Advancing India's Mining Sector: Strategies for Sustainable Growth and Competitiveness

June 2024

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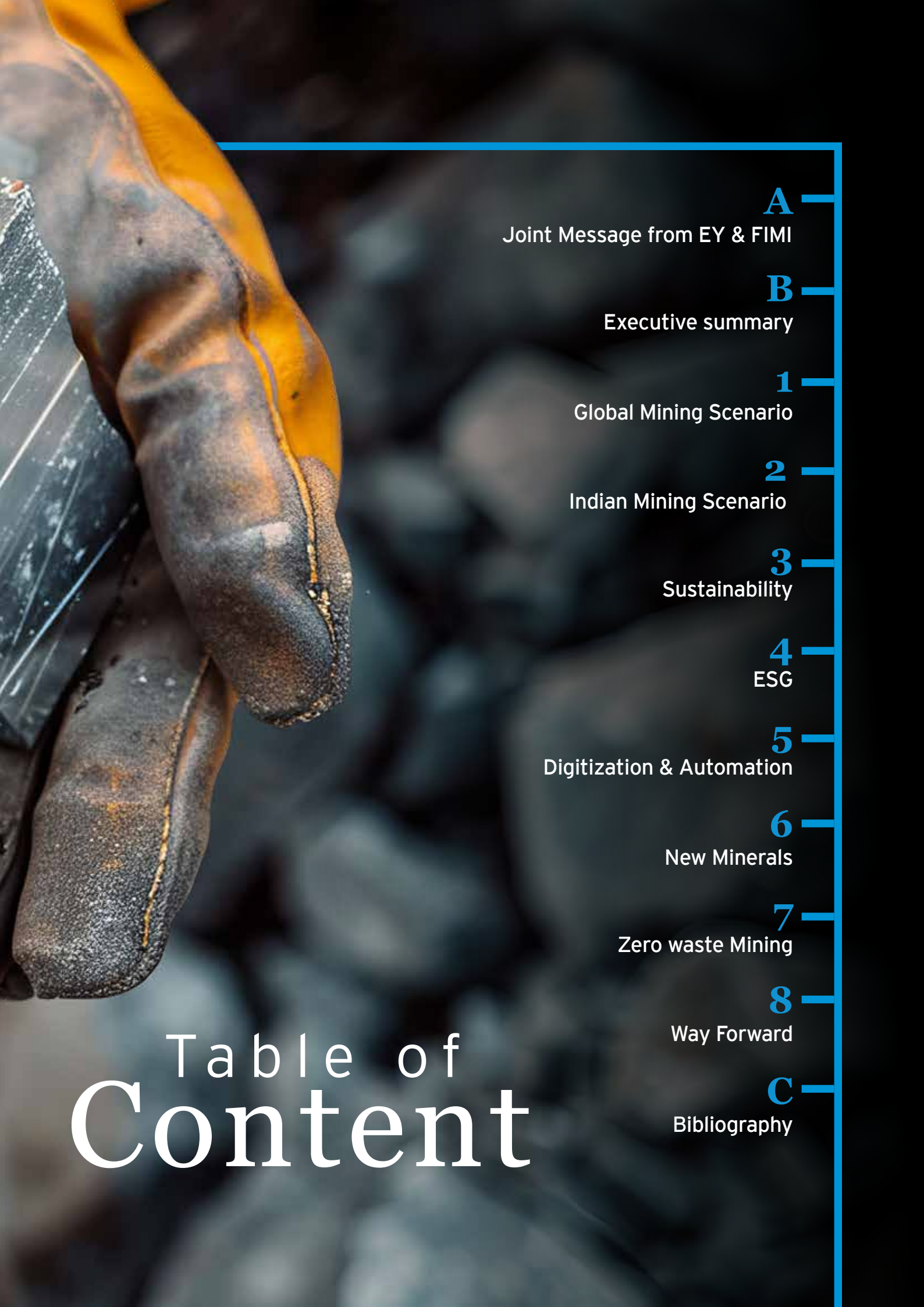

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Leading the Future: Innovation and Collaboration in India's Mining Sector

As we present this document in partnership, EY and the Federation of Indian Mining Industries (FIMI) envision a future where India's mining sector stands at the forefront of innovation, sustainability, and global leadership. This report is not just a reflection of the current state of the industry, but a beacon guiding us towards a future defined by ingenuity, resilience, and collaborative growth.

Our journey is anchored in the belief that the mining sector is more than just an economic driver; it is a cornerstone of India's path to a sustainable and prosperous future. The challenges we face—from technological disruptions to environmental sustainability—are not mere hurdles but opportunities to redefine and reinvigorate our practices.

Innovation is at the heart of this transformation. The adoption of cutting-edge technologies such as digital twins, blockchain for supply chain transparency, and predictive analytics are revolutionizing how we approach mining operations. These advancements enable us to improve efficiency, enhance safety, and reduce environmental impact. As we embrace these technologies, we position India as a global leader in smart mining practices.

However, technology alone is not enough. The human element—our workforce—plays a crucial role in this evolution. Investing in skill development and fostering a culture of continuous learning ensures that our industry is equipped to tackle future challenges. We envision a workforce that is not only skilled but also adaptive, ready to innovate, and committed to sustainable practices.

Collaboration extends beyond our borders. International partnerships and knowledge exchanges bring fresh perspectives and innovative solutions to our industry. By learning from global best practices and integrating them with local expertise, we can create a robust and competitive mining sector that meets both domestic and international demands.

Moreover, our commitment to sustainability goes beyond regulatory compliance. It is about creating a legacy of responsible mining that future generations can be proud of. We are dedicated to reducing our carbon footprint, restoring ecological balance, and ensuring that our mining activities contribute positively to the communities we serve.

This document also underscores the importance of a supportive regulatory environment. Recent reforms

Message

provide a solid foundation, but continuous dialogue and collaboration between the government, industry players, and other stakeholders are essential to refine and enhance these frameworks further. Together, we can create a conducive environment that fosters innovation, ensures transparency, and attracts sustainable investments.

In envisioning the future of India's mining sector, we recognize the importance of social and community engagement. Our focus should be on fostering partnerships that respect and uplift local communities, ensuring that the benefits of mining extend beyond economic gains. By encouraging responsible practices and sustainable development, we aim to create a harmonious balance between industrial growth and social well-being.

As we look to the future, we are filled with optimism and a steadfast resolve to drive positive change. This is a call to action for all stakeholders in the mining sector: let us harness the power of innovation, strengthen our collaborations, and commit to sustainable practices. By doing so, we can ensure that India's mining sector not only thrives but also sets new benchmarks for excellence on the global stage.

Together, let us lead the way in building a mining sector that is innovative, sustainable, and inclusive, propelling India towards a future of shared prosperity and sustainable development.

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Executive Summary

"Advancing India's Mining Sector: Strategies for Sustainable Growth and Competitiveness," authored in collaboration between EY and the Federation of Indian Mining Industries (FIMI), was crafted to outline a forward-looking vision for India's mining industry. It aims to foster sustainability and innovation by integrating advanced technologies and sustainable practices, thereby enhancing the sector's operational efficiency and minimizing environmental impact. The document provides strategic recommendations for policy reform, regulatory compliance, and economic growth, positioning India as a leader in the global mining landscape.

Global Mining Scenario

The global mining industry is at a transformative crossroads, driven by rapid technological advancements, surging mineral demand, and a strong emphasis on sustainability. The sector faces the challenge of aligning with sustainable development goals (SDGs), necessitating minimized environmental impacts and fair distribution of benefits. In response, companies are adopting green energy solutions, improving energy efficiency, and incorporating circular economy principles. Technological innovations such as digitalization, automation, and AI are crucial for enhancing operational efficiencies and safety standards. The industry must invest substantially to support the energy transition, with an estimated US$1 trillion needed over the next 15 years to meet global carbon emission targets and support renewable energy systems.

Indian Mining Scenario

India's mining sector, rich in diverse minerals, faces both significant challenges and opportunities. The government promotes 'Atmanirbhar Bharat' to enhance self-reliance, focusing on maximizing domestic mineral utilization and boosting coal production. Technological adoption, though present, needs further enhancement to improve efficiency and sustainability. Key trends include sustainability investments, digital transformation, and value addition. Regulatory reforms like the National Mineral Policy 2019 aim to foster transparency and attract private investment. However, the sector must address issues like stringent environmental regulations, slow technological adoption, and financial constraints to realize its full potential.

Sustainability

Sustainability in mining is increasingly vital, driven by environmental, social, and economic imperatives. The industry is focusing on reducing greenhouse gas emissions, adopting renewable energy sources, and integrating circular economy principles to minimize waste and enhance resource efficiency. Companies are investing in sustainable practices, such as green energy solutions and improved waste management, to align with global sustainability standards and mitigate their environmental impact. These efforts are essential for the sector's long-term viability and social license to operate.

ESG (Environmental, Social, Governance)

ESG principles are becoming central to mining operations, with companies striving to meet higher standards of environmental stewardship, social responsibility, and governance. This involves transparent reporting, ethical business practices, and active community engagement. The integration of ESG factors is critical for managing risks, enhancing reputation, and ensuring regulatory compliance. Companies are increasingly held accountable by investors, regulators,

and the public for their ESG performance, driving the need for comprehensive strategies that address environmental impacts, social equity, and governance practices.

Digitization & Automation

Digital transformation and automation are revolutionizing the mining sector by enhancing operational efficiency, safety, and productivity. Technologies such as the Internet of Things (IoT), artificial intelligence (AI), and machine learning are being integrated into mining operations for predictive maintenance, real-time monitoring, and data-driven decision-making. These advancements reduce operational costs, improve resource management, and increase the sector's competitiveness. Automation also addresses labor shortages and enhances safety by minimizing human involvement in hazardous tasks.

New Minerals

The demand for new minerals, especially those critical for renewable energy technologies and electric vehicles, is rising. Minerals like lithium, cobalt, and rare earth elements are essential for batteries and green technologies. The mining industry is focusing on exploring and developing new mineral resources to meet this growing demand. Strategic investments in these minerals are crucial for supporting the global energy transition and achieving climate goals. Ensuring a stable supply of these critical minerals involves overcoming challenges such as geopolitical risks, supply chain disruptions, and environmental concerns.

Zero Waste Mining

Zero waste mining aims to minimize waste generation and maximize resource efficiency through innovative practices and technologies. This approach involves recycling, reusing, and repurposing mining waste to create a circular economy within the sector. Technologies for waste rock sorting, tailings management, and resource recovery are being developed and implemented. The goal is to reduce the environmental footprint of mining operations and contribute to sustainable resource management. Zero waste mining not only addresses environmental concerns but also enhances economic efficiency by recovering valuable materials from waste streams

The document concludes by emphasizing the importance of adopting these innovative and sustainable practices to ensure the long-term viability and environmental stewardship of the mining industry. The future of mining lies in balancing economic growth with responsible resource management and environmental conservation.

01 Global Mining Scenario

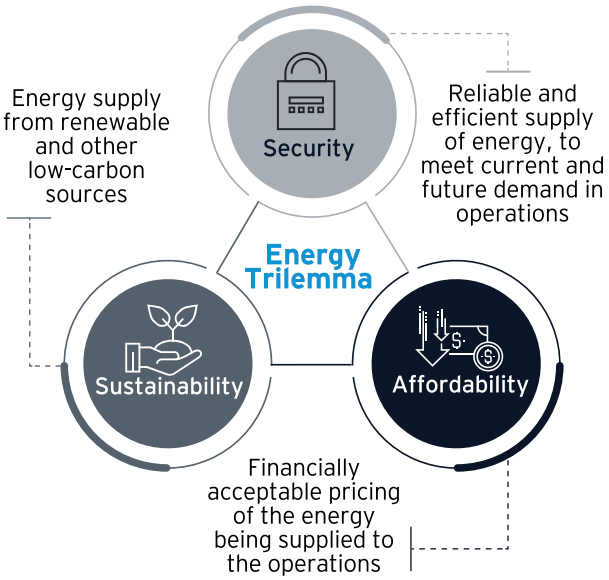
1.1 Introduction

The global mining industry stands at a critical juncture, marked by the interplay of rapid technological advancements, increasing demand for mineral resources, and a heightened focus on sustainability. As the global population continues to grow and the quest for higher living standards persists, the demand for minerals has surged. These minerals form the backbone of modern infrastructure and technology, underpinning everything from construction and transportation to electronics and renewable energy systems.

However, this increasing demand comes with significant environmental and socio-economic challenges. The mining sector is under immense pressure to align its operations with sustainable development goals (SDGs). This involves minimizing environmental impacts, reducing greenhouse gas emissions, and ensuring the fair distribution of benefits among all stakeholders. The emphasis on sustainability has never been greater, and it necessitates a comprehensive approach that integrates economic, environmental, and social governance (ESG) principles.

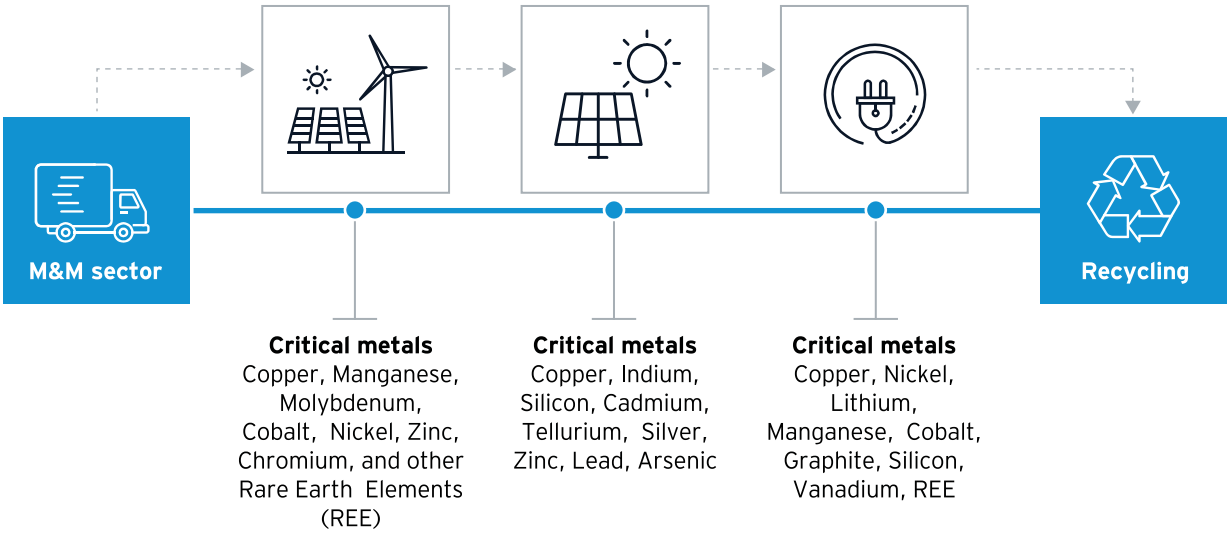
In response to these challenges, the global mining industry is undergoing a transformative shift. Companies are increasingly adopting green energy solutions, improving energy efficiency, and integrating circular economy principles into their operations. Technological innovations such as digitalization, automation, and the use of artificial intelligence (AI) are playing pivotal roles in enhancing operational efficiencies, reducing environmental footprints, and improving safety standards.

As the world intensifies its focus on mitigating climate change with proactive carbon emission targets, it is increasingly evident that there can be no energy transition without the essential metals and minerals provided by the mining and metals (M&M) sector. The development of renewables, energy storage systems, green infrastructure, and electric vehicles is fundamentally dependent on the supply of these critical inputs.



Achieving this transition will necessitate substantial investment. The sector requires approximately US$1 trillion over the next 15 years to mine, process, and recycle the necessary materials to support an accelerated energy transition aimed at limiting the average global temperature increase to 2°C by 2050. Consequently, the global production of critical minerals used in renewables and electric vehicles is projected to see dramatic increases by 2050: 965% for lithium, 585% for cobalt, 383% for graphite, and 173% for vanadium.

In response to this rising demand, larger mining companies are significantly boosting their interest in commodities essential for the energy transition. For instance, Rio Tinto has recently invested in scandium and tellurium, while BHP has invested in Tanzania's Kabanga nickel project. These strategic investments underscore the crucial role the mining and metals sector plays in facilitating a sustainable and climate-resilient future.



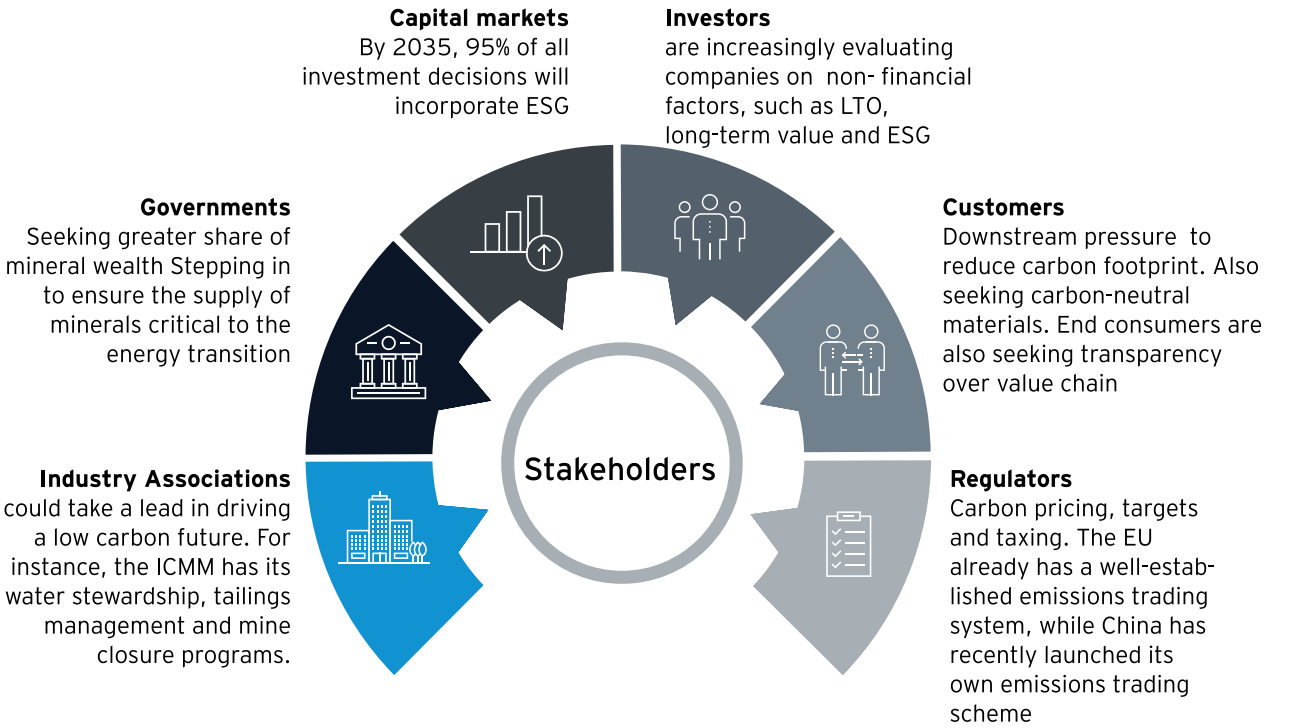
The global economic landscape adds another layer of complexity to the mining sector's outlook. Price volatility persists due to weaker global demand. Global economic growth is projected to decline to 2.3% in CY 2024 from 2.7% in CY 2023. Inflation, which began easing in CY 2023, is expected to decrease further in CY 2024, potentially leading to interest rate cuts by central banks, with the US Federal Reserve possibly delaying cuts until mid-year. China's property sector remains under pressure, with new home construction and property investment falling by approximately 21% and 10% respectively in CY 2023. Manufacturing contractions in China, the EU, and Japan have reduced the demand for metals.

Battery metal prices have plummeted due to increased supply and weaker demand. In February 2024, lithium prices dropped to about US$14,000 per ton and nickel to US$16,000 per ton, from highs of approximately US$67,000 and US$28,000 per ton in January 2023. Consequently, lithium and nickel miners are cutting production and laying off workers. Despite the slower economic growth, investment in the energy transition is keeping aluminium and copper prices higher than the 10-year average. Although aluminium and copper inventories are rising, the demand driven by the energy transition is likely stabilizing prices.

Positive outlooks remain for precious metals, with gold prices rising due to geopolitical tensions, steady demand supporting silver prices, and platinum group metals (PGMs) expected to recover in 2024. The EU's demand for critical minerals for clean energy is anticipated to increase approximately 30 times by 2030, though supply remains a significant challenge.

The global economic outlook for 2024 remains weak compared to pre-pandemic levels, although there are tentative signs of improvement at the start of the year following a sluggish end to 2023. Inflation is broadly declining, and while it remains above central bank targets, several central banks have paused their rate hikes.

The journey towards sustainable mining is further driven by regulatory frameworks and investor expectations. Stakeholders across the globe demand transparency, accountability, and tangible actions towards reducing the carbon footprint of mining activities. As such, the industry is moving towards more responsible mining practices that not only cater to the present demands but also secure resources for future generations without compromising the health of our planet.



The figure above depicts the diverse stakeholder landscape influencing the mining industry.

This global shift towards sustainable mining practices is essential for achieving net-zero emissions targets and supporting the transition to a low-carbon economy. It is within this context that the Indian mining sector finds itself at a pivotal transition phase, striving to decarbonize and integrate innovative technologies to ensure long-term sustainability and resilience.

The semiconductor shortage, which emerged in late 2020 and persists into 2024, is attributed to disruptions caused by the COVID-19 pandemic, a surge in demand for consumer electronics due to remote work, rapid recovery of the automotive industry, and geopolitical tensions, particularly between the U.S. and China. This shortage highlights the crucial role of critical minerals like silicon, cobalt, nickel, and rare earth elements in semiconductor manufacturing. Silicon is vital for semiconductor wafers, while cobalt and nickel are essential for advanced semiconductors used in energy storage and high-performance applications. Rare earth elements are indispensable for producing high-performance magnets in semiconductor production equipment and the semiconductors themselves. Consequently, the increased demand for these minerals has spurred significant growth in global mining activities, impacting supply chains and raising environmental and geopolitical concerns.

1.2
Key trends in the mining & metals sector

Mining companies are dealing with widespread market volatility and geopolitical disruption. To navigate volatility and capture future opportunity, mining companies need to reassess their business models and portfolios to capture optimal value. Options for growth exist such as expanding along or across the value chain or investing in new commodities or materials or a circular economy. Transforming the business by taking an integrated value chain approach can support organizations in increasing return on investment and identifying more opportunities to find digital solutions to some of miners' biggest challenges, including ESG, climate risk, productivity, and costs.

There are four key trends at play in the mining and metals sector:

Urbanization and the energy transition will fuel long-term minerals and metals demand: Metal demand from ongoing urbanization will compete with the rapidly increasing new demand fuelled by the energy transition. Rising sales of electric vehicles will push demand for lithium and nickel up by ~40 times by 2040. EV makers are actively increasing investments in the critical minerals value chain, as nearly half of the total global vehicle sales will be EVs by 2030.

Bringing new supply online to meet this exponential new demand will be a significant challenge: Supply growth will not just be impacted by demand and capital but location of reserves, access to water and green energy, as well as a range of geopolitical implications. Cumulative investment of US$450 billion is required into critical minerals by 2030 to meet expected demand. Moreover, increasing community and environmental expectations, along with competition for scarce resources, are making it increasingly difficult to obtain and maintain a license to operate (LTO).

Resilient supply chains of minerals needed for energy transition will be an increasingly important geostrategic imperative: Companies are navigating a range of geopolitical considerations - what incentives to take advantage of – such as the US IRA or the EU critical minerals act - or where to take extra precautions in case of nationalization of mining assets; rising royalties and other initiatives.

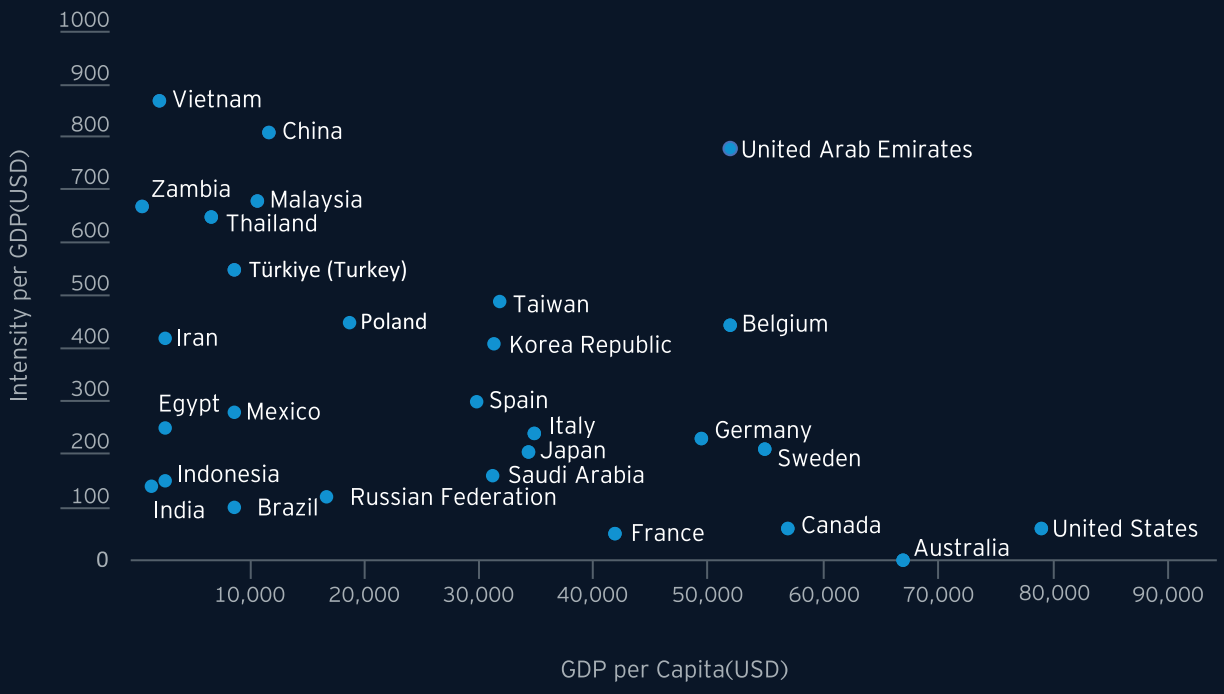
The path to net zero emissions and net positive on ESG will drive significant transformation: Achieving net-zero is now considered the baseline requirement across all aspects of ESG to attract capital and retain LTO. All factors of ESG are facing scrutiny, and miners need to go beyond policy to gain investor confidence and community acceptance. Scope 3 emissions account for most of the mining sector's emissions, and pressure is growing from investors, communities and governments to take a strategic approach to their reduction. Miners that identify the source of Scope 3 emissions, and which of these they can control and influence, can gain an advantage.

1.3

Drivers of growth in the mining & metals sector

a. Urbanization will drive long-term demand for minerals and materials, with 43% of the world's population still living in rural areas, offering significant potential for industrialization and increased metals demand. The red intensity curve shows how copper use is high in emerging markets and tapers off as GDP per capita increases

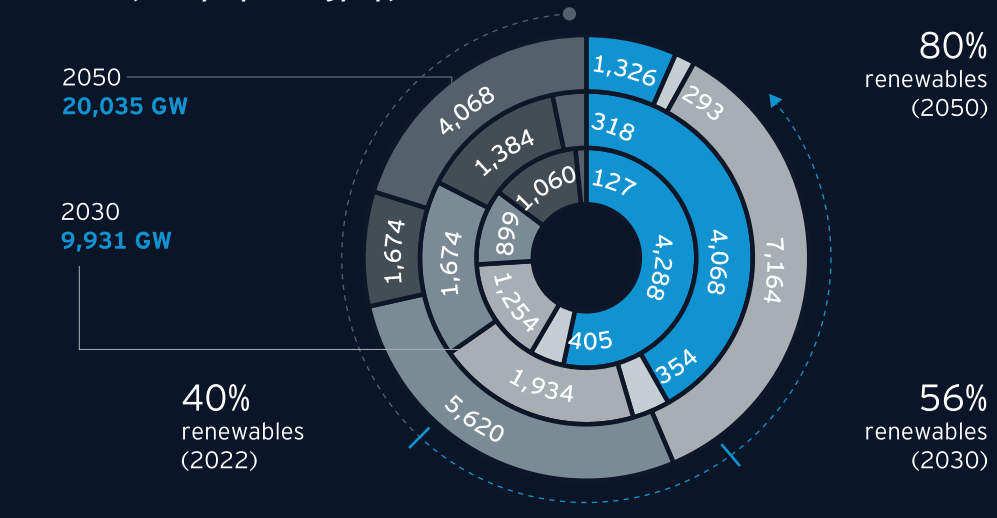
Intensity of Copper Usage



Source: EY Knowledge analysis of data from The World Copper Factbook 2023 and IMF

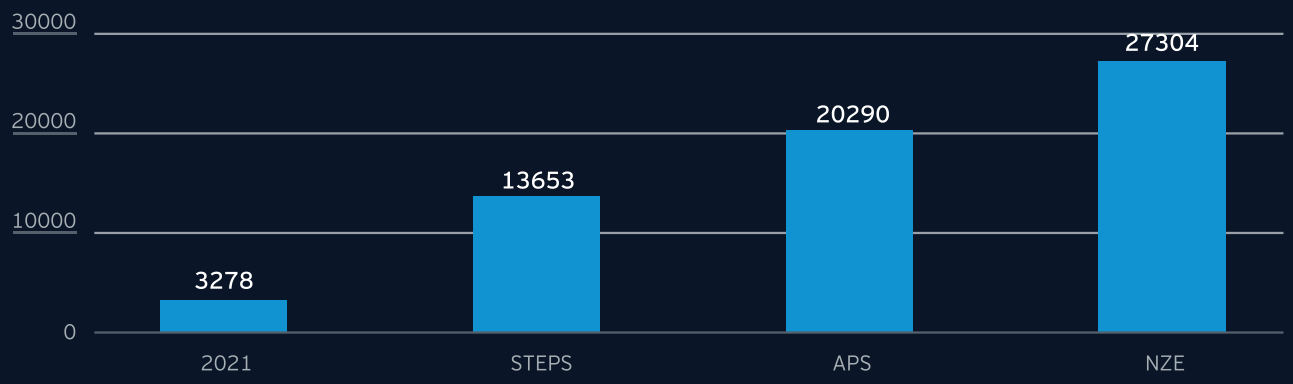
b. The global power system is projected to nearly triple in size by 2050, dominated by renewable technologies

Total installed capacity by energy type (GW) 2022-2050



Source: EY Knowledge analysis of ETA - current trajectory scenario, and IEA Critical minerals database and report

Renewable energy capacity forecast(GW) 2021-2050E

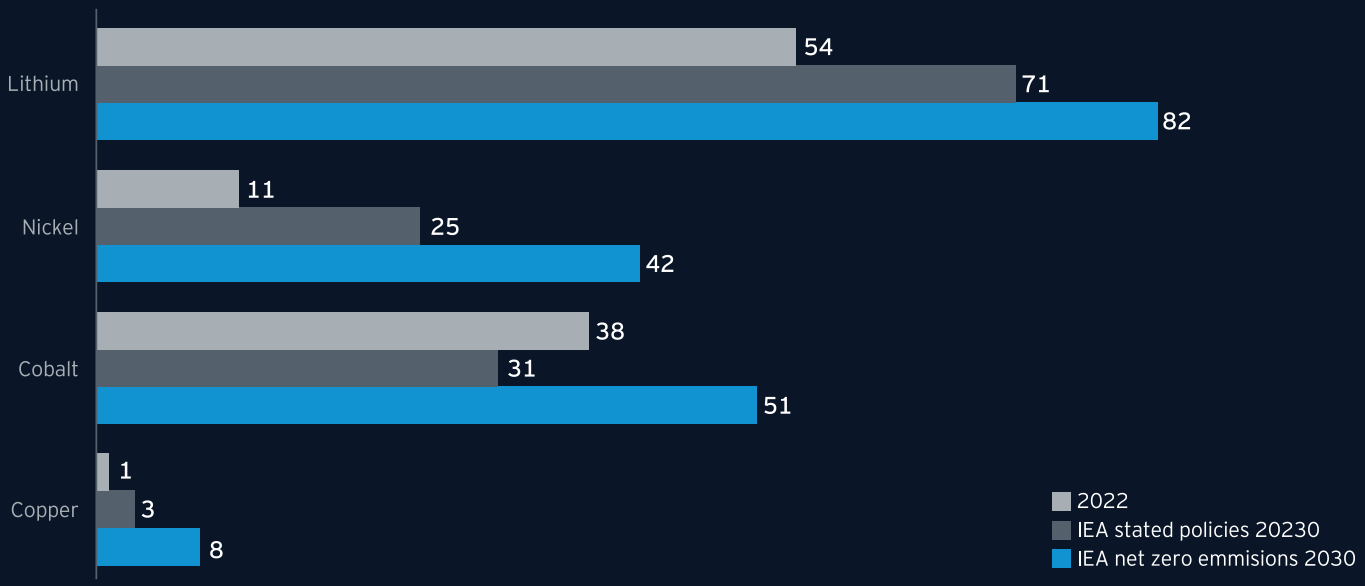


Source: EY Knowledge analysis of ETA - current trajectory scenario, and IEA Critical minerals database and report

c. The growth in electric vehicle sales will lead to an exponential rise in demand for critical minerals, while accelerated investment in renewable electricity infrastructure will boost demand for copper and aluminum.

EY forecast over half of total global vehicle sales will be EVs by 2030

EV-related metal demand as a % of total demand

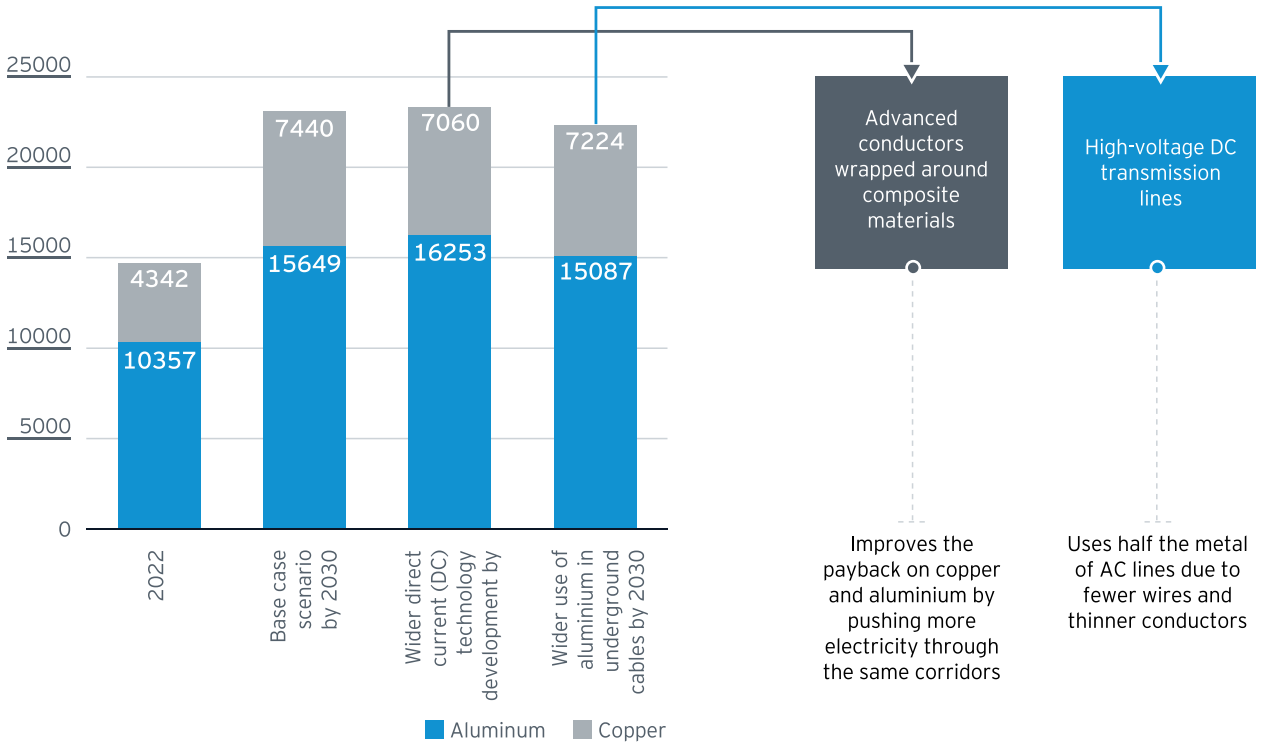


Source: EY Knowledge analysis of data from EY Mobility lens forecaster and IEA Critical Minerals Data Explorer (2023)

d. The projected mineral demand for clean energy technologies, focusing on copper and aluminium, under various scenarios aligned with announced climate pledges. By 2030, the base case scenario anticipates significant increases in demand for both minerals, with copper reaching 15,649 kt and aluminium 7,440 kt. Enhanced use of aluminium in underground cables and wider adoption of direct current (DC) technology could further boost demand, with copper reaching 16,253 kt and aluminium 7,060 kt in the former scenario, and copper at 15,087 kt and aluminium at 7,224 kt in the latter. To balance this rising demand alternatives such as advanced conductors wrapped around composite materials, which can improve efficiency by transmitting more electricity through existing corridors, and high-voltage DC transmission lines, which use half the metal of AC lines due to fewer wires and thinner conductors. These alternatives aim to enhance grid efficiency and meet the growing mineral requirements of the clean energy sector.

Mineral demand by clean energy technology for different alternatives in the announced pledges scenario

Alternatives to make grid lines more power efficient - to balance Copper and Aluminium demand with supply



Source: EY Knowledge analysis of data from IEA

e. Also vertical integration will ensure sufficient investment in critical minerals and secure their supply. By collaborating, miners can enhance the flow from mine to market, gaining greater visibility into the supply and demand of critical minerals by breaking down silos. This collaboration allows margins to be leveraged along the value chain and reduces volatility in downstream positions.

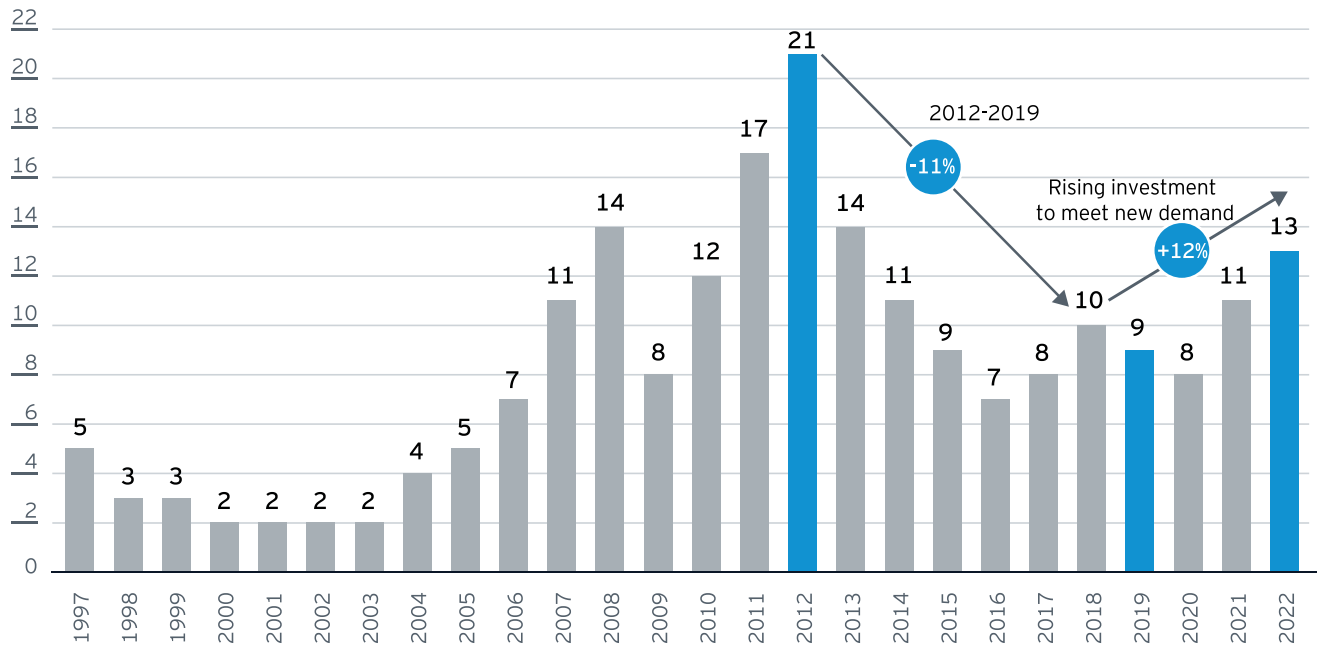
f. The mining and metals sector is experiencing robust growth driven by the escalating demand for steel, which in turn increases the demand for essential raw materials such as coal and iron ore. Steel is a fundamental component in various industries including construction, automotive, and manufacturing, fueling the need for substantial quantities of coal (used in steelmaking as coking coal) and iron ore (the primary raw material for steel). The global infrastructure development boom and the rise in automotive production are key factors driving steel consumption. Consequently, the heightened demand for steel is propelling the mining activities for coal and iron ore, leading to significant investments and advancements in mining technologies. This symbiotic relationship underscores the critical role of coal and iron ore in the growth dynamics of the mining and metals sector, as these materials are indispensable for steel production, which remains a cornerstone of industrial development and economic growth worldwide.

(Resource: Key Sector Trends in Mining and Metals, Impact of deglobalization and geopolitics on the supply of critical minerals)

1.4
Challenges faced by global mining sector

Investment in critical mineral mining must increase significantly to approximately US$450 billion to meet the expected demand. While anticipated investments in copper and nickel mining stand at US$171 billion, an additional US$213 billion will likely be necessary. Historically, lower exploration budgets have adversely impacted both current and future project pipelines for several commodities.

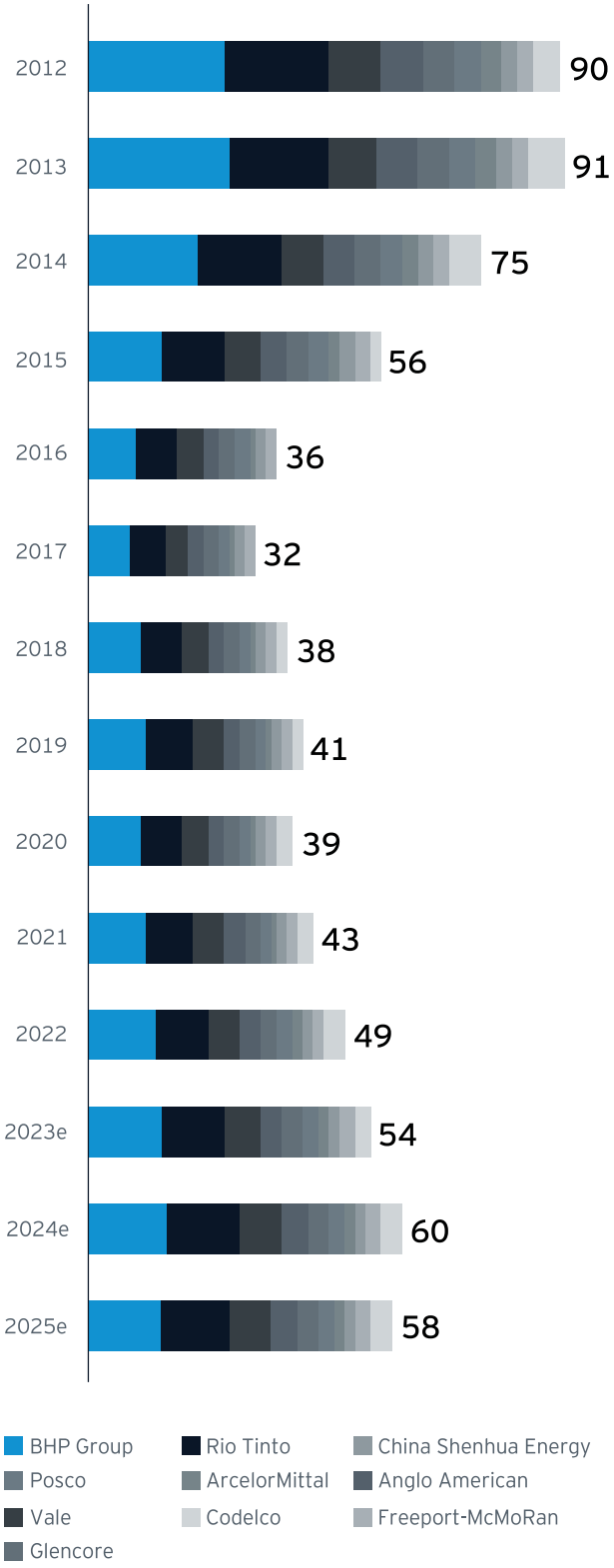
Global annual non-ferrous exploration budgets (in US$b) 1997-2022



Source: EY Knowledge analysis of data from S&P and capital IQ

Although exploration budgets are gradually rising, overall capital expenditure is projected to increase by only 2.3% from 2023 to 2025, indicating a need for more substantial financial commitment to meet future demand

Capital spending of top 10 highest spending miners (US$b) 2012-2025e



. Source: EY Knowledge analysis of data from S&P and capital IQ

The European Union is grappling with insufficient investment in critical minerals, with only US$3.3 billion allocated compared to the substantial US$369 billion invested by the United States in green subsidies under the U.S. Inflation Reduction Act. This disparity is further exacerbated by permitting challenges that result in lengthy approval times. The EU's goal to domestically mine around 10% of strategic minerals is hindered by legislative obstacles in Sweden and Finland, alongside community opposition in Portugal. Corruption concerns have led activists to call for a suspension of permits for the Barroso and Montalegre lithium mines in Portugal. In Sweden, the Talga Group's efforts to develop the Nunasvaara graphite mine—the only one in Europe—into a vertically integrated battery metals supply chain have faced significant permitting issues.

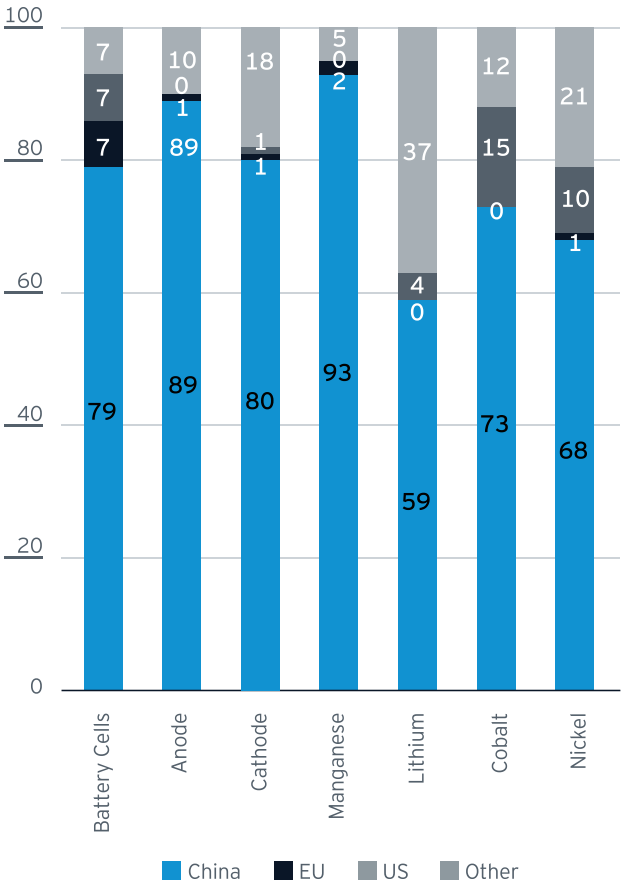
(Resource: Monthly MM Commodity March 2024,Mining sector challenges from Utkrisht bharat, Key Sector Trends in Mining and Metals)

1.5 Geopolitical developments & its impact on mining policies

The impact of deglobalization and geopolitical shifts on the supply of critical minerals is profound, as evidenced by key geopolitical developments in 2023. The ongoing conflict in Ukraine has far-reaching regional and global political and economic ramifications, while the trend of China-Western decoupling is gradually eroding economic connectivity. Geopolitical swing states are poised to wield substantial influence on global dynamics, and a heightened focus on economic self-sufficiency is reshaping investments and supply chains in strategic sectors.

In this volatile environment, the race for minerals and metals vital for the energy transition is intensifying, driven by rising commodity demand projections from 2022 to 2050. Notably, the production and processing of minerals remain geographically concentrated, with China holding significant market share in the processing of battery minerals.

China controls significant market share in processing of battery minerals (% of the market)



Source: EY Knowledge analysis of IEA report "The Role of Critical Minerals in Clean Energy Technology"

Other impact of deglobalization and geopolitics on the supply of critical minerals.

- Starting in August 2022, Mexico nationalized its lithium assets, signalling heightened government participation in the sector.
- In the same month, the US enacted updated regulations aimed at reducing reliance on Chinese imports.
- Subsequently, in November 2022, Canada introduced new limits on foreign state-owned companies investing in critical minerals.
- In December 2022, Zimbabwe implemented an export ban on unprocessed lithium, while the Philippines contemplated similar measures for nickel ore exports.
- Following suit, Namibia enforced an export ban on unprocessed lithium and critical minerals in August 2023. Additionally, China imposed restrictions on graphite exports in December 2023.
- China tightened its grip on mineral exports by restricting the export of gallium and germanium in the same month.
- In December 2023, Chile enacted a new Royalty Act set to come into effect in January 2024, aimed at regulating mineral royalties.

Government policies are being enacted to mitigate exposure to supply chain disruptions and ensure a stable supply of critical minerals. Recent updates to critical material strategies emphasize diversifying supply chains and enhancing domestic production. For instance, the EU Critical Minerals Act targets the domestic production of approximately 10%, processing 40%, and recycling 15% of critical materials.

In the US, the Inflation Reduction Act (IRA) provides investment tax credits of 10% and production tax credits of +0.3 cents/kWh for critical minerals produced domestically or within US trade partner countries.

Australia has announced a comprehensive critical minerals strategy, outlining plans for 81 major projects valued between US$30 billion and US$42 billion. Additionally, Australia intends to establish a ministerial-level taskforce on critical minerals in collaboration with the US.

Canada's federal budget for 2023 includes initiatives to support critical minerals production, with a strategic innovation fund of US$1.1 billion allocated for clean energy projects, including the extraction and processing of critical minerals.

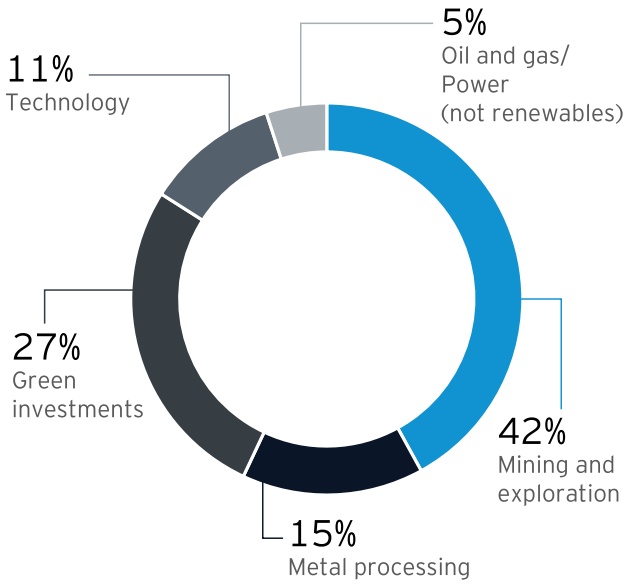
(Resource: Impact of deglobalization and geopolitics on the supply of critical minerals, Key Sector Trends in Mining & Metals)

1.6

How mining companies are ramping up progress on new business model

Mining companies are actively advancing innovative business models to bolster their value propositions. This entails embracing strategies such as shared value frameworks, vertical integration, joint ventures, circular economy principles, offtake agreements and horizontal market integration.

Yet, the primary challenge confronting miners is twofold: they must strike a delicate balance between investing in these novel business models while upholding financial discipline and ensuring returns for stakeholders. In this evolving landscape, miners are presented with a unique opportunity to redefine their operational paradigms, thereby unlocking optimal value across the industry.



Source: EY analysis of publicly available information

Between 2018 and 2022, an analysis of investments by 12 top mining firms, including POSCO Holdings, Anglo American, Glencore, Newmont, ArcelorMittal, Fortescue, BHP, Zijin Mining, Nucor, Rio Tinto, Teck, and Vale.

These investments reflect a focus on core activities, sustainability, innovation and diversification. In the face of ongoing disruption and volatility, mining companies are not only evaluating but also adapting their business models to stay competitive. By aligning their strategies with emerging trends and stakeholder expectations, they aim to secure long-term success and resilience in a rapidly changing global market.

Below are the drivers of change and their impact on business model:

Driver of change	Impact on business model
Changing trade flows	Reassessing relationships and global trade model
Reshoring of critical mineral production	Vertical integration into processing and refining of minerals
Pressure from investors on coal mining	Divesting coal operations to smaller or private companies or demerging into standalone entities
Reaching net zero emissions targets	Investing in renewable energy but also extending the ownership of that into a new line of business
Lack of capital to fund new mines	Offering future production through offtake agreements with downstream producers
Rising demand for green or decarbonized metals	Changing production methods to reduce carbon emissions (early stage and not all commercially viable)
Sustainable use of products and minimization of waste	Implementation of circular economy principles

Recent developments in Generative AI (GenAI) present significant opportunities for the mining and metals sector. These advancements can enhance contractor management, regulatory and tax compliance, safety, ESG (Environmental, Social, and Governance) practices, energy management, and compliance processes. GenAI aids in streamlining operations, improving safety and compliance, and addressing sustainability challenges, thereby driving efficiency and resilience across the value chain.

(Resource: Impact of deglobalization and geopolitics on the supply of critical minerals, Key Sector Trends in Mining and Metals)

1.7
Key imperatives relevant for India from a global context

India's mining sector stands at a pivotal juncture, poised to draw critical lessons from various global counterparts to fuel its growth. By examining the strategies of countries like China, Australia and Canada, India can adopt best practices and avoid common pitfalls, propelling its mining industry towards sustainable and efficient growth.

China's economy has witnessed immense growth in the past couple of decades, driven by substantial investments in infrastructure. In 2023, China's GDP was $18.53 trillion, nearly five times that of India's $3.94 trillion. China's industrial policy has prioritized the development of critical infrastructure, including comprehensive transportation and logistics networks, which support its trade capacity and export-oriented economy. India, with its ambitious growth plans, can benefit from liberalizing policies further and creating a business-friendly environment to attract investments in its mining sector. Moreover, integrating sustainable practices in infrastructure development, as China is now emphasizing, is crucial to avoid environmental degradation and social unrest.

Australia, a leading mining nation, offers valuable insights into leveraging advanced technologies and maintaining stringent safety standards. The Australian mining sector is known for its high level of automation and use of cutting-edge technology, such as autonomous vehicles and remote operation centers. These innovations not only boost productivity but also enhance safety and reduce operational costs. India can adopt similar technologies to modernize its mining operations, improving both efficiency and safety standards.

Canada's mining sector provides a model for environmental stewardship and community engagement. Canada places a strong emphasis on sustainable mining practices, including rigorous environmental assessments and active community involvement in mining projects. These practices ensure that mining activities do not adversely impact the environment and that local communities benefit from mining operations. India can implement similar frameworks to ensure sustainable mining practices and build trust with local communities, which is essential for long-term success.

In addition to these examples, several other nations offer valuable lessons. For instance, South Africa's approach to mineral beneficiation and value addition can help India maximize the economic benefits from its mineral resources. By processing and refining minerals domestically, India can create more jobs and increase the value derived from its mining sector.

Furthermore, fostering global partnerships and collaborations can strengthen India's mining sector. Engaging with international mining leaders and organizations can provide access to best practices, advanced technologies and investment opportunities. Learning from global standards and innovations will help India navigate the complexities of modern mining operations, from regulatory compliance to environmental stewardship.

In conclusion, India's mining sector can achieve significant growth by drawing on global examples from China, Australia, Canada and other leading mining nations. By adopting sustainable practices, integrating advanced technologies and fostering international collaborations, India can position itself as a competitive player in the global mining industry, driving economic growth and ensuring long-term sustainability.

Incentivizing is a crucial intervention for India to enhance its mining and metals sector in response to global demand for steel and its raw materials, coal and iron ore. By offering tax benefits, subsidies, and infrastructure development support, India can attract both domestic and foreign investments, boosting the exploration and extraction of these key resources. Environmental incentives and research grants can promote sustainable practices, while local content requirements and support for SMEs can strengthen domestic production and create jobs. Export incentives and regulatory reforms can enhance the global competitiveness of Indian mining companies. Overall, a strategic incentivizing approach can drive economic growth and position India as a leading player in the global mining industry.

02
Indian Mining Scenario

2.1
Introduction

India is richly endowed with minerals, producing up to 95 different types, including four fuels (e.g., coal), ten metallic minerals (e.g., iron ore), 23 non-metallic minerals (e.g., limestone), three atomic minerals (e.g., uranium), and 55 minor minerals. These are extracted from an extensive network of approximately 1,300 mines. The country is largely self-sufficient in several key minerals such as bauxite, chromite, limestone, iron ore and sillimanite. However, it faces shortages in minerals like manganese, kyanite and coal, necessitating imports to meet its demands.

To maintain global competitiveness, India aims to maximize the utilization of its domestic reserves, particularly for coking coal used in iron ore reduction. Despite its mineral wealth, the sector has significant untapped potential, offering ample opportunities for further development.

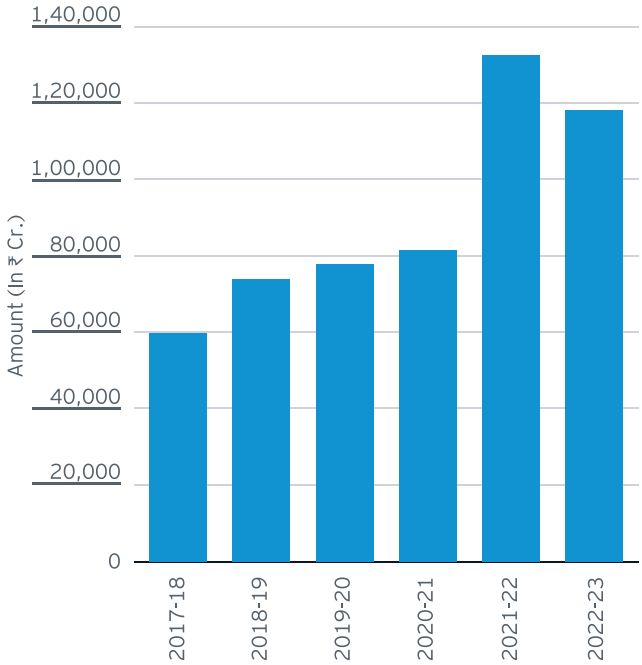
The Government of India is promoting 'Atmanirbhar Bharat' (self-reliant India) by implementing policy initiatives and regulatory changes in areas such as auction processes, duty levies and land availability. While coal remains a major driver of mining demand, its demand is projected to grow until alternative renewable energy sources are sufficiently developed, despite its large imports. Consequently, the government aims to boost coal production to over 1 billion tons by 2024-25. The private sector mining coal for both captive and commercial use is also adopting new technologies, automation and digitization, though there remains significant room for improvement.

In terms of coal reserves, India ranks among the top five nations. Indian coal reserves are predominantly of the bituminous type, characterized by higher ash content and generally non-coking grade, which is widely used in power generation.

India is among the top ten countries with significant iron ore resources, primarily consisting of Banded Iron Formations (BIF) dating back to the Precambrian era. The country's iron ore reserves mainly include hematite and magnetite, with hematite being the most important due to its higher-grade quality, making it the preferred type for the Indian steel industry.

India is largely self-sufficient in iron ore production. Although the pandemic caused a 17% decline in iron ore production in FY21, there was a 24% increase in FY22 due to rising steel demand and the government's focus on boosting infrastructure.

The booming construction industry for commercial and residential structures ensures steady demand for metallic minerals. Rapid infrastructure development offers numerous growth opportunities for the mining sector. The industry also benefits from increasing emphasis on energy efficiency in major construction projects.



Source: EY analysis of publicly available information

The 'Make in India' initiative and the shift towards timely, quality project delivery have led to higher demand for modernized mining methods. Equipment manufacturers are encouraged to adopt digitization and innovative automated technologies for sustainable growth.

The data on the production of various minerals, Iron ore production stands at 258 million metric tonnes, valued at Rs. 79,931 Crore, ranking 4th globally with a 100% self-sufficiency rate. Chromite has a production quantity of 3.56 million metric tonnes, valued at Rs. 4,805 Crore, also ranking 4th globally with a 98% self-sufficiency rate. Bauxite production amounts to 23.8 million metric tonnes, valued at Rs. 2,787 Crore, and it holds the 4th global rank with an 87% self-sufficiency rate. Limestone production is the highest at 406 million metric tonnes, valued at Rs. 10,881 Crore, ranking 3rd globally with a 94% self-sufficiency rate.

2.2
Key trends in Indian mining and metal sector

The Indian mining and metal sector is undergoing a transformative phase, propelled by several key trends that are shaping its trajectory and fostering sustainable growth. Among these trends, there is a notable emphasis on sustainability and environmental responsibility, exemplified by initiatives like Hindustan Zinc's commitment to invest $1 billion by 2025 to achieve net-zero carbon emissions. This shift towards greener practices is vital for mitigating environmental impact and aligning with global standards.

Moreover, digital transformation is revolutionizing the sector, with companies like Tata Steel leveraging advanced technologies such as automation, artificial intelligence, and IoT to enhance efficiency and safety standards.

In the context of India's aspirations for self-sufficiency and growth, the mining industry plays a crucial role. However, its disruptive nature is a significant concern given the global dialogue on a shared sustainable future. Indian mineral deposits often overlap with biodiversity-rich zones and important catchments. Additionally, the remote locations of these deposits present challenges such as access, infrastructure, poverty, and insurgency. Therefore, it is essential to develop a step-by-step guideline for responsible mining practices, monitor sustainable development in and around mines, and measure progress. This approach would ensure smooth and responsible execution while addressing demographic and economic challenges. The mining industry's readiness to adapt to changing national (green credits) and global (carbon, water, biodiversity, community) standards is vital for its sustained growth.

Mr. Kailash Pandey,
Head Mining Business
and Cluster Head,
Hindalco Industries Ltd.

This integration of digital solutions not only optimizes operations but also enhances competitiveness in the global market.

Value addition and downstream integration are also gaining prominence, with investments in beneficiation and processing capabilities. Vedanta's expansion in aluminium smelting and power generation underscores the sector's drive to extract maximum value from raw materials, thereby bolstering domestic production and reducing reliance on imports.

Furthermore, strategic partnerships and collaborations, both domestic and international, are fostering knowledge exchange and investment inflows. For instance, collaboration between India's leading steel player and Japan's major steel corporation with highlights the sector's efforts to produce high-grade steel for critical industries like automotive.

Overall, the Indian mining and metal sector's growth trajectory remains promising, demonstrated by its resilience and potential on the global stage. With continued emphasis on sustainability, innovation and strategic partnerships, the sector is well-positioned for robust growth and increased competitiveness in the years to come.

2.3 Contribution of mining sectors to the Indian economy

India's journey towards achieving its ambitious $5 trillion economy target by 2025 is gaining momentum, as evidenced by the International Monetary Fund's (IMF) upward revision of its economic projection for India to 6.3% for the current year, up from the previous 6.1% stated in the October 2023 World Economic Outlook (WEO) report. These projections highlight India's pivotal role in driving global economic growth, with the IMF maintaining its forecasts for China at 5.2% for 2023 and 4.0% for the following year.

A deeper analysis of the mining sector highlights its significant contribution to India's economic growth. A 1% increase in the mining sector results in approximately a 1.3% rise in industrial production and a 0.3% boost in India's GDP. Over the past five years, the mining sector's contribution to India's Gross Value Added (GVA) has steadily increased at a Compound Annual Growth Rate (CAGR) of 9%, maintaining a solid ~2% share of the overall Indian GVA. Realization of our growth

aspirations, particularly with substantial investments in infrastructure, hinges significantly on further developing India's mining and coal sectors. Although India's mining sector contributes less than 2.5% to its GDP, it remains a vital component of the economy, comparable to countries like Russia, Chile, China, Indonesia, and Australia, where mining and quarrying contribute 7-10% to their GDP.

The mining sector stands as a cornerstone of India's economy, exerting a significant influence on national growth. Beyond its direct contribution to GDP, it serves as the linchpin for the development of various industries such as Cement, Steel, Power, Iron and Electrical. Moreover, the sector is a major source of employment, both directly in mining operations and indirectly in related industries, thus bolstering economic growth. Mining companies are increasingly engaging in Corporate Social Responsibility (CSR) initiatives, focusing on community development, education, healthcare and environmental sustainability to address the sector's impacts. Furthermore, India's abundant mineral resources, including coal, iron ore and metals, play a crucial role in exports, enhancing foreign exchange earnings and the trade balance.

2.4
Drivers of growth in the mining and metals sector

The mining and metals sector in India stands as a vital pillar of economic growth, propelled by several key drivers. Infrastructure development, characterized by ambitious government initiatives like PM Gati Shakti, Housing for All, and the National Infrastructure Pipeline, is poised to bolster the sector further. Forecasts indicate a robust growth trajectory, with steel consumption projected to surge to 230 million tons by 2030 from the current 136 million tons in 2023-24. Similarly, aluminium consumption is anticipated to triple, reaching 9.5 million tons by 2030, driven by escalating infrastructure demands.

Rising power demand emerges as another significant growth driver. India, positioned as the third-largest electricity consumer globally, is primed to surpass the United States by 2030.

The escalating demand, fueled by rural electrification, urbanization and industrial expansion, underscores the necessity for coal, constituting 60% of India's electricity generation. Moreover, the surge in power needs amplifies the demand for metals like copper, projected to elevate per capita consumption to around 1 kg from the current 0.6 kg.

Supportive government policies play a pivotal role in catalyzing sectoral growth. Initiatives such as The Mines and Minerals (Development & Regulation) Act (MMDR) 2023 and the National Mineral Policy, 2019 streamline operations, enhance transparency, and promote sustainable practices. Facilitating foreign direct investment (FDI) of up to 100% in exploration, mining, and minerals processing under the automatic route augments the sector's global competitiveness. Removal of export duties for select metals like steel further fortifies India's position in the global market.

The capital expenditure outlay by the Government of India (GOI) serves as a pivotal gauge of its dedication to infrastructure expansion, which encompasses investments in vital areas such as mining and metals. This allocation encompasses planned expenditures on diverse infrastructure projects, including those pertinent to mining like roads, railways, ports, and power supply. A heightened capital expenditure outlay serves as a robust indicator of the government's commitment to fostering economic growth, job creation, and industrial advancement. Moreover, such investments in infrastructure trigger a multiplier effect on the economy, whereby enhancements in transportation infrastructure streamline the movement of raw materials and finished goods, consequently reducing logistics costs and augmenting the competitiveness of mining and metals enterprises. Additionally, government spending on infrastructure projects often acts as a catalyst for private sector investment in the mining and metals domain, facilitating an environment conducive to exploration, mining operations, and downstream industries. Furthermore, the capital expenditure outlay reflects the government's policy priorities and long-term vision for economic progress, thereby enabling stakeholders to forecast policy shifts, regulatory alterations, and investment prospects in the mining and metals sector.

Moreover, the mining sector's contribution to India's GDP, estimated between 2.1% and 2.5% over the last decade, harbors immense potential. Projections suggest that the industry could propel India towards a USD 30 trillion economy by 2047, potentially creating an additional 25 million jobs and contributing an extra USD 500 billion to the GDP. These figures illustrate the pivotal role of the mining and metals sector in India's socio-economic fabric, driving infrastructural development, fostering employment, and augmenting overall economic progress. As India continues its transformative journey, the mining industry stands poised to be a linchpin of growth and prosperity.

In addition to these drivers, the trajectory of the Indian mining and metals sector is shaped by seven some key factors:

01 **Transition to a low-carbon economy:** With a focus on renewable energy and emissions reduction, there is an imperative to align mining operations with sustainability goals.

02 **Exploration of frontier mining areas and innovative extraction technologies:** Adoption of innovative extraction technologies enhances efficiency and sustainability, ensuring responsible resource utilization.

03 **Evolving financing models:** Dynamic financing models are essential to mitigate risk and improve financial stability, enabling greater resilience against market fluctuations.

04 **Establishing a social contract with local communities:** Engaging stakeholders and addressing social concerns foster trust, ensuring the long-term viability of mining projects.

05 **Leveraging big data for transparency and stakeholder relations:** Data-driven insights facilitate informed decision-making and proactive management of environmental and social impacts.

06 **Navigating geopolitical dynamics:** Adapting to geopolitical shifts and building strategic partnerships are crucial for maintaining stability and securing access to critical resources.

07 **Addressing workforce challenges and digital skills:** Managing employment transitions and upskilling workers are essential for building a resilient and adaptive workforce.

08 **Regulatory interventions** in the Indian mining and metals sector ensure adherence to operational standards, environmental compliance, community engagement, and ethical practices, fostering sustainable resource management, investor confidence, and balanced development while mitigating risks and enforcing compliance.

Collaboration, innovation, and adaptation emerge as central themes in navigating these complexities. Industry stakeholders must collaborate to drive innovation and adapt to changing dynamics, ensuring the sector's resilience and long-term success in the face of evolving challenges and opportunities.

2.5
Challenges faced by the Indian mining sector

The Indian mining industry is at a critical juncture, grappling with a myriad of challenges that span across environmental, social, regulatory and technological domains. As the sector aims to balance economic growth with sustainable practices, it faces increasing pressure from stringent ESG requirements, complex regulatory frameworks and geopolitical risks. Efficient resource management, technological advancement and improved

infrastructure are essential to overcoming these hurdles and ensuring the long-term viability and growth of the industry.

01 **Environmental, Social, and Governance (ESG) issues:**

- Navigating ESG requirements is increasingly complex due to varied reporting standards.
- There is a heightened focus on decarbonization, with financial institutions and investors pressuring companies to adopt sustainable practices.
- Social challenges include gaining community acceptance and addressing mining-induced displacement and resettlement.

02 **Technological and digital transformation:**

- Slow adoption of digital technologies and analytics, which could significantly enhance productivity and operational efficiency.
- Potential exists in areas such as carbon emissions reduction, end-to-end mine planning, and optimizing supply chains.

03 **Regulatory and compliance:**

- Cumbersome and complex regulatory requirements lead to inefficiencies and higher compliance costs.
- The need for a more streamlined and transparent regulatory framework to facilitate smoother operations and attract investment.

04 **Geopolitical risks:**

- Political instability across the globe and resource nationalism can disrupt supply chains and affect mining operations.
- Companies need to navigate international trade tensions and protectionist policies that impact global demand and supply chains.

05 **Infrastructure and logistics:**

- Inefficient transportation networks and high logistics costs hinder the efficient movement of materials.
- Infrastructure challenges include inadequate rail connectivity, congested ports and a lack of digitalization in supply chain nodes.

06 **Financial constraints:**

- High costs of financing, especially for capital-intensive projects.
- Limited availability of low-cost finance compared to other countries, affecting competitiveness and expansion plans.

Specific challenges by industry

Iron ore industry:

01 **Resource management:**

- Depleting high-grade reserves necessitate the exploitation of low-grade ores, which increases operational complexity.
- There is a need to move towards sustainable growth by reducing Beneficiation dependence on high-grade ores.

02 **Production scaling:**

- Achieving the target of 300 MT crude steel capacity by 2030-31 requires large-scale mining operations with increased bench heights, larger blast-hole diameters, and greater machinery deployment.
- Managing environmental impact and ensuring minimal degradation due to large-scale operations is critical.

03 **Regulatory and compliance:**

- Compliance with revised mining thresholds for iron ore grades and the obligation to exploit and utilize low-grade ores.

Coal industry:

01 **Environmental impact:**

- Significant environmental concerns due to coal mining's contribution to air and water pollution.
- Sustainable development and community acceptance are critical, with growing opposition to coal projects.

02 **Productivity and efficiency:**

- Declining productivity since the 1990s and the slow pace of digital adoption.
- Need for significant improvements in mining techniques and operational efficiency.

03 **Regulatory and government policies:**

- Initiatives like the National Coal Gasification Mission aim to diversify coal use and reduce environmental impact.
- The government has introduced a single-window clearance system to expedite the approval process for new mines.

2.6 Indian regulatory and policy environment

The Indian regulatory and policy environment for the mining and metals sector has seen significant changes in the recent years, focusing on transparency, sustainability, and investment promotion.
Here are the major recent changes:

National Mineral Policy (NMP) 2019:

- **Objective:** Promote sustainable mining practices
- **Key features:** Enhances transparency, encourages private investment, and aims for sustainable development

Mines and Minerals (Development and Regulation) Amendment Act, 2021:

- **Objective:** Boost mineral production and reduce import dependence
- **Key changes:** Streamlined auction process for mineral blocks, removal of end-use restrictions on captive mines, and introduction of an exploration license regime

Commercial coal mining:

- **Initiative:** Launched in 2020 to open up coal mining to private players
- **Impact:** Increased competition and private investment, with the first auctions conducted for commercial mining

District Mineral Foundation (DMF) Rules update:

- **Objective:** Ensure better utilization of DMF funds
- **Changes:** Enhanced transparency and accountability in the use of funds for the welfare of mining-affected communities

Pradhan Mantri Khanij Kshetra Kalyan Yojana (PMKKKY):

- **Focus:** Development of mining-affected areas
- **Implementation:** Strengthened through better fund allocation from DMF contributions for healthcare, education, and infrastructure

Simplification of Environmental Clearances:

- **Objective:** Speed up project approvals while maintaining environmental safeguards
- **Changes:** Streamlined Environmental Impact Assessment (EIA) processes and faster clearance mechanisms

Incorporation of Khanij Bidesh India Limited (KABIL):

- **Objective:** Ensure critical and strategic mineral supply
- **Implementation:** Overseas investment in Argentina for lithium assets and MoU with Chilean entity and Australia for further collaboration for critical minerals

To foster sustainable development and growth in the mining sector, close collaboration among the government, mine owners, consultants, Mine Development Operators (MDOs), commercial miners, funding agencies and equipment suppliers is essential. Together, they must formulate an approach that ensures economic viability while addressing societal and environmental concerns.

In this collaborative effort, the government plays a crucial role as the primary regulator and facilitator. It should establish transparent and stable laws and regulations to provide investors with confidence for long-term mining projects. Taxes and royalties should balance the state's revenue needs with investors' requirements for a reasonable return on investment.

Facilitation of investment is another key function of the government. Streamlining bureaucratic processes and providing efficient services are essential. Establishing a centralized platform, such as a one-stop-shop for all mining-related permits and approvals, would enable prospective mine operators to obtain necessary permissions seamlessly.

The recent regulatory and policy changes in India's mining and metals sector emphasize sustainable development, increased transparency and greater private sector participation. The National Mineral Policy 2019 and the Mines and Minerals (Development and Regulation) Amendment Act, 2021, are instrumental in creating an enabling environment for responsible mining practices and resource utilization. Through collaborative efforts and a stable regulatory framework, the sector can achieve sustainable growth and development.

> **The entire ecosystem consisting Sustainable Mining, Environmental Conservation and Communities around us can coexist with the right approach by doing Mining Responsibly**
>
> Mr. D.K. Mohanty,
> Director (Production),
> NMDC Ltd.

2.7 Indian mining and metal companies are adapting to dynamic environment

Indian mining and metal companies are proactively evolving to stay competitive and adept in a dynamically changing environment. The sector is witnessing rapid transformations driven by technological advancements, regulatory changes, and fluctuating market demands. For instance, Tata Steel, one of the leading players, has adopted advanced analytics and artificial intelligence to enhance operational efficiency. By integrating these technologies, Tata Steel has been able to predict equipment failures, optimize production processes, and reduce downtime, thereby maintaining a competitive edge in a volatile market.

In addition to technological adoption, sustainability has become a crucial focus for Indian mining and metal companies. Vedanta Resources, a major mining

conglomerate, has committed to significant reductions in carbon emissions and increased investments in renewable energy. The company's Lanjigarh refinery in Odisha has implemented energy-efficient practices and increased its reliance on green energy sources, showcasing its commitment to sustainable operations. This strategic shift not only helps in mitigating environmental impact but also aligns with global sustainability trends, thereby enhancing the company's reputation and market positioning.

Expanding capacity and strategic partnerships are also vital strategies for these companies. JSW Steel has expanded the capacity of its Vijayanagar plant from 13 million tonnes per annum (MTPA) to 18 MTPA with an investment of INR 7500 Crores. The expansion project was completed by March 2024. This expansion will enable JSW Steel to cater to the increasing domestic and international demand for steel. Additionally, global steel players have entered the Indian market, with ArcelorMittal acquiring Essar Steel for INR 420,000 Crores and forming a joint venture with Nippon Steel Corporation. These investments reflect the growth potential of the Indian steel industry and its attractiveness to international investors.

Regulatory compliance and adaptation to new policies are also pivotal for the sector. The Indian government's push for self-reliance (Atmanirbhar Bharat) and reforms in mining policies have prompted companies to reassess and realign their strategies. For example, NMDC Limited, a state-owned enterprise, has ramped up its exploration activities and is focusing on domestic resources to reduce dependency on imports. This move is in response to the government's initiatives to boost domestic production and ensure resource security, which is critical in a dynamically changing geopolitical landscape. By embracing these multifaceted strategies, Indian mining and metal companies are well-positioned to navigate the complexities of a dynamically changing environment and sustain long-term growth.

2.8
Imperatives for the Indian mining industry

Technology adoption: To fully harness the sector's potential, it is imperative to focus on modernization and technological advancement. Adopting state-of-the-art technologies like automation, artificial intelligence and IoT can significantly enhance operational efficiency, safety and environmental sustainability. These technological shifts are essential not only for optimizing resource extraction but also for maintaining a competitive edge in the global market.

Sustainability: As global and domestic scrutiny on environmental impact intensifies, the sector must adopt eco-friendly practices to mitigate its carbon footprint and ensure the responsible management of natural resources. This includes rehabilitating mining sites, conserving biodiversity and implementing water and waste management strategies. Stricter regulatory frameworks and compliance measures will be pivotal in steering the industry towards more sustainable operations, thereby aligning with global environmental standards.

Workforce development: As mining operations become more sophisticated, there is a growing need for a skilled workforce adept in new technologies and sustainable practices. Investing in comprehensive training programs and fostering partnerships with educational institutions will be essential to equip the workforce with the necessary skills. This will not only enhance productivity but also ensure a safer working environment and foster innovation within the sector.

Strengthening the regulatory framework and improving the ease of doing business: Streamlined approval processes, reduced bureaucratic hurdles and clear, stable policies will provide a conducive environment for both domestic and foreign investments. Collaborative efforts between the government, private sector and local communities are necessary to create a transparent and efficient regulatory landscape. By addressing these key imperatives, the Indian mining industry can achieve sustainable growth, contribute significantly to the economy, and enhance its global competitiveness.

03 Sustainability

3.1 Global energy landscape transformation

The mining sector is at an inflection point as technological advances, environmental challenges and changing geopolitical factors reshape the industry. At the heart of this evolution is the shifting paradigm of power systems on mine sites. This discussion examines what is driving this transition from fossil fuels to more sustainable energy sources and its implications for the industry and global society.

Sustainability: A Key Change Maker in Mining Power Systems: In order to reduce its carbon footprint and support the move towards renewables, the industry faces pressure from climate change and environmental degradation. The mining sector is making strides in the adoption of renewable energy solutions, with solar and wind power leading to reductions in fossil fuel extraction. For instance, BHP has integrated renewable energy sources in its South Flank iron ore project in Australia to reduce greenhouse gas emissions. Moving towards sustainability not only reduces environmental impact but also improves long-term operational resilience and cost efficiency.

Technological innovation: Technological innovation is another catalyst driving the evolution of power systems in mining. Advances in automation, artificial intelligence and data analytics are bringing improved efficiency in the way mines are operated and managed. Power management systems like smart grids and energy management systems allow power consumption to be monitored and optimized in real-time, leading to increased efficiency and reliability. Electrification of mining equipment, including haul trucks and drills, is also reducing reliance on fossil fuels and driving down production costs. For example, Anglo American debuted a fleet of hydrogen fuel cell trucks at its Mogalakwena platinum mine in South Africa, a notable step towards decarbonizing its operations.

Geopolitical dynamics: The changing geopolitical landscape also influences the global power mix in mining. Rising geopolitical tensions can directly affect supply chains by leading to a drive by countries for ownership over critical mineral resources. This is evident as the United States moves towards self-sufficiency in the production of strategic minerals, signaling how trade blocs will emerge to stabilize supply chains.

Challenges and opportunities: The move towards sustainable power systems in mining creates opportunities for innovation and growth but is also accompanied by challenges. The initial cost of renewable energy applications can be substantial, especially for isolated or off-grid operations. Broader use still faces technical constraints and needs to be integrated into the grid. Moreover, the shift away from fossil fuels could potentially dislocate mining-based communities and economies. However, amidst these challenges, there are opportunities for cooperation and change. Public-private partnerships, technological cooperation, and policy incentives can accelerate the implementation of renewable energy, realizing sustainable mining regions. Adoption of cleaner energy sources can increase social license to operate and attract investment from environmentally conscious stakeholders.

3.2
Creating and sustaining an ecosystem for sustainable development framework

Mining is integral to global economic progress. Yet, it grapples with environmental, social and governance issues. Sustainable Development Frameworks (SDFs) aim to mitigate these challenges through responsible practices. This essay delves into establishing and nurturing an SDF ecosystem in mining, citing examples and references to underscore effective approaches.

Policy and regulation: Governments wield pivotal influence in fostering sustainable mining via robust policies and regulations. Notably, Canada exemplifies stringent environmental standards and community engagement mandates, ensuring adherence to elevated performance benchmarks.

Financial instruments and products: Various financial tools drive capital toward sustainable mining ventures. Green bonds, for instance, fund projects meeting eco-criteria like emissions reduction. Sustainability-linked loans incentivize companies to enhance environmental and social performance. Initiatives like the Responsible

Sustainable mining represents a transformative approach to the extraction and utilisation of natural resources. By aiming to utilise waste and maximise resource efficiency, these practices seek to minimise environmental impacts and foster a circular economy. Sustainable mining involves implementing advanced technologies and methodologies that reduce energy consumption, limit emissions, and ensure the safe and efficient management of waste materials. It also emphasises the rehabilitation of mining sites, restoration of ecosystems, and support to the local communities. Through the principles of zero waste, the industry can turn by-products and co-products into valuable resources, thereby reducing the burden on landfills and the environment. This holistic approach not only promotes environmental stewardship but also enhances the long-term viability of mining operations, ensuring that resources are available for future generations while protecting our planet.

Mr. Pankaj Satija,
Executive -in-charge
(FMD), Tata Steel Ltd.

Mining Index aid investors in making informed decisions by assessing companies' performance across diverse criteria.

Capacity building and knowledge sharing: Enhancing institutional capacity and sharing expertise are paramount for SDF promotion. Initiatives such as the World Bank's Extractives Global Programmatic Support bolster legal frameworks and governance. Platforms like the Mining, Minerals, and Sustainable Development (MMSD) project facilitate stakeholder dialogue and knowledge exchange.

Partnerships and collaboration: Collaboration among stakeholders is indispensable for fostering sustainable mining. Entities like the Initiative for Responsible Mining Assurance unite diverse actors to develop and certify responsible practices.

Developing and sustaining an SDF ecosystem in mining necessitates concerted efforts across governments, financial institutions, companies and the civil society. Through robust regulation, innovative finance mechanisms, capacity-building endeavors and collaborative ventures, the mining sector can progress towards sustainability, aligning with the Sustainable Development Goals (SDGs) and fostering enduring positive impacts for communities and ecosystems.

3.3 Star ratings and sustainable development goals

The Star Rating System: The Star Rating System, devised by the International Council on Mining and Metals (ICMM), comprehensively evaluates mining operations' performance across environmental, social and governance (ESG) criteria. Criteria encompass water management, biodiversity preservation, community involvement and human rights. By offering a standardized evaluation tool, the system enables mining firms to gauge their performance, pinpoint improvement areas and showcase their dedication to sustainable development. Notably, the coal mining sector is embracing this approach to recognize top performers and propel safer, more efficient practices.

Sustainable Development Goals (SDGs): The SDGs, comprising 17 global objectives established by the United Nations, address diverse social, economic and environmental challenges by 2030. They encompass poverty alleviation, gender parity, renewable energy adoption and climate action. Within mining, the SDGs provide a guiding framework, ensuring industry practices align with broader development aims and foster positive impacts for the society and the environment.

Intersection of Star Rating and SDGs in Mining: The Star Rating System and SDGs converge in their emphasis on sustainable mining development. Both frameworks prioritize environmental stewardship, social responsibility and inclusive economic advancement. By embedding SDGs into the Star Rating System's assessment criteria, mining entities ensure alignment with global development priorities and contribute to specific SDG targets.

For instance, a mining venture employing water recycling technologies to curb freshwater use and pollution not only advances in the Star Rating System's water management category but also contributes to SDG 6 (Clean Water and Sanitation). Similarly, initiatives fostering local employment, skill enhancement and community empowerment bolster SDG 8 (Decent Work and Economic Growth) while earning positive ratings in the Star Rating System's community engagement and social performance realms.

Case Studies and references: Numerous case studies underscore the practical application of both frameworks:

01 The Cerrejón coal mine in Colombia, through biodiversity conservation, community development, and water management strategies, has secured top ratings in the Star Rating System and aligned with multiple SDGs (ICMM, 2021).

02 The Responsible Mining Index evaluates mining companies against ESG criteria, including SDG adherence, offering insights and improvement opportunities (Responsible Mining Foundation, 2020).

03 The Mining, Minerals, and Sustainable Development (MMSD) project offers a holistic view of mining's impacts and furnishes recommendations for achieving sustainable development goals (International Institute for Environment and Development).

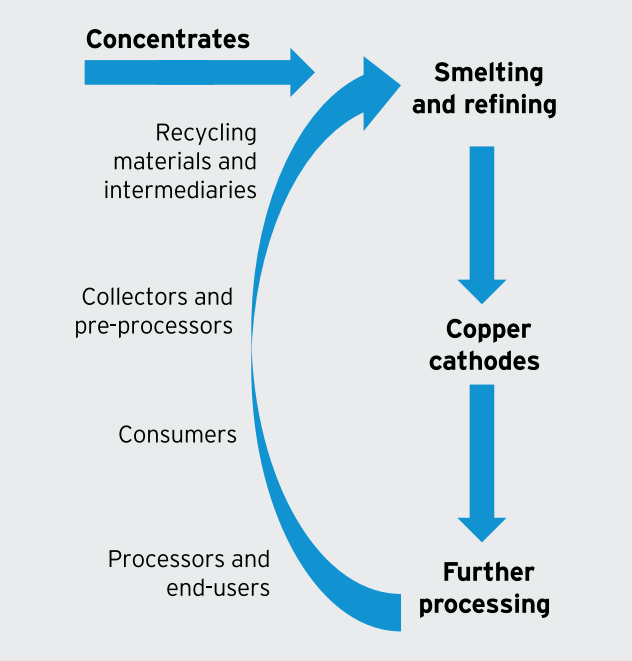
The Star Rating System and SDGs serve as formidable drivers for sustainability in mining. By integrating SDGs into assessment criteria, mining entities not only align with global development aims but also demonstrate commitment to responsible practices. Through collaborative efforts, transparency and continual enhancement, the mining sector can foster positive social, economic and environmental outcomes, paving the way for a sustainable future.

3.4 Improving awareness on sustainable mining

Sustainable mining practices are indispensable for harmonizing economic advancement with environmental preservation and social equity. Despite its significance, awareness regarding sustainable mining remains relatively deficient among stakeholders, spanning governments, industry entities, local communities and consumers. This report illustrates the imperative of augmenting awareness on sustainable mining and strategies to amplify comprehension and involvement in this pivotal domain. Transitioning from recycling to a circular business model presents a substantial opportunity to adopt innovative and sustainable practices in mining operations.

Moving beyond recycling to a circular business model is a significant opportunity to implement new sustainable business models

Miners can consider moving from a linear business model to a close material loop where materials are continuously regenerated, minimizing environmental impact and maximizing value



Circular business benefits for copper producers

01 Metal processing
Multifaceted approach of processing concentrates, scrap and recyclable materials ensures high purity metal production and value-added products

02 Diversification
Different revenue drivers will mitigate the impact of volatility. By prioritizing recycling business, companies can address, sustainability and profitability

03 Three key pillars
- Raw material
- Recycling material
- Product business

Source: EY analysis of publicly available sources

Enhancing stakeholder engagement: Effective communication and stakeholder engagement stand as linchpins in augmenting awareness of sustainable mining. Governments, mining enterprises, civil society organizations and local communities collectively mold the trajectory of the mining industry. Ergo, fostering platforms for dialogue, knowledge dissemination and collaboration among these stakeholders is imperative. Multi-stakeholder forums, community consultations and public hearings furnish avenues for substantive engagement and decision-making pertaining to mining projects.

Education and capacity building: Education and capacity building constitute indispensable facets of enhancing awareness regarding sustainable mining. By furnishing training and resources to mining professionals, government officials and community leaders, stakeholders can bolster their comprehension of sustainable mining practices and their ramifications. Educational initiatives, workshops and online courses can encompass themes such as environmental stewardship, social impact assessment and responsible mineral sourcing, empowering individuals and organizations to champion and enact sustainable mining solutions.

Transparency and reporting: Transparency and accountability represent foundational pillars for engendering trust and confidence in the mining industry. Mining enterprises ought to aspire towards transparency concerning their operations, impacts and performance, encompassing environmental and social metrics. This can be actualized through routine reporting, dissemination of data and participation in independent verification and certification frameworks. By evincing dedication to transparency and accountability, companies can cultivate credibility and engender trust with stakeholders, engendering heightened awareness and endorsement for sustainable mining practices.

Consumer awareness and demand: Consumers wield influence in propelling demand for sustainable mining practices. As consumer consciousness regarding the environmental and social repercussions of their purchases burgeons, including minerals and metals sourced from mining ventures, raising awareness among consumers concerning the significance of sustainable mining can sway their purchasing decisions and incentivize companies to

embrace more responsible sourcing practices. Certification schemes such as Fairmined and Fairtrade Gold facilitate consumers in identifying ethically sourced minerals and championing responsible mining initiatives.

3.5 Evolving technical development for optimizing resources and mineral waste

Advanced exploration and resource assessment: One of the key technical developments in the mining industry is the advancement of exploration and resource assessment technologies. Remote sensing, geophysical surveys and geological modelling techniques are being increasingly used to identify mineral deposits with greater accuracy and precision. These technologies enable mining companies to optimize exploration efforts, reduce exploration risks, and make more informed decisions about resource allocation. By accurately assessing resource potential, companies can maximize the efficiency of mining operations and minimize the need for unnecessary exploration activities, thereby reducing costs and environmental impacts.

Data analytics and predictive modelling: Data analytics and predictive modelling are revolutionizing how mining companies manage and optimize their operations. Through the use of sensors, Internet of Things (IoT) devices, and advanced data analytics software, companies can collect and analyze vast amounts of data in real-time to optimize processes, improve productivity, and reduce waste. For example, predictive maintenance algorithms can help identify potential equipment failures before they occur, allowing for proactive maintenance and minimizing downtime. Similarly, optimization algorithms can optimize production schedules, resource utilization, and energy consumption, leading to significant cost savings and environmental benefits.

Advanced processing technologies: Advancements in processing technologies are enabling mining companies to extract valuable minerals from low-grade ores and waste materials more efficiently. For example, sensor-based sorting technologies use advanced

> **A low-carbon future is going to be metal-intensive, and sustainable mining has a pivotal role in realizing a greener tomorrow. By adopting new-age technologies, innovative practices, and active collaboration across the sector, businesses can minimize their environmental footprint through responsible utilization of resources, minimizing waste, prioritizing reclamation, and empowering communities. The mining fraternity has started recognizing sustainability as the cornerstone of growth and has made it a core tenet empowering all business decisions. From decarbonization initiatives to integrating renewable power sources to reducing freshwater consumption, these are just some of the ways that mining companies can reduce their environmental footprint, thus ensuring we meet today's needs without compromising those of tomorrow. The metals & minerals revolution coupled with a green value chain is crucial to the global energy transition and transforming the planet.**
>
> Mr. Arun Mishra,
> CEO Hindustan Zinc Ltd
> & Executive Director
> Vedanta Ltd.

sensors and sorting algorithms to separate valuable minerals from gangue based on their physical properties. This allows companies to recover valuable minerals that would otherwise be discarded as waste, increasing resource recovery rates, and reducing the environmental footprint of mining operations. Additionally, advancements in hydrometallurgical and bioleaching processes are enabling the extraction of metals from complex ores and waste streams with lower energy and water consumption, further enhancing sustainability and resource efficiency.

3.6 Sustainable reporting and tracking

Importance of sustainable reporting: Sustainable reporting serves as a mechanism for mining companies to communicate their ESG performance to stakeholders, including investors, regulators, local communities, and civil society organizations. By disclosing information about their environmental impact, social initiatives, and governance practices, companies can build trust, enhance reputation, and attract investment. Moreover, sustainable reporting enables stakeholders to hold companies accountable for their actions, identify areas for improvement, and track progress towards sustainability goals.

Key frameworks and standards

Introduction

Several frameworks and standards have been developed to guide sustainable reporting and tracking in the mining industry. The Global Reporting Initiative (GRI) provides a comprehensive set of guidelines for reporting on economic, environmental, and social performance. The International Council on Mining and Metals (ICMM) has developed the Sustainable Development Framework, which outlines principles and commitments for responsible mining practices, including transparency and accountability.

Best practices in sustainable reporting

Effective sustainable reporting goes beyond mere compliance with reporting standards; it requires companies to adopt best practices that enhance the credibility and usefulness of their reports. These practices include:

- **Materiality assessment:** Helps companies identify and prioritize the most relevant ESG issues for their business and stakeholders.
- **Stakeholder engagement:** Ensures that reporting reflects the interests and concerns of all relevant stakeholders, fostering transparency and trust.
- **Data verification:** Independent third-party verification enhances the reliability and credibility of reported information.
- **Integration of sustainability into corporate strategy:** Embedding ESG considerations into decision-making processes ensures that sustainability is central to corporate strategy.

04 ESG

4.1 Net zero emission targets and promotion of ESG initiatives

Transforming India to a net zero emission energy system

Energy is at the heart of economic development, and perhaps no country is more challenged by that association than India, as it strives to create a better life for its population of almost 1.4 billion people. It is an opportune time for India to re-evaluate its energy strategy and examine the choices, opportunities, and risks across the energy sector. Energy efficiency, electrification, and a switch towards decarbonized fuels are the three main pillars of India's energy strategy, with the need for a transformative move towards renewable electricity, hydrogen, and bioenergy as key fuels.

Today, the government of India is focusing on maintaining strong growth to achieve its aim of being a $5 trillion economy by 2025 and addressing the continuing inequality gap across the country. Its goals include:

Increasing the manufacturing share of **GDP to 25% by 2025**

Providing **housing for all by 2022**

Doubling the **income of farmers by 2024**

Making substantial progress on **universal access to healthcare by 2030**

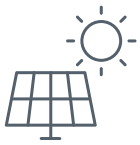
Historical evidence – combined with future possibilities for improvements in structural and end-use energy efficiency and with detailed studies from developing economies – suggest that about 100 gigajoules (GJ) per capita per year of primary energy is needed for people to experience a decent, modern quality of life. Consumption in India in 2019 was 25 GJ per person.

As has been the case for all countries, fossil fuels have enabled the energy demand required for industrialization and in turn contributed to rising carbon dioxide (CO_2) emissions. India's per capita CO_2 emissions – at 1.8 tons per person in 2015 – was around a ninth of those in the USA and around a third of the global average of 4.8 tons per person. However, overall, India is now the planet's third-largest emitter of CO_2, behind China and the USA. Some costs of the country's dynamic growth are increasingly visible, namely major congestion in urban centres and declining air quality.

Key actionable insights

- Re-evaluate energy strategy to align with economic growth and sustainability goals.
- Focus on energy efficiency, electrification, and the adoption of decarbonized fuels.
- Prioritize renewable electricity, hydrogen, and bioenergy in the energy mix.
- Aim for 100 GJ per capita per year of primary energy to ensure a decent, modern quality of life.
- Address the challenges of urban congestion and air quality to mitigate the environmental impact of growth.
- Increase transparency and accountability in tracking progress towards net zero emissions.

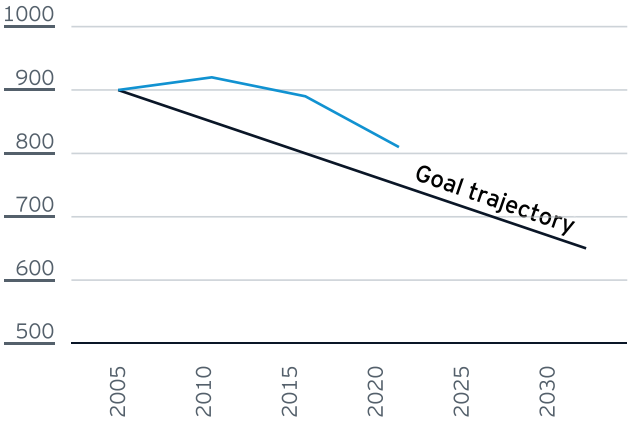
India is making significant strides in delivering on its Paris Agreement commitments. One of the key targets is to reduce carbon emissions intensity of GDP by 33-35% by 2030 from 2005 levels. Additional commitments include:



Achieving **40% cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030**

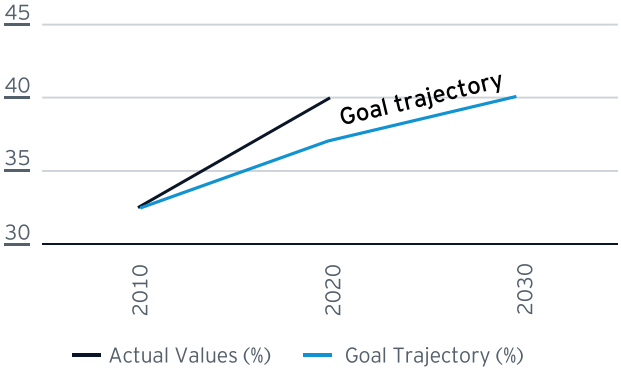
Creating an **additional carbon sink of 2.5-3 billion tons CO_2** through forest and tree cover by 2030

Fuel combustion CO2 per GDP, grammes CO2 per $ (Constant US 2010)



Source: TERI and Sheel analysis based on historical IEA data and World bank data

Percent non-fossil fuel-based generation capacity

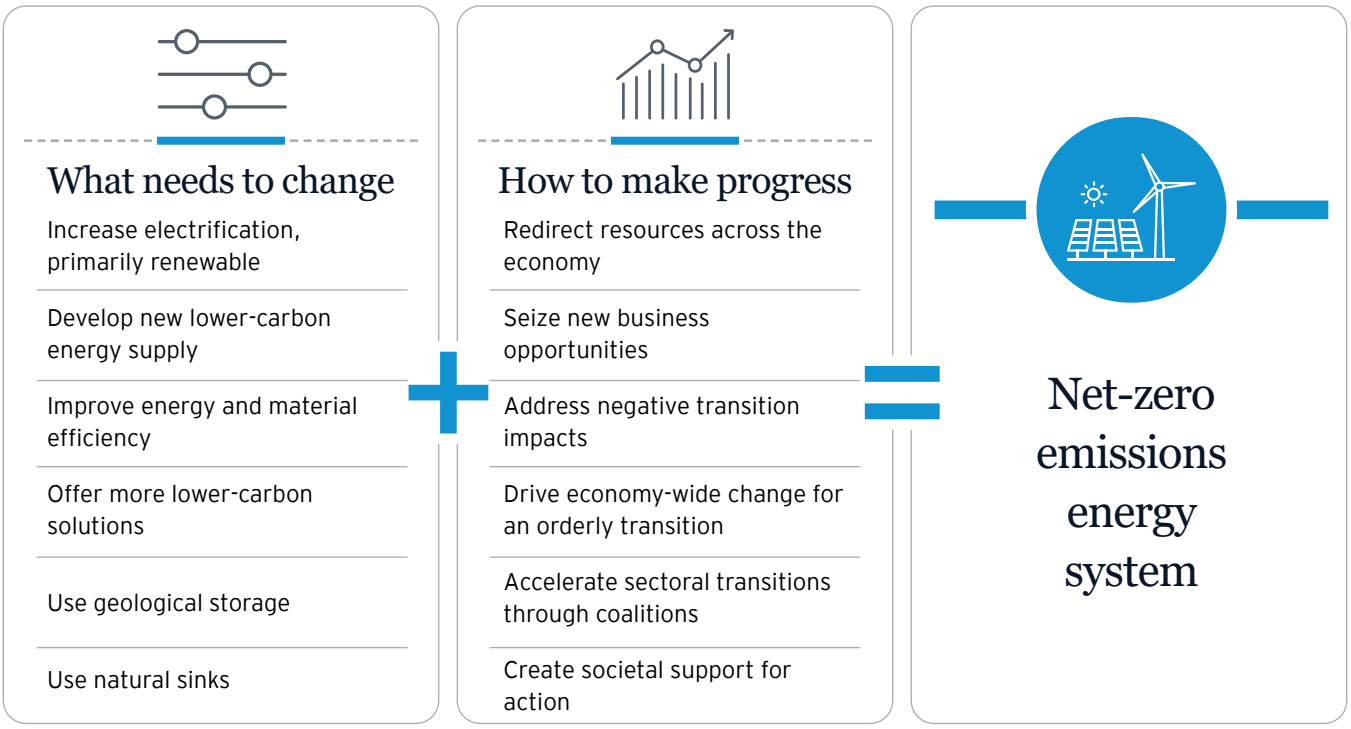


Source: TERI and Sheel analysis based on historical IEA data and World bank data

Note: Non-Fossil generation includes variable renewable, hydro, nuclear, and biomass

Forest sequestration, Gt CO2 per year

Source: Forest Service of India



Source: India_Transforming_to_a_net-zero_emissions_energy_system.pdf (teriin.org)

ESG initiatives in mining sector

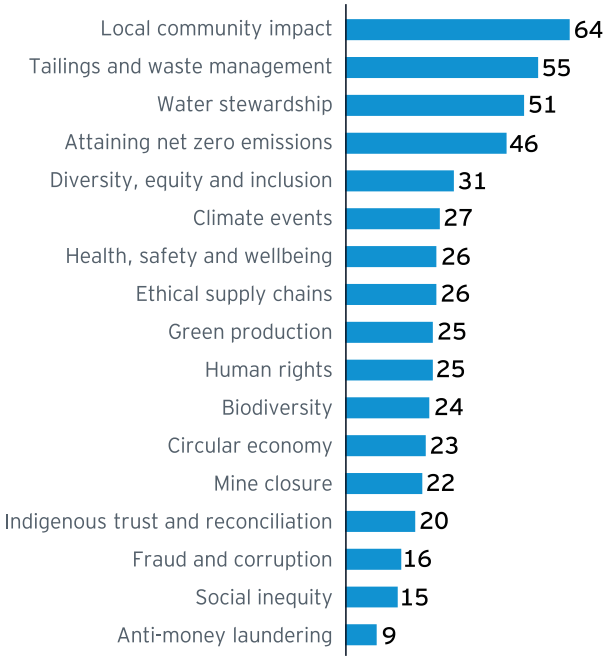
ESG considerations are gaining prominence in the mining sector, aligning with Sustainable Development Goals (SDGs) and fostering socio-economic benefits. The Union Ministry has mandated a 30-40% reduction in carbon footprint by 2030 through sustainable initiatives. Opportunities for emissions reduction include decarbonizing electric supply, implementing smart microgrids, and electrifying equipment. Tata Steel in India is exploring cleaner fuel adoption, like hydrogen, to reduce emissions by 30-40%. Additionally, companies in the mining sector are increasingly prioritizing suppliers with high ESG ratings and decarbonization targets.

Moving beyond net zero: a holistic approach

Miners are urged to move beyond net zero and embrace a holistic approach to ESG. Differentiation will favor companies that are net positive on ESG, emphasizing the need for comprehensive strategies to gain investor confidence and community acceptance. Achieving sustainability goals requires a concerted effort across environmental, social, and governance aspects, positioning companies for long-term success in a rapidly evolving landscape.

ESG factors are facing increased scrutiny, and miners need to go beyond compliance to gain investor confidence and community acceptance

Q Which are the top ESG issues (in %) that the M&M sector will face the most scrutiny from investors in 2024?



Source: EY Knowledge analysis of data from the business risks and opportunities paper

Miners need to manage waste across the value chain, integrate recycling, and improve collaboration and transparency with customers

Miners need more innovative solutions to monitor and manage tailings, and also to extract value from waste

Determining the baseline for net positive measurement is key to meeting the high and growing level of reporting requirements and stakeholder expectations

Scenario planning can help miners prioritize, identify potential trade-offs and create real, long-term positive impact

Decarbonization journey in steelmaking

The steelmaking sector plays a critical role in supporting net-zero targets but faces its own decarbonization challenges. Various decarbonization technologies, ranging from commercial deployment to decades away, offer different greenhouse gas reduction potentials. From biofuel usage to green hydrogen direct reduced iron (DRI) production, each technology presents opportunities for reducing emissions and advancing sustainability goals.

Decarbonization technology	Status	GHG reduction potential
BF/BOF with biofuel	Commercial	20-50%
Natural gas DRI	Commercial	40%
Smelting reduction	Commercial	4-20%
Scrap-EAF	Commercial	80%
Iron electrolysis	20-30 years	~90%
Green hydrogen DRI	10-20 years	80-95%
Smelting reduction with CCUS	5-10 years	Up to 85%
BF/BOF with top gas recycling	5-10 years	Up to 30%
Blue hydrogen DRI	10-20 years	TBD
BF/BOF with hydrogen	~10 years	TBD

Source: Balancing economic feasibility with environmental responsibility - Key trends in metallurgical coal, October 24, 2023

EU battery regulation and ESG implications

The revised EU battery regulation aims to enhance accountability and transparency across the battery value chain. It introduces stringent due diligence requirements for battery manufacturers, promoting ESG efforts by eliminating unethical mining practices and reducing severe environmental impacts. Non-compliant companies risk exclusion from the European battery market, highlighting the importance of ESG compliance in the sector.

4.2
Application of circular economy in mining

Circular economy in mining aims to minimize waste and optimize resource use. Globally, the sector contributes to a significant portion of greenhouse gas emissions, estimated at 20-30%. In India, the mining industry is a crucial economic contributor, but it also faces environmental challenges. By 2030, India targets a 30-40% reduction in its mining-related carbon footprint- through sustainable initiatives.

More miners are implementing circular economy design into the metals and mining value chain with closed material loops

Transformation

Value chain	Action	Benefit	Market examples
Extraction	Remove inefficiencies, re-use resources (e.g., water) and design waste out of processes	▸ Improved resource efficiency, and better waste management	AngloAmerican Reduce water consumption by 50% against 2015 and increase water recycling by 75% by 2030
Processing	Reprocess wastes, tailings and scrap	▸ Create by-products and keep materials and products in use	Teck Jetti Resources is providing heap leach technology at Teck mines to recover remaining copper in the ore
Logistics	Data analytics to optimize freight	▸ Reduce costs ▸ Remove carbon emissions ▸ Sainsbury's is switching from using plastic to creating its signature coffee pods out of aluminium, which is infinitely recyclable	RioTinto BHP Consortium to decarbonize iron ore shipping
Manufacturing	Collaborate with customers to develop new products that can be re-used in the future	▸ Reduce costs ▸ Minimize waste ▸ Improved resource efficiency	KGHM KGHM cuts carbon-intensity via strategic partnerships in copper, silver, and other metal operations
Consumer use	Data and technology to enable transparency of source of materials	▸ Increased investment ▸ Greater accountability ▸ Reduction in illegal practices	CMOC GLENCORE RelSource to trace responsible cobalt from the mine to the electric car

Rising environmental concerns and mineral recycling policies are driving the promotion of a circular economy in the steel sector.

Steel recycling policies

- National Automobile Scrappage Policy in India
- The Chinese government continues to offer a 30% tax rebate to recyclers

Government funding

- The UK government funds Tata Steel and British Steel (~US$323m each) to decarbonize and use local steel scrap
- Spain provides US$500m to decarbonize a steel plant
- South Korea proposes ~US$115.9m to support low-carbon steel production

Alliances

- Tata Steel signed an MoU with the Punjab state government to establish a steel plant with a scrap-based electric arc furnace (EAF)

4.3
Case study in CSR and community engagement in mining sector

The latest approach to Corporate Social Responsibility (CSR) emphasizes novel stakeholder-driven models that incorporate community engagement, leading to socially relevant and inclusive community development. Corporate-community engagement strategies are evolving in response to a new regulatory landscape, increasing stakeholder demands, heightened community knowledge and awareness, and innovative communication methods.

Changing CSR landscape in India's mining sector

Legislation regarding the role of business in societal development varies globally. India uniquely mandates CSR, requiring certain companies to allocate 2% of their net profit (average of the current year and preceding two years) towards CSR projects addressing poverty eradication, employment, decent work, social inclusion, quality education, basic healthcare, safe drinking water, sanitation, and more. Since mandatory CSR was implemented in 2014, top 500 companies in India have spent over INR500 billion on CSR by March 2019.

Six mining companies listed on the Bombay Stock Exchange (BSE) have a combined market capitalization of about 3.45%. These companies rank eighth out of 19 top BSE-listed companies in terms of CSR spending, often exceeding the mandatory 2% contribution.

While CSR investments in India have increased since 2014, companies are exploring new directions beyond conventional CSR practices.

- **Corporate Community Engagement**
- **Corporate community engagement has** been a topic of extensive debate among practitioners and researchers. Increasing concerns over the uneven distribution of benefits between businesses and communities have led to greater business participation in community development through CSR initiatives.
- **Community development requires a holistic approach** involving various stakeholders such as government institutions, traditional institutions, opinion leaders, philanthropists, associations, and religious groups, all of which play significant roles in community development.
- **Continuous engagement with diverse stakeholders** is crucial for businesses to create a robust and socially relevant CSR agenda.
- **CSR initiatives that drive social change** often include health programs, skills training, employment initiatives, business development, and community development.
- **Sustainable Livelihood Development:** Case Study

Project overview: The project was implemented in Muriadih coal mines in Jharkhand, India, with the collaboration of TERI School of Advanced Studies, Bharat Coking Coal Ltd, Dhanbad, and Central Mine Development Research Institute, Ranchi. The goal was to develop social entrepreneurial and vocational skills among community members, focusing on women and other marginalized groups, thereby empowering them through economic opportunities.

Project phases: The project spanned five phases over three years, following these steps:

1. **Need and resource assessment:** Evaluating the needs and resources of the community.
2. **Stakeholder consultation:** Engaging with stakeholders to gather insights and support.
3. **Training program implementation:** Rolling out training programs to develop necessary skills.
4. **Market and financial linkage discovery:** Identifying market opportunities and financial linkages to support sustainable livelihoods.

The successful implementation of a sustainable livelihood-based CSR project involves several critical success factors, key learnings, and the roles of various stakeholders. Here are the insights gained from the project:

01 **Stakeholder involvement:** Businesses must engage local stakeholders, including NGOs and opinion makers, for successful project implementation. Local media played a vital role in creating publicity for training programs and mobilizing local communities.

02 **Community mobilization:** Support from local opinion leaders across different classes is crucial for mobilizing communities. Opinion makers can convince people to participate in training programs and offer support for entrepreneurship development. For instance, a past village headwoman's continuous engagement significantly boosted local support.

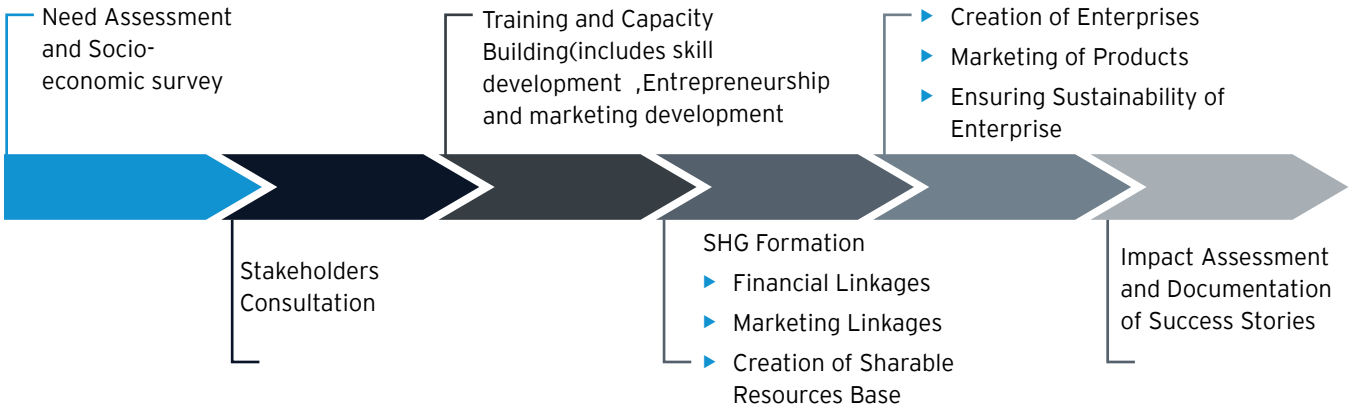
03 **Business-community interaction:** Initially, local communities may not respond directly to businesses due to differing objectives. Businesses should support from the background and let local agencies lead in the initial phases to build trust. As the project progresses, business reputation improves.

04 **Social cohesiveness:** Mobilizing communities at the local level often requires overcoming barriers related to caste, gender, and religion. Ensuring project benefits reach all community classes is essential. Greater social cohesiveness can lead to better outcomes in skill development and entrepreneurship.

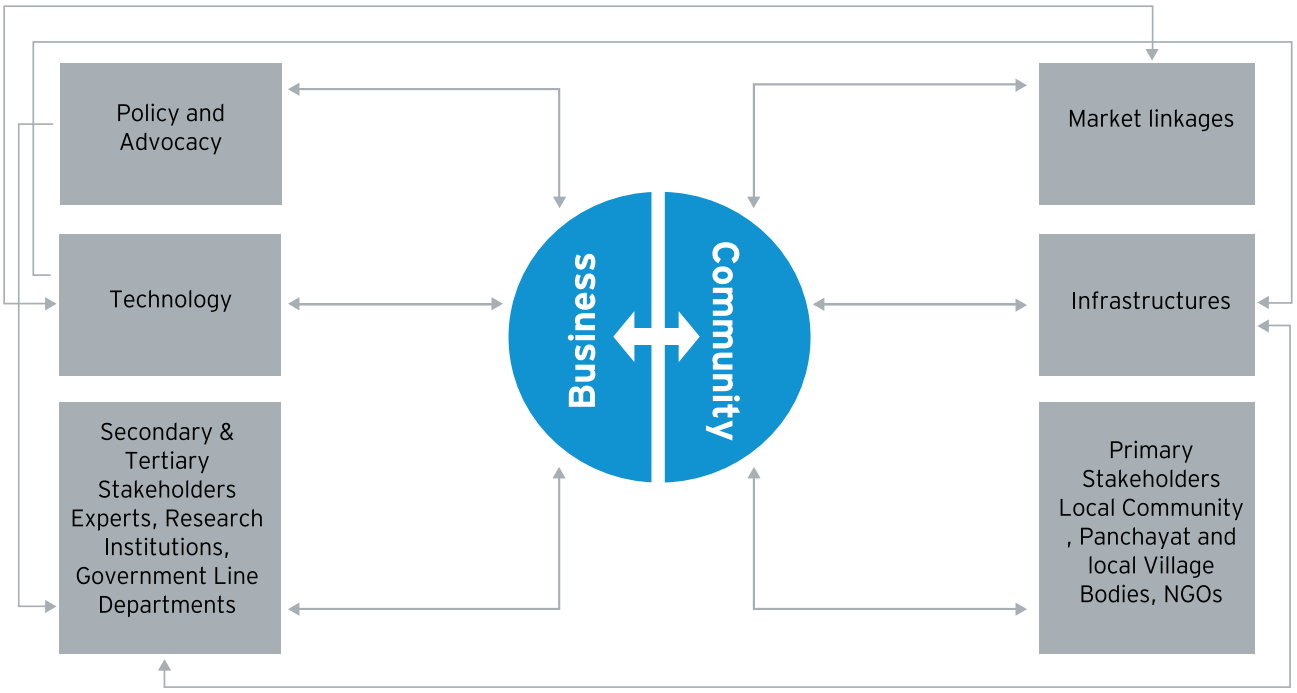
05 **Group financing:** Forming Self-Help Groups (SHGs) is crucial for creating financial opportunities for trained individuals. Local agencies play an important role in building SHGs, which provide microfinance support, enabling trained individuals to undertake risks and secure loans for their enterprises.

06 **Sustainability:** The sustainability of enterprises is crucial for long-term success. If the products have market potential and are supported by local resources, the enterprises are more likely to be sustainable, maintaining community interest even after project completion.

07 **Hand-holding:** Local communities often lack awareness of government schemes and available infrastructure. Projects must provide support in discovering market and financial linkages, helping communities navigate these resources effectively.



Source: Sci-Hub | | 10.1002/bsd2.64 (et-fine.com)



Source: Sci-Hub | | 10.1002/bsd2.64 (et-fine.com)

Through well-designed and implemented CSR initiatives, mining companies can enhance community skills and support sustainable livelihoods. The focus should not only be on skill enhancement but also on ensuring the sustainability of these skills. The design and implementation of the project should consider the resources available and the community's needs.

Various stakeholders play significant roles at different project stages, including identifying needs, building trust, and executing the project smoothly. Based on project implementation, a proposed framework for the business-community interface in community development projects emphasizes:

- **Policy:** Supportive policies are essential for enabling long-term success.
- **Technology:** Advanced technologies can enhance project efficiency and impact.
- **Infrastructure:** Adequate infrastructure supports the sustainability of community enterprises.
- **Markets:** Access to lucrative markets ensures the economic viability of the projects.

4.4

Reclamation, Rehabilitation, ECO restoration of mined out areas, mine closure, waste management, and eco-tourism on mines reclaimed land

Mine reclamation restores mined-out areas to a safe, environmentally sustainable, and suitable state for future land use. It mitigates negative mining impacts on ecosystems and communities through measures like minimizing erosion, restoring vegetation, rehabilitating water bodies, and addressing contamination. Community engagement, including indigenous peoples, ensures long-term sustainability and compatibility with local needs.

Key points on mine reclamation in India

Regulatory framework: India has a regulatory framework for mine reclamation, including environmental impact assessments, mine closure plans, and reclamation activities. Stakeholders monitor compliance, and perceptions of enforcement influence views on reclamation practices.

Community engagement: Mining impacts local communities, especially in tribal and rural areas. Effective community engagement through consultations, information sharing, and incorporating traditional knowledge builds trust and positive perceptions.

Environmental impacts: Mining activities cause land degradation, deforestation, soil erosion, and water pollution. Effective reclamation practices like revegetation, soil stabilization, and water treatment improve perceptions by showing a commitment to minimizing environmental harm.

Social and economic benefits: Reclaimed mine sites can be repurposed for agriculture, forestry, renewable energy, or other sustainable uses. Ensuring local communities benefit from these opportunities and sharing economic benefits contributes to positive perceptions.

Transparency and accountability: Transparent reporting on reclamation progress, monitoring data, and environmental outcomes builds trust. Accessible information for stakeholders demonstrates commitment to responsible mining practices and effective reclamation efforts.

Traditional knowledge and cultural heritage: Mining often impacts areas with rich cultural heritage and traditional knowledge. Incorporating traditional knowledge and respecting cultural sensitivities can positively influence perceptions. Engaging indigenous communities and integrating their perspectives into reclamation plans helps preserve cultural heritage.

> **ESG (Environmental, Social, and Governance): "At Adani Cement, we firmly believe that effective ESG initiatives must align seamlessly with national priorities. To this end, we have made a decisive commitment to invest in green transition. Our products are green with more than 85% blended cement. Building a sustainable future requires the cement industry to transform itself. We can no longer be satisfied with incremental changes. By aggressively pursuing ESG goals, we can turn cement from a climate challenge into a climate solution by reducing our carbon footprint, promoting social well-being, and maintaining strong governance. Our success lies not only in financial gains but also in leaving a positive legacy for generations to come."**
>
> Mr. Ajay Kapur,
> CEO – Cement Business,
> Adani Group

Effective reclamation strategies- early planning and site-specific approaches: Essential for successful reclamation. Ecosystem-Based Restoration: Recontouring land to match original topography, stabilizing soil through amendments and erosion control, and using native plant species foster successful vegetation establishment and biodiversity recovery. Water Management: Techniques like constructed wetlands and sedimentation ponds preserve water quality and aquatic habitats.

4.5
Skill development to sustain growth and improve mines safety

Increasing skilled manpower in mining significantly enhances safety and efficiency. Collaboration across stakeholders, led by the government, is essential to prepare the workforce for future mining needs. This requires action on three levels:

Policy level interventions

- **Integration of stakeholders:** Develop a policy framework to integrate science labs, universities, government agencies, and industry partnerships, promoting advanced R&D for innovation.
- **Aligned policies:** Align technology, research, and innovation with an integrated policy to identify high-impact areas.
- **Establishment of a nodal agency**
- **Technological and skill development:** Address technological upgrades, product innovation, skill development, and productivity through a comprehensive policy framework, considering mining's potential for high employment generation, particularly in remote areas.
- **Adapting to modernization:** With increased mechanization and digital technologies, focus on:
  - **Core skills training:** Ensure training programs deliver core skills for new technological opportunities.
  - **Re-skilling programs:** Educate the existing workforce on new tasks to avoid redundancy and ensure productivity.
  - **Dynamic learning initiatives:** Incorporate continuous learning to keep pace with technological progress.

Miners can retain workers through reskilling and development programs as well as retention incentives

Mining industry faces a significant talent shortage, primarily due to the younger workforce's growing awareness of climate change and the increasing resistance against fossil fuels

Reskilling and upskilling

Reskilling programs will enable workers gain new skills and help them gain confidence to diversify towards other industries.

Financial Incentives

Coal miners can provide financial incentives to retain qualified candidates

Whitehaven Coal introduced quarterly retention bonuses in FY22 to address labour shortages. The company is also likely to spend up to A$17m on employee housing in the NSW Gunnedah basin to secure skilled labour.

ESG considerations

Improving worker health, safety and community welfare can improve social license to operate for miners

Moreover, coal miners could proactively demonstrate their commitment by having a firm portfolio strategy that aligns with long-term climate goals.

Source: EY Knowledge analysis of publicly available sources

Skill development and enhancement programs

- **Training for next-generation machines:** Focus on operation and maintenance of machines with advanced electronics, sensors, and digital capabilities.
- **Attracting talent:** Mining must attract young talent by offering career growth and a sense of purpose. Engage with young talent early to establish a positive image of mining as a career opportunity.
- **Collaboration with training institutions:** Work closely with training institutions to upgrade curriculums. Evaluate dual-education initiatives like those in Germany to revitalize ITI and trade skill institutions, fostering practical skill development and stronger industry ties.
- **Digital and decarbonization talent:** Adapt workforce requirements to digitization and decarbonization trends. Mining companies need to update their methods of finding and retaining digital talent, focusing on diversity by tapping into talent pools such as women and locals.

Developing a robust human capital strategy will attract and retain talent in the mining industry

Mining industry faces a significant talent shortage, primarily due to the younger workforce's growing awareness of climate change and the increasing resistance against fossil fuels

Strategies to address the talent gap

- Embracing training in cross-functional competencies, including digital management, circular economy, and data analysis, offers opportunities for upskilling and re-skilling
- Cross-industry collaboration is imperative to bridge the talent gap. For instance, Copper For Tomorrow CRC's industry-led collaborations between industry, researcher organisations and the community aims to address the challenges across the copper value chain, including talent
- Partnership with educational and industrial institutions to create specialized programs and offering internships, apprenticeships, and specialized training to attract and develop young talent
- Implement diversity and inclusion initiatives to attract a broader range of talent, including women and underrepresented groups.
- AI or virtual reality simulations could help fill training gaps, offer real-time opportunities to improve skills and, potentially reduce its dependence on manual labor, through automation

Mining and processing

- Processing copper ore into usable metal requires ore characterization, chemical, and metallurgical expertise
- Expertise in geology, regulatory and technical expertise are needed to obtain regulatory permits

Innovation and research

- Expertise to explore new materials and production methods to reduce copper usage in energy transition applications

Engineering and design

- Engineering expertise to design and construct renewable energy infrastructure
- Chemical engineers are needed for new technologies to extract ore from lower grades and process efficiency innovation

Supply chain management

- Expertise in responsible sourcing of copper
- Technological skills for ethical copper verification and tracking

Source: Key Trends copper: April 2024; page number 32

Enhancing local workforce

- **Super localization:** Develop skills within local communities, reducing attrition and building stronger community relationships. Proactively recruit talent from mine localities and support local education and supply chains.

Increasing diversity

- **Inclusion of women:** Improve female representation in the mining workforce, from entry-level to executive roles. Mining companies should proactively address gender diversity to tap into a broader talent pool.

05 Digitization & Automation

5.1 Digitization- a critical enabler of productivity and better asset utilization

Digitization is rapidly transforming the mining industry, emerging as a critical enabler of productivity and better asset utilization. By integrating digital technologies into mining operations, companies can significantly enhance their efficiency, safety and overall performance. This digital shift encompasses a wide range of technologies, including advanced data analytics, Internet of Things (IoT), artificial intelligence (AI) and machine learning (ML), which collectively enable more informed decision-making and optimized resource management.

One of the primary benefits of digitization is the ability to gather and analyze vast amounts of data in real-time. Sensors and IoT devices installed on mining equipment and infrastructure collect continuous data on various parameters such as equipment performance, environmental conditions, and operational processes. This data is then processed using advanced analytics and AI algorithms to provide actionable insights. For instance, predictive maintenance powered by AI can foresee equipment failures before they occur, reducing downtime and maintenance costs. This proactive approach ensures that machinery operates at peak efficiency, thereby improving overall productivity and extending the lifespan of assets. Rising inflationary pressures have accelerated the adoption of such technologies, as they help mitigate the impact of increasing costs of goods and services by enhancing efficiency and reducing operational expenses.

Digital technologies facilitate better asset utilization through enhanced monitoring and control systems. Real-time tracking of assets allows for more efficient allocation and deployment of resources. For example, automated fleet management systems optimize the movement and scheduling of vehicles and machinery, reducing idle time and fuel consumption. This not only boosts productivity but also contributes to significant cost savings. Additionally, digital twin technology, which creates a virtual replica of physical assets, enables operators to simulate and test different scenarios, optimizing performance and identifying potential issues without risking real-world operations. Despite their benefits, digital twins are still underutilized due to a lack of awareness of their capabilities and the upfront cost of on-site sensor implementation.

Digital tools also play a crucial role in enhancing safety and compliance within the mining sector. Technologies such as IoT sensors, drones, and AI can monitor working conditions in real-time, identify potential dangers, and ensure safety regulations are followed. These tools help in reducing accidents and improving the overall safety of mining operations. Furthermore, digital solutions can track and manage environmental impacts, support sustainable practices, and improve transparency and reporting for

ESG (Environmental, Social, and Governance) initiatives. This alignment with ESG goals is increasingly critical as stakeholders demand more responsible and transparent business practices.

In addition to improving operational efficiency and safety, digitization supports strategic alignment and flexibility. Organizations should adopt a tech-agnostic approach, selecting the best tools and solutions to meet their specific needs without being tied to a single provider. This flexibility allows for the integration of various technologies and ensures that digital initiatives are aligned with the overall goals of the organization. Additionally, the pace of digital transformation drives the need for greater cybersecurity measures. Handling and sharing more complex data increases the risk of cyber attacks, making it essential to implement strong cybersecurity protocols such as advanced encryption, multi-factor authentication, and continuous monitoring to protect sensitive information.

Finally, breaking down organizational silos and fostering a culture of collaboration are essential for the successful adoption of digital technologies. Empowering cross-functional teams to lead digital projects helps gain support across the organization and facilitates the seamless integration of new technologies. As AI and other advanced technologies become more prevalent, they can enhance data management capabilities, but they also highlight the importance of maintaining high-quality data. Ensuring data accuracy and integrity is fundamental to leveraging AI effectively and achieving desired outcomes.

5.2
Digitization interventions across the mining value chain

Digitization is revolutionizing every stage of the mining value chain, from exploration to processing and logistics. By leveraging digital tools and technologies, mining companies can enhance operational efficiency, reduce costs, and improve safety across their entire operations. Here, we examine how digitization is impacting key phases of the mining value chain:

Exploration and resource evaluation: Digitization begins with the exploration phase, where advanced technologies such as remote sensing, geographic information systems (GIS), and machine learning algorithms are used to identify and evaluate mineral deposits. However, traditional methods face challenges such as manual data uploads, limitations in field data capture, and the cumbersome management of large amounts of geospatial data. Data is often collected or purchased multiple times, leading to inefficiencies.

To address these challenges, mining companies can leverage advanced sensing technologies and analytics to characterize mineralogy,

geochemistry, rock hardness, and other properties. Online geospatial data services and a "one-stop-shop" for nationally consistent data can streamline the process. Additionally, cloud-computing infrastructure can host data and applications, providing authoritative data to support informed decision-making and enabling problem-solving applications that are built once and used multiple times.

Mine planning and design: Mine planning and design benefit significantly from digitization yet face typical challenges such as the lack of integration between planning tools like SURPAC and Minex, siloed AutoCAD systems, and delays in information coordination.

Potential interventions include implementing integrated systems for planning and scheduling, ensuring a single version of truth, and utilizing effective short-term mine planning tools. By integrating new measurements, communication, and technologies, mining companies can create more accurate and efficient mine plans.

Extraction and production: The extraction phase benefits significantly from automation and real-time monitoring technologies. However, mine operations face several challenges:

- Lack of visibility into contractor performances, deviations, and root cause analysis (RCA)
- Manual communication of plans and schedules to contractors
- Low understanding of process complexity impacts on KPIs and deviations
- Decentralized and reactive decision-making and execution
- Absence of optimization in the removal-haulage cycle
- Lack of real-time fleet monitoring
- Manual tracking of lead for overburden (OB) and coal with Excel-based analysis of related KPIs
- Limited visibility into the planning, construction, and maintenance of catchment areas, sumps, culverts, and water garlands
- Limited visibility into overall equipment effectiveness (OEE) and operational performance of movable assets
- Absence of datasets and benchmarks and lack of standard operating procedures (SOPs) for compliance with such benchmarks
- Lack of analytical capabilities to make data-driven decisions on productivity and asset utilization

To address these challenges, mining companies can implement the following interventions:

- **Drone-based aerial inspection:** Utilizing drones for aerial inspections can provide real-time, high-resolution data on mine conditions and operations, enhancing situational awareness and safety.
- **Real-time geolocation of moving assets:** Tracking the real-time location of heavy equipment and vehicles ensures efficient utilization and coordination, reducing idle times and enhancing productivity.
- **Real-time haulage cycle optimization:** Using optimization algorithms for haulage cycles based on real-time data can significantly improve the efficiency of material transportation.
- **Actionable insights through visualization and predictive analytics:** Role-based dashboards offering real-time data visualization, optimization, and predictive analytics can provide actionable insights for decision-makers.
- **Digital Twin technology:** Creating digital twins of physical assets allows for real-time simulation and analysis, helping in predictive maintenance and operational optimization.

Processing and refining: In the processing stage, digital technologies streamline operations and improve efficiency. Advanced process control systems use real-time data to optimize crushing, grinding, and separation processes, ensuring maximum recovery of valuable minerals. Machine learning models analyze historical and real-time data to predict and adjust processing parameters, enhancing throughput and reducing energy consumption. Additionally, digital twins of processing plants allow operators to simulate different processing scenarios, identify bottlenecks, and implement improvements without disrupting actual operations. This results in higher efficiency, lower costs, and improved product quality.

Transportation and logistics: Efficient transportation and logistics are critical to the success of mining operations. Digital tools such as fleet management systems, GPS tracking, and automated dispatch systems optimize the movement of materials from the mine to processing plants and ports. These systems ensure that vehicles and equipment are used efficiently, reducing fuel consumption and operational costs. Real-time tracking and data analytics improve supply chain visibility, enabling companies to respond quickly to disruptions and optimize inventory levels. Additionally, blockchain technology can be used to enhance transparency and traceability in the supply chain, ensuring that minerals are sourced and transported responsibly.

Environmental monitoring and compliance: Digitization plays a crucial role in monitoring and managing the environmental impact of mining activities. IoT sensors and remote monitoring systems continuously track environmental parameters such as air and water quality, noise levels, and land disturbance. This data is used to ensure compliance with environmental regulations and to implement measures to mitigate negative impacts. Advanced data analytics and AI models help predict potential environmental risks and develop proactive strategies for sustainable mining practices. Digital reporting tools enhance transparency and facilitate communication with stakeholders, demonstrating the company's commitment to environmental stewardship and ESG initiatives.

Health and safety: Safety is paramount in the mining industry, and digital technologies significantly enhance worker safety. Wearable devices equipped with sensors monitor vital signs and environmental conditions, alerting workers and supervisors to potential hazards. Real-time location tracking ensures that workers can be quickly located and assisted in case of an emergency. Virtual reality (VR) and augmented reality (AR) training programs provide immersive safety training experiences, helping workers understand and respond to dangerous situations effectively. By leveraging these digital tools, mining companies can create safer working environments and reduce the incidence of accidents and injuries.

5.4
Automated technological solutions for sustainable capacity expansion

The pursuit of sustainable capacity expansion in mining necessitates a paradigm shift towards innovative technological solutions. From mobile crushing plants to cutting-edge material transport systems, automation plays a pivotal role in enhancing operational efficiency while minimizing environmental impact. In this section, we explore a range of automated technological solutions poised to revolutionize the mining industry's approach to sustainable growth and expansion.

1. **Mobile crushing plants:** Mobile crushing plants offer a transformative solution for mine operations by facilitating on-site material processing immediately after blasting. This strategic shift reduces reliance on truck haulage by replacing it with efficient belt conveyors, thereby minimizing fuel consumption and operational costs associated with maintaining a large fleet of trucks. Beyond economic benefits, the adoption of mobile or semi-mobile crushing plants significantly mitigates noise and air pollution, aligning mining operations with environmental regulations and enhancing social acceptance, especially in proximity to residential areas.

2. **Advanced surface mining equipment innovations:** Modern surface mining equipment advancements revolutionize operational efficiency through versatile machinery capable of simultaneous cutting across multiple benches. These machines, spanning up to 20 meters in height, streamline material handling processes by efficiently discharging material onto the ground, loading it onto dumpers, or feeding it onto conveyors. Operating on electric power ensures resilience to adverse weather conditions, enabling uninterrupted operations regardless of rain, fog, or nighttime. By minimizing reliance on trucks and optimizing operational efficiency, these innovations elevate productivity while reducing environmental impact.

3. **Cutting-edge material transport solutions:** Long-distance belt conveyors, including trough and pipe conveyors, represent a paradigm shift in material transportation efficiency across varied terrains. These conveyors offer seamless horizontal and vertical curve navigation, minimizing the need for material transfer between conveyors, thereby enhancing operational efficiency and reducing pollution. Their capability to traverse diverse landscapes with minimal environmental disruption underscores their contribution to preserving surrounding ecosystems while optimizing material transportation.

4. **In-pit crushing and conveying system (IPCC):** Implementing IPCC systems presents a sustainable approach to mining operations, with crushers and conveyors located within the pit for enhanced operational efficiency and reduced environmental impact. Unlike traditional truck and shovel methods, IPCC systems offer flexibility in mine planning and execution, demanding tailored designs to accommodate their requirements. Relocatable and modular ramp conveyors play a pivotal role in facilitating system scalability and adaptability over time, while low-profile truck dump stations enhance mobility and efficiency, contributing to a smaller environmental footprint.

06 New Minerals

6.1 Emergence of EV and the need for new minerals

The 2021 United Nations Climate Change Conference (COP 26) has driven increased momentum as more countries set carbon reduction targets, with many governments announcing net zero targets in line with the Paris Agreement. This has led to a surge in the deployment of clean energy technologies, including renewables, battery storage, and electric vehicles, along with the associated infrastructure. By 2030, it is projected that EVs will account for 62% of the global vehicle fleet. The increasing adoption of EVs is driven by technological advancements, government incentives, and growing consumer awareness of environmental issues. However, achieving this penetration rate will require addressing several challenges, particularly the need for new minerals essential for EV production.

To meet the projected demand for EVs by 2030, the supply of lithium and nickel will need to increase significantly—by 1.2 to 1.3 times, respectively. These materials are essential for the production of lithium-ion batteries, which are the backbone of modern EV technology. However, while the demand for lithium and nickel is set to rise, the cobalt market is expected to experience a surplus of 62 kilotons. This surplus could help stabilize the supply chain for battery production by reducing the pressure to increase lithium and nickel supplies. Efficiently managing the supply and demand of these materials will be crucial to ensuring the scalability and sustainability of EV production. Strategic investments in mining, refining and recycling technologies will be essential to balance these market dynamics and support the growing EV industry.

In this context, the importance of recycling cannot be overstated. Recycling plays a critical role in reducing the need for new mineral extraction, thus mitigating the environmental impact associated with mining activities. By reclaiming lithium, nickel, cobalt, and other valuable materials from end-of-life batteries and manufacturing scrap, the industry can create a more sustainable supply chain. Recycling helps to decrease dependence on finite natural resources, reduce greenhouse gas emissions, and lower the overall environmental footprint of EV production. Furthermore, advancements in recycling technologies can improve the efficiency and cost-effectiveness of these processes, making them an integral part of the strategy to support the growing EV industry.

6.2
Lithium, nickel and cobalt - the new minerals

01 Lithium

- **Usage:** Lithium is a fundamental component of lithium-ion batteries, which power most EVs.
- **Supply challenges:** The rapid increase in lithium demand has put pressure on mining and extraction processes. Sustainable and environmentally friendly methods of lithium extraction are needed to prevent ecological degradation.
- **Recycling potential:** Recycling lithium from used batteries can help meet future demand and reduce the environmental impact of mining. Technologies for lithium recovery are improving, though they currently lag behind cobalt and nickel recycling in terms of efficiency and cost-effectiveness.

02 Cobalt

- **Usage:** Cobalt is used in the cathodes of lithium-ion batteries to improve energy density and lifespan.
- **Ethical and supply issues:** A significant portion of cobalt is sourced from the Democratic Republic of Congo, where mining practices have raised ethical concerns, including child labor and poor working conditions. Recycling high-cobalt batteries presents a lucrative opportunity for companies, with potential revenues of up to US$22 per kilowatt-hour (kWh). This practice not only offers significant financial benefits but also reduces environmental harm by minimizing the need for new mining activities.
- **Recycling potential:** Recycling cobalt from batteries is highly lucrative and environmentally beneficial. The process involves extracting cobalt along with other valuable materials like lithium and nickel, which can then be reused in new battery production. Companies are increasingly investing in recycling technologies to tap into this potential and create a circular economy for battery materials.

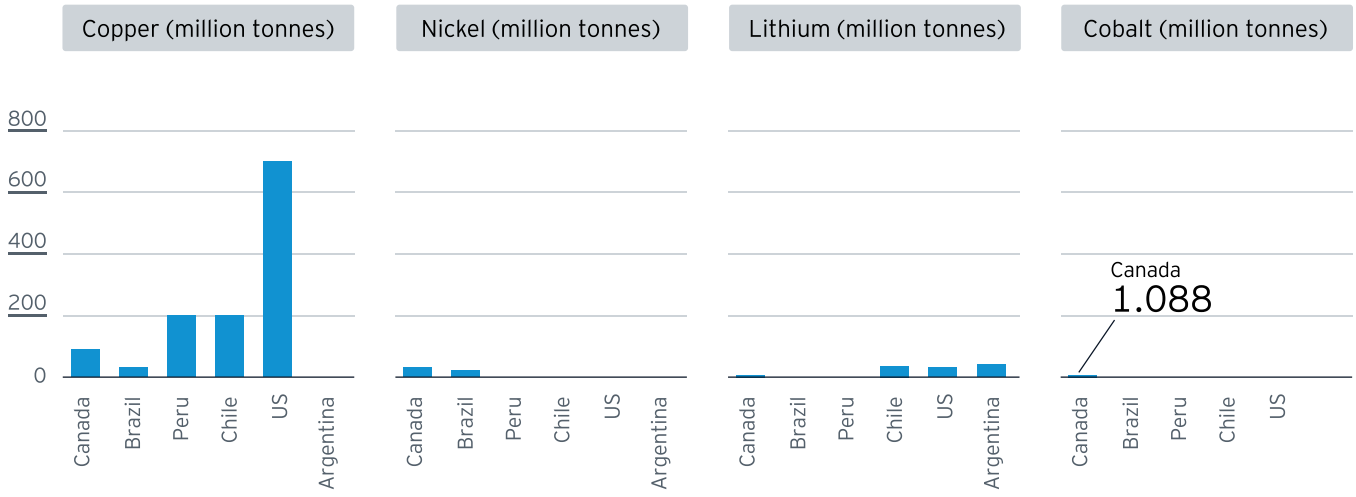
03 Nickel

- **Usage:** Nickel is used to increase battery energy density and storage capacity.
- **Resource management:** Ensuring a stable supply of nickel involves addressing environmental concerns associated with its mining, such as habitat destruction and pollution.
- **Recycling potential:** Nickel is one of the most recycled materials in the battery industry. Recovering nickel from spent batteries is not only economically beneficial but also reduces the need for new mining operations. Efficient recycling processes can reclaim a high percentage of nickel, supporting a more sustainable supply chain for EV batteries.

04 Rare earth elements

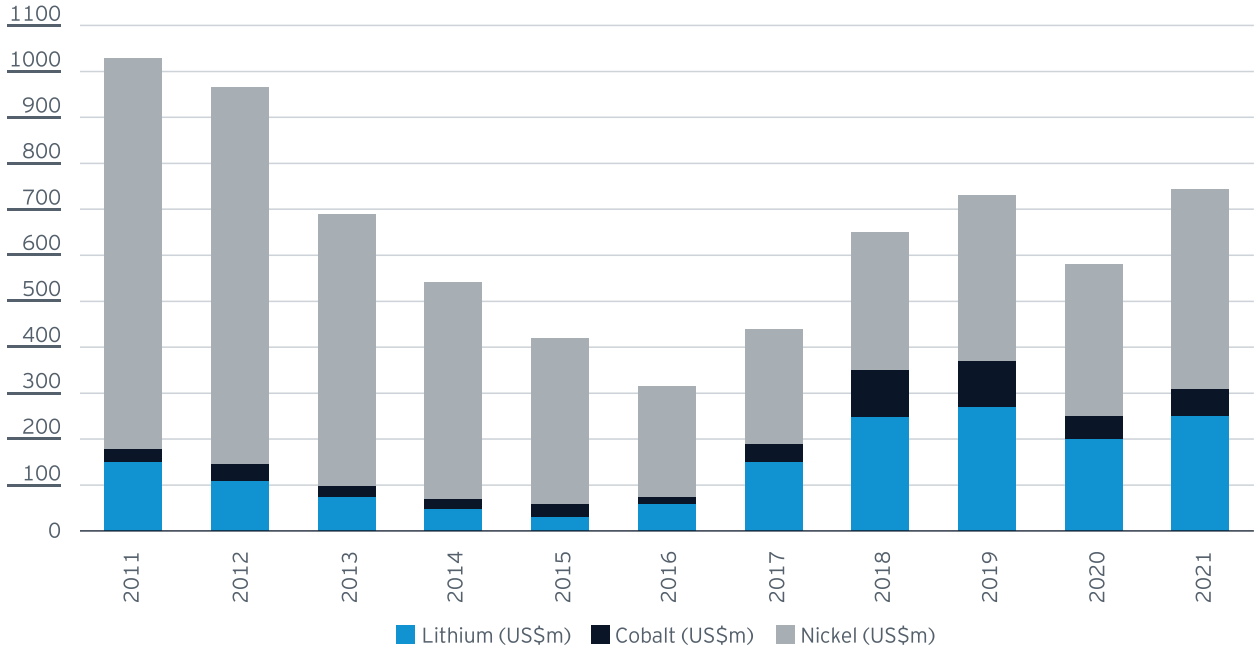
- **Usage:** These elements are essential for the production of powerful magnets used in EV motors.
- **Geopolitical concerns:** The majority of rare earth element production is concentrated in a few countries, leading to supply chain vulnerabilities and geopolitical tensions.

Existing reserves and resources (million tonnes)



Source: S&P Market Intelligence Platform, USGS

Exploration budget by commodity - US$m



Sources: S&P Market Intelligence, EY Knowledge analysis.

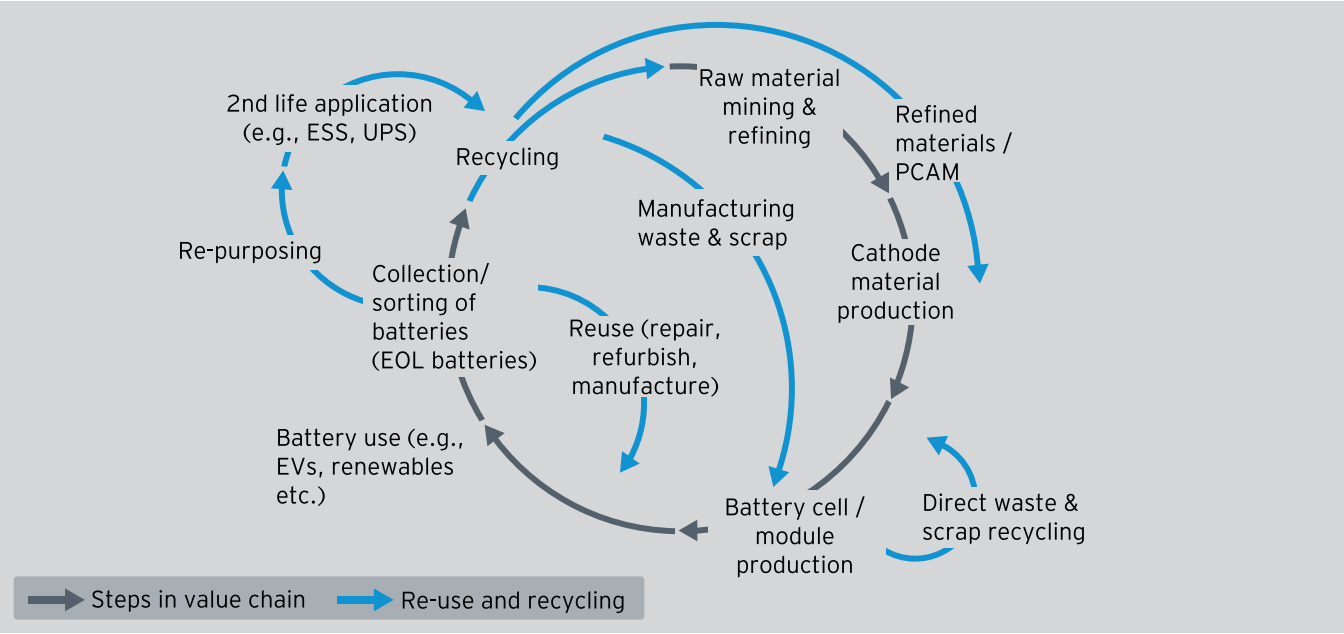
Historically, there has been little investment in critical minerals, and the project pipeline is thin compared to the demand outlook. However, this is changing as countries like Canada, the US, Chile, Peru, and Brazil seek to capitalize on their reserves. Canadian provincial governments are beginning to make strategic investments in projects to access plentiful reserves of graphite, nickel, aluminium, copper, lithium, cobalt, manganese, molybdenum, and rare earth elements. EV manufacturers are partnering with mining companies in Canada to secure a stable supply of these critical minerals. For instance, companies like Giga Metals are working to ensure a steady nickel supply.

Despite these efforts, chronic underinvestment in commodities over the last decade may lead to a supply deficit in the near to medium term. For example, the absolute investment in copper exploration budget in 2023 was US$2.7B as opposed to US$0.7b in lithium, highlighting the disparity in funding allocation. While the potential for an exponential increase in battery minerals demand has attracted the interest of large, diversified miners, there is a lack of sizeable, well-advanced projects in low-risk jurisdictions ready for immediate development.

6.3

Battery recycling and circular economy will help establish resilient supply chain

Recycling will play a critical role to plug the deficit, with the feedstock landscape shifting from manufacturing scrap to end-of-life batteries by 2030. By 2021, scrap comprised 78% of the total, while end-of-life batteries accounted for 22%. However, projections indicated a shift by 2025, with end-of-life batteries expected to rise to 40%, and scrap to decline to 60%. Looking ahead to 2030, a substantial increase in end-of-life batteries to 59%, alongside a decrease in scrap to 41%, is anticipated. This transition marks a significant stride in bridging the deficit.



Source: EY Knowledge analysis of publicly available sources

Using 50% recycled metals in production processes can lead to a 26% reduction in carbon emissions. This reduction is achieved because recycling metals like aluminium, steel, and copper requires significantly less energy compared to producing these metals from virgin ores. The process of recycling involves collecting, processing, and reusing materials from old products, which avoids the energy-intensive steps of mining and refining. This not only conserves natural resources but also significantly lowers the overall carbon footprint of manufacturing.

Recycling high-cobalt batteries, for instance, offers significant financial benefits and reduces environmental harm by minimizing the need for new mining activities. Promoting battery recycling can contribute to creating a circular economy where materials are continuously reused, leading to both economic and environmental gains.

The landscape of global battery recycling is undergoing significant transformation, driven by distinct regional approaches in core electric vehicle (EV) markets. China, commanding 49% of the global recycling capacity, has long been a frontrunner in this domain. However, with new facilities emerging in Europe and the United States, the dynamics are shifting. In the United States, an incentive-led approach is taking shape, with initiatives such as California's Lithium-ion Car Battery Recycling Advisory Group proposing policies at the state level. Additionally, federal efforts like the Inflation Reduction Act (IRA) are incentivizing the localization of battery supply chains within the US and Free Trade Agreement countries. In Europe, a regulation-led strategy prevails, characterized by stringent mandates such as the EU's Critical Raw Materials Act (CRMA) and battery directive. These regulations mandate specific percentages of annual consumption to originate from recycled sources by 2030 and impose requirements on the production and handling of batteries within the EU. Moreover, transparency measures demand disclosure of carbon footprints for EVs, light transport, and industrial batteries, with compliance deadlines set for 2027. Meanwhile, China's capacity-mandated approach underscores its historical leadership in battery recycling. Despite facing capacity shortages,

China has instituted recycling targets at the provincial level and implemented a national battery tracking system. Interim measures for recycling, collection, and tracing of batteries for new electric vehicles are in place, with automakers assuming responsibility for closing the loop on batteries through the establishment of recycling channels and service outlets. As these diverse strategies unfold, they collectively shape the trajectory of global battery recycling, offering unique insights into the evolving dynamics of sustainable technology adoption.

Companies are moving towards a circular economy by going beyond battery recycling to establish a resilient supply chain. To achieve a circular economy, companies must integrate themselves into the value chain and foster collaboration. In the automotive sector, there's a notable trend of automakers setting ambitious battery production targets and joining forces with recyclers to establish closed-loop recycling systems. Take Toyota, for example, which has partnered with Redwood Materials to pioneer closed-loop EV battery recycling in the US. This approach to circularity not only encourages innovation but also promotes the repair, reuse, and recycling of second-life batteries. Supportive policies like the EU Recirculate initiative, aimed at advancing battery dismantling and sorting technologies, further catalyze growth in the battery recycling sector. An intriguing aspect of this shift is the evolving business models it inspires. Instead of traditional ownership, we're seeing the emergence of leasing arrangements between mining companies and manufacturers, automakers, or third parties. This leasing model promotes responsibility throughout the battery lifecycle, ultimately leading to increased reuse and recycling rates.

6.4
Building a stronger circular battery recycling economy: favorable policies and technological advancements

Actions for recycling value chain players

01 **Drive technological innovation:** Investment in research and development is crucial to pioneer new recycling methods that enhance recovery rates. Conducting pilot projects can demonstrate the technical and financial feasibility of these innovations. For instance, innovative processes like direct lithium extraction (DLE) technology are being explored to improve lithium recovery rates from batteries, thus reducing dependency on virgin resources.

02 **Forge partnerships and alliances:** Collaboration with stakeholders is essential to address gaps in technological innovation and waste management. Forming alliances that leverage collective expertise and resources can drive sustainable solutions. Companies are partnering with academic institutions and research organizations to develop and commercialize advanced recycling technologies, ensuring the scalability of these solutions.

03 **Automate recycling processes:** Integration of advanced machinery and robotics streamlines recycling operations, reducing reliance on manual labor. This approach not only enhances efficiency but also minimizes human exposure to hazardous substances. Automation technologies such as AI-driven sorting systems are revolutionizing battery recycling facilities, improving accuracy and throughput rates.

04 **Ensure supply chain transparency:** Implementing tracking mechanisms like a battery passport system enhances visibility and transparency throughout the battery lifecycle. This ensures the availability of critical data for informed decision-making. Blockchain technology is being explored to create immutable records of battery provenance and lifecycle, enhancing transparency and traceability.

05 **Adopt agile business models:** Embracing flexibility in business models is essential to accommodate emerging technologies. This adaptive approach mitigates risks associated with evolving battery technologies, ensuring resilience and sustainability. Companies are exploring novel business models such as battery-as-a-service (BaaS), where customers pay for the use of batteries rather than owning them, promoting circularity and resource efficiency.

Actions for policymakers and industry bodies

01 **Extend producer responsibility:** Holding Original Equipment Manufacturers (OEMs) accountable for the entire lifecycle of batteries, including collection and recycling costs, is critical. Providing incentives to OEMs can encourage the development of efficient recycling processes. For example, the European Union's Extended Producer Responsibility (EPR) framework requires producers to finance the collection and recycling of batteries, incentivizing eco-design and recycling initiatives.

02 **Incentivize domestic capacity:** Encouraging the growth of local recycling infrastructure through financial incentives like tax breaks is essential. Foster public-private partnerships to bolster domestic recycling capabilities, reducing reliance on overseas markets. For instance, countries like the United States are offering grants and subsidies to incentivize the establishment of battery recycling facilities within their borders, promoting job creation and economic growth.

03 **Standardize regulations:** Implementing standardized regulations for battery labelling aids in sorting and recycling processes. Establishing consistent State of Health (SOH) metrics informs decisions regarding second-life applications and promotes global design standards for batteries. International bodies like the International Electrotechnical Commission (IEC) are developing standards for battery performance and safety, facilitating interoperability and circularity.

By implementing these actions, stakeholders can contribute to building a stronger circular battery recycling economy, ensuring sustainable resource management and environmental stewardship in the electric vehicle industry.

07 Zero waste Mining

Zero-waste mining aims to minimize waste generation, maximize resource efficiency, and promote sustainable mining practices. According to the "National Mineral Policy, 2008," zero-waste mining is a national goal, requiring upgraded mining technology to ensure the extraction and utilization of the entire run-of-mine. The latest trends include net-zero operations, tailings management, sustainable supply chains, unmanned mining, and digital twins.

7.1 Key principles of zero-waste mining

A Resource efficiency

Resource efficiency aims to maximize output from resources while minimizing waste. Companies need to closely monitor their water, electricity, and material consumption to ensure maximum resource utilization and minimal waste production. Although the implementation may vary, common practices include recycling, reusing materials, and reducing waste to create a resilient economy. The goal is to meet current needs without compromising future resources.

Key areas of resource efficiency

01 **Resource conversion**

- **Energy-conserving measures:** Install solar panels, reduce energy consumption, and switch to energy-efficient machinery and devices.
- **Full utilization of resources:** Ensure all resources are fully utilized to avoid waste

02 **Efficient resource extraction**

- **Precise extraction techniques:** Implement selective mining techniques such as cut & fill mining, room & pillar mining, longhole open stopping, and sensor-based sorting to reduce waste rock and overburden.

03 **Sustainable procurement**

- **Responsible suppliers:** Acquire materials from sustainable suppliers, considering the entire life cycle of products from extraction to disposal. Prioritize suppliers committed to resource efficiency to enhance supply chain sustainability and reduce environmental impact.

04 **Waste reduction**

- **Recycling and reusing:** Establish waste reduction goals and implement recycling and reusing measures to minimize waste.

05 **Employee engagement**

- **Promote a culture of responsibility:** Encourage employees to contribute ideas for improving resource efficiency. Recognize individuals for promoting sustainability measures.

06 **Process optimization**

- **Update and optimize processes:** Use efficient separation and beneficiation processes to maximize mineral recovery. Stay updated with the latest techniques to meet efficiency standards and goals.

07 **Technology and innovation**

- **Advanced tools:** Utilize remote sensing, geological mapping, and automated machinery to achieve resource efficiency. Automation, workflow management, and business intelligence help exceed sustainability goals.

08 **Best practices for resource efficiency**

To attain resource efficiency, strategies should be tailored to specific needs and program results. Here are some best practices to start with:

- **Conduct regular audits:** Regularly audit efficiency to identify areas for improvement.
- **Use energy-efficient technology:** Incorporate energy-efficient technologies in operations.
- **Train workforce in efficiency:** Educate employees on resource-efficient practices.
- **Source responsibly:** Choose suppliers who adhere to sustainable practices.
- **Promote circular economy:** Adopt practices that support a circular economy.

B Waste minimization

Current waste production: India generates over 170 million tonnes of mining-related solid waste annually, expected to exceed 300 million tonnes per year with increasing mineral production. This includes metals, industrial minerals, coal, and decorative rocks like granite and marble.

Types of mining waste: Mining waste comprises solid, semisolid, and liquid materials from ore extraction and processing. This includes waste rock, soil, mine water, sludge, tailings, gangue, and processed materials. Safe and environmentally responsible disposal is crucial to prevent environmental pollution.

Environmental impact: Improper waste management can lead to severe pollution, affecting ecosystems and local populations

through groundwater contamination and health issues. Addressing waste from both active and legacy mines is essential. Legacy mines continue to pose environmental challenges, requiring costly and time-consuming remediation.

Innovative waste management techniques

- **Slag utilization methods:** construction materials: Waste slag from pyrometallurgical processes can be used in construction and land remediation.
- **Recycling in steel industry:** Steel slag is widely recycled, with over 80% utilization in countries like Japan, the US, and Europe. This reduces the need for new steel production materials.
- **Fertilizers and carbon sequestration:** Due to its nutrient content, steel slag has been used historically in fertilizer production and can aid in carbon sequestration.
- **Hydrometallurgy techniques:** Methods like acidic leaching can extract valuable metals from slag. For example, zinc extraction rates of 87% were achieved from slag in Turkey using sulfuric acid.

  Biometallurgy in slag reprocessing: Microbial Leaching: Microorganisms can extract metals from slag through bioleaching, which is energy-efficient and produces fewer hazardous by-products.

Tailings recycling

- **Construction materials:** Tailings can be repurposed in road construction, cement, and asphalt, enhancing material performance and reducing environmental harm.
- **Environmental benefits:** Recycling tailings helps mitigate acid mine drainage and reduces the volume of waste stored in tailings ponds.

Recycling and reuse of mining waste: Mining and mineral-processing wastes are significant environmental concerns. Effective reuse of these materials can aid sustainable development, but thorough assessment of environmental impacts is essential. Properly evaluated, mining waste can be reused to extract additional minerals, provide fuel, supply construction materials, and repair land structures altered by mining.

7.2
Strategies being used for zero-waste mining

A Tailings management

Global Industry Standard on Tailings Management

Overview: The Global Industry Standard on Tailings Management (GISTM) is a significant milestone aimed at achieving zero harm to people and the environment from tailings facilities. It emphasizes a comprehensive approach to tailings management to prevent catastrophic failures and enhance the safety of mine tailings facilities globally.

Key aspects of the standard:

- **Engagement with affected communities:** Ensures meaningful involvement of communities throughout the lifecycle of the tailings facility.
- **Human rights requirements:** Strengthens the requirements related to human rights.
- **Environmental protection:** Enhances environmental protection measures, including attention to climate change impacts and restoration.
- **Risk classification:** Implements a robust approach to risk classification for existing and planned facilities.
- **Governance mechanism:** Establishes governance for tailings management, assigning high-level responsibility for standard implementation.
- **Transparency and public disclosure:** Promotes transparency and public disclosure of information related to tailings facilities.

Eco-friendly tailings treatment

Technologies for water recovery from mine tailings and disposal

Conventional Technologies (WRCT)

- **Overview:** Conventional tailings storage facilities (TSFs) can achieve water recoveries of 65-75% in well-operated systems, controlling pond volume and location, and ensuring adequate seepage recovery.

- **Environmental impact:** Improperly managed TSFs can lead to dam failures, causing catastrophic environmental damage, including water contamination and habitat destruction.
- **Mitigation strategies:** Enhancing water recovery systems and regular monitoring can reduce the risk of failures and environmental harm.

02 **Thickening Technologies (WRTT)- Thickened Tailings Disposal (TTD)**

- **Overview:** Tailings are thickened before discharge, resulting in high water recovery (80%) and self-supporting deposits with sloping sides, reducing the need for large dams.
- **Environmental impact:** While TTD reduces the risk of dam failures, improper implementation can still lead to stability issues and seepage.
- **Mitigation strategies:** Engineering tailings properties to match the disposal site's topography and regular inspections can improve stability and environmental safety.

03 **Paste tailings technologies (WRPTT)**

- **Overview:** Applied at small production scales, this method results in medium water recovery and eliminates the need for large dams, although it involves higher capital and operating costs.
- **Environmental impact:** The high viscosity of paste tailings reduces the risk of environmental contamination but requires significant infrastructure investment.
- **Mitigation strategies:** Utilizing advanced pumping systems and optimizing tailings transport can enhance operational efficiency and environmental protection.

04 **Filtering technologies (WRFT)- Filtered Dry Stacked Tailings**

- **Overview:** This technique recovers 90% of water, reduces the TSF footprint, and enhances physical stability. It also improves community perception and has seen advancements in operational reliability and filter capacity.
- **Environmental impact:** Dry stacked tailings are less prone to dam failures and environmental contamination but require careful management to prevent dust generation and erosion.
- **Mitigation strategies:** Implementing dust control measures and ensuring proper compaction can enhance the environmental safety of dry stacked tailings.

05 **Hybrid Technologies (WRHT)**

- **Overview:** Combining sea and fresh water supply with dewatering tailings technologies promotes high water recovery. Methods like the Sand Slimes Split (SSSTT) enhance water recovery by managing different particle size distributions of tailings.
- **Environmental impact:** These methods can significantly reduce environmental risks but require comprehensive planning and site-specific adaptations.
- **Mitigation strategies:** Developing tailored hybrid solutions based on mineral characteristics and local conditions can optimize environmental outcomes.

Despite advancements in the mining sector and geotechnical engineering, tailings dam failures still occur. Since 2014, seven significant failures have made international news, affecting countries like Canada, Mexico, Brazil (twice), China, the USA, and Israel. Effective management of mine tailings is crucial for any large-scale mining operation to prevent environmental disasters and ensure safety.

Overview of environmental issues related to major tailings storage and disposal techniques:

Options	Advantages	Disadvantages
Impoundments – Without dewatering	▸ More economical construction. ▸ Maintaining water in the tailings reduces the possibility of acid mine drainage by restricting oxidation of sulphides.	▸ Water-intensive. ▸ Considerable risk of seepage. ▸ Elevated risk of damage in the event of dam failure due to large volume of water. ▸ Large footprint and habitat disturbance. ▸ Rehabilitation only possible after mine closure.
Impoundments - With thickened or past tailings	▸ Lower risk of damage caused by dam failure. ▸ Lower risk of seepage due to smaller volume of water. ▸ Reduced volume of tailings. ▸ Slightly smaller footprint.	▸ Additional costs (thickening, paste, pumping). ▸ Large footprint and loss of habitats. ▸ Moderately water intensive. ▸ Paste tailings can be costly to pump. ▸ Rehabilitation only possible after mine closure.
Impoundments - With co-disposal of tailings and coarse grained waste	▸ Lower risk of damage caused by dam failure. ▸ Lower risk of seepage due to less water. ▸ Smaller footprint to store separate waste streams.	▸ Additional costs (Thickening, Paste, Pumping, larger dam required). ▸ Large footprint and habitat loss. ▸ Moderately water intensive. ▸ Paste tailings can be costly to pump. ▸ Rehabilitation only possible after mine closure.
Impoundments – With dewatering after closure	▸ Economical construction (a drain system must be installed before operation).	▸ Only slightly more costly than impoundments without dewatering. ▸ Post-closure drain seepage needs passive treatment.
Backfilling - Paste tailings and	▸ Reduced surface storage area. ▸ Minimal risk of groundwater contamination. ▸ More water is recycled, and more volume of tailings is reduced. ▸ Minimal rehabilitation required.	▸ Additional costs (thickening, paste, pumping, barricade, binder). ▸ Seepage. ▸ Only for underground mines.
Filtered tailings - Dry stacking	▸ Reduced water use. ▸ Elimination of the risks of catastrophic tailings flow associated, with dam failures. ▸ Reduction of risk of groundwater contamination through seepage. ▸ Reduced storage footprint enabling progressive rehabilitation during mines operation. ▸ Easier to gain a permit for. ▸ Potential for treatment of long-term seepage if potentially acid generating (PAG) material is dry stacked. ▸ Progressive reclamation possible.	▸ High capital costs and moderate operational costs with modern filtration and conveying technology. ▸ Requires surface management system to prevent wind and water erosion.
River – (RTD)	▸ Low capital and operating cost.	▸ Environmental contamination and disturbance. ▸ Difficult to gain a permit for. ▸ Water-intensive due to low water recovery. ▸ Difficult or impossible to mitigate impacts.
Sub-marine and deep marine - (STD, DSTD)	▸ Low capital and operating cost.	▸ Environmental contamination and disturbance. ▸ Mass wasting from the ground sites. ▸ Difficult to gain a permit for. ▸ Water-intensive due to low water recovery. ▸ Lack of data on environmental impacts. ▸ Difficult or impossible to mitigate impacts.

Efficient new-age technologies for tailings management

The conventional method of tailings disposal through impoundment poses significant environmental risks, particularly in the event of spillage, and is costly due to space and water requirements. However, emerging technologies offer efficient alternatives:

1. **Tailings storage and recycling:** Modern tailings management facilities integrate sensory, surveillance, and filtration technologies to mitigate risks. By employing techniques such as thickening, filtration, and dry stacking, mining companies can process tailings and recycle water, metals, and minerals. Actionable Insight: Robust surveillance technology ensures environmental safety and community satisfaction.
2. **IoT, Automation, and AI:** The adoption of IoT, automation, and AI is critical to prevent future disasters. By utilizing mobile IoT devices, networked sensors, and satellite data, mining operators can continuously monitor tailings storage facilities worldwide. Data-driven insights enhance preventive maintenance procedures, ensuring safety and fostering transparency through education campaigns. Actionable Insight: Implementing a comprehensive monitoring system using IoT and AI technologies can significantly reduce the risk of tailings dam failures.
3. **Digitization:** Digital solutions are transforming waste management in the mining sector. Collaborative platforms like Shell and IBM's Oren Solutions facilitate end-to-end integration of digital solutions, enabling efficient emission and waste management on a large scale. Actionable Insight: Mining companies should explore partnerships with technology providers to leverage digitization for improved waste management and environmental sustainability.
4. **Geopolymer technology:** Geopolymers offer a sustainable solution for tailings management. By utilizing tailings as precursors for polymerization, geopolymer technology reduces storage volumes, eliminates risks associated with traditional disposal methods, and promotes a circular economy. This innovative approach decreases construction and monitoring costs while enhancing environmental sustainability. Actionable Insight: Investing in research and development of geopolymer technology can lead to long-term cost savings and environmental benefits for mining operations.

B Waste rock utilization

Recycling waste rock in mining not only reduces significant production costs but also contributes to the generation of new materials with useful properties while significantly reducing environmental pollution. Key findings from a study on recycling waste rock during coal mining for aggregate use in concrete production include:

- Waste rock from coal mining can effectively serve as aggregates in concrete production, demonstrating a high compressive strength exceeding 100 MPa in both dry and saturated states.
- The aggregate samples exhibit a low chloride-ion content, meeting requirements for use in mortar and concrete without susceptibility to alkali-silica reaction.
- Recycled aggregate from coal mining waste can produce concrete with a compressive strength exceeding 30 MPa and an elastic modulus surpassing 24 GPa, with no significant differences in physical and mechanical properties compared to traditional aggregates.

Additionally, mine waste (MW) represents a valuable resource for various applications, including road construction, building materials, and brick manufacturing.

In the USA, several examples of utilizing mine tailings (MW) in road construction have been reported over decades, such as the historical "Million Dollar Highway" in Colorado built with gold MW. MW can be categorized for road construction into four main types:

- Direct use without treatment.
- Stabilization with hydraulic binders (cement/lime) in the presence or absence of soil/clay.
- Stabilization through geopolymerization process.
- Use with asphalt.

Whether untreated, cement-stabilized, or asphalt-stabilized, MW exhibits satisfactory engineering properties suitable for road construction material. Various methods of utilizing MW as aggregates include:

- Direct use of coarse coal wastes (1–16 mm) as gravels for pipeline ditch refill and gravel surfaces.
- Employment of screened tailings (sandy 1–4 mm) as aggregates for cobbling.
- Utilization of fine tailings (<1 mm) as fillers in the cement industry.
- Characterization and utilization of mine tailings (MT) for embankment applications following wet and dry compaction processes.

Ore sorting

Revolutionizing mining efficiency with ore sorting

Ore sorting emerges as a transformative technology with significant long-term potential, especially in an industry grappling with processing progressively lower grade ore bodies efficiently. It involves identifying and removing waste and below-grade ore to preconcentrate the process plant feed, yielding higher and more stable head feed grades. This process optimizes processing capacity for economic ore—ore with higher value than processing costs. Ore sorting not only reduces variability but also enhances value delivery to the concentrator on an hourly basis.

Enhancing sorting precision with Advanced Sensor Technologies

Successful ore sorting relies on advanced sensor technologies that can effectively differentiate acceptable ore. Miners can choose from a range of sensors for particle-based or bulk sorting, or both. Particle-based sorting utilizes properties like density, magnetism, or color to separate particles individually, often employing high-pressure air ejectors. On the other hand, bulk sorting analyzes larger samples through compositional analysis, typically done by continuously scanning ore on a moving conveyor belt. Techniques like prompt gamma neutron activation analysis are preferred for bulk sorting due to their ability to provide more representative analysis compared to surface-scanning techniques like X-ray fluorescence.

Addressing integration challenges and considerations

Integrating ore sorting into a plant involves numerous considerations, including ore characteristics, feed size, preparation and feed rates, sensor calibration, conveyer speed and tonnage, ore washing, optimal calibration, sensor setup, and belt occupancy. Each part of the plant requires careful adjustment to prevent masking effects and ensure proper functioning. Since every deposit is unique, different assessment techniques and technical solutions are necessary for different ore bodies.

Innovative solutions for complex challenges

Incorporating hyperspectral imaging (HS) into sensor-based ore sorting (SBOS) systems presents a promising solution, particularly in addressing challenges within the copper extraction industry. Hyperspectral imaging enhances SBOS systems by providing detailed mineral characterization, enabling precise mineral identification and classification based on spectral fingerprints. Techniques like Neighborhood Component Analysis (NCA) for wavelength selection optimize ore sorting systems, focusing on specific spectral bands that effectively distinguish desired minerals, thereby enhancing efficiency and selectivity. This convergence of advanced technologies offers a pathway to sustainable mining practices amidst increasing demand for minerals in renewable energy and electric vehicles.

Innovative extraction methods

Transforming mining through technology

The mining industry has advanced significantly with cutting-edge technologies, enhancing efficiency, safety and sustainability.

01 **Autonomous mining vehicles:** Self-driving trucks and drilling machines improve safety and productivity by navigating complex terrains without human intervention.

02 **Drones and aerial surveys:** Drones provide vital aerial views, mapping terrain, monitoring impacts, and identifying mineral deposits, facilitating faster decision-making and cost reduction.

03 **Remote sensing and satellite imagery:** Multispectral and hyperspectral sensors detect mineral-rich areas, aiding informed decision-making and reducing exploration costs.

04 **Real-time monitoring and control systems:** IoT devices and sensors collect data on equipment performance and environmental conditions, ensuring safety and optimizing operations.

05 **Advanced ore sorting technologies:** Modern sorting methods separate valuable minerals efficiently, reducing energy consumption and environmental impact.

06 **Sustainable mining practices:** Technologies optimize water usage, manage waste, and ensure responsible tailings disposal, meeting regulatory requirements and enhancing environmental performance.

These innovations drive productivity while minimizing environmental impact and prioritizing worker safety, shaping a more sustainable future for mining.

7.3 Benefits and challenges to zero- waste mining

Unlocking the benefits of zero-waste mining

Zero-waste mining presents multifaceted benefits across environmental, economic, and social realms.

Environmental impact:

- Mining activities generate massive solid waste, contributing to significant environmental degradation through airborne pollution and water leaching.
- Embracing zero waste mining mitigates environmental harm, fostering sustainable resource extraction and safeguarding ecosystems.

Economic advantages:

- By aligning with sustainable development principles, mining can generate wealth while minimizing environmental impact.
- Adopting a circular economy approach reduces waste generation, enhances resource efficiency, and lowers overall project costs.

Social benefits:

- Addressing community concerns and conflicts associated with mining activities is crucial for fostering positive relationships.
- Zero waste mining initiatives mitigate environmental harm, promote community health, and stimulate economic growth through job creation and development initiatives.

By transitioning to zero waste practices, mining companies can not only improve environmental stewardship but also enhance community well-being and economic prosperity.

Overcoming barriers to zero-waste mining

Achieving the objectives of zero waste mining faces significant barriers across technological, economic, and regulatory fronts:

Technological barriers:

- The complexity of implementing a circular economy model in mining requires collaborative efforts due to multifaceted challenges.
- Advancing mineral processing techniques, such as bioleaching and advanced separation technologies, is crucial for optimizing mineral recovery.
- Addressing the heterogeneous nature of waste materials and understanding their properties and interactions with the environment are essential for effective circularity strategies.

Economic constraints:

- Substantial capital investment is required for developing and integrating zero waste mining technologies, posing challenges for long-term economic viability.
- Low cost of virgin raw materials and logistical challenges associated with remote waste locations hinder the competitiveness of mine waste-based products.
- Insufficient consumer awareness about the safety and efficacy of these products impedes market acceptance and adoption.

Regulatory and policy issues:

- Absence of standardized regulations tailored to zero waste mining practices complicates implementation.
- Robust policy support and incentives from governmental bodies are necessary to encourage companies to embrace zero waste initiatives.
- Lack of legislation and permitting for the reuse and recycling of mine wastes beyond the mine site hampers their sustainable utilization.

To overcome these barriers, collaborative efforts among industry stakeholders, government bodies, and regulatory authorities are imperative. Implementing supportive policies, investing in technological innovation, and fostering consumer awareness are key steps toward realizing the vision of zero waste mining.

7.4 Use cases of zero-waste mining from industry

Rio Tinto mine of the future

Rio Tinto is advancing mining with cutting-edge technologies:

- Remote Operations: Autonomous fleet at Gudai-Darri, managed from Perth, and autonomous haul trucks.
- Digital Efficiency: Digital asset replicas and tablets for a paperless, connected environment.
- Safety Innovations: New reclaimer bucketwheel design and robots improve safety.
- Sustainable Utilization: Extracting metals from waste at Kennecott and lithium from waste rock.
- Renewable Energy: 34 MW solar plant at Gudai-Darri cuts CO2 emissions.
- Research Collaboration: Working with the U.S. Department of Energy on critical mineral recovery.

Barrick's Gold's reuse of tailings

Barrick Gold focuses on sustainability:

- Climate Resilience: Reporting and achieving emissions reduction targets; net-zero by 2050.
- Water Stewardship: Prioritizing lower-quality water, comprehensive management, and community engagement.
- Responsible Production: Waste management and recycling at Veladero, including scrap manganese and tires.
- Tailings Management: Enhanced dewatering and backfilling to minimize environmental impact.

Developing a Circular Economy at Veladero

Veladero mine reduces waste and supports local communities:

- Reduce and Reuse: Partnering to rehabilitate drilling tools, saving costs.
- Manganese Recycling: Recycling scrap manganese with cost benefits.
- Tires to Turf: Recycling tires and plastics into useful materials, benefiting local economies.

Leaching the Way: Glycine Leaching Technology

Barrick Gold's GLT offers a safer gold extraction method:

- Eco-Friendly: Uses non-toxic glycine, reducing sodium cyanide use.
- Bulyanhulu Trial: Significant cyanide reduction, safer tailings disposal.

Boliden's Closed Loop System

Boliden, ABB, and Arcelor Mittal's digital integration:

- Operational Efficiency: Short interval control and closed-loop scheduling.
- Predictive Maintenance: Enhances equipment availability.
- Flow Optimization: Real-time ore tracking for optimal production.
- Real-Time Awareness: Improved decision-making and collaboration.

These case studies highlight how innovative technologies enhance safety, efficiency, and sustainability in mining.

08
Way forward

India's mining sector plays a crucial role in the country's economy, contributing significantly to industrial growth, employment generation, and infrastructure development. With a rich and diverse mineral resource base, India is one of the world's leading producers of several key minerals, including coal, iron ore, bauxite and copper.
The mining industry encompasses a wide range of activities, from exploration and extraction to processing and transportation, involving both public and private sector entities.

Key trends driving the mining industry

In 2023 and early 2024, the mining industry saw increased demand and investment due to the energy transition. However, this demand outpaced supply, necessitating rapid technological advancement. Global trends, including rising societal and investor expectations, technological progress, and geopolitical issues, require companies to adapt quickly. These trends also challenge workforces, potentially leading to confusion and anxiety if not addressed.

Global trends for sustainable mining

Sustainable mining practices are being promoted through international standards, corporate initiatives, and environmental impact assessments. Certification programs enhance transparency and responsible sourcing, boosting consumer confidence. These efforts aim to reduce the industry's environmental footprint and promote social and economic growth, ensuring a sustainable and equitable future for all stakeholders.

Challenges faced by the mining industry and their impact on sustainability and the environment

Mining faces challenges like resource depletion, requiring extraction in remote areas, leading to ecological damage and biodiversity loss. It demands substantial water, exacerbating scarcity and conflicts with communities. High energy use increases greenhouse gas emissions and pollution. Significant waste generation leads to waterway pollution and land degradation. Social impacts include community disruption and displacement. Weak regulatory enforcement worsens environmental degradation.

Acceleration of technology

Technological advancements are transforming mining by enhancing safety, reducing emissions, and increasing productivity. Automation, including autonomous vehicles and AI, is revolutionizing operations. Rapid AI development introduces new complexities, requiring ethical and responsible approaches. The industry must adapt to these changes while maintaining core values.

The necessity of automation in the mining industry

Automation improves mining safety and efficiency by reducing human exposure to hazards and enabling continuous production. Automated systems increase productivity, lower operational costs, and enhance profitability. By performing dangerous tasks, automation minimizes the risk of accidents and health issues.

The scope of automation in the mining industry

Automation enhances various mining operations, such as precise drilling, load and haul, and mineral processing. Autonomous machinery improves efficiency and reduces labour reliance. Drones and robotics aid monitoring and maintenance. Remote control centres enhance safety and operational oversight.

Environmental sustainability and resource utilization benefits of automation

Automation reduces mining's environmental impact through precise techniques that minimize land disturbance and emissions. Energy-efficient machinery lowers greenhouse gas emissions. Automated systems optimize water usage and recycling, improving sustainability. They also enhance resource extraction efficiency, extending mine life and ensuring compliance with environmental regulations.

Government initiatives

Governments are increasingly collaborating with the mining industry to support the energy transition, economic recovery, and geopolitically influenced supply chains. Initiatives focus on enhancing regulatory frameworks, providing financial incentives, and funding research and development to promote sustainable practices. India's Sustainable Development Framework (SDF) and District Mineral Foundation (DMF) plans emphasize responsible mining and local development. Financial incentives and subsidies, outlined in the National Mineral Policy, encourage the adoption of environmentally friendly technologies and conservation efforts. Collaboration with institutions like CSIR and IITs drives innovation in waste reduction and environmental management.

Capacity building and training programs equip mining professionals with the knowledge to implement best practices, while community engagement ensures local stakeholders are involved in decision-making processes. Monitoring and reporting requirements enforce accountability and highlight the importance of sustainable practices. Additionally, initiatives like Swachh Bharat Mission and Made in India campaign promote resource conservation and waste reduction, supporting a circular economy

and reducing the environmental impact of mining operations. These comprehensive efforts aim to balance economic growth with environmental stewardship in the mining industry.

Federation of indian mineral industries initiatives

The Federation of Indian Mineral Industries (FIMI) has emerged as a beacon of progressiveness in India's mineral sector, spearheading initiatives aimed at advancing ESG standards and sustainability. Through strategic advocacy efforts, FIMI has influenced policymaking towards sustainability, fostering laws that prioritize community engagement, environmental conservation, and ethical mining practices. Moreover, FIMI's commitment to capacity building is evident through its workshops and training programs, equipping mining professionals with the skills and knowledge necessary for integrating ESG principles into their operations. By fostering dialogue between mining companies and local communities, promoting technological innovation, and advocating for comprehensive ESG reporting, FIMI is paving the way for a future where the Indian mining industry thrives economically while prioritizing environmental stewardship and social responsibility. With a legacy of achievements and a forward-looking vision, FIMI is poised to lead the transformation towards a more sustainable and ethically driven mineral sector in India.

Mining companies future practices and initiatives

In response to the evolving landscape of sustainability and ESG standards, mining companies in India are charting a course towards zero-waste practices and responsible initiatives. Embracing the principles of resource recovery, circular economy, and waste-to-energy solutions, these companies aim to minimize environmental impact while maximizing resource utilization. Simultaneously, they are prioritizing ESG activities, including environmental conservation, social responsibility and ethical governance, to foster inclusive growth and uphold ethical standards. Leading examples include Vedanta Limited's waste management program and community development projects, Tata Steel's "Zero Waste to Landfill" initiative, and Coal India Limited's environmental and social welfare programs. Through such concerted efforts, Indian mining companies are poised to shape a sustainable and responsible future for the industry, contributing to environmental stewardship and socio-economic development.

Mining consumers sustainable initiatives and practices

As pivotal stakeholders in the mining ecosystem, consumers wield significant influence in promoting environmental, social, and governance (ESG) excellence and sustainability. Embracing the principles of zero waste mining and ESG practices, consumers are driving demand for responsibly sourced raw materials and encouraging suppliers to adopt sustainable practices throughout the supply chain. Initiatives such as demanding supply chain transparency, supporting community engagement and development, and promoting sustainable practices are key strategies employed by mining consumers in India. Examples include the automotive industry's sustainable sourcing guidelines, the electronics sector's support for recycling and e-waste management programs, and the construction industry's adoption of green building materials and techniques.
By leveraging their purchasing power and advocating for sustainable practices, Indian mining consumers have the opportunity to catalyse positive change and propel the industry towards a more ethical, transparent, and environmentally conscious future.

Scope for new minerals in the mining industry

For India's overall growth and economic prosperity, strategic focus on key minerals within the mining industry is paramount. India's abundant coal reserves support energy security and industrial growth, while substantial iron ore reserves bolster steel production crucial for infrastructure development. Expanding bauxite mining for aluminium production can diversify industries like aerospace and automotive, while developing copper reserves supports technological advancement. Limestone extraction drives cement production vital for construction projects, and investment in gold and rare earth elements enhances economic competitiveness and innovation. Emphasizing sustainable practices ensures long-term socio-economic benefits and minimizes environmental impacts, paving the way for sustainable development and prosperity.

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