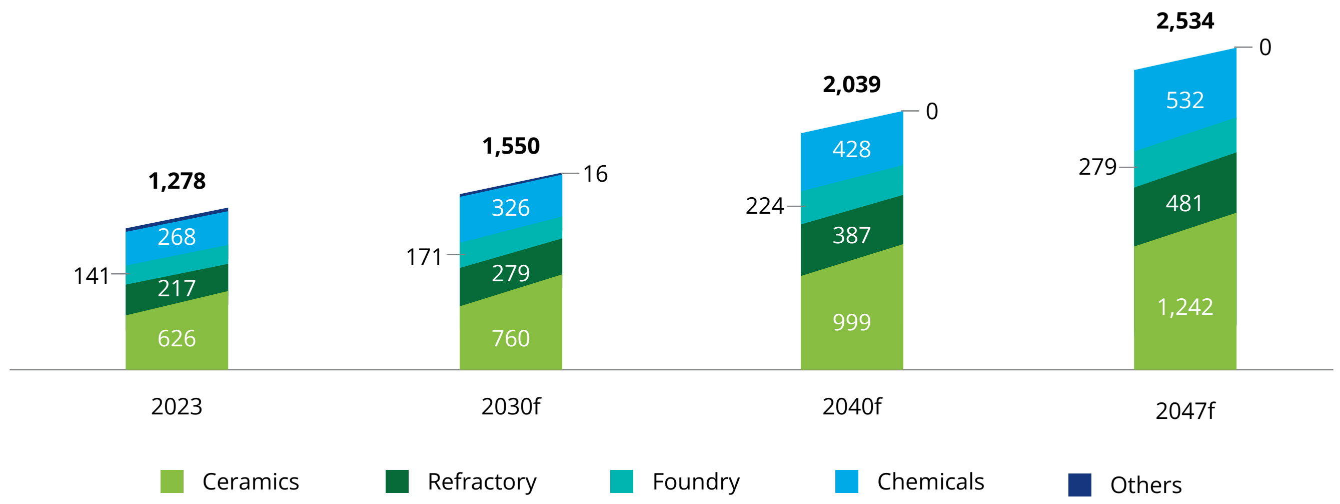
Figure 9: Demand outlook for titanium feedstock[33] (kt)



Zircon

The demand for Zircon is expected to rise from 1,278 kt in 2023 to 2,534 kt by 2047. A significant portion of this growth is found in the ceramics sector, which is expected to see a demand increase of 1,242 kt.

Figure 10: Demand outlook for zircon (kt)

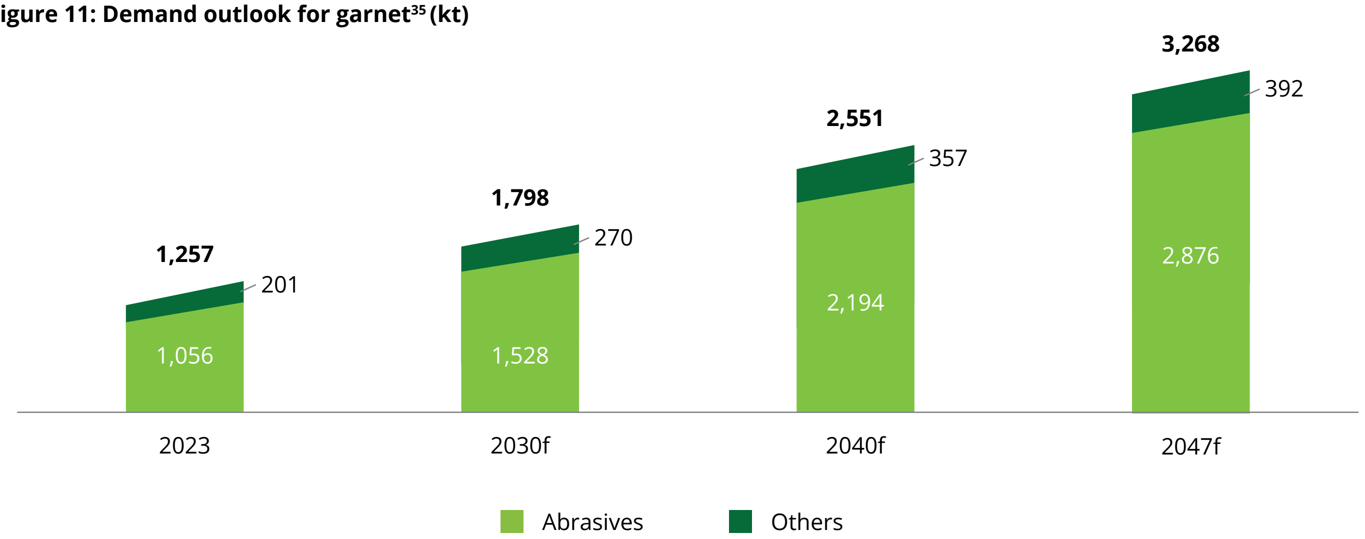


[33]https://www.astronlimited.com.au/wp-content/uploads/2023/04/20230426-Definitive-Feasibility-Study.pdf
[34]https://www.astronlimited.com.au/wp-content/uploads/2023/04/20230426-Definitive-Feasibility-Study.pdf

Garnet

The demand for garnet will be driven by an increase in infrastructure spending and the adoption of water jet-cutting technology. The total demand is expected to rise from 1,257 kt in 2023 to 3,268 kt by 2047. The majority of this demand will be for abrasives, which are expected to grow from 1,056 kt in 2023 to 2,876 kt in 2047.

Figure 11: Demand outlook for garnet[35] (kt)



The market landscape for these minerals is highly dynamic and rapidly evolving, with countries increasingly recognising the strategic importance of heavy minerals and lithium. Governments worldwide have identified minerals critical to their economies and implemented diverse policies to secure stable supplies, reduce dependencies and position themselves advantageously in the evolving market. Among the most critical minerals globally are lithium, cobalt and REEs (found in heavy minerals such as monazite).

[35] https://www.astronlimited.com.au/wp-content/uploads/2023/04/20230426-Definitive-Feasibility-Study.pdf

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Table 1: Global policy analysis

Country	Key policies
United States	• In 2018, the U.S. Department of the Interior identified 35 critical minerals, updating the list to 50 in 2022.[36] • The Energy Act of 2020, Bipartisan Infrastructure Law, CHIPS and Science Act, and Inflation Reduction Act allocated more than US$8.5 billion to critical minerals activities.[37] • In 2022, MSP was announced, which is a collaboration of 14 countries and the European Union to catalyse public and private investment in critical minerals supply chains globally.[38]
Australia	• Launched its Critical Minerals Strategy in 2022 to boost the sector and attract investment.[39] In June 2023, the country released a new Critical Minerals Strategy for 2023–2030.[40] • The Modern Manufacturing Initiative, introduced in 2021, aims to provide grants for critical minerals processing projects.[41]
Canada	• In 2022, Canada introduced the Canadian Critical Minerals to increase the supply of critical minerals and support the development of domestic and global value chains.[42] • Provides funding for critical minerals projects through its Strategic Innovation Fund.[43]
European Union	• In 2020, the EU launched the European Raw Materials Alliance to ensure access to critical and strategic raw materials.[44] • In 2023, it introduced the Critical Raw Materials Act to secure the EU's supply of critical raw materials.[45]
China	• "Made in China 2025" industrial policy includes plans to secure critical mineral supplies.[46] • Implemented export restrictions, including export quotas and taxes on certain critical minerals to maintain its dominant position in the global critical minerals supply chain.[47]
India	• In the 2024 budget, India announced the National Critical Mineral Mission, which aims to enhance domestic production, recycling and overseas acquisition of critical minerals.[48] The country introduced customs duty exemptions on 25 critical minerals, including lithium.[49] • It established a major joint venture company (comprising key domestic mining firms) to explore opportunities for the acquisition of overseas critical minerals assets such as lithium.[50]
Chile	• In 2023, Chile announced the "National Lithium Strategy", which includes plans for a state-owned lithium company and public-private partnerships for new lithium contracts.[51]
Bolivia	• In 2017, Bolivia set up the public company YLB to oversee the production chain of lithium. • In 2023, the country partnered with a Chinese consortium, to construct two lithium plants using advanced DLE technology.[52]

[36] https://www.usgs.gov/news/national-news-release/us-geological-survey-releases-2022-list-critical-minerals
[37] https://bipartisanpolicy.org/blog/expanding-us-critical-mineral-supply/
[38] https://www.state.gov/minerals-security-partnership/
[39] https://www.australiaminerals.gov.au/__data/assets/pdf_file/0008/120797/2022-critical-minerals-strategy.pdf
[40] https://www.industry.gov.au/publications/critical-minerals-strategy-2023-2030
[41] https://business.gov.au/grants-and-programs/modern-manufacturing-initiative-manufacturing-integration
[42] https://www.canada.ca/en/campaign/critical-minerals-in-canada/canadian-critical-minerals-strategy.html
[43] https://www.iea.org/policies/18024-strategic-innovation-fund
[44] https://erma.eu/european-raw-materials-alliance-for-a-more-resilient-and-greener-europe/
[45] https://ec.europa.eu/commission/presscorner/detail/en/ip_23_1661
[46] https://www.goldmansachs.com/insights/articles/resource-realism-the-geopolitics-of-critical-mineral-supply-chains
[47] https://www.sciencedirect.com/science/article/abs/pii/S0301420715001002
[48] https://pib.gov.in/PressReleaseIframePage.aspx?PRID=2035583
[49] https://timesofindia.indiatimes.com/business/india-business/budget-2024-fm-announces-exemption-of-customs-duty-on-critical-minerals/articleshow/111952629.cms
[50] https://kabilindia.in/
[51] https://investmentpolicy.unctad.org/investment-policy-monitor/measures/4305/chile-launches-a-new-national-strategy-for-lithium
[52] https://www.crugroup.com/knowledge-and-insights/insights/2024/can-catl-kickstart-bolivia-s-lithium-industry/

The growth drivers and policy landscape changes indicate a positive trajectory for the overall heavy minerals and lithium consumption outlook. However significant challenges may hinder this growth. Innovation and the adoption of advanced mining and processing technologies are expected to be the key differentiators for success in producing geographies, such as India.

Table 2: Industry challenges and mitigation strategies

Challenge	Detail	Mitigation strategies
Regulatory and environmental pressures	Stringent environmental and safety regulations increase operational costs.	Adopt comprehensive environmental management systems, use low-impact mining techniques and invest in continuous monitoring and reporting.
High operational costs and market volatility	Energy-intensive processes and price fluctuations happen due to global demand and geopolitical tensions.	Diversify energy sources, invest in renewable energy to reduce carbon costs and enter long-term supply contracts to stabilise costs.
Depletion of high-quality resources	Need for exploration of remote areas and use of lower-grade ores.	Invest in advanced exploration technologies, recycle and develop alternative sources.
Geopolitical tensions and supply chain disruptions	Concentration of production in specific regions makes supply chains vulnerable.	Develop strategic partnerships, diversify supply sources and invest in local processing facilities.
Technological and innovation challenges	High costs and expertise required for adopting new technologies for efficiency and sustainability.	Collaborate with research institutions, invest in R&D and adopt best practices from other industries.

Disruptive technologies and innovations for exploration, mining and processing

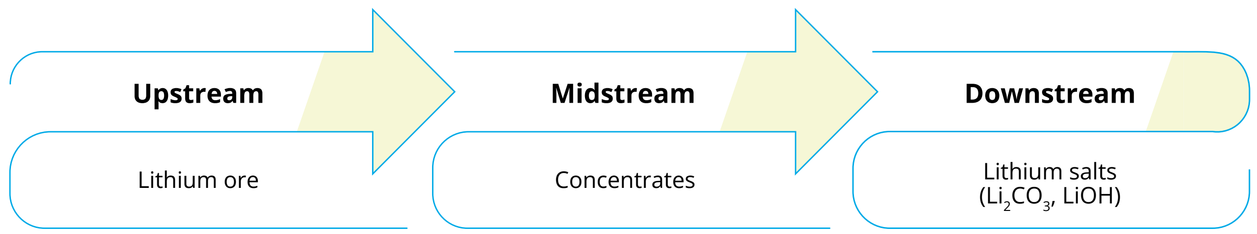
The exploration, mining and processing of lithium and heavy minerals have seen significant advancements through disruptive technologies and innovations. These aim to improve efficiency, reduce environmental effects and meet the growing demand for these essential resources.

Lithium

Current technologies available for the exploration, mining and processing of lithium

The lithium value chain begins with exploration and extraction (upstream), followed by ore concentration (midstream), and then the processing of concentrates into refined products such as lithium carbonate (Li_2CO_3) and lithium hydroxide (LiOH).

Figure 12: General lithium value chain



The exploration and extraction of lithium have traditionally relied on methods, such as geophysical surveys, drilling boreholes and open-pit mining. Survey methods such as gravity surveys, magnetic surveys, electrical surveys and sounding have been successfully used to identify some lithium deposits across China and India. The extraction of lithium has two major sources in the form of pegmatite and brine. Among all pegmatites, spodumene (a lithium aluminum silicate) is considered to be a major source of lithium.

Table 3: Technologies in lithium mining

Deposit type	Presence in India	Mining method	Processing technologies	Technology supplying country
Clay	☑	Open-pit mining followed by acid leaching or roasting with sulfuric acid to extract lithium from clay minerals	Acid-leaching DLE Chemical precipitation	Canada
Brine	☒	Pumping of lithium-rich brines from underground reservoirs into evaporation ponds, followed by concentration and chemical processing to extract lithium	DLE Electro-chemical process	France, Canada, USA
Pegmatites	☑	Hard-rock deposits typically extracted through open-pit or underground mining, followed by ore crushing, concentration and chemical processing (often involving roasting and leaching) to obtain lithium	Hard rock lithium technology Electric kiln technology Alkaline leach process	Finland, Canada, Australia
Lepidolite	☑	Lepidolite, such as pegmatites, mined via open-pit or underground methods and processed using techniques such as flotation, acid extraction, alkali extraction or salt roasting, followed by leaching to recover lithium	L-Max, L-OH Max Lithium extraction from mica through sulfate method	Australia, United Kingdom

Innovations in the exploration, mining and processing of lithium

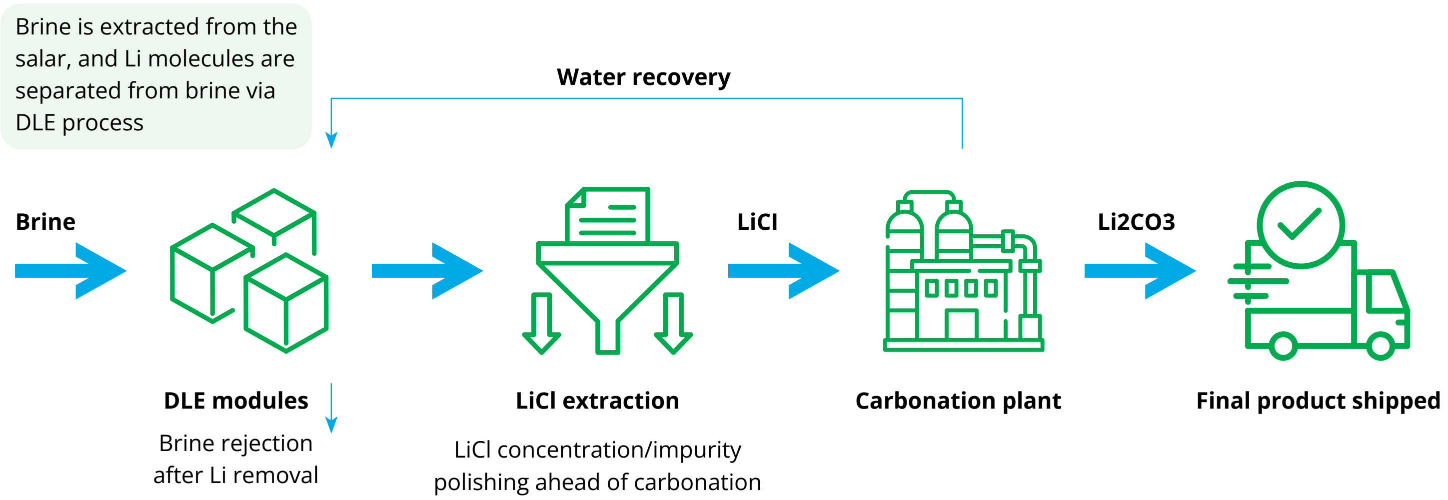
Emerging technologies, such as Audio-frequency Magneto-Telluric (AMT) and Magneto-telluric are effective in exploring lithium deposits in pegmatite and brine formations, respectively. For instance, Magneto telluric surveys have successfully identified lithium deposits in the Andean Plateau, while AMT has been employed in the Chinese Altai orogenic belt.

For on-site geochemical analysis, advanced handheld technologies such as LIBS and ICP-MS are used to assess lithium content in geological samples. Another breakthrough, ANT or "Exosphere," provides 3D subsurface mapping and has helped Core Lithium Exploration in Australia find new pegmatites.

In addition, ANNs have proven effective in exploration, as demonstrated in the Bajoca Mine, Portugal, where they successfully identified lithium ore bodies.

Exchange innovations such as DLE technologies are implemented to increase the efficiency of lithium production and reduce the environmental impact of traditional extraction methods. DLE is an efficient and environmentally friendly alternative to traditional evaporation pond methods. It uses techniques such as adsorption, ion exchange and membrane filtration to selectively extract lithium from brine, significantly reducing water usage. Companies such as Summit Nanotech and Lilac Solutions are pioneering these technologies, which promise to deliver higher yields and faster processing times.[53,54]

Figure 13: Schematic showing Direct Lithium Extraction



Geothermal brine recovery,[55] another notable advancement, uses naturally occurring hot water reservoirs rich in lithium. This method involves extracting the brine, harnessing its heat for power generation and then recovering lithium through DLE or similar techniques. This approach is sustainable, minimises environmental impact and offers economic benefits by integrating lithium extraction with geothermal power plants.

Another recent innovation is the use of adsorption-coupled electrochemical technology, which improves lithium extraction efficiency by using specialised adsorbents to capture lithium ions. These are then released through electrochemical desorption. This method ensures high purity and energy efficiency and applies to both brine extraction and recycling of lithium ion batteries.[56]

[53]https://www.reuters.com/markets/commodities/dle-companies-racing-reshape-global-lithium-production-2023-06-16/
[54]https://spectrum.ieee.org/direct-lithium
[55]https://www.energy.gov/eere/geothermal/articles/can-geothermal-energy-solve-lithium-shortfall
[56]https://www.sciencedirect.com/science/article/pii/S2666790824000296#:~:text=Adsorption%2Dcoupled%20electrochemical%20technology%20represents,and%20 renewable%20energy%20storage%20systems.

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Case studies

A direct lithium extraction project in the southern United States was spearheaded by an American lithium producer.

This project, led through a JV of two leading natural resources corporations in the US, is currently in the development stage and the first production is targeted for 2027. The project uses DLE on the Smackover Formation, which contains some of North America's highest-grade lithium brine resources with concentrations up to 597 mg/L. The project aims to produce enough lithium to supply more than a million EVs annually. The project uses existing brine infrastructure from bromine production, promising faster extraction, lower water usage and minimal land disturbance compared with traditional methods.[57]

A lithium and clean power project by an American thermal resources company using geothermal brine recovery technology

Located in California's Salton Sea, this project combines geothermal power generation with lithium extraction from geothermal brines. It aims to produce up to 34,000 tonnes of lithium carbonate equivalent and up to 140 MW of geothermal power annually using a closed-loop system. The project demonstrates the integration of renewable energy with mineral extraction, potentially setting a new standard for sustainable lithium production.[58]

A lithium hydroxide project in Namibia, by a leading Australian lithium developer

At present, this project is in the advanced planning stage, with mining operations expected to commence in 2024 and chemical plant commissioning planned for 2025. The project focuses on extracting lithium from lepidolite using proprietary technologies such as L-Max® and LOH-Max®. The concentrate will be produced in Namibia and shipped to a chemical conversion plant in Abu Dhabi. The project aims to produce 4,000–5,000 TPA of lithium hydroxide, demonstrating the potential of diversifying lithium sources beyond traditional brine and spodumene deposits.[59]

These advancements improve efficiency and sustainability and pave the way for a more responsible and scalable lithium supply chain.

[57]https://www.standardlithium.com/projects/arkansas-smackover
[58]https://www.hatch.com/Projects/Energy/Hells-Kitchen-Integrated-Lithium-and-Power-Project
[59]https://lepidico.com/company-overview

Heavy minerals

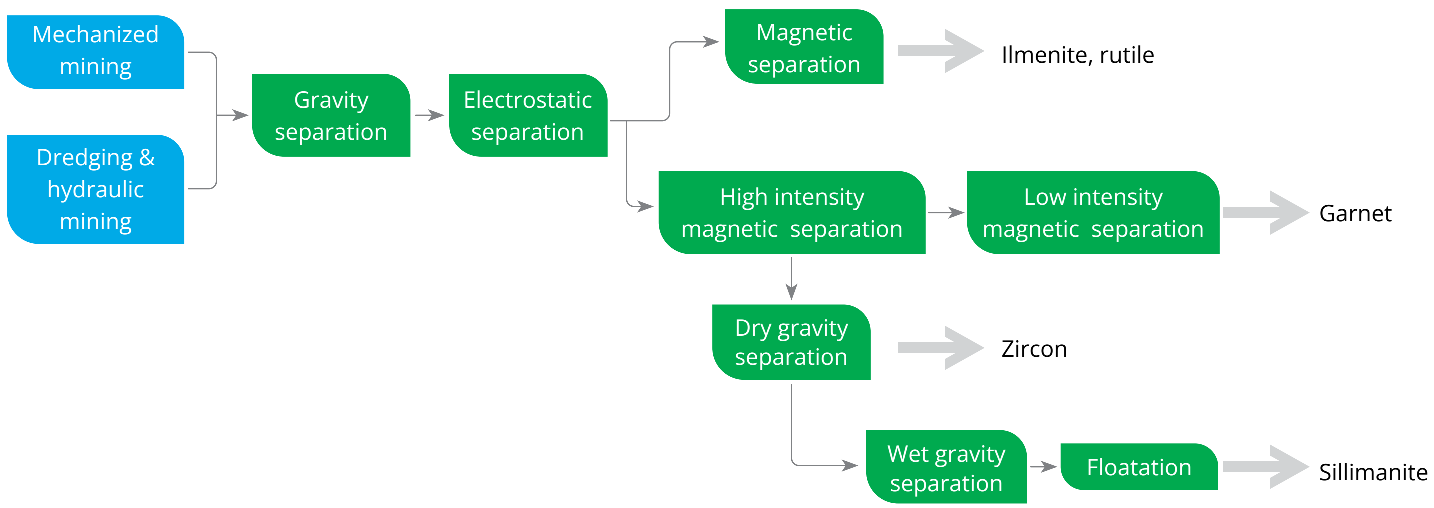
The value chain begins with identifying and evaluating deposits of economically valuable heavy minerals. Geophysical techniques such as airborne magnetic and radiometric surveys, can identify magnetic minerals such as ilmenite, and radioactive minerals such as monazite over large areas. Geochemical approaches such as stream sediment sampling and soil surveys can be used to detect chemical signatures of heavy minerals. Modern exploration techniques combine geochemical and geophysical methods to maximise the chances of discovery.

The mining of mineral sand deposits containing heavy minerals is mainly conducted through three routes:

- Suction dredging: Ore is lifted from a pond using a dredge and transported through a pipe to a separating plant. Clean sand tailings are spread behind for revegetation.
- Open-cut mining: Higher-grade deposits are mined with shovels and dumpers. The ore is screened and processed through spirals to remove tailings and clay fines, then stockpiled for separation.
- Hydraulic mining: Ore is washed down with a water cannon and pumped as slurry to a concentrator, where valuable minerals are separated from waste.

After mining, sand is processed through gravity separation or flotation to obtain a HMC. This concentrate is further separated using magnetic, electrical and electrostatic methods. Electrostatic separation techniques are used to separate conductors (such as rutile and ilmenite) from non-conductors (such as zircon and monazite), while magnetic separation is used to separate magnetic minerals (such ilmenite and monazite) from non-magnetic ones (such asrutile and zircon). Monazite is cracked to produce mixed rare earth concentrates and subsequently refined to produce separated high-purity rare earths. India is among the top three to four countries globally with the capability to produce refined rare earths.

Figure 14: Schematic demonstrating the general production process of heavy minerals



Recent innovations in exploration techniques have significantly enhanced mineral detection. Advances in Airborne Geophysical Surveys, such as airborne gravity gradiometry, offer greater accuracy in locating high-density minerals. New methods such as X-Ray Fluorescence (XRF) provide precise elemental analysis, which was observed in the exploration of titanium minerals in Indonesia. Other advanced methods such as Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy (SEM-EDXS) and Laser-Induced Breakdown Spectroscopy (LIBS) provide detailed insights into mineral morphology and composition.

Gravity separation is a traditional method used for concentrating heavy minerals, which uses the density differences between heavy minerals and lighter gangue materials. It is often followed by magnetic and electrical separation to further refine the mineral concentrates. Recently, HGMS has become the most common means of selectively enriching fine weakly magnetic minerals and purifying non-metal ores.

Technologies such as sensor-based sorting (using optical, X-ray, and near-infrared sensors for pre-concentration); dry processing techniques (such as air classification and triboelectric separation to address water scarcity concerns); microwave pre-treatment (for improved mineral liberation); and advanced flotation methods (for specific heavy minerals) are used to complement HGMS.

Case studies

A leading mining company in southern Australia

A leading mining company operates major heavy sand resources in Southern Australia and Sierra Leone. The project is the world's largest zircon development, with a production capacity of around 3,00,000 TPA.

Mining occurs in an inland open-pit deposit, using dozer push techniques. Material is transported to a Mobile Upgradation Plant (MUP) for processing, where oversize material is separated, and sand is mixed with water to form a pulp. Topsoil and subsoil are removed with tractor scoops, while overburden is handled by trucks and excavators.[60]

A heavy mineral project by a world leader in heavy mineral sand extraction

A leading global mining company operates a major heavy mineral sands project in northern KwaZulu-Natal, South Africa. This operation is the country's largest mineral sand producer, focusing on ilmenite, rutile and zircon. Situated near the coast, the operation employs dredge mining to extract mineral sands. A fleet of dredgers and separation plants processes the dredged slurry, with minerals and sand separated at the processing plant. The sand is then pumped back into the dunes to replenish the area.[61]

Innovative heavy mineral extraction technique used by Australian miners in South Africa

This project, located on the west coast of South Africa and operating since 2014, uses a unique beach mining method to extract heavy minerals such as zircon, rutile, ilmenite and garnet from coastal sands. The innovative aspect of this operation lies in its use of a mobile mining unit that moves along the beach, extracting and processing the heavy mineral-rich sands before returning them to their original location. This method allows for continuous replenishment of the mineral sands by natural wave action, making it a sustainable and environmentally friendly approach to heavy mineral extraction. The project employs advanced separation techniques, including spiral concentrators and magnetic separators, to efficiently recover valuable heavy minerals.[62]

[60] https://amcconsultants.com/experience/digging-deeper-ilukas-jacinth-ambrosia-largest-zircon-development/
[61] https://www.riotinto.com/en/operations/south-africa/richards-bay-minerals
[62] https://www.mineralcommodities.com/operations-projects/south-africa/tormin-mineral-sands-operation/

The Indian perspective

India is endowed with resources of heavy minerals mainly concentrated in five[63] coastal states. Ilmenite and rutile are major heavy minerals used as feedstocks to extract and manufacture TiO_2, the primary raw material in manufacturing aircraft parts, sporting equipment, paints, plastics, refractories and ceramics.

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Table 4: Mineral concentration zones

Name of the deposit	State	District	Stretch	Operating companies
OSCOM	Odisha	Ganjam	18 km	IREL
Brahmagiri	Odisha	Puri	30 km	IREL
Brahmagiri	Odisha	Puri	7.7 km	IREL-IDCOL
Bhavanapadu	Andhra Pradesh	Srikakulam	25 km	-
Kudiraimozhi and Sattankulam	Tamil Nadu	Thoothukudi	-	IREL-TAMIN
MK	Tamil Nadu	Kanyakumari	6 km	IREL
Chavara	Kerala	Kollam	22 km	IREL

However, the production of these resources in India lags behind that of other resources such as coal, iron ore, bauxite and zinc. For example, India is reported to have ~12.3 percent of the world's ilmenite deposits, yet its production accounts for only about ~3 percent. This is mainly due to uncertainties regarding resource quality, including factors such as grade, grain size, CRZ regulations and eco-sensitive zones.

Table 5: Mineral-wise global vs. Indian scenario

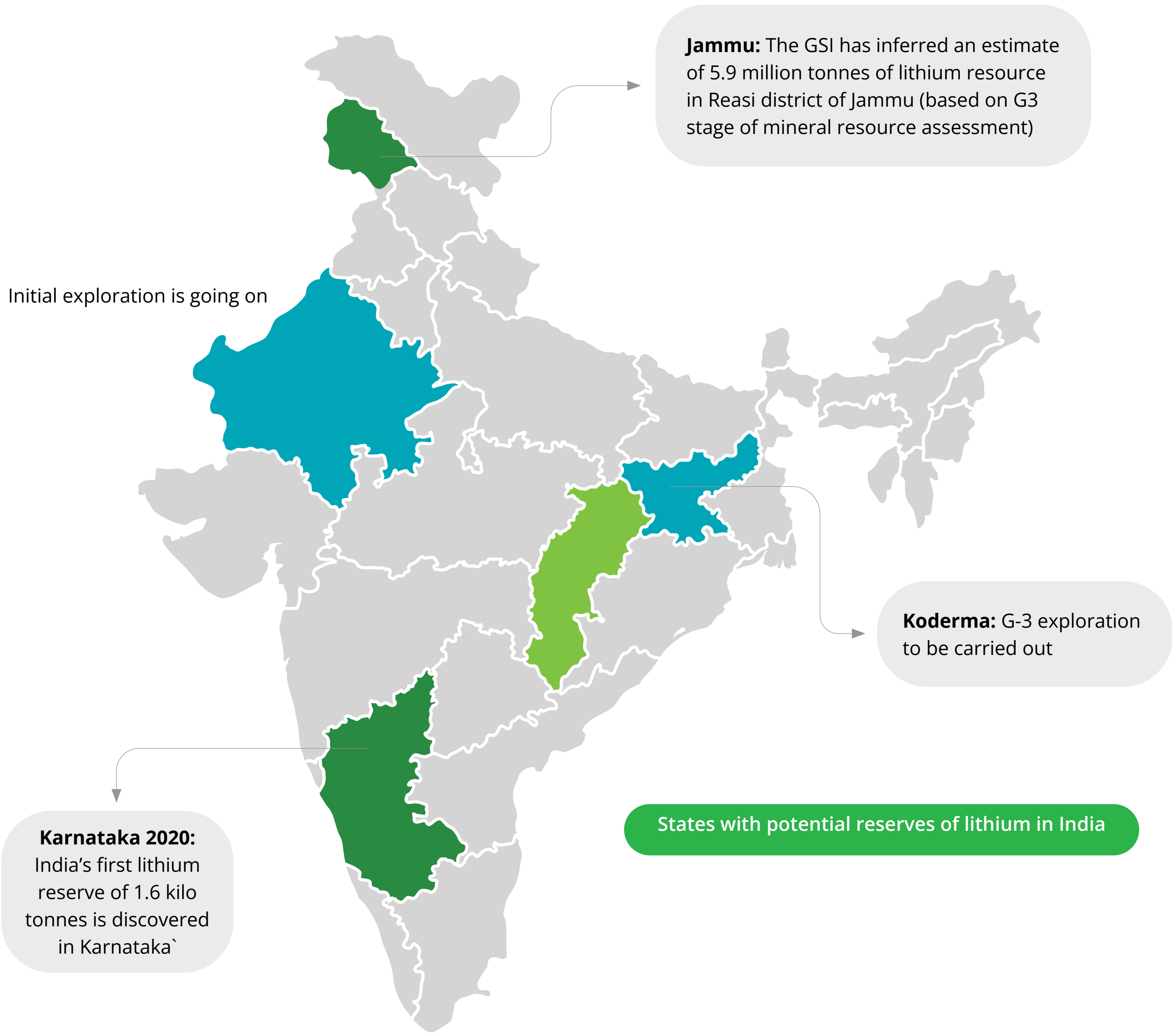
S No	Mineral	% of the world's deposit	% of the world's production
1	Coal	9.9%	11.10%
2	Iron-ore	3.1%	8.5%
3	Bauxite	2.2%	6.9%
4	Zinc	3.0%	6.0%
5	Ilmenite	12.3%	3.0%
6	Rutile	13.4%	2.2%

The Ministry of Mines notification reduced the threshold limit of monazite content in total heavy minerals from 0.75 percent to 0.00 percent.[64] Since monazite is an atomic mineral, this classification brings heavy minerals under the jurisdiction of the DAE.

Apart from heavy minerals, the demand for lithium is also going to increase manifold due to the transition towards cleaner and more sustainable energy solutions. Several initiatives have been taken by the government to strengthen the exploration and extraction of lithium in India. These include the inclusion of lithium in the critical mineral list, Part-D of the MMDR Act, the auction of lithium blocks and the introduction of exploration licences. At present, India's lithium requirements are primarily met through imports.

[63] IBM Minerals Yearbook
[64] https://sansad.in/getFile/loksabhaquestions/annex/175/AU4737.pdf?source=pqals

Figure 15: Lithium deposits in India[65]



This section delves into the current scenario of heavy minerals and lithium in India, highlighting production, demand and some of the key opportunities and challenges that must be addressed to boost the heavy minerals and lithium production in India.

[65]https://ficci.in/api/pdf1/EMP?fileID=23782&fileName=New_Age_Energy_Minerals.pdf

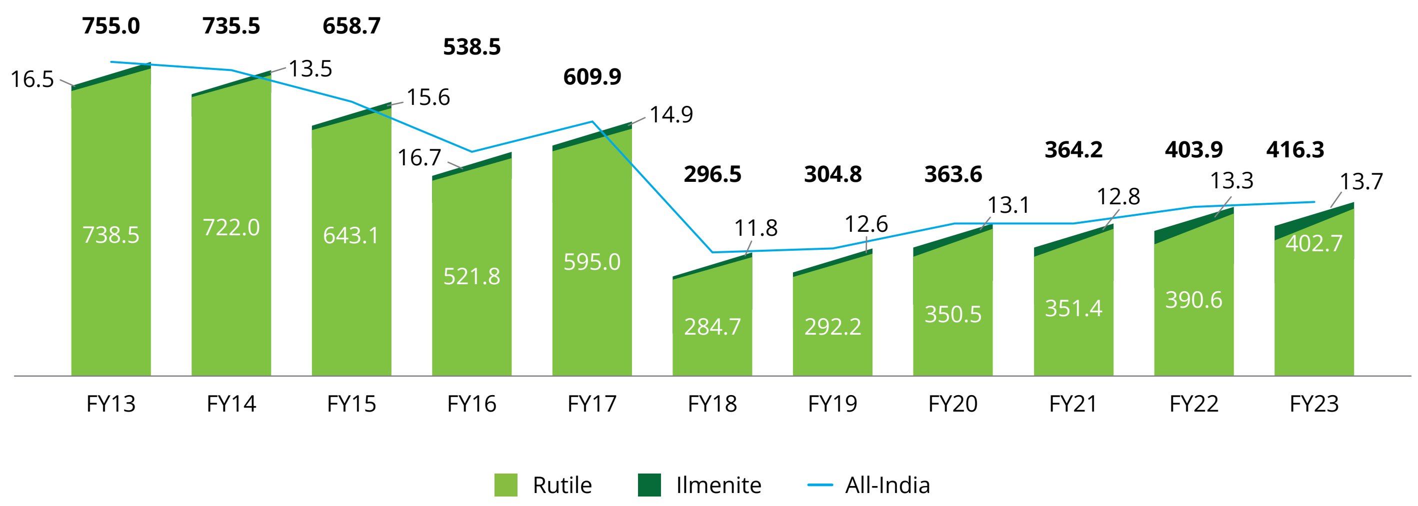
Present demand for heavy minerals and lithium

Heavy mineral

The heavy minerals industry in India is characterised by a few key players. IREL (India) Limited is a significant player with multiple operations across Tamil Nadu, Kerala and Odisha. KMML is another major player, particularly in the production of ilmenite, rutile, zircon and sillimanite.

At present, the heavy minerals in India are extracted only in Odisha, Kerala and Tamil Nadu. Odisha is the major producer of ilmenite and rutile in the country and produces ~60 percent of the total production. The production of ilmenite and rutile in India had decreased from ~755.0 kt in FY13 to ~296.5 kt in FY18. However, the production has shown consistent recovery growing at ~8 percent CAGR to reach ~416.3 kt in FY23.

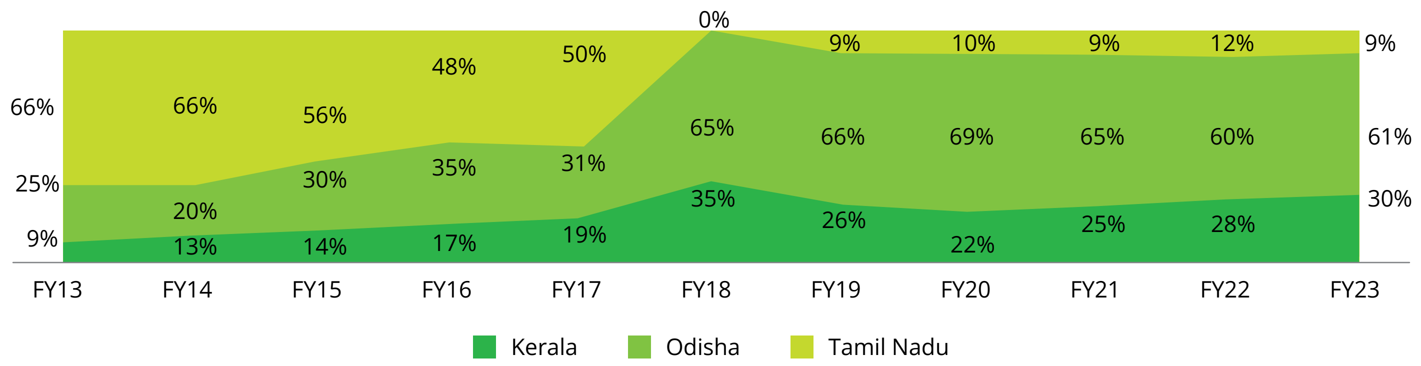
Figure 16: Production of ilmenite and rutile in India[66] **(kt)**



Tamil Nadu, once the largest producer of ilmenite now contributes only ~9 percent of India's production. Whereas Kerala almost tripled its share in ilmenite production. Odisha is the leading state in ilmenite production contributing ~61 percent of total India's production.

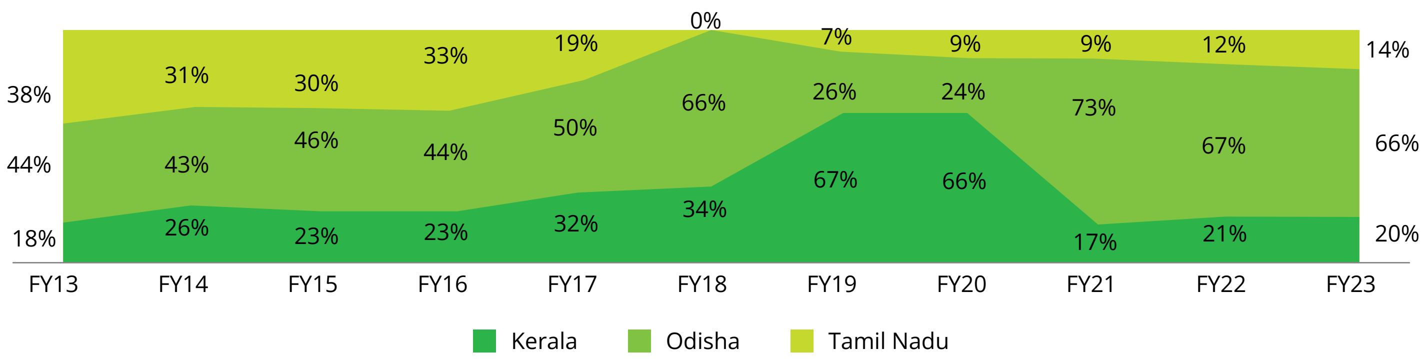
[66]https://sansad.in/getFile/loksabhaquestions/annex/1715/AU695.pdf?source=pqals

Figure 17: State-wise share of production of ilmenite in India[66] (%)



Odisha is the leading state in rutile production contributing ~66 percent of total India's production followed by Kerala (~20 percent) and Tamil Nadu (~14 percent).

Figure 18: State-wise share of production of rutile in India[67] (%)

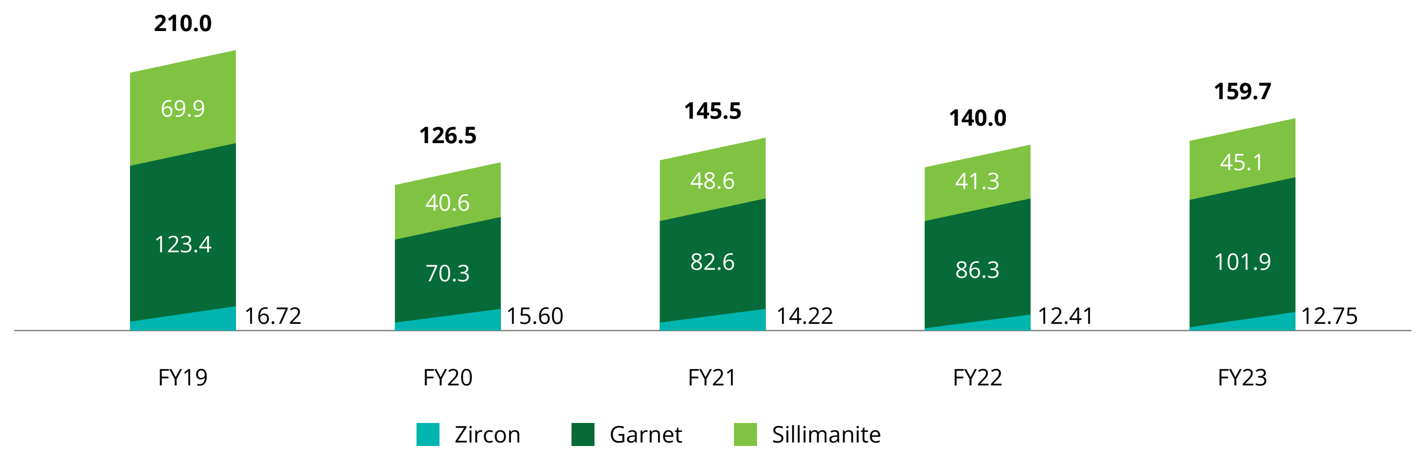


Other heavy minerals such as zircon, garnet and sillimanite constitute ~30 percent of the total heavy mineral production in India. In FY23, India produced 101.9 kt of garnet followed by 45.1 kt of sillimanite and 12.75 kt of zircon.

India is largely import-dependent in terms of zircon as only ~7.8 percent of the demand is met through domestic production. However, in case of garnet, the domestic market is over-supplied and in case of sillimanite it is self-sufficient.

[67]https://sansad.in/getFile/loksabhaquestions/annex/1715/AU695.pdf?source=pqals

Figure 19: Production of zircon, garnet and sillimanite (kt)

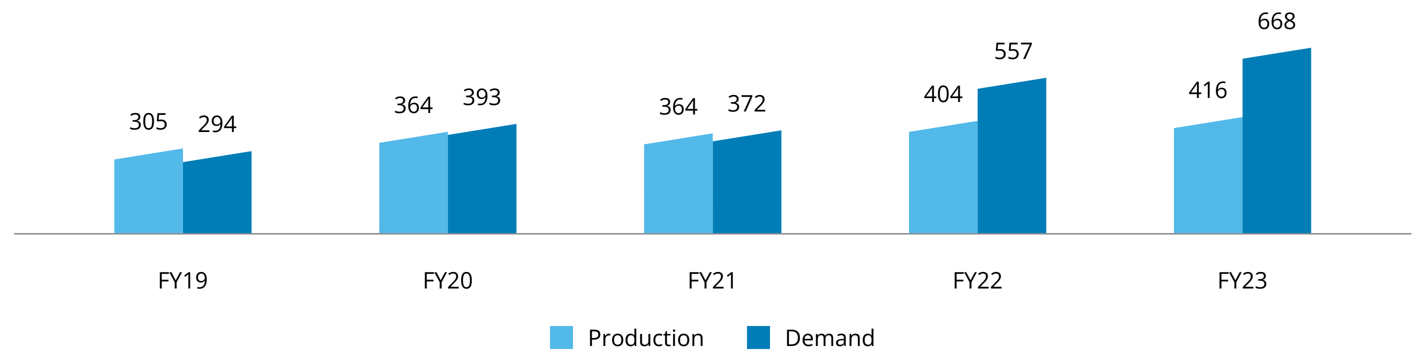


Present demand for heavy minerals and lithium

Demand for ilmenite and rutile

In India, demand for ilmenite and rutile is primarily driven by the demand for TiO_2. The market for titanium ores in FY23 is ~694 kt. India is largely dependent on imports of titanium-based products.

Figure 20: Production and demand of titanium ores in India[68] (kt)

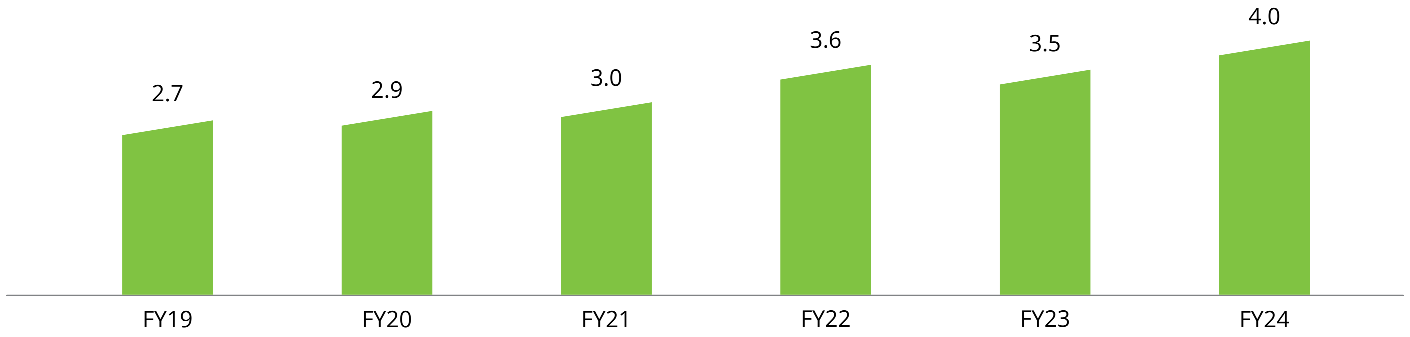


The imports of TiO_2 and its associated products increased ~50 percent since FY19 and reached ~US$1.1 billion in value. The majority of TiO_2 in India is consumed in the paint industry followed by the paper and pulp and plastic industry. This is on account of guarded technology in the value chain of titanium.

In FY23, India imported ~60 kt and exported ~144 kt of titanium ores and concentrates. Also, there is a reduction in exports seen in titanium bearing minerals from FY19 onwards due to increase in domestic demand.

[68]https://sansad.in/getFile/loksabhaquestions/annex/1715/AU695.pdf?source=pqals

Figure 21: Import of TiO_2 and associated products[69] (lakh tonnes)

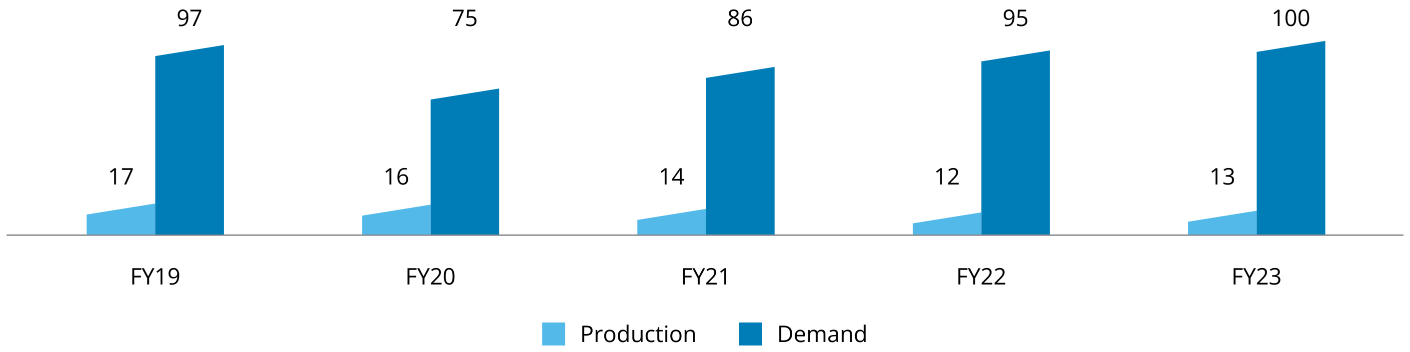


Demand for zircon, garnet and sillimanite

Zircon: It is primarily consumed in the ceramic industry followed by refractory industries domestically. The current demand for zircon is ~100 kt and India will be largely dependent on imports to meet the growing demand because of the low grade in the mineral assemblage.

In FY23, India imported ~82.8 kt of zirconium ores and concentrates increased from ~76.1 kt in FY19. Its use across sectors such as chemicals, foundry, and castings, glass and fibre had driven the imports throughout the years.

Figure 22: Production and demand of zirconium ores in India[70] (kt)

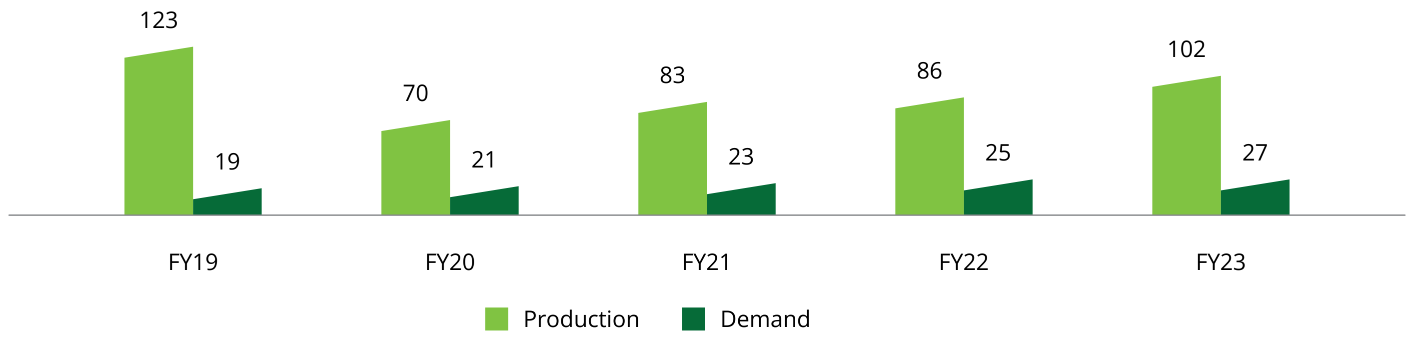


Garnet: About 90 percent of the production of abrasive garnet is used for manufacturing garnet-coated papers, clothes and discs. The remaining 10 percent of output is used in the form of loose grains for surfacing and polishing soft stones (such as marble, slate and soapstone).

The garnet market in India is over-supplied and most of the garnet produced in India is exported to the US and Middle Eastern countries. In FY23, ~103.4 kt of garnet was exported. The highest consumption of garnet is witnessed in the United States and the Middle East petroleum industry. Indian garnet has developed a brand value because of its consistent quality.

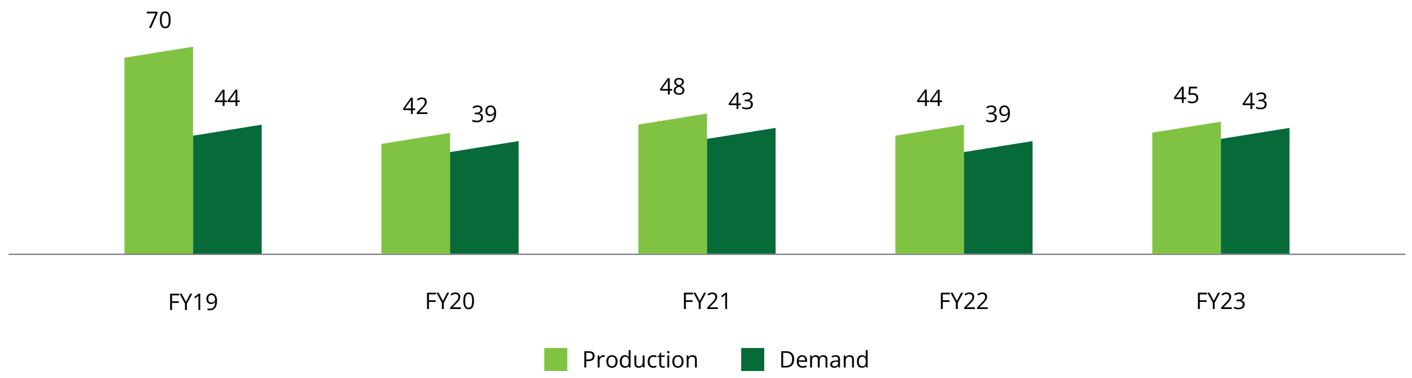
[69]Ministry of Commerce
[70]IBM Year Book 2022, Annual reports of IREL & KMML

Figure 23: Production and demand of garnet in India[50] (kt)



Sillimanite: It is mainly used in refractories and ceramic products because of its ability to form the mullite phase at high temperatures. The domestic production of sillimanite is self-sufficient in terms of demand and ~78 percent of the sillimanite production in India is used the refractory industry. Indian imports of sillimanite remained stable throughout the years and exports have decreased from 10 kt in FY19 to 2.2 kt in FY23 to meet the domestic demand.

Figure 24: Production and demand of sillimanite in India[71] (kt)

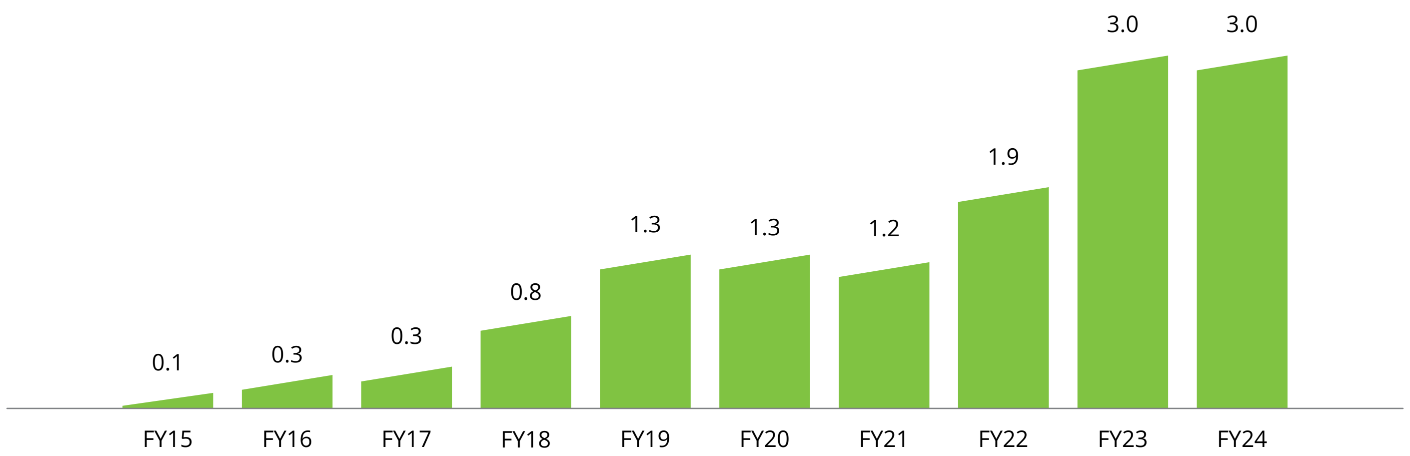


[71]IBM Year Book 2022, Annual reports of IREL & KMML

Demand for lithium

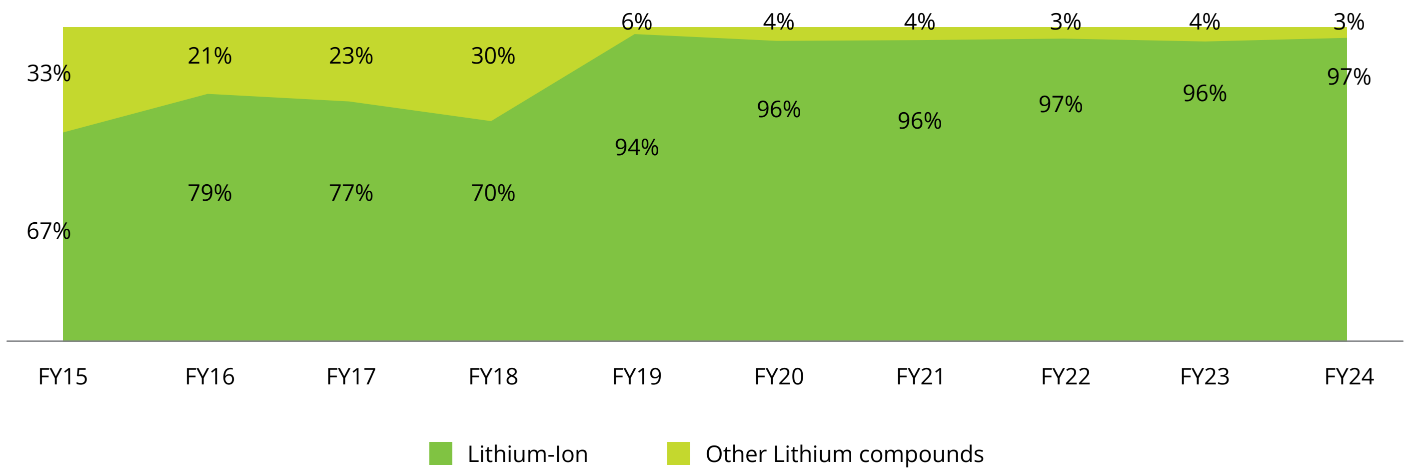
In FY24, India imported ~2.3 kt of lithium carbonate and lithium hydroxide of ~US$53.94 million to meet the domestic demand. India is one of the world's largest importers of lithium-ion batteries and imported lithium-ion worth US$3.0 billion in FY24.

Figure 25: Year-wise import of lithium compounds[72] (US$ billion)



Over the years, the share of lithium ion in total imports increased from 67 percent in FY15 to 97 percent in FY24 due to an increased focus on EV and battery ESS.

Figure 26: Share of lithium-ion in total imports (%)[73]



[72]Ministry of Commerce
[73]Ministry of Commerce

Key challenges and opportunities

The supply of heavy minerals and lithium is constrained in India despite possessing significant resources due to the following challenges:

Low level of exploration

The low level of exploration led to a lower resource-to-reserve conversion ratio for heavy minerals and lithium. India's mining potential remains underutilised with many minerals still largely at the resource level and further exploration is required to take them to the reserve stage. The Atomic Minerals Directorate (AMD) conducted extensive exploration activities along India's coastline, covering a total coastal length of 5,921 km spread across Odisha, Andhra Pradesh, Tamil Nadu, Kerala, Karnataka, Maharashtra, Goa, Gujarat and West Bengal. This exploration is categorised as detailed exploration (451 km), G3 (1,873 km) and preliminary exploration (112 km). However, a coastal length of 2,272 km remains unexplored due to various reasons such as mangrove forests and port activities, leaving an unexplored coastal length of 1,214 km.

High lead time for operationalisation

Historically, obtaining various permits, licences and approvals for mining operations in India has often involved lengthy processes. This caused significant delays for mining companies. It takes about 8–9[74] years to secure the lease for mining in mineral sand deposits and the separation of heavy minerals. Site inspections at various levels, Coastal Regulation Zone (CRZ) clearances and other surveys are long lead items in the process.

Lack of mine operator ecosystem in mineral sand mining, a deterrent for scaling

The prevalence of large contractors is prominent in bulk deposits such as in coal and iron ore. The competent mine operators are limited in mineral sand exploration and mining providing opportunities to develop an ecosystem of contractors and mine operators for mineral sands.

Limited technology advancements

Capital intensive nature of the projects and complex technology necessiates long gestation periods for heavy mineral separation in India. Teri deposits are characterised by a wide size range of minerals, higher proportion of slimes and the presence of near gravity products such as kyanite and corundum, all of which necessitate an altogether different approach if optimum exploitation. The close densities of these heavy minerals often pose major challenges during concentration by gravity. Indian companies do not invest adequately in R&D related activities for beneficiation and are still dependent on foreign technologies. In contrast, the Australian mining industry has invested US$30 billion[75] in R&D since 2005, becoming a global critical driver of industry innovation.

Import policy for Titanium Dioxide

At present, the import policy allows for the free import of TiO_2 without a special import licence. In recent times, high volumes of TiO_2 have been dumped in India with low prices, which led to diminished value for exports (export prices are computed based on director general system transaction-wise import data).

[74]https://economictimes.indiatimes.com/industry/indl-goods/svs/metals-mining/simplify-norms-for-mining-beach-sand-minerals eai/articleshow/26686832.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst
[75]https://safetowork.com.au/australian-mining-has-invested-30b-in-rd/#:~:text=Australian%20mining%20has%20invested%20%2430%20billion%20in%20research%20and%20development,Council%20of%20Australia%20(MCA).

Key opportunities

Increase in pigment consumption (ilmenite and rutile)

- About 90 percent[76] of titanium pigment usage, primarily in paint, plastics, inks and specialty coatings, is expected to grow at ~4–5 percent driven by urbanisation, shortening of paint cycles and new application areas, such as polyolefin (automotive light-weighting).
- Government spending on housing development (for example PMAY in India). However, the sector facing a slowdown will impact growth.
- Per capita pigment consumption is expected to increase by 20 percent[77] from 2.3 to 2.8 kg/capita.

Demand for tiles, ceramics and sanitaryware (zircon)

- About 50 percent of zircon is used in tiles, sanitary ware and tableware. It is expected to grow at a CAGR of 7–8 percent.[78]
- About 20 percent infused zirconia is used in chemicals and specialty applications in electronics, catalytic converters, fibre optics and nuclear fuel rods.
- About 30 percent of zircon is used in refractory and foundry for further use in steel, cement, glass and casting.

Demand in petroleum, aircraft, shipbuilding and water filtration industry (garnet)

- 60 percent of garnet is used for abrasive air-blasting and as a substitute for silica in sandblasting due to less dust and emissions. This market is expected to grow at ~5 percent.[79]
- Garnet is widely used in the petroleum industry for cleaning pipes, secondary recovery and oil-field stimulation.
- 20 percent of garnet is used in waterjet cutting for industrial applications in steel, rubber, non-ferrous and glass.
- 10 percent of garnet is used for water filtration in water-intensive industries such as power, steel and aluminium processing.

Demand for refractory industry (sillimanite)

- Steel production capacity is expected to reach 300 Mt by 2030, driving the associated refractory consumption.
- The growing construction sector in the country has increased the demand for ceramic tiles, sanitaryware, pipes, etc., which is expected to drive the refractory market.

[76]Iluka Resources (https://iluka.com/CMSPages/GetFile.aspx?guid=bd24ecdc-5b71-4681-9340-87c85555cca5)
[77]Iluka Resources (https://iluka.com/CMSPages/GetFile.aspx?guid=bd24ecdc-5b71-4681-9340-87c85555cca5)
[78]USGS, GII research, IBM, Mordor intelligence, Adamas intelligence, Deloitte Analysis
[79]USGS, GII research, IBM, Mordor intelligence, Adamas intelligence, Deloitte Analysis

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Policies and initiatives

India has implemented several policy initiatives to boost the exploration, production and self-reliance in the heavy minerals and lithium sector. Some of these include the following:

AMCR, 2016

These rules have been amended by the Government of India in alignment with the strategic importance of the minerals.

Table 6: Timeline of key changes to AMCR, 2016

S No	Rules	Notification date	Key provisions related to mineral sand
1	AMCR, 2016	11 July 2016	The threshold value for uraniferousallanite , monazite and other thorium minerals is set at 60 ppm U_3O_8 and/or 250 ppm ThO_2 and/or 0.75 percent monazite.
2	Atomic Minerals Concession (Amendment) Rules, 2019	19 February 2019	Power to central government accorded for revising threshold values after consultation with the department.
3	Atomic Minerals Concession (Second Amendment) Rules, 2019	20 February 2019	The threshold value for uraniferousallanite, monazite and other thorium minerals is set at 60 ppm U_3O_8 and/or 250 ppm ThO_2. All cases of Beach Sand Minerals and other placer deposits associated with monazite were revised to 0.00 percent monazite in total heavy minerals, irrespective of monazite grade.
4	Atomic Minerals Concession (Amendment) Rules, 2020	5 November 2020	The non-refundable fee for submission of composite mining plan is revised.

MCDR, 2017

This amendment states that in the case of mineral sand deposits comprising ilmenite, rutile, zircon, monazite, sillimanite, garnet, Leucoxene, etc., sufficient precautions will be taken to separate and stack the waste sand or tailings from the associated minerals to avoid mixing of waste sand with the associated minerals.

The Mines and Minerals (Development and Regulation) Amendment Bill, 2021

This Act has made certain changes to the process of granting atomic mineral leases. As an amendment to section 5 of the MMDR Act, it is now clearly mentioned that in respect of minerals specified in Part B of the 1st Schedule (atomic minerals) where the grade of atomic mineral is equal to or above the threshold value as notified by the Government of India, a composite licence or mining lease will be granted to government, government company or corporation only.

The Coastal Regulation Zone Notification 2011

Introduced the concept of classification of CRZ into four zones with the following delineation:

- **CRZ I-** Ecologically sensitive areas such as mangroves, coral reefs, salt marshes, turtle nesting ground and the inter-tidal zone
- **CRZ II-** Areas close to the shoreline, and which have been developed
- **CRZ III-** Coastal areas that are not substantially built up, including rural coastal areas
- **CRZ IV-** Water area from LTL to the limit of territorial waters of India

Further under the CRZ III zone, areas up to 200 m from HTL were earmarked as NDZ. Here no major construction works were permitted except for projects related to the DAE.

The Coastal Regulation Zone Notification, 2019
It was notified in January 2019, which subdivided the CRZ III zone into CRZ III A and B based on population density and reduced the NDZ to 50 m from 200 m from HTL for CRZ III A zones. This will directly affect projects related to the DAE as human interaction and urbanisation will increase. As a result, it may pose a threat to the smooth functioning of IREL operations.

Offshore auctions
The Amendment Bill introduces competitive bidding and operational rights for private sectors, including production leases and composite licences. The PSUs are granted rights in reserved mineral-bearing areas, while atomic minerals remain exclusively for PSUs. The Bill also establishes an Offshore Areas Mineral Trust to fund exploration and manage offshore mining impacts.

Mineral Security Partnership (MSP)
India joined the MSP to ensure responsible production, processing and recycling of critical minerals, aligning to support growth in green and renewable energy sectors.

Case studies

Heavy mineral mining and processing at India's flagship sand mining facility in Odisha[80]

India's leading mineral sand mining company conducts heavy mineral mining and processing in OSCOM region of Chatrapur district. The plant operates on a mining lease area of 2,464 hectares, containing an average grade of 10–11 percent heavy minerals along the coastal stretch. While the plant employs both dredging and dry mining techniques to extract minerals from the beach sand deposits, the primary mining method is dredging, supplemented by dry mining to meet production requirements. The mineral separation plant uses various separation techniques, including magnetic, gravity and electrostatic methods, to process the mined sand. The plant has recently undergone expansion to increase its ilmenite production capacity to 470 kilotonnes per annum. The plant also houses a rare earth extraction plant with an installed capacity of 11.2 kilotonnes per annum of mixed rare earth chlorides. The plant operates in an environment-friendly and sustainable manner, adhering to ISO 9001:2015, ISO 14001:2015, and ISO 45001:2018 certifications.

Titanium Dioxide production and strategic titanium sponge manufacturing in Kerala[81]

India's leading integrated TiO_2 plant operator runs an advanced facility in Chavara, Kerala, with a production capacity of 100 tonnes per day of TiO_2 pigment. The company mines ilmenite and other heavy minerals from beach sand deposits along the Kerala coast using inland mining and beach washing methods. The ilmenite is processed through beneficiation, chlorination and oxidation to produce TiO_2 pigment. In 2011, the company established India's first titanium sponge plant as a JV with ISRO and DRDO, with an annual capacity of 500 tonnes. The plant uses titanium tetrachloride from the company's pigment operations as feedstock. The titanium sponge is a critical input for India's space and defence sectors, used in satellite launch vehicles, missiles and naval applications.[82]

[80]https://www.irel.co.in/oscom
[81]https://www.kmml.com/manufacturing-facility
[82]https://environmentclearance.nic.in/DownloadPfdFile.aspx?FileName=dxLrMQREiUs+eKncqU5uFykXY5EjCMxBgCqo06GQizvYOxyrEElcackhspkaoh0pNCM7kwoUMeBpZOd8p8BuzUqG5v5UabjruErgEQ/CcYs=&FilePath=93ZZBm8LWEXfg+HAlQix2fE2t8z/pgnoBhDlYdZCxzUlDadBGu7t8v4JoQvNU6UBlSmL0YQ7WQYaxkvlQvexKQ==

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Potential 2030 and 2047 market for heavy minerals and lithium

Projected demand for ilmenite and rutile in India

About 92–94 percent of the ilmenite and rutile are used to produce TiO_2, which is applied in the chemicals, paint and pigments industry. Growth in titanium bearing minerals is driven by the increasing trend of urbanisation and industrialisation.

In India, new trends of light-weighting in the automotive and emerging aerospace sectors demand titanium metal/alloy and ferroalloys. Rutile finds application in the welding electrodes sector dominated by MSMEs.

The Indian ilmenite market is estimated at ~668 kt in FY23 and is slated to grow at a CAGR of ~4–5 percent to an estimated ~787–1,029 kt in FY30. Furthermore, the Indian rutile market is estimated at ~25 kt in FY23 and is slated to grow at a CAGR of ~5–6 percent to an estimated ~32–42 kt by FY30.

Figure 27: Estimated demand projection of ilmenite in India (kt)

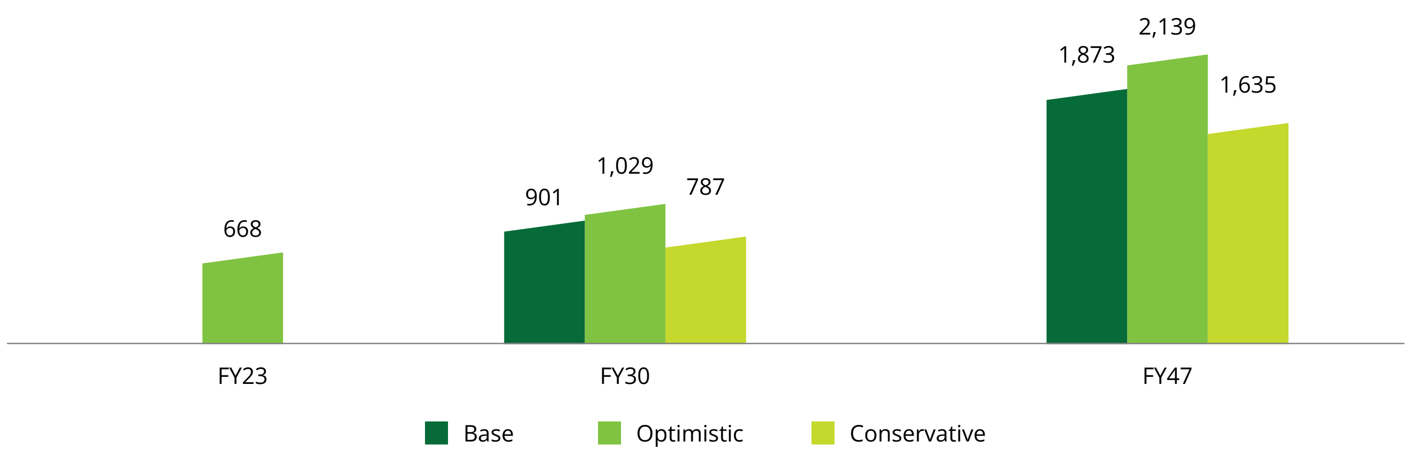
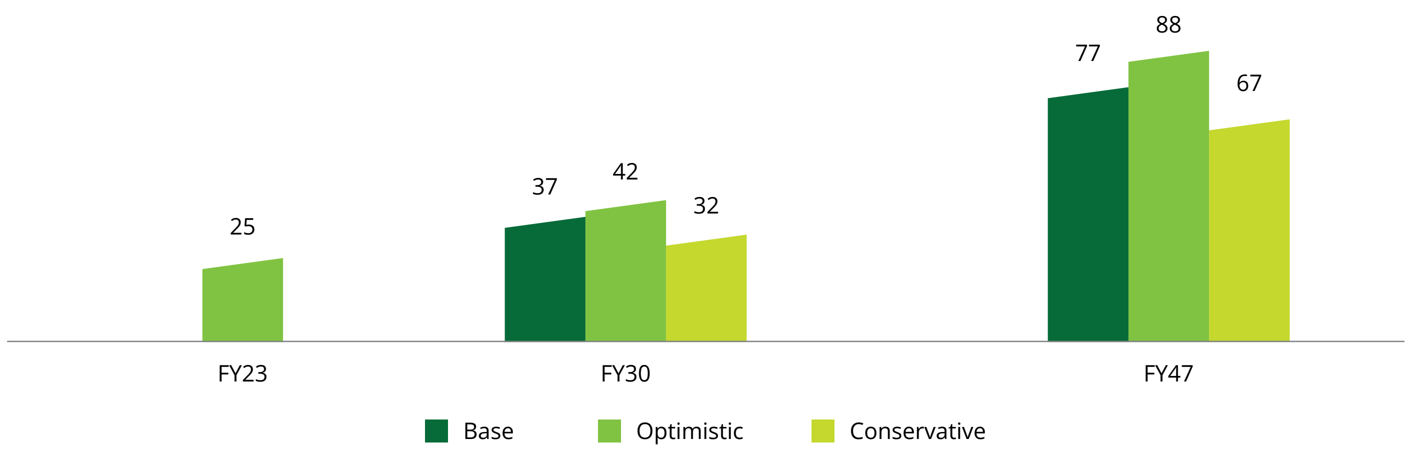


Figure 28: Estimated demand projection of rutile in India (kt)

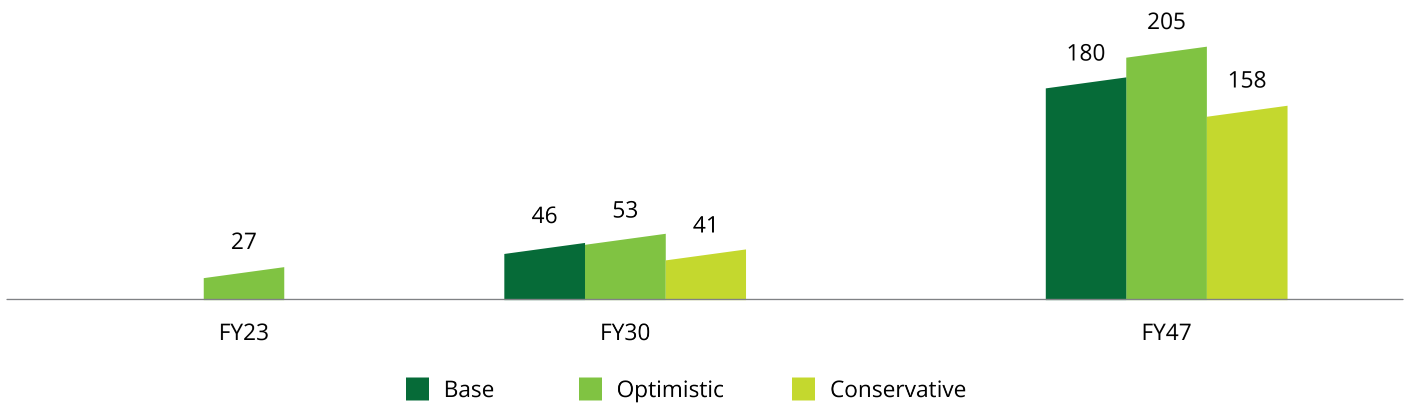


Projected demand of garnet in India

The major end uses of garnet, in descending order of consumption, include, abrasive blasting, water-filtration media, water-jet-assisted cutting and other end uses, such as in abrasive powders, nonslip coatings and sandpaper. Large industries that consume garnet include aircraft and automotive manufacturers, ceramics and glass producers, electronic component manufacturers, filtration plants, glass polishing, oil & gas industry, shipbuilders, textile stone washing and wood-furniture-finishing operations.

The demand for industrial garnet is expected to be largely driven by export markets, as the current domestic market is oversupplied. In FY23 total production was ~102 kt. The domestic garnet market demand is estimated at ~27 kt in FY23 and is expected to grow at a CAGR of ~5–6 percent to an estimated demand of ~41–53 kt by FY30.

Figure 29: Estimated demand projection of garnet in India (kt)



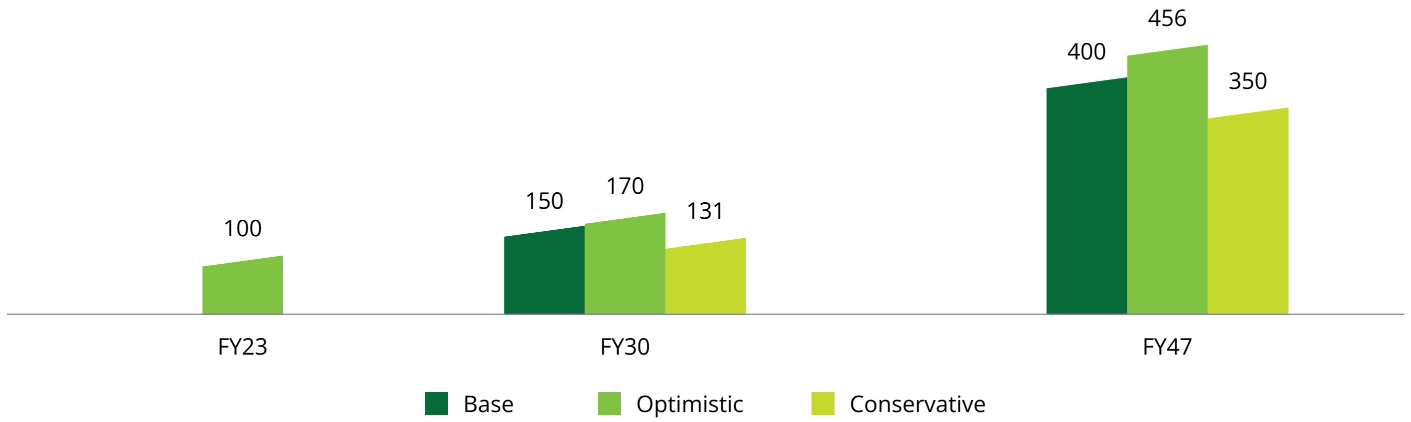
Projected demand of zircon in India

Digital printing of ceramic tile patterns has the potential to increase demand since for zircon. This is because a higher zircon content in the base tile is required to impart aesthetically appealing product and optimise the cost of the digital printing process. Zircon containing 65 percent ZrO_2 is preferred in ceramics.

Zirconium metal or sponge is used in the nuclear industry due to a requirement for minimum content of hafnium. Hafnium-free zirconium metal is used as a cladding material in atomic reactors due to its low absorbing cross-section for thermal neutrons. The requirement for India's Atomic Energy programme is entirely met from domestic resources.

The existing zircon market is undersupplied because of its lean content in Indian resources as current demand is 100 kt and domestic supply/production is only 13 kt. The domestic zircon market demand is expected to grow at a CAGR of ~5–6 percent to an estimated demand of ~131–170 kt by FY30.

Figure 30: Estimated demand projection of zircon in India (kt)

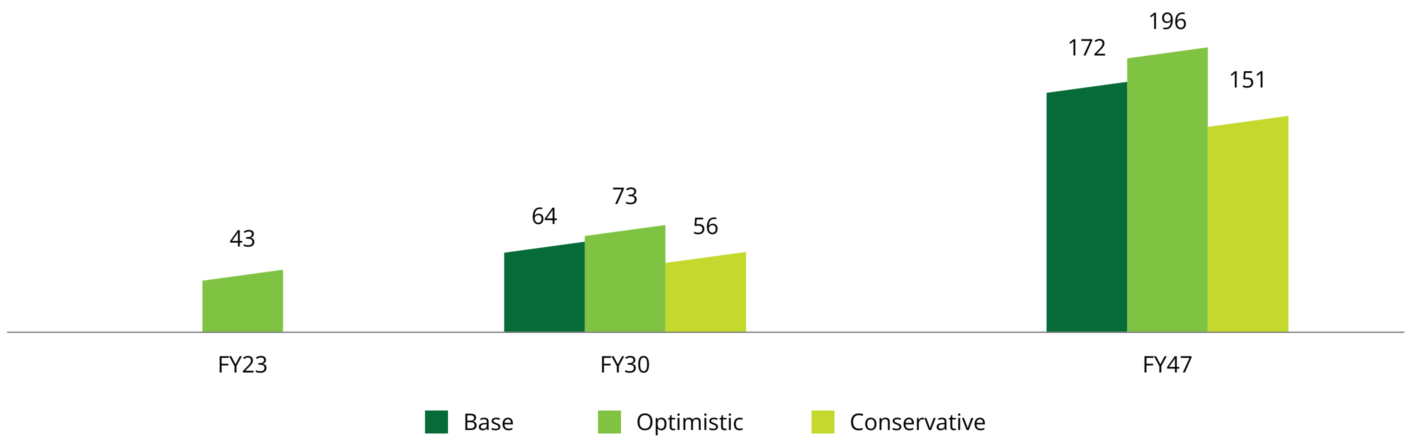


Projected demand of sillimanite in India

The demand for high-quality raw and calcined sillimanite minerals is closely linked to the need for high-performance refractories with increased operational lifespans. As the predominant consumer of refractory products, the steel manufacturing industry, provides a reliable market indicator of the demand for sillimanite minerals.

The existing domestic sillimanite market is almost balanced. The current production/supply of sillimanite is 45 kt and the domestic sillimanite market is estimated at 43 kt in FY23. This market is expected to grow at a CAGR of ~5–6 percent, reaching an estimate of ~56–73 kt by FY30. When compared with IREL production projections, sillimanite production capacity is expected to reach 122 kt by 2031, creating an oversupplied domestic market.

Figure 31: Estimated demand projection of sillimanite in India (kt)



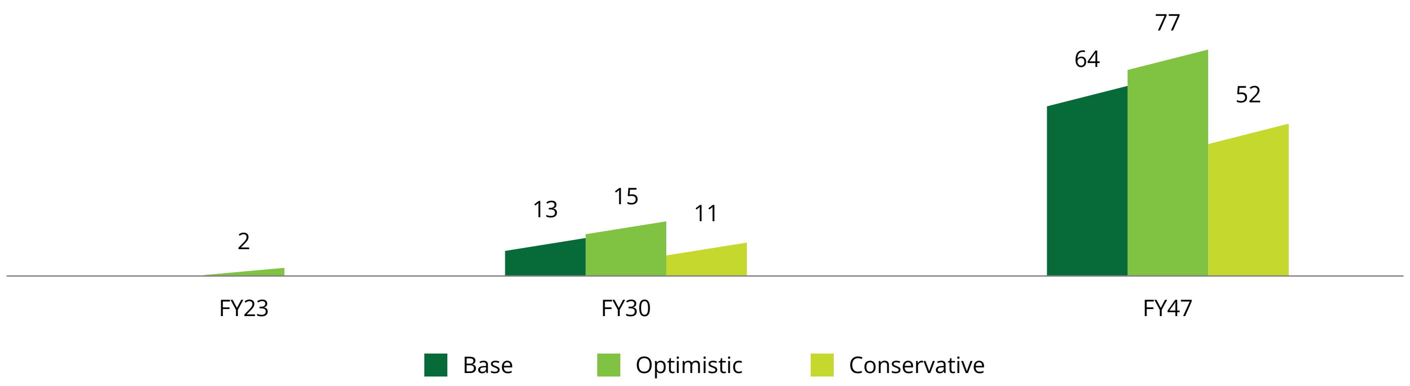
Projected demand for lithium in India

The lithium industry continues to be at the forefront of the transition to battery power, with demand growth closely linked to vehicle electrification rates, the installation of power storage utilities and the sales of personal transportation equipment and electronics. As the primary ingredient in lithium-ion batteries, lithium will become increasingly important as demand for EVs increases.

At present, India imports 100 percent of its lithium in various industrial forms, including lithium oxide and lithium hydroxide (around 1.14 kt) and lithium carbonate (around 1.15 kt). Lithium cells and battery packs are also imported for smaller electronics products and mobile phones. Lithium is primarily imported as lithium-ion batteries for EVs and ESS.

Given the outlook, lithium demand is expected to be between 11–15 kt by FY30[83] and 52–77 kt by 2047. This is due to increase in the share of EVs from present ~6 percent to ~30 percent by FY30 (optimistic case) in the overall domestic vehicle sales. Also, per National Electricity Plan (2022–32), a BESS capacity of 47.24 GW/236.22 GWh may be required to fulfil the storage requirement of the grid by 2031–32, which in turn may result in higher lithium requirement.

Figure 32: Estimated demand projection of lithium (kt)



[83]Deloitte analysis

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Initiatives for unlocking the potential of heavy minerals and lithium in India

Short- to medium-term initiatives (2030)

Conduct strategic exploration and resource mapping

- Conduct comprehensive geological surveys: Use cutting-edge technologies, such as remote sensing and AI to enhance exploration efforts.

  For instance, Australia uses remote sensing for mineral exploration, significantly reducing the time and cost involved. In a partnership between two Australian companies (an exploration technology company and a leading copper producer), the first igneous PGE-nickel-copper mineralisation was found in the Lachlan Fold Belt, New South Wales, Australia.[84]

- While the government has made progress in encouraging private sector participation in mineral exploration, improvements are still needed. Allowing private firms to directly sell discoveries and providing clearer revenue-sharing during exploration could further incentivise investment and increase private sector participation.

  In regions such as Australia, junior exploration firms take on financial risks to discover potential mines. Once they find these resources, they sell them to larger mining companies for development. This approach boosts the number of exploration projects and speeds up the exploration process through private sector involvement.[85]

Incentive-driven private sector engagement

- Establish PLIs for setting up heavy mineral and lithium processing and refining units. To improve financing, it is important to relax import restrictions on critical minerals and scrap, offer incentives for lithium battery recycling and encourage exploration and refining of critical minerals. Provide tax breaks and subsidies for investments in extraction and refining technologies.

  Australia has introduced CMPTI, committing A$7 billion over a decade to bolster the processing of critical minerals, including lithium and rare earths.[86]

- Provide viability gap funding for lithium battery recycling, and encourage exploration, mining and refining. In addition, offer tax breaks and subsidies for investments in extraction and refining technologies.

  For example, the various financial and non-financial incentives from the Chinese government for new energy vehicles have significantly boosted the country's lithium battery industry.[87]

[84]https://www.mining.com/legacy-uses-ai-to-discover-platinum-in-australia/
[85]https://www.thehindu.com/news/national/explained-the-push-to-bring-the-private-sector-into-mineral-exploration/article67168185.ece
[86]https://treasury.gov.au/consultation/c2024-541266
[87]https://www.spglobal.com/marketintelligence/en/news-insights/research/china-continues-support-for-new-energy-vehicles-despite-subsidy-phaseout

Supply chain development and integration

- Create SEZs: Develop SEZs for lithium and heavy mineral processing industries. Encourage vertical integration from mining to end-product manufacturing.

  Australia has successfully created SEZs to attract investment in its mining sector.[88] The Pilbara region is a significant mining hub, particularly for lithium and iron ore. The region has been designated as an SEZ to attract investment in mineral processing.[89]

International collaborations

- Strengthen international collaborations: Collaborate with countries such as Australia, Canada and Argentina for JVs and technology sharing. Secure long-term supply agreements and invest in emerging lithium-rich markets.

  Bolivia is enhancing its lithium extraction capabilities through strategic partnerships, notably with China, which is heavily investing in developing the Bolivian lithium facilities.[90]

  India has already signed lithium agreements with Argentina and Australia and is discussing processing technology with the United States.[91]

Regulatory framework

- Implement a single-window clearance system for lithium and heavy mineral projects to reduce bureaucratic hurdles. Create a centralised portal for all regulatory approvals, ensuring transparency and efficiency. Develop clear guidelines for environmental impact assessments specific to lithium and heavy minerals.

  For instance, the Government of South Australia has adopted a streamlined "one window to government" regulatory approach for mining and energy resource activities. This streamlined approach has been recognised as world-leading for its regulatory efficiency and competitiveness.[92]

[88]A Special Economic Zone in Northern Australia (www.aph.gov.au)
[89]https://www.oecd.org/content/dam/oecd/en/publications/reports/2023/10/mining-regions-and-cities-case-of-the-pilbara-australia_f1f52007/a1d2d486-en.pdf
[90]https://www.mining.com/web/chinas-cbc-increases-stake-in-bolivia-lithium-mining/#:~:text=The%20latest%20agreement%20adds%20to,lithium%20extraction%20(DLE)%20plants.
[91]https://eastasiaforum.org/2024/01/27/indias-long-road-to-lithium/
[92]Hydrogen and Renewable Energy Act (www.energymining.sa.gov.au)
[93]Hydrogen and Renewable Energy Act (www.energymining.sa.gov.au)

Establish dedicated processing hubs

- The government should create dedicated processing hubs for heavy and critical minerals to centralise facilities, foster innovation and develop long-term capacity. These hubs would reduce import dependence, enhance India's global standing and attract private sector investment through incentives and streamlined regulations.

  A successful global example of such an initiative is Chile's lithium processing hub in the Atacama Desert.[94] This hub has positioned Chile as the world's second-largest lithium producer, with advanced extraction and processing facilities, research centres and a skilled workforce dedicated to lithium production.[95] In India, there is already a government push to establish a similar hub in Ahmedabad, Gujarat, which could serve as a model for future mineral processing centres across the country.

Long-term initiatives

By 2047, India aims to have a robust policy framework that ensures the sustainable and strategic use of heavy minerals and lithium. This includes continuous updates to the MMDR Act and other relevant policies to adapt to global market changes and technological advancements.

Advanced manufacturing and value addition

- Advanced recycling technologies: Implement advanced recycling technologies for lithium batteries and heavy mineral-based products. According to NITI Aayog, India's lithium battery recycling capacity will have to increase about 60 times over the coming years, from the current levels to match the rise in batteries from EVs.[96]

  The European Union has invested heavily in battery recycling technologies to reduce dependence on raw lithium.[97]

  China a leader in battery recycling, offers substantial subsidies and grants to companies engaged in battery recycling. China has also launched a platform for tracing batteries, where every vehicle battery produced or imported into China has a unique serial number. This platform helps track the battery throughout its lifecycle, ensuring proper recycling and reducing the risk of environmental harm.[98]

- Urban mining framework: Create a comprehensive framework for urban mining of e-waste and end-of-life clean energy equipment.

  Japan has implemented a comprehensive urban mining framework to extract valuable metals from e-waste. This initiative supports the circular economy by recovering precious metals and rare earths from e-waste.[99] The EU has developed policies to support urban mining of e-waste and end-of-life clean energy equipment.

[94]https://www.sciencedirect.com/science/article/pii/S2214790X23000990
[95]https://www.sciencedirect.com/science/article/pii/S2214790X23000990
[96]https://economictimes.indiatimes.com/industry/renewables/is-india-ready-to-recycle-millions-of-end-of-life-ev-batteries/articleshow/112217778.cms?from=mdr
[97]https://ec.europa.eu/commission/presscorner/detail/en/ip_22_7588
[98]https://dialogue.earth/en/pollution/how-can-china-address-its-ev-battery-recycling-challenge/
[99]https://www.witpress.com/Secure/elibrary/papers/WM14/WM14001FU1.pdf

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Domestic R&D promotion

- Dedicated research institutes: Set up research institutes focused on lithium and heavy minerals to support the entire value chain. Offer incentives to private enterprises for R&D, including prolonged patent rights and milestone-based rewards.

  The Horizon Europe programme offers substantial funding for private enterprises engaged in R&D for battery technologies, including recycling and critical mineral processing.[100]

Implement and invest in sustainable practices

- Circular economy policies: Implement sustainable mining practices to reduce environmental degradation.

  Countries such as Chile and Bolivia are exploring DLE to minimise the environmental effect and preserve water resources.

Human capital and innovation ecosystem

- Develop educational programme for heavy minerals and lithium. Set up innovation hubs and incubators for lithium and heavy minerals. Promote continuous innovation through industry-academia partnerships and international exchanges.

  The Australian Government has committed A$75 million to establish a "Resources Common User Facility, which will serve as a hub for mining companies to trial new production processes for the extraction and processing of critical minerals. The initiative involves collaboration with the University of Queensland's "Sustainable Minerals Institute" to explore new ways to source minerals from mine waste and develop circular economy solutions.[102]

Deep sea mineral exploration and extraction

- Invest in deep-sea exploration and environmentally responsible mining technologies for lithium and heavy minerals, while establishing a sustainable legal and regulatory framework in collaboration with international partners.

  China has made huge investments in deep-sea exploration and mining technologies, including the development of oceanographic drilling ships capable of mining at depths of up to 10,000 metres. The Chinese government has heavily funded state-owned enterprises and private companies to develop commercial deep-sea mining robots and intelligent mining control systems by 2025.[103]

[100]https://bepassociation.eu/horizon-europe-batteries-partnership-sets-out-new-vision-for-research-funding/
[101]https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/dle-technology-can-overcome-challenges-in-bolivia-us-lithium-8211-energyx-ceo-78007582
[102]https://www.uq.edu.au/about/organisation/governance/vice-chancellor/speeches-and-articles-vice-chancellor/critical-minerals-collaboration-and-training
[103]https://www.newsecuritybeat.org/2023/08/china-leads-race-bottom-deep-sea-mining-critical-minerals/

Conclusion

The growth trajectory is expected to play a critical role in shaping the journey of India's strategic sectors, including energy transition, specialty steel, electronics and allied and aerospace and defence. With the country's ambitious EV projects and urbanisation drive, the demand for heavy minerals and lithium is set to surge significantly in the coming years. This presents a promising outlook for the energy transition sector, offering abundant opportunities for expansion and innovation.

As India charts its path towards becoming a global powerhouse in critical and heavy minerals powerhouse, stakeholders must collaborate closely, using technological advancements, sustainable practices and policy support to drive inclusive growth across the country. By harnessing the collective potential and fostering a conducive environment for innovation and investment, India can meet its energy transition and clean technology needs. It can emerge as a beacon of opportunity and progress in the global critical minerals arena. This transformative journey, coupled with governmental policies to drive end-user industries, will pave the way for a brighter and more resilient future for the industry and India.

The budgetary proposals and allocations reflect our ambition of an Atmanirbhar Bharat and will propel India into becoming a US$5 trillion economy.[104]

The proposed launch of the National Critical Minerals Mission (NCCM) will address the entire supply chain of critical minerals, "including domestic production, recycling and the acquisition of critical mineral assets abroad".

It will also address issues of trade and market access, scientific research and technology development in various stages of the critical minerals value chain, building expertise and a skilled workforce in this domain and recycling critical minerals.

[104]https://www.thehindu.com/business/Economy/india-to-become-third-largest-economy-with-gdp-of-5-trillion-in-three-years-finance-ministry/article67788662.ece

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Glossary

Abbreviation	Description
AMD	Atomic Minerals Directorate
AMCR	Atomic Minerals Concession Rules
ANNs	Artificial Neural Networks
ANT	Ambient Noise Technology
BCD	Basic Custom Duty
BESS	Battery Energy Storage Systems
CAGR	Compound Annual Growth Rate
CBC	Chinese consortium (CATL, Brunp Recycling and CMOC Group)
CHIPS	Creating Helpful Incentives to Produce Semiconductors Act
CMPTI	Critical Minerals Production Tax Incentive
CRZ	Coastal Regulation Zone
DAE	Department of Atomic Energy
DAP	Defence Acquisition Procedure
DLE	Direct Lithium Extraction
EEZ	Exclusive Economic Zone
ESS	Energy Storage Systems
EU	European Union
EV	Electric Vehicle
FY	Financial Year
G3	General Exploration (stage of mineral resource assessment)
GDP	Gross Domestic Product
GSI	Geological Survey of India
HGMS	High-gradient Magnetic Separation
HMC	Heavy Mineral Concentrate
HTL	High Tide Line
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
IREL	Indian Rare Earths Limited
JV	Joint Venture
KABIL	Khanij Bidesh India Ltd.
KMML	Kerala Minerals & Metals Ltd
kt	Kilo tonnes
LIBS	Laser-Induced Breakdown Spectrometry
LTL	Low Tide Line
MCA	Minerals Council of Australia
MCDR	Mineral Conservation and Development Rules
MMDR	Mines and Minerals (Development and Regulation) Act
MSMEs	Micro, Small, and Medium Enterprises
MSP	Minerals Security Partnership
Mt	Million Tonnes
NDZ	No Development Zone
NITI	National Institution for Transforming India
NMET	National Mineral Exploration Trust
OSCOM	Orissa Sands Complex
PLI	Production Linked Incentive
PMAY	Pradhan Mantri Awas Yojana
PSUs	Public Sector Undertakings
REE	Rare Earth Elements
SEZs	Special Economic Zones
TiO2	Titanium Dioxide
TPA	Tonnes Per Annum
USGS	United States Geological Survey
YLB	Yacimientos de Litio Bolivianos (Bolivian Lithium Deposits)

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