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Indian Mining Industry
The Amrit Kaal Journey

March 2024

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FICCI would like to thank all the stakeholders involved with the development of the report. Special thanks to the FICCI Mining Committee Mentor, Chair, Co-Chair, and Members for conceptualising this report **Indian Mining Industry - The Amrit Kaal Journey** and guiding the team throughout its development with their feedback and suggestions.

FICCI would also like to thank Deloitte for the preparation of the report in consultation with industry and other stakeholders in this sector. The Deloitte team conducted a qualitative survey alongside secondary research to come up with a rich output and holistic perspective, giving 360-degree coverage across the entire gamut of the Indian mining industry.

In the report, an attempt has been made to comprehensively cover the trends and developments, opportunities, challenges, and recommendations pertaining to the Indian mining industry and its transition in the Amrit Kaal Journey.

FICCI also conveys its appreciation for various organisations, associations, and individual experts in the sector for sharing their insights and contributing to the report. Their views have contributed immensely to finalising the recommendations of the report.

At the end, FICCI acknowledges the contribution made by all those associated with the report.

Foreword

S K Pathak
Secretary General – FICCI

FICCI, in association with its knowledge partner Deloitte, is happy to present the Report **Indian Mining industry: The Amrit Kaal Journey** report**.**

In our pursuit of Viksit Bharat, a robust mining industry is important. With our abundant mineral wealth, the nation stands at the threshold of unprecedented opportunities in mining. Harnessed to its full potential, the sector would propel the economic growth during our Amrit Kaal Journey.

The report outlines key trends and developments in the global and Indian mining industries, opportunities to be leveraged, and issues to be resolved. The report also has key recommendations for enhancing mineral exploration and production, development of critical minerals' ecosystem, decarbonisation, and the technology landscape.

We trust that all stakeholders will find this report useful.

S K Pathak

Foreword

Rajib Maitra
Partner, Deloitte India

The Indian mining sector is strategically important for India's growth. The next few decades hold the promise of being a period of significant growth for the Indian mining industry. Considering its vast mineral reserves, India is endowed with significant mineral wealth. The mining sector caters to the burgeoning needs of downstream industries like manufacturing and infrastructure. The government's focus on manufacturing and infrastructure development has provided renewed energy and vigour to the mining sector in the Amrit Kaal journey to a Viksit Bharat. With the increased focus, India can play a larger role in the global mining market.

The report provides insights into the Indian mining industry and the opportunities therein. In addition to focusing on exploration, mineral beneficiation and processing, health, safety, and the environment, it offers a set of themes that the industry can implement. These themes include leveraging digital, cost competitiveness, critical minerals, sustainability and decarbonisation, resource efficiency, and building capabilities through industry and government interventions.

We trust that all stakeholders will find this report beneficial.

Executive summary

The Indian mining sector is strategically important for India's growth. The mining sector growth has significant implications for downstream industries such as power, steel, and aluminium, which are closely associated with the economy's manufacturing (e.g., auto, chemicals, steel, and cement) and infrastructure (e.g., road, rail, and real estate) sectors. Considering its vast mineral reserves, India is endowed with significant mineral wealth. The contribution of mining to India's GDP has been estimated to vary between 2.1 percent and 2.5 percent over the last decade. The mining industry has the potential to help propel the country forward to a USD30 trillion economy by 2047. Furthermore, the mining industry can potentially create an additional 25 million jobs (direct and induced) over the business-as-usual scenario by 2047, which would be a significant share of the total non-farm jobs required to absorb India's demographic demands. Moreover, the mining industry could contribute an additional USD500 billion to India's GDP by 2047.

India's mining industry has undergone significant changes in its regulatory landscape since 2010 to improve transparency & efficiency and enhance private sector participation. The demand by end-use sectors continues to create the basis for India's vibrant mining sector. The Indian government has introduced various ambitious programmes, such as "Atmanirbhar Bharat," to expand domestic manufacturing and set targets to achieve net zero by 2070. Many minerals required for the clean-energy technologies, defence, and manufacturing sectors are not domestically produced or processed in the requisite volumes, creating import dependence. Some of the key recent government policies, acts, and policy amendments have positively increased the mineral supply and attracted investments towards mineral value addition. A notable intervention in this direction was introducing a critical minerals policy in 2023, identifying ~30 vital minerals, based on India's net import reliance and the resource/reserve position.

Developing a robust domestic mining industry is also imperative in a relatively turbulent global environment impacted by geopolitics, multiple ongoing conflicts, commodity price volatility, and mineral supply chain disruptions. Global headwinds also indicate a significant focus on sustainability, decarbonisation, critical minerals, and digital technologies.

India's mining sector is relatively small and has been growing slowly than key mining jurisdictions, such as Australia, Canada, South Africa, China, Brazil, and the US.

The Indian mining industry is at an interesting pathway and recently saw various reforms to unlock the country's mineral potential. The government has taken several initiatives, such as granting exploration licences (EL) through auction and omitting 6 minerals from the list of 12 atomic minerals in the MMDR Amendment Act 2023 to attract private players. In addition, there is a significant focus on policy reforms, incentivisation, the development of multidisciplinary exploration capacity and investment to fast-track exploration activities for deep-seated and critical minerals.

India produces only four critical minerals (copper, graphite, phosphorous and titanium (Ilmenite and Rutile)) out of 18 available minerals due to a lack of detailed exploration and the unavailability of proper infrastructure and technology for processing. The Indian government has recently expedited the preparatory works for auctioning of critical and strategic mineral blocks. These are likely to encourage exploration and partnership with international players to establish technological expertise for developing critical mineral security in the country.

Several progressive policies and measures have also been introduced by the government for faster block allocation, mine operationalisation, tax and royalty rate revisions to attract global investors.

Beneficiation and processing technologies along with infrastructure availability are key challenges towards value addition in non-coal minerals for Indian mining industry. The lack of downstream beneficiation is impacting proper waste utilisation and management for Indian miners. The Indian mining sector is vying for investments in R&D to develop indigenous technologies for mineral value addition and policy reforms in PLI schemes and incentives. The government recently introduced provision of financial grants to promising startups in mining and mineral processing technologies. Besides financial grants, these startups will also receive support including mentorship, incubation, and technical advisory throughout their project periods to drive scalability and integration within the mining industry.

The industry is working on the challenges of limited monitoring of progressive rehabilitation, lower financial guarantees from overall mine closure costs, and the absence of a just transition framework for mine closures for long-term sustainable development. Several initiatives have been introduced by both Indian mining industry and the government on mineral resource optimisation, robust community management promotion, effective District Mineral Foundation (DMF) fund utilisation, and transparent reporting such as the star rating of mines. These initiatives will help to mitigate the environmental impact, achieve long-term sustainable future, align with global standards, and attract investments in the Indian mining sector.

To support India's commitment to transitioning to net-zero carbon emissions by 2070, leading Indian miners have already started embracing cleaner technologies and eco-friendly processes in electrification of equipment, alternate fuel technologies for mining fleets, investment in carbon capture, utilisation, and storage (CCUS) technologies. The Indian mining sector is also looking forward to renewable energy microgrids, emissions data management, and R&D for innovation towards achieving net-zero goals.

The Indian mining sector is also addressing long overdue productivity issues related to minimal active working hours, limited visibility on mining operations and the inadequate utilisation of mining equipment. Leading Indian miners are in the process of exploring and adopting emerging technologies, such as IoT, robotics, artificial intelligence (AI), augmented reality/virtual reality (AR/VR), cloud, and drones, to realise benefits through improved asset utilisation, productivity, safety, and environment management.

Over the years, continuous monitoring and compliance checking with stringent health and safety laws have helped the Indian mining industry reduce the number of fatalities from 102 in 2015 to 17 in 2022. Moreover, the Indian mining sector actively focuses on using IoT sensors, smart wearables, predictive analytics tools, and AR/VR to improve mine workers' health and safety and increase safety awareness.

Shortage of industry-ready workforce and skilled human resources has been impacting the growth of the Indian mining industry. Despite having ~6,446 institutions offering engineering and technology courses, only ~168 institutes directly address mining, producing a significant shortage of skilled talent in the mining sector. In the area of gender diversity and inclusion, a regulatory amendment in 2019 opened avenues for female participation in mining. Greater focus is required towards introducing role-based training centres and short-term mining-specific courses to upskill the mining graduates in emerging technologies.

Finally, adequate mineral evacuation infrastructure is a key driver impacting the performance of Indian mining companies. The primary mode of transportation for the Indian mining industry has always been the railways (>50 percent). The Indian government has taken several initiatives, such as PM Gati Shakti, Sagarmala Programme, and Bharatmala Pariyojana, to improve the mineral evacuation network in the country. Furthermore, the Indian mining sector needs to focus on enhancing mechanical evacuation through rapid loading system, augmenting material handling capacity at ports, developing inland logistics capacity, and introducing a smart logistics network for faster and smoother mineral evacuation.

The Indian mining industry has already started showing significant growth in the past few years and can reach its optimal potential. To achieve that goal, the sector and associated stakeholders need to work together towards adopting best practices and a multipronged approach for the sustainable development of the industry and the nation transitioning towards Viksit Bharat.

Introduction

The Indian mining sector is strategically important to the country's growth and the Amrit Kaal Journey. The mining sector growth has significant implications for downstream industries, such as power, steel, and aluminium, which are closely associated with the manufacturing (e.g., auto, chemicals, cement, and steel) and infrastructure (e.g., road, rail, and real estate) sectors. That is, the growth of the mining sector drives the growth of core sectors of the Indian economy.

India is endowed with one of the world's leading mining jurisdictions. The Indian mining sector contributes about 2–3 percent to the country's GDP and provides direct employment to over 1.3 million people.

State of mining in India

The Indian mining sector enjoys an endowment of large mineral resources and has also experienced a significant increase in production volume over the past few decades. The country produces 95 different minerals, comprising 4 fuels, 10 metallic, 23 non-metallic, 3 atomic, and 55 minor minerals.[1] Moreover, India boasts significant reserves of iron ore, bauxite, chromium, manganese ore, baryte, rare earth, and mineral salts.[2]

[1]https://mines.gov.in/webportal/nationalmineralscenario
[2]Ministry of Mines Annual Report 2022-23

Table 1 Benchmark of India's mineral reserves and production in Mt.

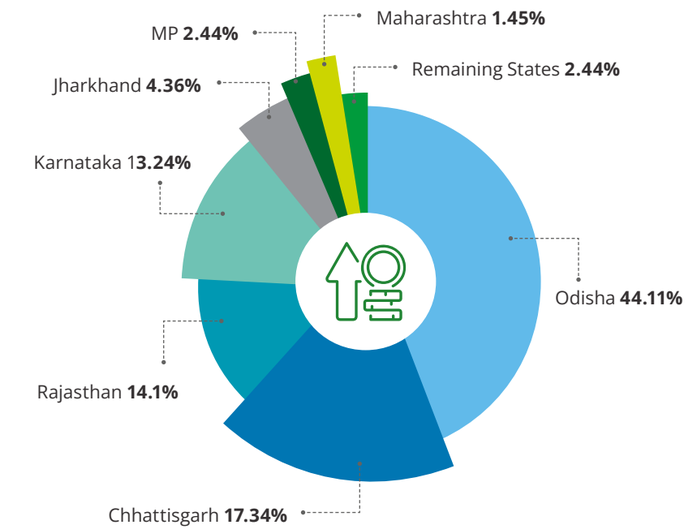
	Global reserves	Indian reserves	Contribution to global reserves	Global production	Indian production	Contribution to global production	Indian production rank
COAL	1069636	105931	9.9%	8076	893	11.1%	2nd
Bauxite	30000	660	2.2%	347	24	6.9%	5th
Iron Ore	180000	5500	3.1%	3040	257	8.5%	4th
Copper	870	2.1	0.2%	20.6	0.03	0.1%	Beyond 10th
Chromite	570	100	17.5%	38.6	3.6	9.3%	3rd
Manganese	1300	34	2.6%	56.6	2.8	4.9%	7th
Zinc	250	7.5	3.0%	13.3	0.8	6.0%	5th

However, the country's mineral resources are yet to be fully explored. Preliminary estimates indicate that less than 10 percent of obvious geological potential (OGP) has been explored, and less than 2 percent is presently mined.[3]

[3] https://timesofindia.indiatimes.com/blogs/voices/with-an-abundance-of-mineral-reserves-india-has-significant-growth-potential-in-drilling-exploration-space/

During 2022–23, mineral production was reported from 19 states, with the bulk of mineral production value coming from seven states. The remaining 12 states have a cumulative share of less than 3 percent of the total value. In comparison, the top three mineral-producing states (i.e., Odisha, Chhattisgarh, and Rajasthan) accounted for more than 75 percent of the country's mineral production by value.

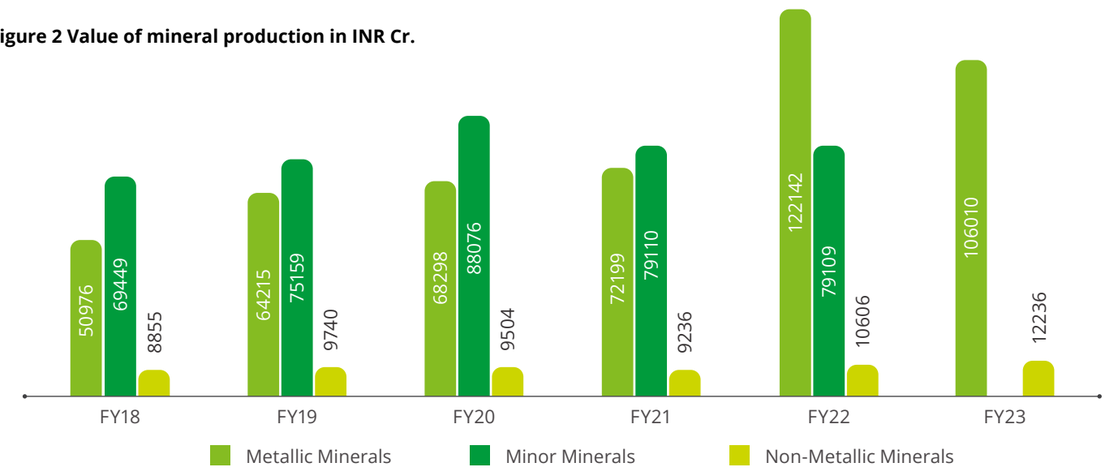
Figure 1 Share of states in mining output by value



Source: Ministry of Mines Annual Report 2022-23

During this period, metallic minerals contributed ~INR106,010 Crore while non-metallic minerals accounted for INR12,236 crore. While during FY18–FY23, mineral production registered a CAGR of 15%.

Figure 2 Value of mineral production in INR Cr.



Source: Ministry of Mines website.

Key trends in the Indian mining regulatory regime over the past decade

India's mining industry has undergone significant regulatory changes since 2010 to improve transparency and efficiency as well as enhance private sector participation.

Some of the key recent government policies, acts, and policy amendments to increase supply and attract investments are given below.

MMDR (Amendment) Act 2015 and its subsequent amendments

1 The Mines and Minerals (Development and Regulation) Act, 1957, was amended in 2015 to enhance transparency in the allocation of mineral concessions by introducing an auction process. Key features of the amendment are as follows:

- Auction of mining lease once a lease expires instead of renewal
- Creation of DMF for the welfare of affected communities
- Establishment of National Mineral Exploration Trust (NMET) to promote exploration
- Imposition of stricter penalties for illegal mining

3 In 2021, the Act was further amended to:

- Remove restrictions on the end use of minerals
- Allow the sale of minerals by captive users
- Transfer statutory clearances upon expiration of mining lease

2 The Act was amended in 2019 to include the following:

- Single-stage licence for exploration and mining and preferential rights for NERP
- Single mining lease grant for small mineral deposits
- Seamless transfer of the concession
- Transfer of 10A2(b) cases
- Time-bound statutory clearances
- Digitisation of the mining approval process

4 Finally, the MMDR Amendment Bill, 2023 includes

- Introducing ELs for deep-seated and critical minerals to incentivise private participation
- Omitting six minerals, including lithium, from the list of atomic minerals opens up opportunities for mining and exploration of these minerals to the private sector

National Mineral Policy 2019

Some of the key highlights of this policy include the following.

- Incentivise exploration at the time of auction
- "No-go areas" and the creation of exclusive mining zones
- Encouragement of mergers and acquisitions of mining entities and transfer of mining leases
- Benchmark and harmonise royalties and taxes with other countries
- Encourage the cluster approach as a single lease for small deposits

FDI policy in mining

The Indian government liberalised the FDI Policy in 2019, allowing 100 percent automatic route investment in mining and exploration, coal and lignite mining for captive consumption, and commercial mining of titanium-bearing minerals. The cumulative FDI inflow in the mining sector accounted for 3 percent of the total FDI inflow received across sectors from April 2000 to March 2023.

Critical minerals policy

Critical minerals are essential to many different industries, such as renewable energy, high-tech electronics, telecommunications, transportation, and defence. In 2023, the government listed 30 essential minerals for both national security and economic growth to reduce reliance on imports for essential minerals such as copper, nickel, cobalt, and lithium. The policy also encourages private sector participation in critical minerals to enhance capital and technology for improved exploration and production.

Recently, the government has listed 38 critical mineral blocks across two separate tranches for auction. Significant interest from bidders has been registered during the first tranche of auction. The government has also rationalised and approved new royalty rates for mining of 24 critical and strategic minerals to encourage mining and private sector participation. In addition, a methodology has been formulated for computing the average sale price (ASP) of these minerals.

Other important policies

The Indian government also introduced the following enablers to enhance the exploration and mining of minerals.

- Single Window Clearance System (SWCS) to establish a platform for obtaining multiple approvals necessary to operationalise mineral blocks.
- Star rating of mines through which mining leases are rated based on the efforts and initiatives taken to implement the Sustainable Development Framework (SDF). Mine rating creates a sense of competition among the miners, resulting in an overall improvement of the SDF parameters.
- The auction of mineral blocks is a significant initiative adopted to expedite the allocation and supply of minerals. Since 2015, 337 mines (excluding coal and lithium) have been auctioned. Iron ore and limestone constituted over 60 percent of the mineral mines auctioned during this period.

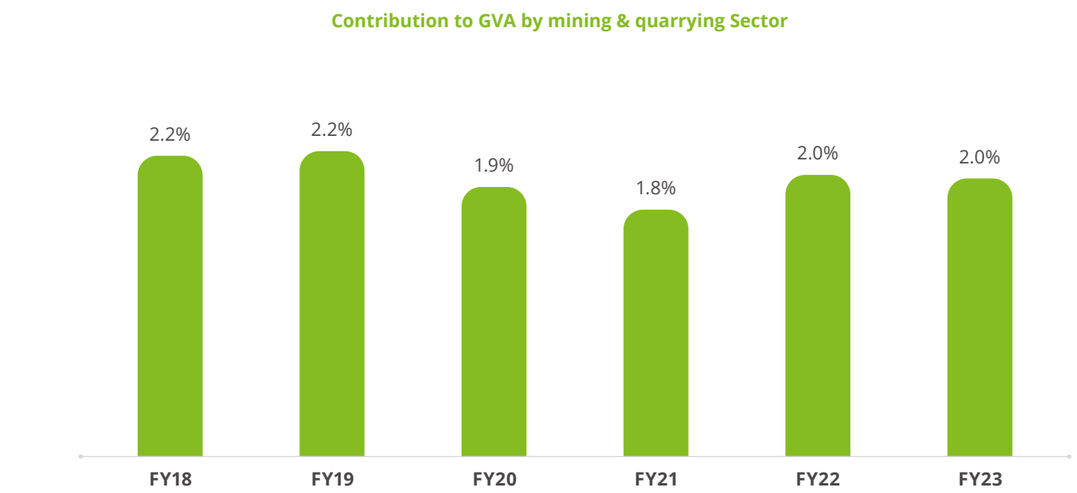
Economic impact of the Indian mining sector

The contribution of mining to India's GDP has been estimated at 2.1–2.5 percent over the last decade. In 2022, referring to leading global mining geographies, mining contributed more than 12 percent and 7 percent of Australia's[4] and South Africa's GDP[5], respectively. If properly tapped, the mining sector's performance will be a key factor for India to achieve the desired GDP growth to become a USD30 trillion economy by 2047, which will help India achieve Viksit Bharat status. In terms of employment generation, the mining sector currently employs ~12 million workers, both directly and indirectly.[6] By some estimates, four informal workers are associated with the industry for every one direct employee.[7,8]

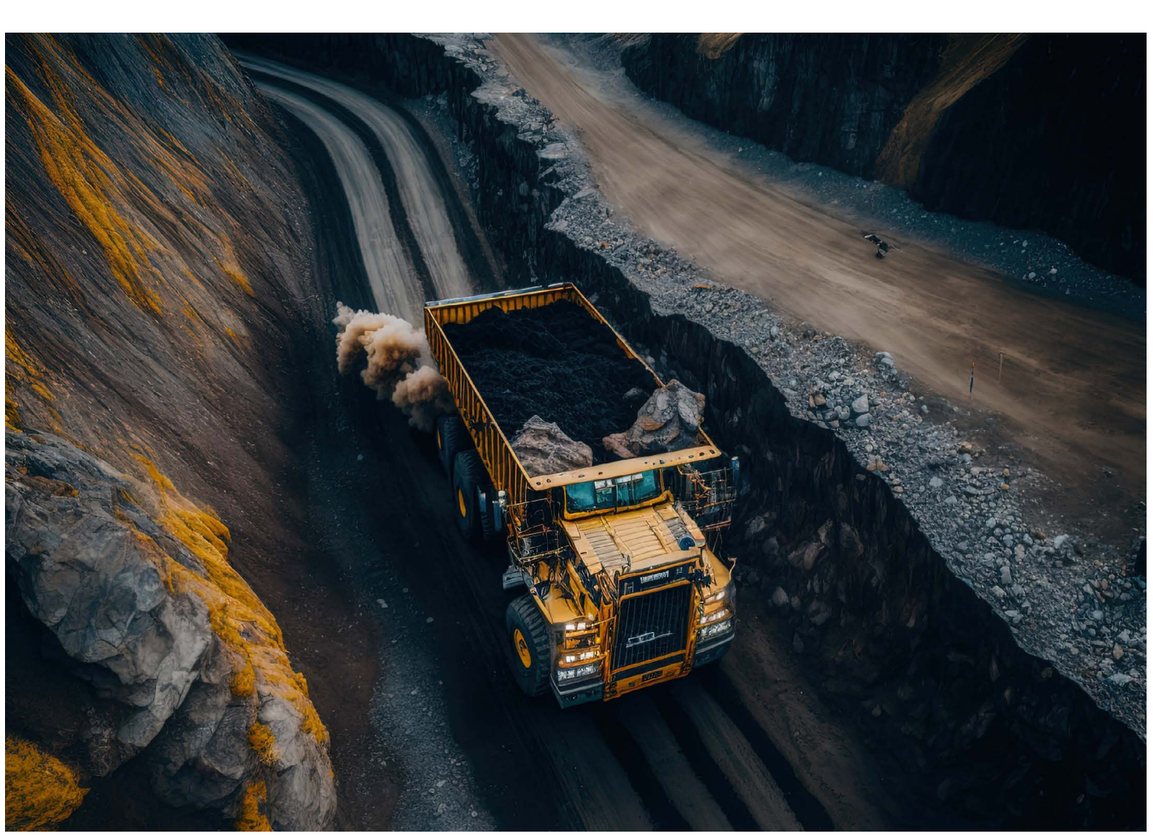
- Accelerated economic growth (GDP growth rate of more than 6–7 percent) can potentially create an additional 25 million jobs (direct and induced) over the business-as-usual scenario by 2047. This would represent a significant share of the total non-farm jobs needed to absorb India's demographic demands.
- Simultaneously, the mining industry could contribute an additional USD500 billion to India's GDP by 2047. However, the complete ecosystem should work together to unlock India's potential in mining. Thus, the mining sector's growth is critical for India's growth over the next two decades.

[4]The Australia Institute
[5]Mineral Council South Africa
[6]Press Information Bureau
[7]Global Energy Monitor
[8]Global Energy Monitor

Figure 3 GVA Contribution trend by mining and quarrying sectors



Source: https://www.mospi.gov.in/sites/default/files/press_release/PressNoteNAD_28feb23final.pdf



Sensing the global mining industry

Tracking the trends

Tracking trends highlights key global trends, indicating the indispensable value the mining sector can deliver. The mining industry supports and enables many sectors globally. As the energy transition accelerates, the demand for minerals will increase. Thus, the mining sector is expected to positively influence social, environmental, and economic development.

1. Impact of geopolitics on mineral price volatility and uncertainty

The calendar years 2022 and 2023 were robust periods for the mining sector, supported by record commodity prices, supply chain constraints, and elevated energy-transition demand. However, late 2022 and early 2023 witnessed declining macroeconomic indicators impacted by various global events, such as geopolitical conflicts, bank failures and ongoing wars, which led to weakening near-term demand expectations and falling commodity prices.

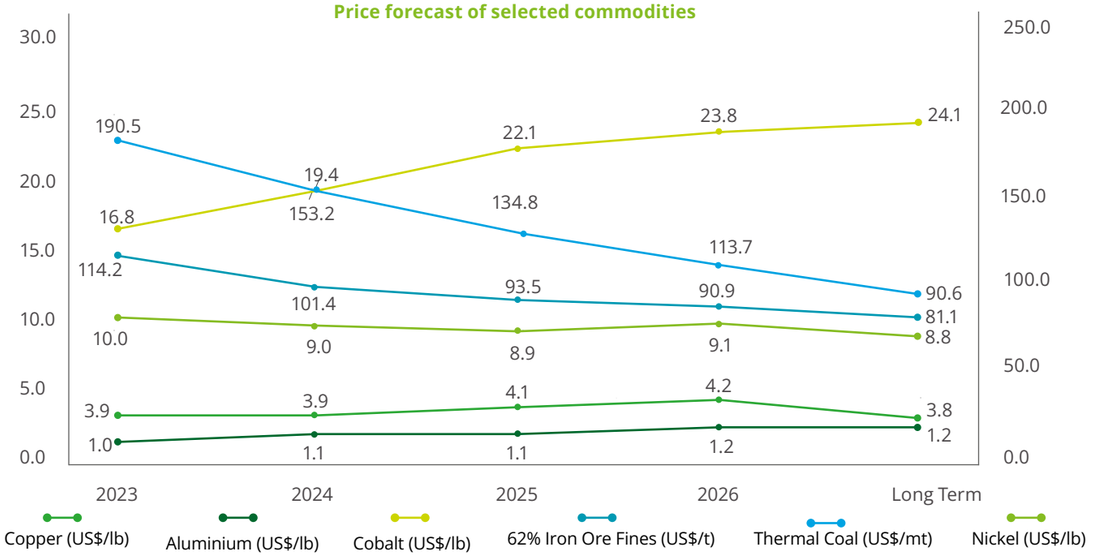
Thus, producers are realising lower margins, and the exploration sector is witnessing restrained activity amidst tighter financing conditions. The global headline inflationary pulse has also clearly peaked, and interest rate relief in absolute terms has yet to be rolled out. While 2023 began with a strong rebound in China's demand in the March quarter, the June quarter was underwhelming, with weak property markets weighing on local government finances and private sector confidence levels, offsetting the positive outcomes seen elsewhere.

The impact of such geopolitical uncertainties in any geography is felt across the global commodity market through supply insecurity and price volatility. Even strikes and labour-related conflicts can lead to production delays, disruptions, and supply shocks.

Demand-side shocks may also adversely affect the commodity market in terms of volatility. For example, in 2022, the world's leading producer of nickel and stainless steel speculated on the fall of the price of nickel and sold its production short. Subsequently, as the drop did not materialise, the producer had to buy back significant amounts of nickel, prompting the London Metal Exchange to suspend nickel trading for one week, resulting in price jumping from USD30,000 to USD100,000 per tonne in a single day.[9]

The continuing trend of divergence amongst commodity clusters, requirement of elevated cost support, and inconsistent policy signals globally indicate that the mining sector continuing to witness volatile commodity prices throughout 2023 and early 2024. However, due to the expanding role of base metals in clean-energy applications, historically low inventories, and tight supply, prices will likely be supported through 2024.[10]

Figure 4 Price volatility and uncertainty of selected commodities



Note: Price forecasts taken as average of leading market analysis and financial institutions

[9]United Nations Conference on Trade and Development, Notes from Multi-year Expert Meeting on Commodities and Development
[10]2023 Outlook for Metals and Mining, S&P Global

2. Collaborate, incubate, and accelerate speeding successful innovation and R&D for greater value

Technological and social innovation can reduce costs and environmental impacts in mining operations, while business model innovation can incorporate circular principles and maximise asset value, among other objectives.

Thus, global miners are embracing innovation through various collaborative initiatives through which the companies aim to acquire minority stakes in start-ups focused on emerging technologies and decarbonisation.

Examples of purpose-driven innovation and R&D in the global mining industry[11,12,13,14]

- The subsidiary of a leading global miner signed a collaboration agreement with Murihiku Hapu of Ngāi Tahu to develop a large-scale and renewable green hydrogen production project in Southland, New Zealand, with first production in early 2025 with an aim to produce 15 million tonnes of green hydrogen by 2030
- A leading global miner is working to develop a circular economy for titanium dioxide, an essential ingredient in paint and plastics. The company is recovering titanium dioxide from waste streams and using it to produce new products.

3. Investing in green: ESG and decarbonisation imperatives in the global mining sector

ESG imperatives are increasingly shaping the mining industry's future. Value generation is being redefined to support a bid for enhanced sustainability, as evidenced by the introduction of carbon pricing, robust environmental, social and governance (ESG) measures, and the evaluation of biodiversity risk, among others. Global players across the mining and metals industry aim to reduce their carbon footprints by implementing energy efficiency, process optimisation, supply chain optimisation, adoption of clean technologies, and the circular economy.

The mining sector has historically progressed on unconscious circularity, such as wastewater recycling and the creation of products from tailings. The sector is rapidly adopting conscious measures, including mine electrification and regeneration of landscapes, focusing on decarbonisation.

Furthermore, green mining, which prioritises reducing environmental impact and carbon footprint, is gaining prominence globally. The green mining market is expected to grow from USD11.0 billion in 2022 to USD17.6 billion by 2027, at a CAGR of 9.9 percent.[15]

Examples of ESG and decarbonisation initiatives in the mining value chain[16,17,18]

- A leading Australian mining company proposed its carbon neutrality target from 2040 to 2030. To achieve this target, the company's subsidiary is advancing projects across Australia to build large-scale renewable energy and green hydrogen production capacity.[1]
- In 2022, a Swedish mining company launched the product Low-Carbon Zinc. With only 1 kg of carbon dioxide per kg zinc emissions, compared with the global average of 3.6 kg, it is one of the market's most climate-friendly products.

[11]https://www.mining-technology.com/data-insights/whos-leading-the-way-top-ranked-mining-companies-in-the-esg-theme/?cf-view
[12]https://chargeoninnovation.com/
[13]https://www.greencarcongress.com/2022/10/20221013-shellmining.html
[14]https://www.processonline.com.au/content/business/news/rio-tinto-develops-method-of-extracting-scandium-from-waste-422032716
[15]https://www.marketsandmarkets.com/Market-Reports/green-mining-market-142994284.html
[16]https://www.rivieramm.com/news-content-hub/news-content-hub/vale-ore-carrier-will-use-silverstreamrsquos-emission-reducing-technology-66689
[17]https://www.moveelectric.com/e-world/wae-showcases-first-prototype-battery-electric-mining-trucks
[18]https://searchev.in/the-mining-industry-in-india-welcomes-its-first-electric-vehicles/

- A South African mining company set ambitious new 2030 goals for its water recycled/ reuse to 80 percent of total water used reduction in freshwater usage by 45 percent (2018 baseline). The company seeks to achieve greater inclusion and diversity by targeting a 30 percent female workforce by 2030.
- A leading global mining company launched Social Way 3.0 in 2020, providing a social performance management framework for all sites.[1] This industry-leading framework aligns with its purpose and strategic business objectives, ensuring stakeholder engagement.
- A leading global mining company is investing in a new solar farm that will generate enough electricity to power its copper mine.[1]

4. Circularity: The role of mining in a circular economy

The circular economy is a concept that aims to eliminate waste and pollution by extending the lifespan of products and materials. In the mining industry, the circular economy can reduce the environmental impact of mining operations and promote sustainable resource management.

The circular economy offers a promising approach to address the environmental challenges and resource scarcity issues the mining industry faces. By adopting circular economy principles and implementing sustainable practices, mining companies can contribute to a more sustainable future for the industry and society.

Recovery of minerals from low-grade tailings offers immense opportunities for promoting circularity in the mining industry. Recent advancement in mineral extraction technologies and declining ore grades in primary deposits have expedited the focus on reprocessing of mine tailings as the potential secondary source of critical minerals. By embracing innovation, implementing efficient processing techniques, and fostering collaboration, the industry can move towards a more sustainable future that maximises resource utilisation and minimises environmental impact.

Mining waste management and conversion of waste to wealth is a key focus area for leading global mining companies. Mining waste produced by the extraction and processing of minerals as well as closed mines are challenges being addressed across geographies. The reprocessing of mine tailings also helps to offset GHG emissions. The global mining waste management market is estimated to reach USD208.33 billion in 2028.[19]

Adoption of wastewater management for the wastewater generated by global mining companies will be an inseparable piece of circularity theme.

Examples of initiatives taken by mining companies towards circular economy[20]

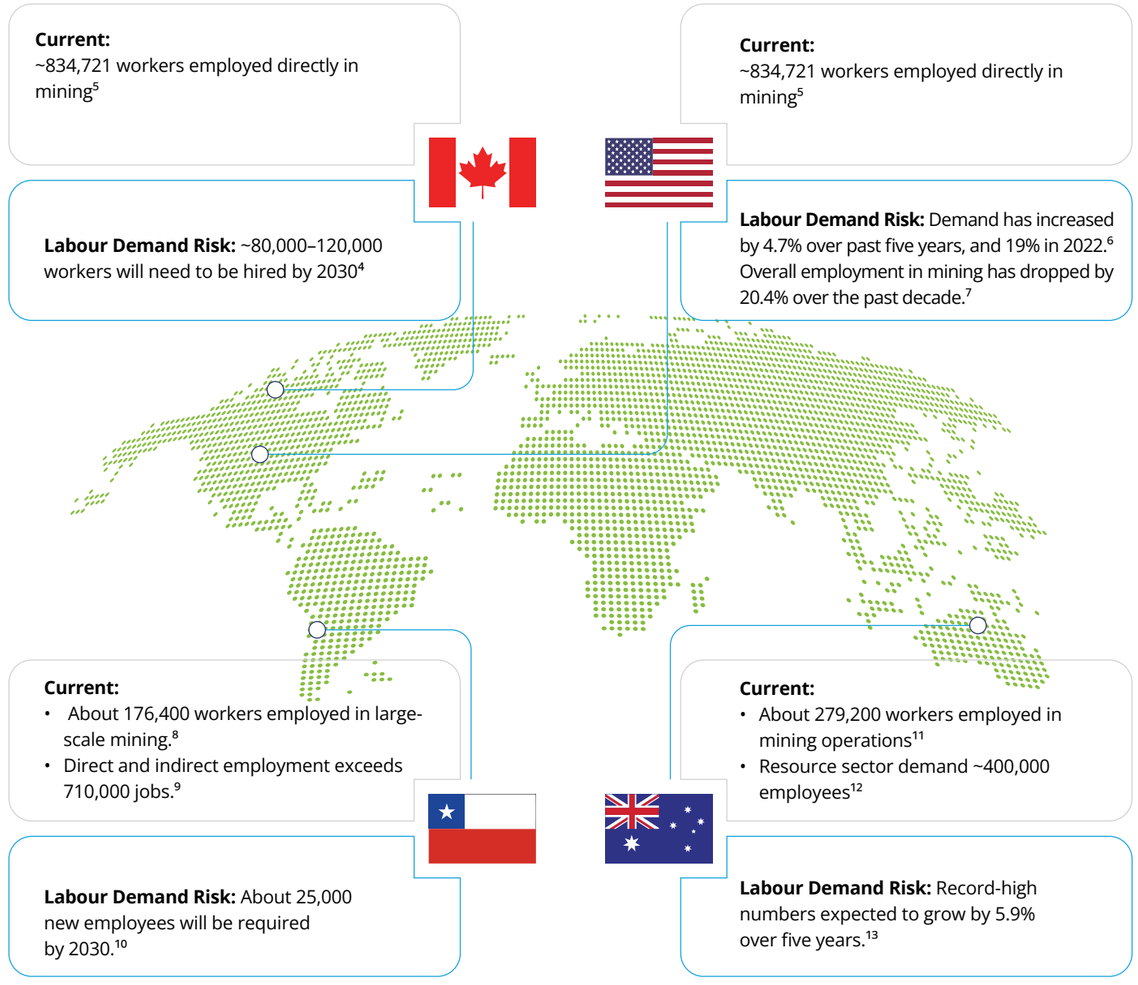
- A Nevada-based miner, is working to improve mercury recovery and removal from mine tailings. Mercury is a significant public health concern in both artisanal and large-scale operations. The miner plans to use the Comstock Lode deposit to test a pilot mercury clean-up operation, backed by Mercury Cleanup and Oro Industries. The joint venture aims to construct a two tonne per hour pilot plant to treat 15 million pounds of poisonous mercury produced over the deposit's life.
- A Finland-based technology company, VTT's MetGrow+ project, a four-year, USD8.7 million initiative, aims to improve the recovery of waste minerals such as cobalt, nickel, and zinc and Europe's metal production self-sufficiency. The project focuses on supply chain optimisation rather than technological innovation, with miners potentially seeing a 20 percent increase in mineral recovery from waste.

[19]https://www.mining-technology.com/features/environmental-waste-management/?cf-view&cf-closed
[20]https://www.mining-technology.com/features/circular-economy-the-projects-leading-the-way-in-mining-waste-recovery/?cf-view&cf-closed

5. Rethinking talent pathways: Solving workforce challenges

Similar to many other global industries, the mining sector continues to experience unprecedented changes impacting its workforce and working methods. Majority of the mine workers are over 46 years of age, with ~50 percent of skilled engineers reaching retirement age in the next decade.[21]

Figure 5 Map showing the extent of skills shortage in key mining markets (2023)



[21]"The Impending Skills Shortage in Mining", Mining International webpage, 2022 https://www.mining-international.org/the-impending-skills-shortage-in-mining/

Companies are facing challenges in a rapidly changing labour market, driven by a global shift towards purposeful employment and the energy transition. Furthermore, the industry is facing a reskilling emergency due to rise in retirements and low recruitment of younger generations.

To address this issue, leaders must balance sourcing new talent with upskilling the existing workforce, improving workforce planning and updating operating models. Diversifying recruitment efforts based on skills and potential, involving multiple stakeholders and evaluating community perception are vital for sourcing, partnerships, and recruitment.

Mining companies continue to put physical safety at the forefront of operational environments, including accommodation and living facilities, transportation, and offices. However, in contrast to sustainability reporting, only 67 percent of companies reported their safety performance to the market. Similar to sustainability, reporting safety outcomes enhances a company's transparency and performance and, therefore, contributes to maintaining a social licence to operate.[22]

Examples of initiatives taken by mining companies for safety and health of miners[23,24]

- A leading global miner conducted studies to manage fatigue-related risks, piloting wearable technology to help employees manage fatigue. This data offered valuable insights into sleep quality and quantity, aiding in risk management. The company developed global training packages and guidance tools for employees and leaders.
- Glencore is overseeing its safety prevention programme, SafeWork, which was revised in 2021 through "SafeWork 2.0." The committee is reviewing fatality outcomes, recommendations, and lessons learned. The group is revamping leadership of fatality investigations, including a training programme and reviewing critical incidents and trends in TRIFR, LTIFR, HPRIs, and other relevant statistics.

6. Building resilient supply chains: securing future metals and minerals supplies

Supply chains are critical for mining companies to run their daily operations. Mining firms are rethinking supply chain fortification to protect raw material sources that sustain their value chain. Companies are turning to AI-based prediction models to understand their exposure better and perform risk assessments on suppliers. Cross-border transactions can be secured using blockchain technology across global supply chains, which will help end duplication and fraud endemic in the industry's present paper-based transaction system.

Example of securing the supply chain through innovative measures[25]

- In December 2021, MineHub Technologies announced that its Hyperledger Fabric-based platform had been adopted by BHP and China Minmetals in the first cross-border copper concentrate trial shipment processed on blockchain technology. This followed BHP's 2020 pilot transaction in iron ore with China Baowu. BHP now has a subscription to the MineHub platform, which will help it "gain improved visibility into its supply chains to proactively mitigate against disruptions," among other benefits.

[22]Benchmarking Analyst Reports
[23]https://www.riotinto.com/en/sustainability/health-safety-wellbeing
[24]https://www.glencore.com/.rest/api/v1/documents/static/63d21a4e-30f6-40ca-b0f6-00ec64a718cf/GLEN_2022_sustainability_report.pdf
[25]https://www.miningreview.com/energy/resilient-supply-chains-securing-future-metals-and-minerals/

7. Critical minerals for energy transition

As the global energy transition accelerates, low-carbon energy technologies are expected to experience rapidly growing markets, driving growth in the demand for a range of critical minerals.

Figure 6 Demand for critical minerals by application

		EVs and battery storage	Solar	Wind	Nuclear	Hydro	Geothermal	Hydrogen	Electricity networks
Minerals used in one or two technologies	Cobalt	Co	↑						
	Graphite	Gr	↑						
	Lithium	Li	↑						
	Rare Earth elements		↑		↑				
Minerals used across a wide range of technologies	Bauxite	Al2O3	↑	↑	↓	↓			↑
	Copper	Cu	↑	↑	↑	↓	↓	↓	↑
	Chromium	Cr	↓		↓	↓	↓	↑	
	Manganese	Mn	↓		↑		↓	↓	
	Molybdenum	Mo		↓	↓	↓	↓	↓	
	Nickel	Ni	↑	↓	↓	↓	↓	↑	↑
	Tantalum	Ta	↓			↓			
	Tin	Sn		↓		↓			
	Titanium	Ti				↓	↓	↓	
	Zinc	Zn	↓	↓	↑	↓	↓		

↑ Higher ↓ Lower

More than 10,000[26] active mining projects operate globally, with hotspots in Australia, South America, Canada, China, India, and South Africa. On the policy front, this shift towards technologies supported by critical minerals is reflected through reinforced commitments by Canada, the EU, the UK, and Australia towards the critical minerals value chain. Notably, the US has recently enacted the Inflation Reduction Act, which aims to inject ~USD370 billion[27] into clean-energy industries and supply chains, significantly increasing public capital for critical minerals investments.

Key advancements in global critical mineral market[28]

- China[29] has a strong position in critical mineral mining and a dominant position in processing and manufacturing. China accounts for 85–90 percent of global rare earth element mine-to-metal refining and refines 68 percent of the world's cobalt, 65 percent of nickel, and 60 percent of lithium of the grade needed for electric vehicle batteries. This over dominance of China can be a cause of concern for other countries solely dependent on imports of critical minerals. They would need to diversify their supply chains.
- Saudi Arabia aims to purchase USD15 billion (SR56.25 billion) worth of mining assets in African countries, including the Democratic Republic of Congo, Guinea, and Namibia, boosting attempts by the US to curb China's role in the global race for cobalt, lithium, and other metals used to process batteries used in electric cars, laptops, and smartphones.
- Canada, with an abundance of cobalt, graphite, lithium, and nickel, tops the list of corporate ownership of critical mineral mines already in operation, with a total production of 508 million tons per annum (MTPA) overseas as of 2022 and a further 118 MTPA at home.
- Indonesia's Ministry of Energy and Mineral Resources (ESDM) passed a decree in mid-September, which includes rare earth metals, tin, nickel, and zircon, to "increase the independence of the supply of mineral raw materials for national strategy."
- o Australia's AUD225 million "Exploring for the Future program" offers precompetitive geoscience data, encouraging investment in new resource projects, with 419 exploration tenements approved by 49 companies thus far.

Strategic mineral supply partnerships

Global capacity for extraction and processing of critical minerals is concentrated in a small number of markets. This creates vulnerability in critical minerals supply chains, including for supplying minerals, and processing and manufacturing components for magnets, lithium-ion batteries, cell chemistry, and special alloys. This has paved the way for international collaboration to build integrated mining and mineral processing supply chains. For example, the Supply Chain Resilience Initiative between Australia, India, and Japan can support development of a reliable supply chain for critical minerals involving these countries.[30]

In addition, India became part of a global alliance for Mineral Security Partnership (MSP) in June 2023. The other member countries are United States, Australia, Canada, Finland, France, Germany, Italy, Japan, Norway, the Republic of Korea, Sweden, the United Kingdom, and the European Commission. The partnership seeks to ensure that critical minerals are produced, processed and recycled by catalyzing investments from governments and private sector across the full value chain. The partnership will help India in harnessing its critical minerals potential.

[26]https://wwwn.cdc.gov/niosh-mining/MMWC/Mine
[27]https://www.whitehouse.gov/wp-content/uploads/2022/12/Inflation-Reduction-Act-Guidebook.pdf
[28]https://www.mining-technology.com/news/us-and-saudi-in-talks-to-secure-metals-from-african-nations-wsj-reports/
[29]https://www.goldmansachs.com/intelligence/pages/resource-realism-the-geopolitics-of-critical-mineral-supply-chains.html
[30]https://economictimes.indiatimes.com/news/economy/foreign-trade/india-japan-australia-decide-to-launch-resilient-supply-chain-initiative-in-the-indo-pacific-region/articleshow/77870346.cms?from=mdr

8. Future of mining: AI and digital technologies

The mining industry is going through significant changes primarily driven by the adoption of AI technology. According to recent data, the worldwide market for mining AI was valued at USD702 billion in 2022 and is predicted to reach USD909 billion by 2030, increasing at an impressive average annual increase of 35.2 percent.[31] Some of the leading companies spearheading the integration of AI into mining processes include Goldspot Discoveries, Earth AI, Minerva Intelligence, DroneDeploy, Hikvision, Imago, Caterpillar, Komatsu, and Microsoft.[32]

Mining companies now lean heavily on advanced analytics and AI-based solutions to produce more minerals with fewer resources and a minimal footprint. By delivering better operational performance using new approaches, systems thinking, design and modelling can add value. Systems thinking involves understanding and characterising a system by examining its elements' linkages and interactions, helping companies identify the micro-level changes and macro-level disruptions affecting individual companies and the value chain ecosystem. Moreover, organisations must embed systems thinking into their wider work practices, decision-making processes, and strategies to make impactful change.

By thinking differently, mining and metals companies can generate new social and environmental value. Some companies have moved to advanced simulation and modelling technologies to rapidly assess the implications of different plans and designs over the long term. Integrating digital twins and virtual reality technologies into mining is crucial to mine designing and eliminating waste from mining systems. Simulation-based training also helps to improve safety of workers in the mines.

Key advancements towards AI in the global mining industry[33]

- A leading global miner uses AI and ML to boost copper production. The companies use real-time data from the copper concentrators and machine learning to make hourly predictions.
- One of the world's largest gold mining companies has used AI for mine exploration for several years. The company uses AI algorithms to process geological and geophysical data, help identify potential mining locations, and optimise drilling operations.
- Systems thinking can revolutionise mining operations, as seen at an iron ore mine in Australia. The mine's autonomous assets are remotely monitored, and a digital replica of the processing plant is created for data collection and virtual reality training. This flexibility allows for better management decisions in response to variable renewable power generation and volatile metal prices.
- A global mining company, launched its first AI centre in Espírito Santo in 2020, enhancing sustainability, safety, and environmental management through advanced ore analysis and sorting methods.

[31]https://www.statsmarketresearch.com/download-free-sample/7826040/global-artificial-intelligence-mining-forecast-2023-2032-412
[32]https://www.mining-technology.com/buyers-guide/leading-ai-companies-mining/
[33]https://miningdigital.com/articles/top-10-uses-of-artificial-intelligence-in-mining

Indian mining sector: The next growth orbit

Overview

The mining industry is a critical driver of growth for the Indian economy and serves as the basis for energy and manufacturing sectors. The mining industry is wholly or predominantly self-sufficient in minerals, which constitute primary raw materials supplied to industries such as power, iron and steel, aluminium, and cement but lacks on the critical mineral front.

India plays a significant role in the global mining industry as an exporter and importer of minerals and metals. The country is a major producer of iron ore, bauxite, coal, and other minerals and imports various minerals and metals to meet domestic demand.

India is a leading exporter of iron ore, accounting for ~15 percent of global exports in 2022. The country also exports significant quantities of bauxite and other minerals, such as chromium, manganese, and limestone. In FY23, India's total mineral exports were valued at ~USD24 billion.

India is a net importer of minerals and metals, with imports exceeding exports in most years. The country imports a variety of minerals, metals, and precious stones, including copper, lead, nickel, zinc, gold & diamonds, etc. In FY23, India's total mineral imports were valued at ~USD73 billion.[34]

According to the Ministry of Mines report, in FY22, the share of public and private sectors of the total value (including metallic and non-metallic) were 41.46 percent and 58.54 percent, respectively.[35]

The mining sector is a vital segment of the Indian economy. Nevertheless, India's mining industry has not achieved the expected growth, as evidenced by its declining contribution to GDP. The mining industry's share (GVA terms) of India's GDP was 2.3 percent in FY22, down from 2.5 percent in FY18.

Considering India's rich mineral reserves, there is significant potential for growth. To unlock the growth potential, subsequent sections deliberate on eight key trends and challenges faced by the industry in India, which must be addressed to boost the Indian mineral production, enhancing its growth in the Amrit Kaal Journey.

Key growth themes for Indian mining industry

Exploration

The Indian mining sector faces the following exploration challenges:

Limited focus and expenditure on mineral exploration: It is estimated that less than 10 percent of India's OGP has been explored. India's spending on exploration projects is only 0.3 percent of global expenditures (compared with 19 percent for Canada and 12 percent for Australia).[36] The figure below shows the percentage shares of the leading countries in the global exploration budget.

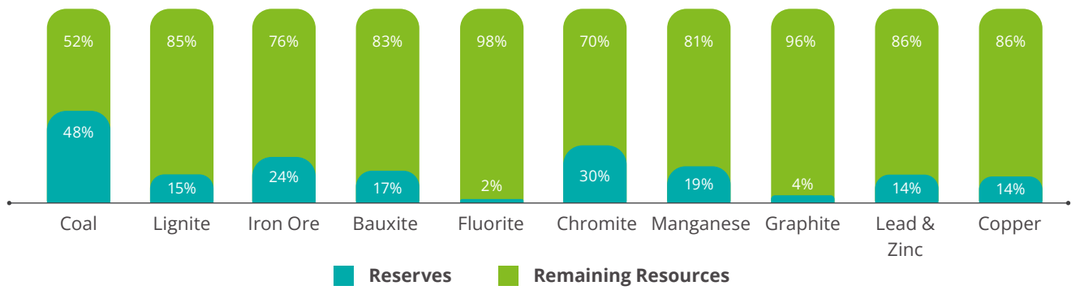
Inadequate conversion of resource to reserve: The low level of exploration spending leads to a lower resource-to-reserve conversion ratio for some minerals. As a result, India's mining potential remains underutilised and many minerals are still largely at the resource level, with further exploration required to take them to the reserve stage.

Limited participation from private players and foreign "junior" exploration agencies: Exploration is conducted by Indian PSUs such as GSI, MECL, and CMPDI, with limited participation from private sector players. This is in stark contrast with Australia, where junior companies' expenditures account for about 40–50 percent[37] of the entire country's exploration spending. Indian government agencies have inadequate resources (in terms of workforce, advanced technologies, and funding) to meet the exploration needs of the entire nation, while the private sector and junior miners are not much willing to participate due to the existing policies, which do not reward the exploration agencies for their findings.

The Indian mining sector has seen recent reforms in the exploration market, which are expected to attract further investors.

Focus on exploration of critical minerals and attracting private players: In the MMDR Amendment Act 2023, the government has omitted six minerals from the list of 12 atomic minerals. Demand for these six minerals (i.e., lithium, beryllium, zirconium, titanium, niobium, and tantalum) is expected to increase significantly as the focus shifts towards clean energy.

Figure 7 Resource-to-reserve conversion for some of the major minerals in India



Source: IBM Yearbook 2021

[34]https://mines.gov.in/webportal/content/export--import
[35]https://mines.gov.in/webportal/content/export--import
[36]https://www.dfat.gov.au/sites/default/files/minisite/static/07db88b0-d450-4887-9c90-31163d206162/ies/pdf/dfat-an-india-economic-strategy-to-2035.pdf
[37]https://minexconsulting.com/recent-trends-in-the-the-australian-junior-sector/#:~:text=After%20adjusting%20for%20inflation%2C%20Australia's,A%241720%20million%20in%202022.

India is primarily dependent on imports as there is limited exploration or mining of these minerals due to existing legal provisions and limitations on private sector participation. Upon removing these six minerals from the list of atomic minerals, exploration and mining of these minerals will be open to private sector, which may lead to a significant increase in exploration and mining in the country.

Introduction of ELs for deep-seated and critical minerals: The government has introduced provisions for granting an EL through an auction process. The licence shall permit the licencee to undertake reconnaissance and prospecting operations for critical and deep-seated minerals. Preferred bidders for ELs shall be selected through reverse bidding for shares in auction premiums payable by the mining lease (ML) holder. The bidder quoting the lowest percentage bid shall be the preferred bidder for the EL. This new regulation is expected to create a legal environment conducive to attracting FDI and junior mining companies in the country.

Incentivisation of exploration agencies for mineral exploration: The government has recognised the need to incentivise greenfield exploration (G4) and included an Exploration Incentive (EI) of 10% of the approved costs under NMET, which was applicable for exploring precious metals, base metals, strategic / critical minerals, and fertiliser minerals. The Exploration Incentive (EI) was paid on the cost of G4 work completed by the implementing agencies. During September 2023, the Exploration Incentive (EI) was enhanced to 25% of the project cost to encourage more projects for gold, base metals, other precious minerals, strategic / critical minerals, and fertiliser minerals in the country, if successfully auctioned or upgraded. The incentive is applicable for public as well as private exploration agencies.

Private companies are adopting new technologies for exploration: Some startups are investing in new technologies for exploration:

- A Bengaluru-based startup has deployed a UAV-enabled drone-based technology for mineral prospecting and exploration. The company deployed the technology at the Gujarat Mineral Development Corporation, Ambaji, Gujarat. The technology is equipped with nonradioactive laser-pumped ceasium vapour with a total field scalar magnetometer that enables mapping of shallow and deep-seated virgin mineral deposits ranging from 600 to 800 m below ground level.[38]

Opportunity for the Indian mining industry: The existing policies should be amended to ensure that exploration agencies are incentivised and rewarded for investing in exploration. To attract private junior exploration companies, the government may make appropriate changes to the MMDR Act, 1957 and its Mineral (Non-Exclusive Reconnaissance Permits) Rules, 2015. A multidisciplinary exploration capacity needs to be developed to ensure that nationwide exploration can be conducted, and the latest exploration technologies are used efficiently to locate deep-seated or concealed mineral deposits.

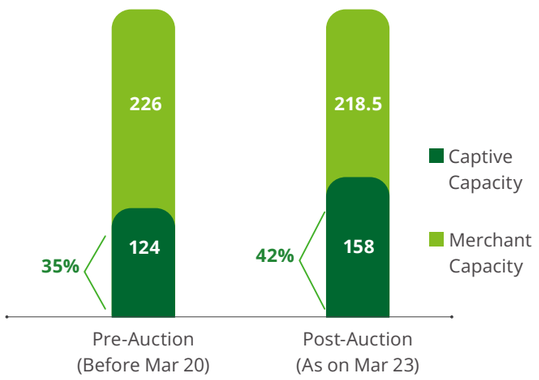
Mineral block allocation and operationalisation

The Indian mining sector faces the following challenges regarding mining lease allocations and grant policies.

High auction premiums and tax rate: Under the current two-stage auction methodology, high winning bids, (more than 100 percent) coupled with India being one of the highest tax jurisdictions for mining, has contributed to the shift of iron ore block ownership towards captive players. An illustrative comparison of the winning bids of captive and merchant miners for iron ore, along with the effective tax rates, is provided below.

Thus, mining companies are left with a limited value of the minerals due to high bid premiums and taxes. In such a scenario, captive miners are better placed to sustain high bids as they can transfer losses to other business verticals. Due to this, the Indian iron ore sector has witnessed significant transition in mine ownership over five years from pure play merchant capacities to capacities owned by integrated steel producers (as shown in the figure below).

Figure 8 Iron ore mine capacity of captive and merchant miners in Mt.



Source: Steel Mint, Deloitte Analysis

[38]https://www.manufacturingtodayindia.com/sectors/squadrone-deploys-drone-based-technology-at-gmdc

While various policies are being promulgated to enhance competitiveness among the mining players in India, the practice of a two-stage auction may also need to be re-evaluated, as the system has resulted in exorbitant bids, resulting in a downwards trend of merchant miners in the country.

Timeline for Grant of Licences: Historically, obtaining various permits, licences, and approvals for mining operations in India has often involved lengthy processes, causing significant delays for mining companies. A report from the CAG office notes that 89 percent of the EIA proposals were recommended beyond the prescribed time limit of 105 days for EC.[39] A comparative overview of timelines for granting licences in leading mining economies is provided below.

Table 2 Comparative overview of timeline for grant of licences

Policy Parameter	Timeline for granting licences
South Africa	Notification to applicant within 14 days from receipt of application Regional manager forwards application to Minister of Mineral Resources and Energy within 14 days Licence approval (or refusal) within 30 days by Minister of Mineral Resources & Energy
Western Australia	No time-bound programme for grant
Canada (Manitoba)	Varies by province. Manitoba ranks best in terms of approval times. Grant within 1–2 months. Timeline similar to provinces of British Columbia, Ontario, and Quebec
China	Usual timeframe for deciding on an application for an exploration licence is 40 days

Source: Transparency International South Africa, Fraser Institute, Herbert Smith Freehills

Opportunity for the Indian mining industry: Regulatory changes must be implemented to reduce the timeframe for granting licences, helping the Indian mining industry attract global investors and position itself as a leading global destination for mining. The industry appreciates the initiatives taken by Ministry of Mines to expedite operationalisation of the blocks. However, the same should not be in a penalty format but of rewarding in nature and should be thought through consultation.

[39]Audit Report, Chapter 2: Process of Grant of Environment Clearance, Union Government Report no. 39 of 2016, CAG

Mineral royalty rates

Benchmarking the leading mining jurisdictions reveals a much higher royalty rate in India. An illustration using iron ore mining is shown below:

Figure 9 Comparative overview of royalty rates in iron ore mining

	Royalty rate	Royalty base	Royalty system	Auction premiums
India	15%	Average sale price	Ad-valorem	Yes
Western Australia	5%, 7.5% (beneficiated ore, raw ore)	Sales revenue	Ad-valorem	No
Queensland	~AUD 1.25/T + 2.5% if price > AUD 100	Per tonne and sales revenue	Hybird	No
Northern Territory Australia	Max. of 20% (less AUD 10,000) or 1%, 2%, 2.5%	Net value or sales revenue	Hybird	No
Brazil	3%	Sales revenue	Ad-valorem	No
China	1–9% (iron ore concentrate)	Sales revenue	Ad-valorem	Yes

Source: Centre for Social and Economic Progress (CSEP), Mineral Royalty Rates: A Policy Review

In the current statutory framework, royalties are included in the average selling price of minerals. Subsequently, it is computed on an ad valorem basis, leading to double taxation, or "royalty-on-royalty." Statutory levies are paid on the base price, and statutory levies lead to increased costs of raw materials and the overall cost of end products.

Opportunity for the Indian mining industry: The committee constituted to develop the National Mineral Index has also examined the double calculation of royalties and has submitted the third and final report to the Ministry of Mines.[40] Reconsidering its royalty policies will reduce the royalty burden on miners and attract more international investors to the Indian mining industry.

[40]Press Information Bureau

Financing ecosystem

The financing needs of the Indian mining industry are expected to grow rapidly due to capacity expansions across greenfield and brownfield mining projects. Given mining projects are capital intensive, the miners do face challenges in availing financial assistance to operationalise mines including high cash margin in BG issuance, stringent pre-disbursement conditions etc.

Opportunity for the Indian mining industry: For example, multiple stakeholder consultations involving coal mine allottees and representatives from financial institutions / banks were conducted recently to streamline financing of commercial coal mining projects. During the consultations, banks and financial institutions expressed willingness to finance coal mining projects, provided project viability and equity infusion visibility were demonstrated through detailed business plans. Moreover, banks and financial institutions have undertaken steps such as identification of nodal branches (acting as single windows for financing) and formulation of board-approved policies to extend time bound financial support. Similar policies and stakeholder consultations between the mine owners and banks / financial institutions are required in non-coal sector to expedite operationalisation of mineral blocks.

In addition, introduction of alternative financing such as production-based financing (companies can secure cash by selling rights to receive future production from their assets), private equity financing etc. may enable mine owners to secure funds for mine development and setting up mining and beneficiation facilities. Royalty and streaming finance have been used in some of the advanced mining geographies for funding mining projects. These types of financing provide attractive investment options for institutional investors, who do not have to invest directly into the mining company but may take advantage of potential upside and income generation from a portfolio of mining projects.

Mineral beneficiation, processing, and value addition

Lack of incentives for beneficiation in non-coal minerals: No incentives are provided on royalties for utilising low-grade minerals or for extracting mineral from tailings. This is in contrast to the other leading mining geographies as given below:

- In Western Australia, the royalty rate for beneficiated or concentrated ore is lower. For bulk minerals (unprocessed), concentrates, and metal, the royalty rates are 7.5 percent,[41] 5 percent, and 2.5 percent, respectively. Therefore, beneficiation is incentivised.
- South Africa stipulates that mineral beneficiation outside South Africa be undertaken only after giving written notice to the Minister of Mineral Resources followed by consulting with the Minister. The Minister has the power to prescribe the level of beneficiation that must be undertaken.

Small size of mines and tailing management issues make beneficiation too expensive: The Indian mining industry is characterised by many small mines. According to the Ministry of Mines, about 51 percent of the mining leases in India are less than or equal to 10 hectares in size.[42] Therefore, the economy of scale is insufficient to justify large capex investments. There are paltry incentives for high capex-intensive beneficiation plants (e.g., import duty exemption for imported equipment). As tailing disposal would need large amounts of land, commercial feasibility is a challenge. While India has proposed a new iron ore beneficiation policy, it must still address the high capex and land and disposal issues.

Lack of technology and R&D: Most 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 USD30 billion in R&D since 2005, becoming a global critical driver of industry innovation.[43]

Opportunity for the Indian mining industry: India may explore establishing centralised beneficiation plants in key mining districts so that miners can pay a beneficiation charge on a tolling basis. Beneficiation activities should be incentivised by charging a lower royalty on beneficiated products for at least low-grade ores and providing capex-related incentives. Notably, multidisciplinary R&D capability must be developed to ensure that available mineral deposits or waste materials are effectively utilised for commercial purposes.

Lack of value addition in critical minerals: The Ministry of Mines has identified 30 critical minerals in 2023.[44] Recently, India has increased its focus on exploring these minerals and has already launched two tranches of auction. However, India depends entirely on imports of finished products for critical minerals such as lithium, cobalt, and nickel. India has no mineral processing facility for processing critical minerals and has recently started manufacturing EV batteries. Meanwhile, China has developed its critical mineral processing industry to such an extent that it has only 7 percent of global lithium reserves yet controls 80 percent of the world's raw material refining.

[41]http://www.dmp.wa.gov.au/Minerals/Royalties-1544.aspx
[42]https://mines.gov.in/webportal/nationalmineralscenario
[43]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).
[44]https://pib.gov.in/PressReleasePage.aspx?PRID=1942027#:~:text=These%20minerals%20are%20Antimony%2C%20Beryllium,%2CZirconium%2C%20Selenium%20and%20Cadmium.

Although Indonesia has no lithium mine, it is building a lithium refinery and an anode material production facility. This initiative is targeted to further boost Indonesia's existing battery materials industry, since it wants to position itself as a global manufacturing hub for electric vehicles.

As India auctions its critical minerals, it should ensure that policies are designed to ensure the value addition of the critical minerals within the country. For example, Zimbabwe has prohibited the export of raw lithium from its mines, and as a result, Chinese mining companies are planning to establish lithium-processing plants in Zimbabwe.[45]

Opportunity for the Indian mining industry: Role of startups in low cost indigenous technology development and widespread adoption across Indian mining industry will be critical going forward.

The government recently introduced provision of financial grants to promising startups in mining and mineral processing technologies. Besides financial grants, these startups will also receive support including mentorship, incubation, and technical advisory throughout their project periods to drive scalability and integration within the mining industry.

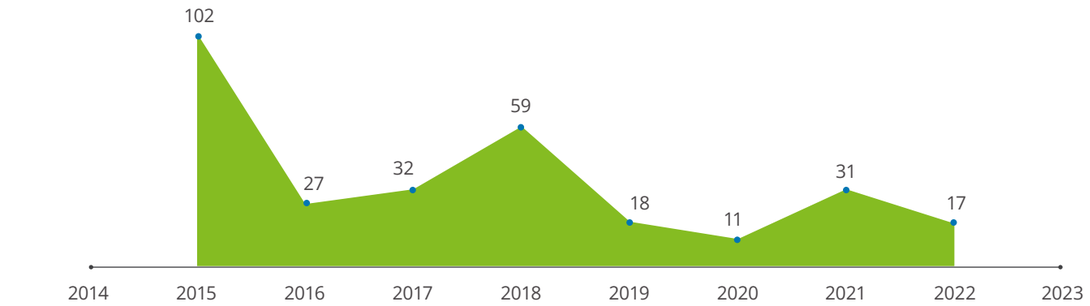
Health, safety and productivity

The recent increase in production levels has mandated an increased focus on the health and safety of mine workers.

Initiatives taken by DGMS to improve the health and safety of workers: Risk-based inspection systems are being implemented through the Shram Suvidha Portal, a dedicated portal for fast-tracking approvals, National Safety Awards (Mines) and implementation of "Online Annual Return" and "Accident Statistics."

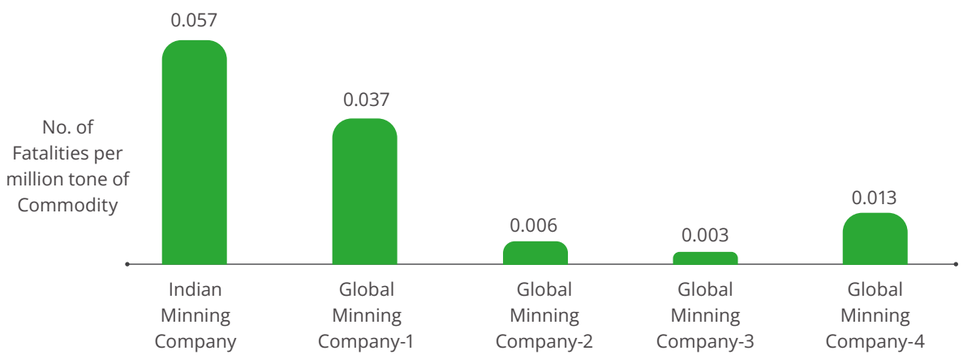
The number of fatalities in the Indian mining industry has reduced over the years from 102 in 2015 to 17 in 2022. The year-wise fatalities in the Indian mining industry are presented in the chart below:[46]

Figure 10 No. of fatalities in the Indian mining industry over the years



Furthermore, in terms of "Fatality Rates", Indian mining companies lag their global peers.[47]

Figure 11 Fatality rate of Indian mining company benchmarked with the global peers



[45]https://www.africanews.com/2023/07/06/chinese-mining-company-opens-lithium-processing-plant-in-zimbabwe//#:~:text=A%20Chinese%20mining%20company%20opened,the%20largest%20reserves%20in%20Africa.
[46]https://ismenvis.nic.in/Database/Mining_Accidents_in_India_24483.aspx
[47]Deloitte Analysis

Therefore, going forward, a special focus on health and safety in the Indian mining industry is needed. This may be through application of digitally driven technologies, ranging from automation and robotics to AI and machine learning, ensuring compliance with the safety and health laws.

Digitalisation is the future of mine safety: The Indian mining industry should adopt digital solutions for safety and other processes to improve the health and safety of mine workers. The role of digitalisation in different aspects of health and safety is demonstrated below.

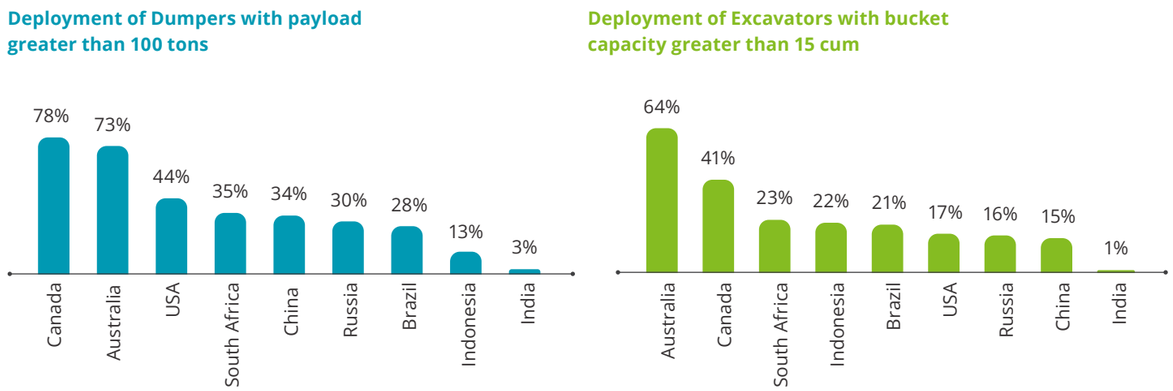
Table 3 The role of digitalisation in different aspects of health and safety

Cause/ Type		How can digitalisation help?
Seismic activity, loud blasts, landslides, etc. lead to cave-ins, flooding, etc.	**Accidents**	Use of **predictive analytics tools** to predict the cause earlier
Health hazards such as lung diseases and hearing loss due to exposure to dust, noise, and repetitive motion	**Health hazards**	**Real-time data** updates on mine environment to the workers
Temperature variations affect the workers and the equipment	**Exposure to extreme temperatures**	**IoT sensors** IoT sensors can be used to determine the suitable working temperature of the place and equipment
Isolated and confined nature of mining work can harm mental health, leading to depression, anxiety, and other psychological disorders	**Mental health issues**	**Big data analytics** in health care determines the employees' admissible working conditions
Accidents involving equipment can cause severe injury or death	**Machinery accidents**	**Automation** can be used to optimise processes, reduce downtime, and improve safety and efficiency

The Indian mining sector faces the following challenges in terms of lower productivity and adoption of technology:

Use of smaller capacity equipment in mines
The graph below shows that India lags significantly behind other countries in deploying high-capacity dumpers and excavators. This can also be attributed to the fact that India has a large number of small mines compared with average mine size globally.

Figure 12 Benchmarking deployment of HEMM equipment by country



Limited technology adoption in Indian mines, impacting overall productivity

- Only a few miners have adopted technology solutions to predict equipment failures and optimise drilling and blasting in real time. Furthermore, the adoption of digital technologies to optimise pit operations and equipment performance at a shift level using real-time data analytics has thus far been limited.
- There is a need for strengthening safety measures through the use of smart wearables. Countries such as Australia and Canada have used AR/VR effectively to enhance safety, simulate high-risk scenarios, and train human resources.
- Lack of digital education and understanding. Most mining companies lack a digital implementation roadmap and are thus grappling with aligning existing data systems with their future vision.
- R&D spending is low, leading to inadequate digital and productivity improvement focus.

Opportunity for the Indian mining industry: The penetration of digitalisation and Industry 4.0 in the Indian mining sector can be enhanced with greater awareness about the benefits of adopting digital technologies. This will need government and mining industry investments and a vibrant ecosystem, including METS players, to help sustain the digitalisation drive. Government may consider incentivising R&D, innovation and technology adoption/ upgradation.

Talent attraction

Talent attraction: The Indian mining industry expects an estimated shortage of ~110,000 workers by 2025.[48] The country needs more role-based training centres to produce many more mining graduates.

- Countries such as Canada, Australia, and the US are facing a similar challenge in terms of a shortage of talent. By 2030, Canada anticipates a shortfall of 80,000-120,000 workers in its mining industry.[49]

Skill development: Despite having 6,446 institutions offering engineering and technology courses, only 168 directly include mining, reflecting a mere 0.5 percent of the total intake capacity.[50] Vocational training institutes contribute significantly; nevertheless, the sector faces a shortage of skilled talent, particularly at higher skill levels.

- Students should be incentivised to enrol in mineral, mining, geology, and metallurgy courses. Mining companies should fund a certain percentage of seats in premium institutions' undergraduate and postgraduate programmes so that more talent can join the industry after completing their studies.
- To upskill the mining industry professionals, the ministry could work with the HRD ministry to increase the number of seats in mining engineering in relevant institutes over the next 10–15 years, including short-term mining-specific courses for delivery through IITIs.
- In South Africa, the Minerals Council and the Mining Qualifications Authority actively engage in skills development initiatives, ensuring a pipeline of skilled professionals for the mining sector's sustainable growth.

Industrial training and apprenticeship through Industry-Institute linkage: It will be imperative to collaborate with industry associations and large employers to facilitate apprenticeships and placement opportunities in mining companies (core and ancillary) and bring graduates from smaller colleges to larger placement drives. PSUs can be encouraged to offer more apprenticeships to engineers as well as diploma and ITI graduates to reduce the need for on-the-job training after placement. Apprenticeships can also be used to impart health and safety training and soft skills to trainees.

Gender diversity and inclusion: Despite strides towards inclusivity, the sector grapples with a gender diversity imbalance. Only 4 percent of the mining workforce are women, a figure significantly below other sectors, such as agriculture, manufacturing, education, and construction. While regulatory amendments in 2019 opened avenues for female participation, entrenched perceptions and limited awareness continue to hinder substantial enrolment of women in mining programmes. Educational institutions, including the prestigious IIT (ISM) Dhanbad, have initiated efforts to promote female participation, but barriers persist. Estimates suggest that women comprise 10 percent of the global mining workforce. India should strive towards achieving the same goal.

Mining and digital technologies

The latest trends in mining—path to decarbonisation, smart operations, zero harm, continual cost leadership, and short interval control—suggest a compelling industry shift towards utilising digital technology tools to deliver modern, safe, and productive mines. More than 90 percent of mining leaders are increasing their IT investment to capitalise on the growth, focusing on data analytics, AI, and integrated automation.

The Indian mining industry is presently experiencing a lot of changes. On one hand, the sector is opening up with 100 percent FDI and auction of mining blocks; on the other hand, there are significant challenges with tightening EHS regulations, rising cost, demand uncertainty, and productivity issues. To address these challenges and achieve long-term strategic business goals, leveraging emerging digital mining solutions towards end-to-end transparency, total cost control, operational risk management, operational flexibility, and responsible and compliant mining is imperative.

Digital transformation in mining has become a necessity for growth. Prevalent digital themes and technology tools, such as IT–OT integration with cyber security, IoT and sensorisation, robotics, advanced analytics and AI, mobility, cloud computing, integrated and remote operation centres, AR/VR, smart wearables, drone/satellite imagery analytics, are expected to be adopted in the Indian mining sector in the near future.

The Indian mining industry still has a long way to go regarding advancements in technological usage in mining. However, Indian miners have started investing in digital to improve visibility, operational efficiency, and safety.

- Alliance with global and domestic players and adoption of an end-to-end digital transformation programme
- Collation, assimilation, and integration of the geophysical and geochemical data to identify more areas for mineral exploration
- State-of-the-art technologies in exploration and mine planning for building a digital inventory of the deposits
- Implementation of an IT-enabled system to ensure end-to-end accounting of minerals
- GPS/GNSS-based technology for real-time fleet management

[48]https://www.skillcms.in/app_files/filemanager/2e2567a0-e413-477e-86a4-d5d165de55dc.pdf
[49]https://www.mining.com/mining-industry-risks-another-lost-decade/
[50]https://www.skillcms.in/app_files/filemanager/2e2567a0-e413-477e-86a4-d5d165de55dc.pdf

- Application of drones for mine progress monitoring, safety enhancement, and surveillance

Digital is not solely about incorporating a gamut of technologies; it should be supported by a clear vision and long-term strategy with leadership commitment, as well as a future-ready and digitally enabled workforce.

Sustainability

Sustainability is critical for the mining industry, as it ensures responsible resource extraction, mitigates environmental impact, and promotes long-term viability, aligning economic goals with ecological preservation for a lasting and responsible future.

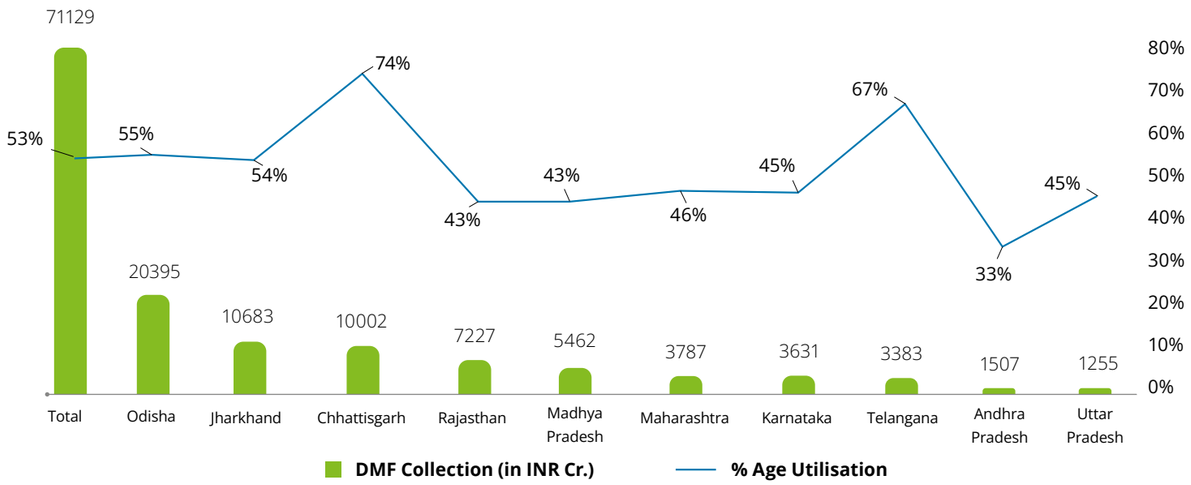
Indian mining companies are implementing sustainable mining practices: A leading Indian zinc producer is integrating sustainability through digital transformation, such as using drones in underground mining operations for volumetric measurement of material, computer vision to detect unsafe mining practices and technology for real-time decision-making such as IIOT sensors and cloud technology, as well as advancing renewable energy adoption and optimising resource efficiency and safety across its value chain.[51]

Sustainability ratings and rankings: Sustainability ratings encompassing ESG measures are essential for Indian mining companies as they comprehensively evaluate ESG practices across various parameters. ESG helps Indian firms benchmark their performance, attract international investments, and align with global standards. Indian mining companies are making strides in sustainability and ESG metrics by bringing in environment-friendly practices and waste reduction, including circularity in their value chain and efficient management.

Comprehensive sustainable development plan: Indian mining companies committed to transparent reporting, eco-friendly technologies, and robust community engagement are crafting a holistic approach to sustainability under their sustainable development plans, which is also reflected in the ratings and rankings of leading mining companies in India. The initiatives being covered under these plans include the development of ecological parks in mining areas or reclaimed land, utilisation of mine water towards irrigation, supply of treated mine water to nearby rural areas, extraction of sand from overburden (OB) to be used as construction and stowing material, use of slurry pipelines instead of railways or roadways for transportation of material, encouraging tree plantation and bio reclamation of OB dumps.

DMF fund utilisation for societal development: The DMF was introduced under the MMDR Act following the Hoda Committee recommendations in 2005 to ensure that mining activities positively contribute to the well-being of local communities and the sustainable development of mineral-rich regions, thereby addressing the social and environmental dimensions associated with mining operations.

Figure 13 DMF Collection of top 10 states and percent utilisation.[52]



The utilisation of DMF funds at the national level is merely 53 percent. Chhattisgarh has the highest utilisation of DMF at 74 percent; however, most states cannot effectively utilise more than 50 percent of the DMF funds due to several reasons.

[51]https://www.hzlindia.com/media_press_releases/paving-to-safe-smart-sustainable-mining-at-hindustan-zinc/
[52]https://karnataka.data.gov.in/resource/state-wise-district-mineral-fund-dmf-collection-and-utilisation-under-pradhan-mantri

Decarbonisation

The mining sector directly accounts for 4–7 percent of Scope 1 and 2 global GHG emissions. Taking the magnitude of emissions coming from the sector globally, decarbonisation must become a central tenet of India's mining sector strategy by embracing sustainable practices, investing in cleaner technologies, and adopting eco-friendly processes. India has committed to achieving net-zero carbon emissions by 2070.

Higher reliance on diesel-powered HEMM: In India, most of the Heavy Earth Moving Machinery (HEMM) used in mining operates on diesel (~50 percent of the mining costs are associated with diesel) and contributes significantly to the Scope 1 emissions. Global mining companies have already identified several opportunities, such as increasing operational efficiencies, electrifying fleet, and collaborating with OEMs to reduce their Scope 1 emissions. According to the Petroleum Planning & Analysis Cell, ~14 percent of total diesel consumption in India is used for mining.[53] Hence, it has become important to reduce reliance on diesel-powered HEMM to achieve decarbonisation goals of individual mining companies and India at large.

Electrification of equipment: The mining companies in India have been actively working to pursue electrified equipment with battery-powered alternatives, requiring storage solutions for operational continuity.

A leading zinc producer in India launched passenger EVs for underground operations and surface mobility for employees in March 2022.[54] It has added electric scooters for its security staff and underground services for mines. These are in addition to the company's collaborations for introducing battery EVs and the in-house solar power that will be used for EV charging.[55] The company plans to replace its diesel-run vehicles and equipment with battery EVs across its eight mines in the next five years.[56]

The use of biodiesel in conventional diesel engines substantially reduces emissions that impact air quality, including unburned hydrocarbons (HCs), carbon monoxide (CO), sulphates, polycyclic aromatic HCs, nitrated polycyclic aromatic HCs, and particulate matter (PM). For example, B20, CO, and unburned HCs can reduce PM emissions by 10 percent, 11 percent, and 21 percent,[57] respectively.

A leading global mining equipment manufacturer has developed diesel-powered machines for the Indian market compatible with B20 (20 percent biodiesel and 80 percent petroleum diesel) biofuel that includes excavators, bulldozers, wheel loaders, motor graders, and dump trucks.[58]

Investment in CCUS technologies:[59] Indian mining companies have also started investing in CCUS technologies for reducing emissions. CCUS technology reduces emissions by capturing CO2 produced by industrial processes and power generation, preventing it from entering the atmosphere. The captured CO2 can then be stored underground or utilised in various applications, contributing to climate change mitigation.

Green bonds and ESG funds: To attract investment for decarbonisation strategies and diversification towards renewable initiatives, Indian mining companies have started targeting financial instruments such as green bonds. Other avenues for attracting foreign investments could be sustainability-linked loans, impact investors, and ESG-focused funds.

Reduce Scope 1 and 2 emissions: For transitioning to complete carbon neutrality, mining companies must change the fuel source of mining equipment by adopting fuel cell electric vehicles, coupled with developing green hydrogen capacity from solar or wind sources or transitioning to a fully battery electric vehicle fleet.

A leading Indian integrated mine-to-metal producer operates an end-to-end digital mining ecosystem in Karnataka, helping it efficiently manage its fleet.[60]

Similarly, another leading player commissioned a 3-MW solar PV power plant in the iron ore mine in Odisha in 2017. The project is expected to reduce CO2 emissions by ~3,000 tons per annum.[61]

The Indian Bureau of Mines undertook a sample survey of 293 mines to install renewable energy plants across the country's mining sites. The total installed renewable energy plant capacity at these sites is 583 MW (wind and solar combined).[62]

Reduce Scope 3 emissions: The mining companies are expected to collaborate and formulate decarbonisation strategies with their downstream industries with the intent to reduce the Scope 3 emissions. The major mining companies' Scope 3 emissions account for ~4 percent of global carbon emissions globally,[63] contributing to more than 95 percent of total emissions, according to a study of the top six mining companies.[64] Thus, the importance of reducing Scope 3 emissions is evident.

[53]https://ppac.gov.in/uploads/rep_studies/1674532665_ICR_December_2022%20(4).pdf
[54]https://auto.economictimes.indiatimes.com/news/industry/hindustan-zinc-signs-mou-with-sandvik-for-battery-electric-underground-mining-fleet/91263739
[55]https://auto.economictimes.indiatimes.com/news/industry/hindustan-zinc-to-invest-1-billion-to-replace-diesel-vehicles-with-battery-evs/84887614
[56]https://renewablewatch.in/2023/04/26/green-moves-adoption-of-sustainable-mining-practices/#:~:text=HZL%20plans%20to%20replace%20its,rare%20earth%20metals%20in%20India.
[57]https://www.nrel.gov/docs/fy11osti/47504.pdf
[58]https://indianinfrastructure.com/2023/03/03/green-moves-adoption-of-sustainable-mining-practices/
[59]https://www.iea.org/energy-system/carbon-capture-utilisation-and-storage
[60]https://www.jsw.in/groups/sustainability-framework-measuring-success-sustainable-mining
[61]https://www.tatapowersolar.com/project/3-mw-solar-power-plant-noamundi-jharkhand/
[62]https://renewablewatch.in/2023/04/26/green-moves-adoption-of-sustainable-mining-practices/
[63]https://www.woodmac.com/news/opinion/top-steps-miners-can-take-to-reduce-scope-3-emissions/
[64]https://www.sinai.com/post/how-to-address-scope-3-emissions-in-the-mining-value-chain

A leading Indian integrated mine-to-metal producer has commissioned a 24-km pipe conveyor, the world's largest of its kind, to transport raw material from an iron ore mining site to the manufacturing unit. It is expected to reduce CO2 emissions by ~3.86 kg/tons of transported iron ore.[65]

Standardised reporting and target setting mechanisms: Within India, monitoring and reporting of CO_2 emissions from companies has been driven by voluntary intent. According to the Paris Agreement, robust monitoring, reporting, and verification play a pivotal role in assessing the carbon footprint of companies or countries at large. Per the CDP India Disclosure Report, only two Indian mining companies have submitted their responses to CDP.[66] Also, companies in India lack target-setting mechanisms to reduce their Scope 1, 2, and 3 emissions. According to SBTi, Science-based targets provide a clearly-defined pathway for companies to reduce GHG emissions, helping prevent the worst impacts of climate change and future-proof business growth.[67] Hence, it is important for India to explore designing and implementing a mandatory emissions reporting scheme for corporates to reduce emissions in general and to use energy, resources, and fuel/materials efficiently.

Opportunity for the Indian mining industry: Replacing diesel-powered mining equipment with electric equipment can significantly reduce emissions. This is a particularly promising opportunity for underground mines, where ventilation systems can be used to capture and control diesel emissions.

Critical minerals

In the last five years, the critical minerals market doubled to USD320 billion and is forecasted to double again before the end of the decade.[68] However, India is at a nascent stage, with a significant reliance on imports of finished products and negligible value-added facilities. The Indian mining sector may strengthen the following areas to develop a critical mineral portfolio within the country.

Enhance focus on exploration: The status of different critical minerals in India is provided below:

Table 4 Status of availability of critical minerals in India[69]

Limited domestic resources*	Not explored well for potential reserves
Bismuth, Gallium, Germanium, Hafnium, Indium, Niobium, Rhenium, Strontium, Tantalum, Tellurium, Selenium, Cadmium	Antimony, Beryllium, Cobalt, Copper, Graphite, Lithium, Molybdenum, Nickel, PGE, Phosphorous, Potash, REE, Silicon, Tin, Titanium, Tungsten, Vanadium, Zirconium

*Most of these are by-products from the recovery process of zinc, copper, and alumina.

Of the 30 critical minerals declared by MoM, 18 are available in India and 12 are unavailable. India produces only four of the 18 available minerals (copper, graphite, phosphorous and titanium (Ilmenite and Rutile)). The other 14 minerals are constrained mainly due to a lack of detailed exploration and the adoption of suitable technology. The current policy framework also needs to be aligned accordingly.

For instance:

- Only 8 percent of the total copper ore resources are being converted to reserves. In FY23, India imported 1.17 MnT of copper ore and concentrates worth INR27,374 crore to meet the domestic demand.[70]
- The case of graphite is the same; only 2 percent of graphite resources are being converted to reserves. As a result, India imported 46 kt of graphite worth INR294 crore during FY23.[71]

Hence, robust exploration programmes fuelled by technology (integration of innovative technologies, including AI, to improve ground selection and geophysical solutions) are needed to unleash the potential of critical mineral resources in India.

Increase preparedness for auction: The Indian government has recently expedited the preparatory works for auctioning of critical and strategic mineral blocks. As a result, 38 critical and strategic mineral blocks came up for auction in the first tranche (concluded and received robust response from the industry) and second tranche (ongoing) together. As most of the blocks being auctioned are CL blocks, there seems uncertainty in determining mineral value due to limited exploration. Hence, for unlocking the real economic potential, it is encouraged to bring the block to at least G3/G2 level based on type of mineral and subsequently put them in auction.

[65]https://www.jsw.in/groups/sustainability-framework-measuring-success-sustainable-mining
[66]https://india-re-navigator.com/public/uploads/1651641639-CDP_AnnualDisclosureReport2021_V7.pdf
[67]https://www.epa.gov/climateleadership/target-setting
[68]https://www.iea.org/reports/critical-minerals-market-review-2023/key-market-trends
[69]IBM Mineral Book
[70]https://mines.gov.in/webportal/content/export--import
[71]https://mines.gov.in/webportal/content/export--import

Develop processing capability: Infrastructure and technology for processing facilities of critical minerals are limited to a few countries. A recent survey by the International Energy Agency found that only three countries controlled between 80 percent and 99 percent of the processing of lithium, cobalt, and rare earth elements. About[72] 72 Indian companies do not have access to commercially viable mining and processing technologies.

Some steps that can be taken to develop processing capabilities in India include:

- Partner with international players to obtain the technological expertise in acid leach process spheroidisation, etc., for setting up downstream industries in India.
- Focus on setting up end-user industries to develop mineral processing capability across the battery value chain.
- Implement favourable policies such as incentivising the setting up of critical mineral processing plants in India by providing capital incentives, tax holidays, viability gap funding (VGF), etc.

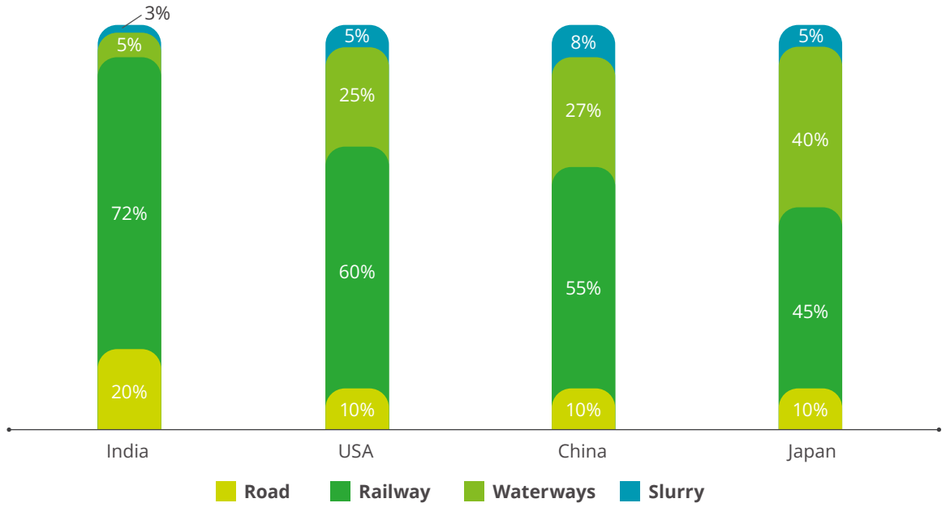
Acquisition of overseas assets: Identification of sources of the strategic and critical minerals in overseas countries, exploration, acquisition, development, processing, and sourcing to India is utmost important to avoid supply chain disruptions and price fluctuations.

Mineral evacuation

Mineral evacuation scenario in India: India, one of the world's fastest-growing major economies, has experienced substantial economic growth in the past five years, driven by increasing demand for goods and services. The extensive movement of goods, domestically and internationally, handles an impressive 4.6 billion tons annually, with a total cost of INR9.5 lakh crore. The primary mode of transportation for the mining industry has been railways (more than 50 percent), supplemented by roads, coastal and inland waterways, pipelines, and air transport.

Global versus Indian mode of transport: The distribution between rail and water transportation varies across countries and is primarily influenced by geographical factors and policy priorities. In the US, rail represents a substantial share in the modal split due to the well-developed US. Class 1 rail, primarily dedicated to freight. Countries with extensive coastlines, such as the EU, often rely on waterways, benefitting from easy access to the Atlantic Ocean and the Mediterranean Sea. Meanwhile, China, characterised by a large landmass and concentrated economic activity along the coast, adopts a mixed mode, utilising both rail and water transport. The modal mix of iron ore transportation for different countries is shown in Figure 14.[73]

Figure 14 Modal mix of iron ore transportation mode by Country



[72]https://www.herbertsmithfreehills.com/insights/2023-09/financing-the-energy-transition-critical-minerals-processing
[73]https://steel.gov.in/sites/default/files/DRAFT%20%20Sectoral%20Plan%20For%20Efficient%20Logistics%20%20for%20Iron%20and%20steel%20sector.pdf

The cost, emissions, and suitability of each mode of transport are different, as discussed below:[74]

Table 5 Cost, emissions, and suitability of various modes of transport

Mode	Cost (INR Cr./ tonne-km)	CO_2 emissions (gm CO_2/tonne-km)	Suitable use cases
Rail	1.6	11.5	Suitable for the long-haul of large, regular flows of low-to-medium-value density minerals
Road	3.6	101	Suitable for non-bulk goods moving over shorter distances and on corridors with lower volumes
Waterways	2	11	Suitable for the long-haul of large, regular flows with less fragmentation along the coastline or navigable inland waterways
Pipeline	2	8	Suitable for liquids and gases, oil, natural gas, biofuels, and ores (slurry form)

Government of India's initiatives to improve evacuation network

- The dedicated freight corridors (DFC) are long-distance, high-capacity freight rail routes the government is developing for freight movement. About 88 percent of the 2,843-km DFC became operational by August this year and the target to complete the project is June 2024.[75]
- The Sagarmala project focuses on developing waterway transport by improving existing ports and developing coastal economic zones. More than 800 projects at an estimated cost of around INR5.48 lakh crore have been identified for implementation.
- The Bharatmala and Golden Quadrilateral projects focus on the development of road highway infrastructure in the country. Bharatmala Pariyojana Phase-I, comprising 24,800 km of various categories of roads and ~10,000 km of residual NHDP projects, has been approved at a cost of INR5.35 lakh crore.
- The Jal Marg Vikas Project is developed for operations of National Waterway 1 and is being implemented at a cost of INR5,369 crore.[76]

Focus areas for future growth of India's evacuation system

- The transport of minerals through the existing rail network can be enhanced by extending train lengths or upgrading infrastructure to accommodate high-speed trains. Currently, the average train length in India is 700 metres, which is significantly lower than the 2,000 metres in the US.
- Slurry pipelines can be established for moving partially and fully processed materials from mining areas to end-user plants. Essar Steel in India used this method for moving iron ore slurry to its steel/pellet plant.
- Conveyor systems can be used as mode of mineral transportation. The pipe conveyor systems are popularly used in countries such as the US, China, Russia, and Brazil. In India, pipe conveyor for coal transportation was first implemented by Jindal Steel and Power and can be now seen in places such as Butawada and Krishnapatnam.

[74]https://www.niti.gov.in/sites/default/files/2021-06/FreightReportNationalLevel.pdf
[75]https://dfccil.com/Home/ProgressStatusImage
[76]http://jmvp.nic.in/

Mine closure

Mine closure is the last step in the mining value chain. It is the most critical activity, ensuring that the environmental footprint of mining is minimised and that local communities can continue their livelihoods sustainably. India currently faces some significant challenges in terms of mine closures:

Lower financial guarantee vis-a-vis advanced mining geographies: The financial guarantee for an open-cast mine (non-coal) is INR5,00,000 per hectare for a Schedule A mine (whose area is greater than 50 Ha) and INR3,00,000 for a Schedule B (area less than 50 Ha) mine.[77] The financial guarantee for a coal mine is INR9 lakh per hectare[78] for OC and INR1.5 lakh per hectare for UG mine. This is lower compared with leading mining geographies.

In comparison, the financial guarantee for Quebec province in Canada is 100 percent of total mine closure costs.[79] In Western Australia, mining companies have to pay an annual amount into a mining rehabilitation fund, and the interest generated from the fund is used to rehabilitate Western Australia's legacy abandoned mine sites.[80]

Enhance the focus on progressive rehabilitation: In India, the progressive mine closure plans are prepared and reviewed every five years.[81] In Western Australia, however, all mine closure plans are reviewed and approved every three years.[82] Therefore, more stringent monitoring in other countries reduces the chance of default.

A just transition framework is absent for mine closure: Mining activities are usually conducted in remote areas, and the public infrastructure is inadequate. The land that is used in mining often becomes unusable and lies barren without purpose. While project-affected families are resettled and rehabilitated, they do not have adequate access to education and quality employment opportunities once the mining activities are over. Therefore, a just transition framework is essential to ensure that mine closures positively impact the local community.

Recently, the Indian coal sector has undertaken efforts to develop a comprehensive mine closure framework based on just transition concepts. It aims to develop a mine closure framework on a trial basis for select mines (abandoned or closed) in Jharkhand and Chhattisgarh.[83]

Opportunity for the Indian mining industry: The opportunities in mine closure in India are significant. Once a mine is closed down, a large quantum of land is available for other economic activities. If properly utilised, such land parcels can boost the local economy significantly. The reclaimed area may be reused for generation of alternate revenue sources, e.g., biodiversity parks, farming, resorts, training centres, mining tourist destinations, etc. The project-affected persons/families who are displaced from their area because of mining activities will also get an opportunity for skill development and increased employability.

[77]https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1770484#:~:text=(ix)%20Amount%20of%20financial%20assurance,mines.gov.in).
[78]https://coal.nic.in/sites/default/files/2020-01/Guidelines-for-Mining-plan-Coal_16122019_0.pdf
[79]https://mrnf.gouv.qc.ca/documents/mining/guidelines-mine-closure.pdf
[80]https://www.dmp.wa.gov.au/Documents/Environment/MRF_The_First_Two_Years.pdf
[81]https://coal.nic.in/sites/default/files/2020-01/Guidelines-for-Mining-plan-Coal_16122019.pdf
[82]https://www.dmp.wa.gov.au/Environment/Mine-Closure-Plan-6034.aspx
[83]https://pib.gov.in/PressReleasePage.aspx?PRID=1885489

Initiatives for unlocking the potential of India's mining sector

The Indian mining sector can play a crucial role in the country's Amrit Kaal journey due to its large reserve of minerals. To achieve this, both the central and state governments must facilitate the industry to flourish. The industry, too, should keep in mind the development of all stakeholders. Startups will play a pivotal role in shaping the future of Indian mining industry as they can revolutionise exploration, extraction and processing methods by leveraging data analytics and modern innovative technologies. They can also bring in latest mineral exploration techniques for efficient resource mapping & extraction. This can lead to increased resource availability and contribute to India's mineral security. Below are some recommendations and initiatives that could accelerate the mining sector's growth trajectory.

Exploration

Short- and medium-term recommendations (2030)

Revenue-sharing model clarity: Address the ambiguity in the revenue-sharing model for ELs introduced in the latest MMDR Amendment. There are concerns about the timeline of the auction and the financial recovery of expenditures incurred during exploration. The EL holder is only eligible for reimbursement after the block is auctioned. To address this concern, the government may formulate a policy to allocate a certain percentage of the value of minerals established by the EL holder after exploration from the NMET funds.

Exploration Incentive Scheme (EIS): Consider implementing a scheme similar to Western Australia's EIS, refunding up to 50 percent of drilling costs for greenfield projects and supporting additional surveys. This will ensure the participation of private and foreign investors and increase the overall funding of the exploration industry.

Incentivise the use of latest technologies: The government should incentivise the use of latest technologies, such as geophysical surveys and remote sensing exploration techniques, using unmanned aerial vehicles (UAVs).[84] These survey methods will reduce the number of deep drill holes needed. Biogeo-chemistry and geomicrobiology techniques may also be promoted to generate insights into the chemical signatures of ore deposits that can lead to new discoveries.

Attract exploration-related talent: Mining companies should fund a percentage of the seats in geological programmes (both undergraduate and PhD) in top higher education institutes. This will ensure that the best talents join the industry.

From 2000 to 2022, junior explorers have accounted for ~71 percent of all mineral discoveries made in Australia and in 2019, 100 percent of mineral discoveries were made by junior explorers.[85]

Long-term recommendations (2047)

Promote joint ventures between Indian and foreign companies: The Indian government can promote joint ventures between Indian and foreign companies for mineral exploration. This will help transfer knowledge and technology to Indian companies and attract foreign investment.

Support exploration tech startups: Foster startups developing exploration-focused technologies, incorporating Industry 4.0 principles, through government and mining company support.

A leading global metal player utilises an AI platform, developed in collaboration with Stanford University, to analyse global geological data from both the private and public sectors. The technology can identify minerals such as nickel and cobalt with tenfold precision compared with traditional exploration methods.

Dedicated funding for junior explorers: A dedicated fund should be established to provide exploration incentives to junior explorers. Furthermore, they may be encouraged by allocating a certain percentage of revenue over the operational life of mines. This will allow the mining sector to have a continuous exploration investment pipeline and also expose the industry to the latest technologies.

Global example: Australian junior mineral explorers can apply to access substantial exploration incentives under the USD100 million Junior Minerals Exploration Incentive (JMEI). The JMEI encourages new investment in small mineral exploration companies to help them make the discoveries needed to lock in the long-term future of Australia's resources sector.

[84]https://single-market-economy.ec.europa.eu/sectors/raw-materials/eip/raw-materials-commitment/new-exploration-technologies_en
[85]https://nextinvestors.com/features/high-risk-exploration-asx-critical-minerals-and-more
[86]https://asia.nikkei.com/Business/Startups/Finding-minerals-faster-with-AI-Investors-flock-to-U.S.-startup#:~:text=In%202021%2C%20Mitsubishi%2C%20BHP%20and,a%20sensor%20that%20identifies%20ores.

Mineral policy reforms

Short- and medium-term recommendations (2030)

One minor mineral policy across India: Enforce one minor mineral policy across India to bring transparency and efficiency to remove overlapping jurisdictions at the state and central levels.

Ranking of states across policy potential and mineral potential index: Develop a framework for ranking states in terms of a possible policy index and mineral potential to attract foreign investments by participating in global surveys of mining companies, such as the Fraser Institute.

Long-term recommendations (2047)

Empanelment guidelines of MDOs and mining contractors: Develop and publish guidelines for selecting qualified MDOs and contractors. The government may maintain a list of empanelled MDOs and contractors with experience securing statutory clearances. Mining companies can use this list to select qualified service providers.

Separate act for land acquisition in mineral-bearing areas: Incorporate the lease model in the land acquisition act for mineral-bearing areas to reduce the burden of the upfront capital of land.

Modernisation of state forest departments: Modern technology (Digital and AI) for regeneration of natural forest and building up the institution involved in the State Forest Department shall be used by the Compensatory Afforestation Fund Management and Planning Authority (CAMPA). Also, digitisation of land records would facilitate compensatory afforestation for the industry as the mapping of land availability would become easier. Inter-sate compensatory afforestation may be considered.

Surface compensation and entry into mining lease: The State government should fix the surface compensation at the time of auctioning and ensure that the land is free from all encroachments, so that the successful bidder does not face any hindrance in starting the mining operation. Here, the role of pre-embedded clearances becomes important and thus the 2020 initiatives of the Ministry of Mines shall be implemented in true spirit.

Sustainability

Short- and medium-term recommendations (2030)

Strategic study on beneficiation: The government should conduct a strategic study of essential minerals (such as iron ore and bauxite) to understand the global beneficiation and processing methodologies for minerals below the cutoff grade and accordingly formulate effective policies for their utilisation.

In India, 15–20 percent[87] of mined ore remains unutilised and discarded as slime. To counter the problem in the case of iron ore, the government may develop a policy to benefit 80 percent of low-grade iron ore and also incentivise the companies by providing a concession of 5–10 percent on the royalty rates on the quantity of low-grade ore beneficiated.

Downstream collaboration: Mining companies should collaborate with downstream industries to optimise resource utilisation, enhance the entire value chain, and promote sustainable practices.

Setting up beneficiation plants in mining clusters by aggregation: Shared facilities for mineral beneficiation hold promise for improving the economic viability and sustainability of the mining sector, particularly for small and medium-scale miners. Addressing the challenges through collaborative efforts, government support, and innovative financing mechanisms can pave the way for wider adoption of this approach.

Set up R&D institutes focused on beneficiation: Mining companies should be mandated to provide a certain percentage of their profits for an R&D fund, which can be used to set up a beneficiation institute in key mining clusters. This will help adopt the best global practices in beneficiation and ensure higher reserve utilisation.

Incentivise recovery from tailings: Provide financial assistance to companies that invest in technologies to extract minerals and metals from mill tailings. By supporting the conversion of mill tailings into wealth, the Indian government can help create a more sustainable and prosperous mining sector.

Global example: In Canada, a company focused on developing technology solutions for carbon capture from stationary sources of pollution is using mill tailings to capture carbon dioxide emissions from power plants and other industrial facilities. They have received funding from the Canadian government.[88]

Long-term recommendations (2047)

State-wise sustainability ranking: The government should introduce a state-wise ranking framework for sustainable mining practices incorporating ESG parameters. This would increase investment attractiveness for those states, encouraging state governments to prioritise sustainability.

Incorporate just transition framework in mine closure regulations: The mine closure regulations should incorporate just transition components by mandating companies to ensure alternative land uses for revenue generation and providing upskilling and employment opportunities for the project-affected families.

Effective DMF fund utilisation: The state governments should strictly ensure the use of DMF funds for their intended purpose. Gram panchayats and project proponents should be mandatorily involved, and local community participation should be enforced.

[87]https://link.springer.com/article/10.1007/s10668-023-03211-2
[88]https://www.marketscreener.com/news/latest/CO2-Solutions-Receives-Additional-Funding-from-the-Government-of-Canada-22135202/

Decarbonisation

Short- and medium-term recommendations (2030)

Renewable energy microgrids: The mining companies in India can target implementing renewable energy microgrids in remote areas for optimised power utilisation. Alternatively, they can also opt for power purchase agreements, which are long-term contracts that provide renewable energy certificates, physical electricity, or both. The mining companies can significantly contribute towards the government's target of producing 500 GW of electricity using renewable sources in India by 2030.

Migration from diesel fleet to battery-powered fleet: The mining companies in India should target converting 30–40 percent of their operating mining fleet with battery-powered/biofuel alternatives by 2030.

Emission data management: Mining companies should implement standard practices to track real-time emission data. The companies need to improve the availability and reliability of data to compare themselves with globally benchmarked practices, gain investors' confidence, and attract foreign investments.

Invest in CCUS technologies: Invest in CCUS technologies for emissions reduction.

Green bonds and ESG funds: Attract investment for decarbonisation through financial instruments such as green bonds, sustainability-linked loans, impact investors, and ESG-focused funds.

Long-term recommendations (2047)

Innovation and technology development: Innovate and develop new technologies to accelerate decarbonisation in the mining industry. Research and development in battery technology, renewable energy integration, and advanced emissions reduction techniques can provide breakthrough solutions for a low-carbon mining future.

Finance for just transition: Create a dedicated financial mechanism for a just transition in the Indian mining sector to foster sustainability, workers' wellbeing, and environmental conservation through concerted public-private efforts and innovative funding models.

Critical minerals

Short and medium-term recommendations (2030)

Encourage exploration: Insert clauses regarding suitable compensation from the government to the EL agency if the block is not auctioned and from the mine owner to the EL agency in case the block is auctioned but there is a delay in operationalisation.

Develop domestic processing capability: Domestic players may partner with international players to get the technological expertise needed for setting up downstream industries in India.

Policymaking: Incentivise the setting up of critical mineral processing plants in India by providing capital incentives, tax holidays, VGF, etc.

Long-term recommendations (2047)

Operationalisation of critical mineral blocks: Roll out critical mineral blocks with pre-embedded clearances.

Promotion of circular economy: Production-linked incentives for extracting critical minerals through recycling.

Acquisition of overseas assets: Leverage the Mineral Security Partnership (MSP) framework and help Indian PSUs in their acquisition of overseas critical mineral assets.

Technology collaborations: The Government at G2G level can facilitate technology driven collaborations among Indian miners and foreign technology firms for expedited adoption of latest exploration & mining techniques for critical minerals.

Mining and digital technologies

Short- and medium-term recommendations (2030)

SWCS supplemented with AI-based clearance process from pre-approved checklist: This allows for faster operationalisation of non-coal mines.

Digitalisation of land records: This will help build land data bank by digitalisation of land records.

Integrated mine planning and scheduling solution: This will ensure dynamic end-to-end planning.

AR-based operational assistance: Smart wearables to assist field maintenance team with remote support and execute maintenance activities more efficiently.

Use of drones: Drones can we used for real-time operations monitoring to enhance safety, data-driven planning, and operational control.

Tracking of mineral from mine to mill: This will offer improved traceability, efficiency, and transparency.

Integrated remote operations centre: It will offer a centralised monitoring, analysis, and reporting group, exception handling, alerts, emergency response, and standardisation of processes by leveraging data connectivity from various sources and analytics platforms.

Long-term recommendations (2047)

Automation in drilling and blasting processes: Autonomous sensorised drills with measurement while drilling for automated rock recognition and assaying to optimise blasting process. Using robotics and automation to perform blasting in open pits and underground mines will eliminate the risk of workers' exposure to hazardous tasks and increase process efficiency.

A leading Swedish multinational engineering company specialising in products and services for mining, rock excavation, rock drilling, rock processing, and metal cutting and machining is developing a fleet of autonomous robots that can perform all aspects of secondary blasting, from drilling blastholes to placing explosives to inspecting the blasted area.

Autonomous trucks: Deployment of autonomous trucks towards improved safety and productivity and reduced operating costs.

AI/ML-based predictive maintenance: IoT-enabled automated machine health data capture and CBM on health parameters improve equipment reliability. AI/ML-based predictive data modelling and analytics identify operational anomalies and potential equipment defects, enabling timely repairs before failure.

A leading Australian multinational mining and metals company uses AI/ML-based predictive maintenance to predict when its mining trucks will likely fail. This allows the company to optimise preventive maintenance and avoid unplanned downtime.

Advance analytics for improving ore beneficiation throughput: predictive analytics and optimisation study for mill throughput increase.

A leading mining and metals company implemented advanced analytics to improve mill throughput for silver, lead, and zinc mines in Australia, enabling robust tuning of the mill grinding circuit.

Health, safety and environment

Short- and medium-term recommendations (2030)

Automation of secondary blasting in underground mines: Using robotics and automation to perform secondary blasting in underground mines will not only eliminate the risk of workers' exposure to hazardous tasks but also increase the efficiency of the process.

Predictive analytics tools for forecasting accidents: Use of predictive analytics tools to predict the cause of accidents.

Dust control and monitoring: Analyse data from dust sensors using AI and ML to identify patterns and trends. This information can then be used to predict when and where dust levels are likely to be high and to develop strategies to reduce dust exposure.

VR-based safety training: Immersive simulator or safety kiosk for improving safety awareness and employee productivity.

Long-term recommendations (2047)

AI-powered ergonomic assessment: Assess and identify ergonomic risks in real time through AI-powered ergonomic assessment, enabling miners to take corrective action before developing ergonomic problems.

Digitally enabled workforce: Effective employee engagement, real-time location tracking and health monitoring, geo-referencing, and zoning to enable a safe workplace.

A leading global miner has deployed smart wearables to its existing operation framework and provides real-time tracking and fatigue alarms to a central control room, which triggers safety interventions.[89]

Talent attraction and development

Short- and medium-term recommendations (2030)

Inclusive workforce development by increasing women's participation: The government may consider reservation for women in all mining and mineral engineering courses nationwide. Similar reservations should be made to employ graduate engineering trainees in all PSU recruitments. Leadership positions for women should also be encouraged strongly.

Upskilling through specialised courses in mining for industry professionals: Mining companies should tie up with leading institutions (such as IITs and NITs) to offer their employees upskilling courses in mining domains (ranging from 2 months to 1 year). Moreover, special focus should be laid on the latest trends in terms of digital and sustainable practices.

Incentive for mining and mineral education: The government should subsidise the fees for graduate and postgraduate courses in the mining, geology, and metallurgy departments to encourage more students to take such courses.

Apprenticeships and placement opportunities in mining companies shall be promoted via industry-academia partnerships.

Long-term recommendations (2047)

Establish AI institutes for mining and geological sciences: AI institutes should be developed in key mining clusters with the help of funding from mining PSUs and private players. These institutes will be focused on conducting field trials of AI applications in mining operations. The technologies or solutions should be patented and distributed to the funding companies.

Develop centres of excellence: Establish centres of excellence in key mining clusters with an R&D focus to develop innovative technologies in mining.

The Centre for Excellence in Mining Innovation (CEMI) is a Canadian mining industry research initiative, collaboratively funded by the private sector and government. CEMI was established in 2007 as a not-for-profit corporation. CEMI's focused research is in hardrock underground mining.[90]

[89] https://www.smartcaptech.com/case-study/hunter-valley-operations-hvo/
[90] https://en.wikipedia.org/wiki/Centre_for_Excellence_in_Mining_Innovation#:~:text=The%20Centre%20for%20Excellence%20in%20Mining%20Innovation,focused%20research%20is%20in%20hardrock%20underground%20mining.

Mineral evacuation

Short- and medium-term recommendations (2030)

Enhance focus on mechanical evacuation through rapid loading and transportation by rail: Mechanical evacuation should be encouraged by providing subsidies for setting up facilities or using tolling arrangements for a common set of mines. The government should also improve the modal share of transportation by railway up to 75 percent under the PM Gati Shakti Plan and reduce road dependency. This will also help reduce the carbon footprint of the dispatch and transportation processes.

Enhance mineral-handling capacity in ports: Enhance the capacity of existing ports under the Sagarmala scheme and develop new landside mega-ports to deal with ultra-large container ships. Approximately INR100,000 crore are estimated to be invested under the Maritime Indian Vision 2030.

Transitioning from fuel powered vehicles to battery vehicles: It is important not only from decarbonisation perspective but also from the commitment to national goals of net zero. Thus, the industry must undertake the conversion on priority. Government may support with incentivisation and policy benefits.

Long-term recommendations (2047)

AutoHaul: Develop an autonomous heavy haul rail network to trains in real time for iron ore and coal. The trains will be equipped with various sensors and cameras that will allow them to navigate the track and avoid obstacles.

Development of inland logistics capacity: Utilise the investment plans of INR230,000 crore (USD27–28 billion) for DFCs with phasing up to 2047 to develop inland logistics. Coastal shipping capacity should also be encouraged by setting up new ports and subsidising freight transport.

Longer trains: Mineral transportation through the existing rail network can be enhanced by extending train lengths. Currently, the average train length in India is 700 metres, one-third of the train length that is used globally. Trains with lengths up to 2000 metres can be used. This will ensure large-scale transportation costs are effectively managed.

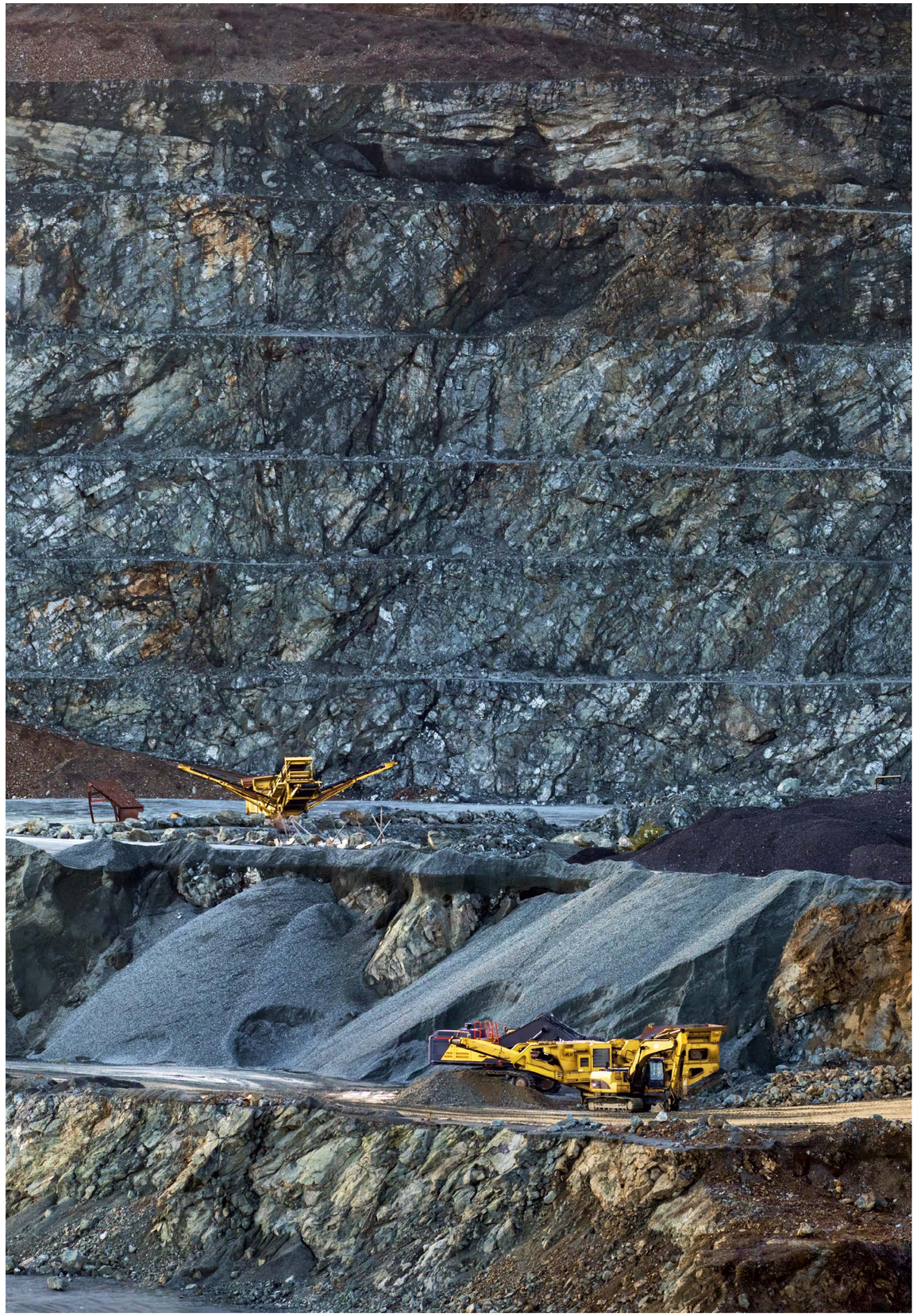
Conclusion

TThe next few decades hold the promise of being a period of significant growth for the Indian mining industry. If properly tapped, the mining sector's performance will be a key factor in India achieving 6 percent–7 percent GDP growth and a USD30 trillion economy by 2047, making India a Developed Nation. This can potentially create an additional 25 million jobs (direct and induced) over the business-as-usual scenario by 2047. This would be a significant share of the total non-farm jobs needed to absorb India's demographic demands. At the same time, the mining industry could contribute an additional USD500 billion to India's GDP by 2047. All of these during the Amrit Kaal Journey would help build the Viksit Bharat.

To achieve this vision, proactive steps must be taken by the government and industry to ensure that the sector is adopting the best practices across the entire value chain. To effectively utilise its mineral reserves, India must convert its resources to reserves through increased exploration spends and the application of advanced technologies. Post exploration, the lease allocation process must be smooth enough for private players as well as foreign investors to invest. Clearances must be expedited to ensure that mines can be operationalised as early as possible. The royalty rates also need to be made comparable with those of other leading mining geographies. Greater focus must be laid on increasing the application of automation or digitisation to increase the productivity of mining operations.

To ensure sustainability in the mining sector, the industry must adopt a multipronged approach to ensure optimum resource utilisation (through beneficiation and waste utilisation), reduce its carbon footprint, strengthen mine closure mechanisms, and develop a ranking framework. The exploration, mining, and processing of critical minerals is also important to support the sustainable growth narrative of the Indian mining sector. The government must set up mineral processing facilities and ensure self-reliance in the critical mineral industry. Evacuation is also expected to play a key role, with coastal shipping and slurry pipelines gaining traction in the Indian context. Rail network capacity is already being increased across the country and is expected to replace road transportation to a large extent.

Notably, mining companies need to effectively engage with the local communities and address the concerns of all stakeholders to create a conducive working environment. Therefore, it is imperative that government and industry stakeholders collaborate to understand the challenges, identify opportunities, and work towards a common goal for the overall development of the industry and the nation.



Abbreviations

Abbreviation	Description
%	Percentage
~	Approximately
AWS	Amazon Web Services
BT	Billion Tonnes
CAGR	Compound Annual Growth Rate
CE	Circular Economy
CIL	Coal India Ltd.
DRC	Democratic Republic of Congo
EC	Environmental Clearance
EIA	Environmental Impact Assessment
ESG	Environmental, Social and Governance
EU	European Union
FC	Forest Clearance
FDI	Foreign Direct Investment
GDP	Gross Domestic Product
GHG	Green House Gases
GoI	Government of India
GRI	Global Reporting Institute
GSI	Geological Survey of India
HEMM	Heavy Earth Moving Machinery

Abbreviation	Description
IBM	Indian Bureau of Mines
IEA	International Energy Agency
IIP	Index of Industrial Production
KABIL	Khanij Bidesh India Limited
M&M	Metals and Mining
MDO	Mine Developer and Operator
MSME	Micro, Small and Medium Enterprises
MSS	Mining Surveillance System
MT	Million Tonnes
MTPA	Million Tonnes Per Annum
NMET	National Mineral Exploration Trust
NMP 2019	National Mineral Policy 2019
NSP	National Steel Policy
OGP	Obvious Geological Potential
OMS	Output per Man Shift
PGEs	Platinum Group Elements
PLI	Production-linked Incentive
USD	US dollar
WEF	World Economic Forum

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Established in 1927, Federation of Indian Chambers of Commerce and Industry (FICCI) is the largest and oldest apex business organisation in India. Mahatma Gandhi addressed FICCI's fourth AGM in 1931. Our 96th AGM was held in December 2023. With our rich legacy, FICCI would play an even greater role as India emergence as the third-largest economy.

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