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INDIAN CHAMBER OF COMMERCE
A Century of Service to the Nation

Mining 5.0 - Emerging mining technologies by 2030

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Acknowledgement

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The ICC also acknowledges and thanks Deloitte for preparing this report in close consultation with industry participants and key stakeholders across the mining ecosystem. The Deloitte team undertook extensive secondary research and engaged in in-depth stakeholder interactions to deliver a comprehensive, insight-driven analysis. Their efforts have yielded a holistic and balanced perspective, offering a 360-degree view of the Indian mining industry and its evolving technological landscape.

The report seeks to comprehensively capture the key trends and developments shaping the future of mining, while also outlining the opportunities, challenges and strategic imperatives associated with the adoption of emerging mining technologies. It aims to serve as a practical reference for industry leaders, technology providers and other stakeholders navigating the transition towards Mining 5.0.

The ICC also expresses its appreciation to the various organisations, industry associations and subject-matter experts who shared their insights and experiences. Their perspectives have significantly enriched the report and contributed meaningfully to its finalisation.

At the end, ICC acknowledges the contribution of all those associated with the report.

Foreword by ICC

The global mining industry is undergoing significant changes driven by digital innovation, sustainability requirements and shifting societal expectations. As the industry moves beyond the automation and digitisation of Mining 4.0, a new phase, Mining 5.0, is emerging. This new phase focuses on people, caring for the environment and collaboration between humans and machines, changing how resources are found, extracted and managed.

This knowledge report introduces Mining 5.0, outlining its key principles and the technological changes that support it. It discusses global views on this transition, showing how leading mining countries are shifting from efficiency-focused digitalisation to more resilient, adaptable and sustainable systems. The report also examines upcoming mining technologies likely to shape the industry by 2030, including advanced sensing, artificial intelligence, robotics and integrated digital systems.

The report pays special attention to India's mining landscape, which faces unique challenges but also offers significant opportunities. With rising demand for critical minerals, strong government support for self-reliance and a growing focus on sustainable development, India is ready to adopt Mining 5.0.

This is becoming more relevant in the context of the current geopolitical situation, where we want to reduce our dependence on overseas fuel and increase our reliance on domestic fuel, including coal and gas. By 2030, these technologies will unlock the economic and strategic value of untapped coal reserves while ensuring efficiency, safety and environmental compliance. This report examines how the country can move towards this new phase by modernising outdated systems, embracing new technologies and strengthening its institutional and regulatory frameworks.

Furthermore, the report evaluates the potential market for Mining 5.0 technologies in India by 2030. It provides insights into investment opportunities, innovative pathways and key strategic areas. By connecting global trends with local needs, it aims to inform policymakers, industry leaders, technology providers and stakeholders throughout the mining value chain.

By 2030, the market for innovative mining technologies is expected to grow rapidly, driven by automation, AI and sustainability needs. This growth will create significant opportunities for innovation, especially in emerging economies ready to adopt next-generation, resource-efficient mining solutions.

As the industry changes, the shift to Mining 5.0 is not just about technology; it is about transformation. It requires rethinking mining to be safer, smarter and more sustainable, balancing economic growth with environmental and social responsibilities. This report aims to be a helpful resource for navigating this transition.

Dr. Rajeev Singh
Director General
Indian Chamber of Commerce

Foreword by Deloitte

The Indian mining industry is at a strategic inflection point. The rising demand for minerals critical to infrastructure, the energy transition and manufacturing is coinciding with heightened expectations around safety, sustainability, productivity and transparency. While Mining 4.0 unlocked important efficiency gains through automation and digitalisation, its impact has often remained fragmented. The next phase of transformation – Mining 5.0 – demands a more integrated, intelligent and human-centric operating model.

Mining 5.0 shifts the industry from asset-level optimisation to system-level value creation. It integrates AI, digital twins, automation and real-time analytics across the mine-to-market value chain, while embedding safety, sustainability and human accountability into daily decision-making. Technology in this model does not replace judgment; it augments it – enabling faster, more consistent and better-governed decisions in complex, safety-critical environments.

For India, the scope of Mining 5.0 is transformational and pragmatic. The industry benefits from strong regulatory reforms, national digital platforms and growing momentum around self-reliance, energy security and decarbonisation. These enablers create an opportunity to leap from isolated digital initiatives towards enterprise-scale, integrated mining systems. By orchestrating existing technologies rather than adding complexity, Indian miners can improve productivity, enhance safety outcomes and strengthen ESG performance at scale.

The way forward requires decisive leadership. Mining 5.0 is not a technology upgrade – it is an operating and governance shift. Success will depend on investing in digital foundations, strengthening data and AI governance, building workforce capability for human-AI collaboration and aligning focus around value rather than volume. Organisations that adopt Mining 5.0 with clarity of intent and discipline of execution will set new benchmarks for resilient, sustainable and globally competitive mining in India.

Rajib Maitra
Partner
Deloitte India

Executive summary

The mining industry is entering a period of structural transition. Declining ore grades, tightening environmental and social expectations, geopolitical pressure on critical minerals and persistent talent constraints are reshaping how value is created and sustained. While the last decade of digitalisation delivered greater operational visibility and localised efficiency gains, many organisations are now confronting a familiar paradox: data abundance without commensurate decision advantage.

India's mining sector is also at a pivotal inflection point. As a foundational pillar of the country's industrial and infrastructure ecosystem, mining underpins critical value chains across power, steel, aluminium, cement, automobiles, chemicals, transport and real estate. With abundant mineral endowments and a sustained contribution of over 2 percent to national GDP, the sector is not merely a supplier of raw materials. It is a strategic enabler of India's long term economic ambition.

Looking ahead to India's aspiration of becoming a US$30 trillion economy by 2047, mining has the potential to play a disproportionately transformative role. Beyond driving output growth, the sector can generate up to 25 million incremental jobs, direct and indirect, helping absorb demographic pressures while contributing as much as US$500 billion in additional GDP. Realising this opportunity, however, demands a fundamental shift in how mining is conceived, operated and governed.

Over the past decade, India has laid strong foundations through regulatory reforms that have enhanced transparency, efficiency and private-sector participation. Simultaneously, national priorities such as Atmanirbhar Bharat, accelerated infrastructure development, a clean-energy transition and net zero commitments by 2070 have sharply increased demand for bulk and critical minerals. India's continued import dependence for several strategically vital minerals, now formally recognised through the Critical Minerals Policy 2023, underscores the urgency of reimagining the sector.

Taken together, these structural reforms and rising national ambitions mark an important shift for India's mining sector. While policy enablers and demand-side tailwinds have set the stage, they also expose the limitations of traditional mining models in meeting future expectations of scale, sustainability, resilience and strategic autonomy. This convergence of opportunity and constraint necessitates a fundamental shift in how mining is planned, operated and governed.

Mining 5.0 represents this next evolution: A shift from volume-centric extraction to a value driven, technology-enabled, sustainable and human centric mining ecosystem. It integrates digitalisation, automation, decarbonisation and circularity with workforce empowerment, community outcomes and national strategic security. For industry leaders and policymakers alike, Mining 5.0 is not optional – it is the operating model required for India's mining sector to remain competitive, resilient and aligned with the country's economic, environmental and geopolitical objectives.

Mining 5.0 describes this shift. An operating model that uses AI, digital twins, automation and advanced analytics to orchestrate end-to-end performance in near real time, with human accountability, safety and sustainability embedded in daily operations.

In this model, value no longer comes from digitising individual tasks in isolation. It is created by integrating planning, production, processing, maintenance, logistics and sustainability into a coordinated, near real-time decision ecosystem. Human accountability remains central, with technology augmenting, rather than replacing, judgment in safety-critical and uncertainty-rich environments.

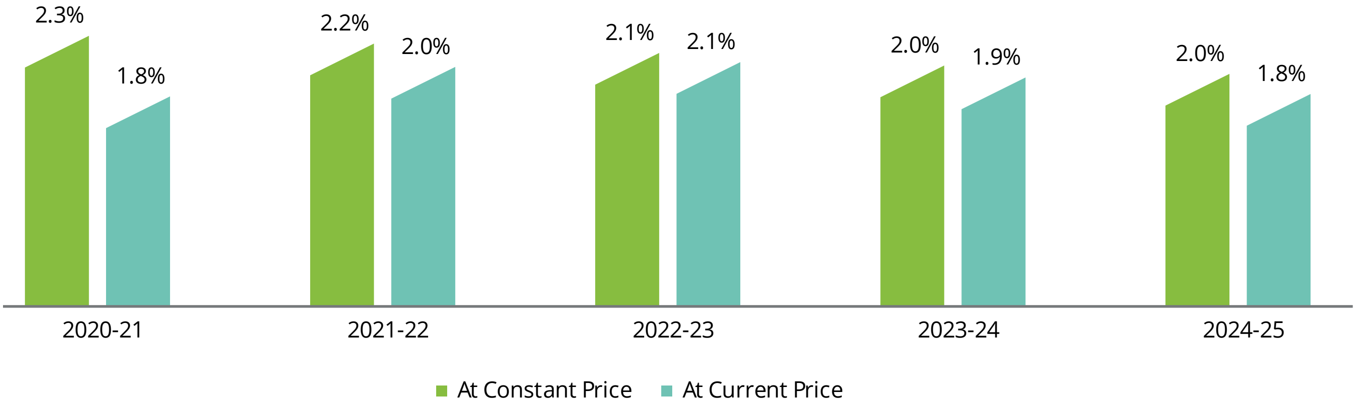
For mining leaders, Mining 5.0 is not a technology upgrade. It is a shift in how mines are governed, how performance is measured and how resilience, sustainability and productivity are balanced at scale.

Introduction to Mining 5.0

a. The mining industry in India

The Indian mining industry is a key pillar of the national economy, supplying essential raw materials for infrastructure, manufacturing and energy. Spanning coal, iron ore, non-ferrous metals and critical minerals, it currently contributes about 2–3 percent of India's GDP directly, with wider indirect multiplier effects across core industries. Supported by policy reforms, technology adoption, sustainability priorities and energy transition demand, its overall economic contribution is projected to rise steadily over the coming decade through higher output and value addition.

Figure 1: Contribution of mining and quarrying to overall GVA[1]



1. GVA at basic prices, Base year: 2011-12; Source: Publications - Reserve Bank of India

India's accelerating industrial and infrastructure growth continues to drive sustained momentum in the mining sector. Rising steel demand – projected to support crude steel capacity expansion to over 300MT by 2030-31 and potentially 500 MT by 2047[2] – is directly translating into higher iron ore extraction and beneficiation activity. Concurrently, steady growth in power generation and infrastructure investment is underpinning coal production, which crossed 1,047 MT in FY25[3] and expected to reach ~1.5 BT by 2030, while aluminium output is expanding to support automotive, renewables and construction demand. In parallel, the National Critical Mineral Mission (NCMM) is accelerating exploration, domestic production and supply chain security of critical and strategic minerals to support clean energy, EVs and advanced manufacturing, broadening mining growth beyond bulk commodities. Overall, these structural growth drivers are reinforcing mining production volumes and long-term sector resilience.

Figure 2: Current growth drivers and trends

Critical minerals as national security assets

In line with NCMM, PLI schemes and Atmanirbhar Bharat goals, critical minerals are considered strategic assets, driving Indian miners towards diversification

Focus on diversification and long-term value

Commodity volatility and regulation are shifting miners towards value-driven portfolios, recycling, and downstream integration, supported by M&A, joint ventures and customer-centric portfolio strategies

Data- and AI-led smart mining operations

AI, GenAI and analytics are enabling mine automation, predictive insights, faster decision-making, safer and more productive operations

ESG and community-centric responsible mining

Responsible mining extends beyond CSR, embedding community development, environmental stewardship and inclusive growth into strategy, which in turn reduces project risk and enhances stakeholder trust

Policy and structural reforms

Indian mining policy increasingly prioritises EoDB, critical minerals security, transparency and sustainability reforms through MMDR amendments, stricter ESG compliance, rationalised royalty

Value-driven, agile operating models

Cost inflation and operational volatility are driving leaner and agile structures, integrated operations and stronger value-chain collaboration through enhanced productivity and capital efficiency

Over the past decade, Industry 4.0 adoption in the Indian mining industry has progressed from basic mechanisation to AI-enabled, digitally integrated and data-driven operations. This evolution has been supported by government initiatives such as online auctions, the National Geoscience Data Repository (NGDR), the Mining Tenement System (MTS), the PM Gati Shakti portal and digital single-window clearance mechanisms aligned with the Digital India and Viksit Bharat agendas. These initiatives aim to improve transparency, efficiency and the ease of doing business.

2. PIB release on Bharat Steel to shape global dialogue on the future of steel
3. PIB release on India's Coal Sector has Crossed the One Billion Tonne Milestone in Cumulative Production for the FY 2024-25

Leading mining companies have responded by deploying integrated mine planning tools, centralised real-time monitoring platforms, IoT, drones, AI and advanced analytics to enhance productivity, safety, energy efficiency and asset reliability. However, while Mining 4.0 has significantly improved operational visibility, results have often fallen short of delivering system-level productivity and sustainability gains. The core challenge lies in technology maturity, as a fragmented system design has created data-rich yet decision-constrained operations. Cumulative investments in digitalisation, automation and smart-mining initiatives are estimated at ~INR10,000–17,000 crore during 2019–2025. While adoption remains concentrated among Tier-1 private players and large PSUs, momentum is accelerating as automation, AI and digital compliance become critical to productivity, safety and sustainable development.

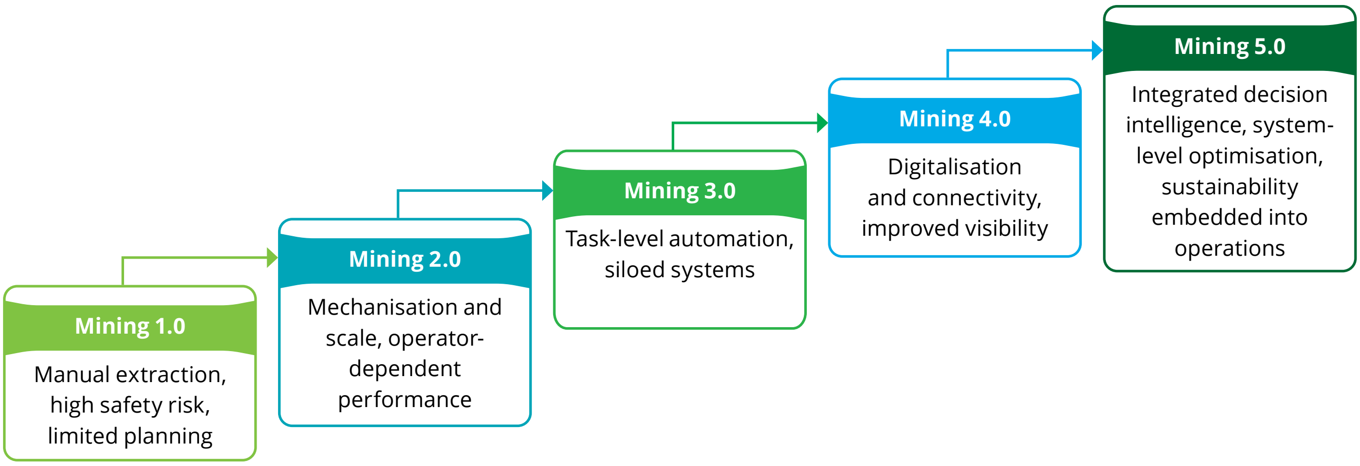
Against this backdrop, Mining 5.0 represents a fundamental shift in how mining systems are designed, governed and operated.

b. Transition from Mining 4.0 to Mining 5.0

Mining 5.0 addresses this structural gap by moving the emphasis from merely digitising processes to actively orchestrating decisions. It uses AI, digital twins and automation to connect systems, reveal trade-offs and facilitate quicker, more consistent and more accountable decision-making throughout the value chain.

Definition: Mining 5.0 is an operating model in which mining activities are managed through integrated, near real-time decision-making, AI-enabled, digital twins and automation, with human oversight and sustainability embedded in daily operations.

Figure 3: Differentiation from prior eras: Mining has evolved through distinct stages



Key elements of Mining 5.0

Human-first

Despite rising automation, mining remains inherently human-led due to geological uncertainty, safety-critical conditions and competing operational priorities. Mining 5.0 augments workforce capability rather than replacing it, strengthening decision confidence, responsiveness and accountability.

A British multinational company's FutureSmart Mining programme approaches automation and digitalisation through a deliberately human-centric lens. Technology is positioned not as a substitute for labour, but to reduce human exposure to hazardous environments, improve safety outcomes and redesign how work is performed across mining operations.[4]

Systems advantage over siloed optimisation

Mining 5.0 replaces asset-centric optimisation with end-to-end value chain coordination. Decisions across exploration, planning, operations, maintenance and logistics are treated as interdependent, enabled by interoperable data, integrated models and cross-functional governance.

An Australia-based global resources company's deployment of integrated digital twins across mine, processing plant, rail and port operations marks a decisive move beyond asset-centric digitalisation. Rather than treating digital twins as engineering or visualisation tools, the company uses them as a decision layer for testing operational scenarios, stress-testing production plans and anticipating disruptions before they propagate through the value chain.[6]

AI as decision co-pilot, not replacement

AI delivers maximum value when positioned as a decision support layer rather than an autonomous authority. Mining 5.0 prioritises transparent, explainable AI systems that align with existing workflows and surface trade-offs, preserving governance, trust and human judgment.

A Chilean state-owned mining company adopted AI as a core enabler of Mining 5.0 at its largest copper mine to manage deeper mines, declining ore grades and rising operational complexity. Through strategic collaboration, AI and advanced analytics augment human decision-making, enhancing safety, efficiency and responsiveness while retaining clear governance, accountability and human-oversight across operations.[5]

Real-time decision intelligence

While real-time data is widely available, decision latency has persisted under Mining 4.0. Mining 5.0 reduces the gap between signal and action by using AI to detect deviations, forecast impacts and enable timely, context-aware operational responses.

A British-Australian mining company's implementation of autonomous drilling and fleet automation technologies improves drilling accuracy, increases utilisation and reduces operational variability.[7] Operating continuously, these systems deliver more consistent upstream execution, stabilising downstream processes such as blasting and material handling.

4. World Economic Forum-Mining's next chapter, Anglo American – FutureSmart Mining™ programme
5. Codelco Microsoft sign AI deal for mining operation
6. BHP-Role of digital twins & AI in enhancing decision making, WEF-How digital twins can boost mining
7. Autonomous drilling and haulage improving efficiency and safety, What are the benefits of automation in mining operations

Balancing operational efficiency with ESG trade-offs

Sustainability is embedded directly into operational decision-making rather than managed as a parallel reporting function. Energy use, emissions and resource efficiency are optimised in real time, enabling adaptive operations under changing ore, equipment and environmental conditions.

A Canadian leading copper miner's tolling agreement with a Chilean state-owned copper mining company continues to reprocess fresh and historical tailings at El Teniente, producing copper and molybdenum from material earlier generations discarded.[8]

Mining 5.0 as a strategic platform for resilience, sustainability and value creation

At its core, Mining 5.0 positions data, AI and operating-model reinvention as strategic enablers of long-term competitiveness. Extending beyond enterprise boundaries, it enables ecosystem-level integration with regulators, communities, OEMs and customers, thereby unlocking resilient, sustainable and value-driven mining ecosystems.

In summary, the following table summarises the core differences between Mining 4.0 and 5.0:

[8] Amerigo Resources / Codelco: operations overview

Dimension	Mining 4.0	Mining 5.0
Strategic intent	Digitise and automate operations to improve productivity and cost efficiency	Orchestrate intelligent, sustainable, and resilient mining systems aligned with ESG and national priorities
Primary value lens	Operational efficiency, safety compliance, and asset utilisation	Value creation with purpose: productivity and sustainability, resilience, and social licence
Overall architecture model	Layered but siloed systems; point solutions optimised locally	Fully integrated, layered architecture with closed-loop intelligence across L0–L5
Role of autonomy	Task-level and asset-level autonomy (e.g., autonomous haulage, drill automation)	System-level and enterprise-level autonomy with human in the loop oversight
L0 – Physical and environmental systems	Instrumented equipment and basic environmental monitoring	Instrumented, continuously sensed physical and environmental systems feeding real-time twins and ESG engines
L1 – Edge, control and automation	PLCs, DCS and autonomous vehicles operating largely independently	Edge computing is tightly integrated with AI, enabling adaptive, context-aware control
L2 – Connectivity and communications	Private LTE/early 5G enabling telemetry and remote operations	Pervasive private 5G / mesh networks enabling real-time video, AI inference, and mission critical autonomy
L3 – Data, digital twin and integration	Data lakes and dashboards; limited or static digital twins	Enterprise digital twins, integrated operations centres, and real-time simulation-driven decisioning
L4 – AI, analytics and decision systems	Predictive analytics and rules-based optimisation supporting human decisions	AI/ML and agentic systems executing autonomous planning, optimisation, and risk responses
L5 – Human-centric and sustainability orchestration	ESG and compliance handled as reporting or after-the-fact controls	Sustainability control towers, circular economy systems, and human + AI decision enablement embedded by design
Human role	Operator and controller of automated systems	Conductor, supervisor, and governor of intelligent human–machine ecosystems
Sustainability integration	Compliance-oriented; emissions and water tracked retrospectively	Proactive, systems-driven sustainability with real-time carbon, water, and nature intelligence
Data governance	Fragmented data ownership; limited interoperability	Enterprise-grade data fabric with governance, explainability, and regulatory assurance
Operating model	Asset-centric and functionally siloed	Value-chain and ecosystem-centric, integrated across partners and regulators
Risk management	Reactive or predictive at the asset level	Predictive and prescriptive across safety, environment, geopolitical and supply-chain risks

Reframing the mining technology stack from digitised operations to cognitive orchestration

The transition to Mining 5.0 represents a fundamental re-architecture of the mining technology landscape. Instead of adding incremental tools, systems are re-designed for enterprise-wide orchestration. L3 and L4 layers emerge as the system-of-record and system-of-decision, integrating digital twins, integrated operations centres and AI/ML platforms. Intelligence is operationalised through decision engines spanning planning, fleet optimisation, safety and supply chain execution, enabling adaptive and self-optimising operations.

Figure 4: The ISA-95 pyramid re-envisioned for Mining 5.0

L5: Human-centric and sustainable orchestration

- ESG management systems
- Decision enablement platforms (Human + AI)
- Sustainability control towers
- Circular economy systems (Waste, water, energy reuse)
- Compliance and regulatory systems

L4: AI, analytics and autonomous decision systems

- AI/ML platforms (Model training and deployment)
- Predictive maintenance systems
- Fleet optimisation systems
- Computer vision safety systems
- Autonomous planning engines

L3: DATA, digital twin and integration systems

- Digital twin platform (Mine simulation)
- Data lake/data warehouse
- SCADA/MES integration systems
- Cloud platforms + edge computing
- Integrated Operations Centre (IOC)

L2: Connectivity and communication systems

- Private 5G/LTE networks
- Industrial Wi-Fi/Mesh networks
- OT communication protocols (MQTT, OPC-UA)
- Real-time video and telemetry systems

L1: EDGE, control and automation systems

- Programmable Logic Controllers (PLCs)
- Distributed Control Systems (DCS)
- Autonomous vehicle systems (Haul trucks, drills)
- Robotics and remote operation systems
- Edge computing gateways

L0: Physical and environmental systems

- Mining equipment (Excavators, crushers, conveyors)
- Geological and survey systems
- Environmental monitoring systems
- Energy systems (Renewable + grid + storage)

Mining 5.0 embeds intelligence directly into operational workflows, transitioning from descriptive and advisory analytics to autonomous and agent-enabled execution. Core functions are delivered through AI-native capabilities supported by edge computing, private 5G networks and real-time spatial data. As a result, human involvement shifts toward oversight, governance and exception management within increasingly self-directing operational systems.

Collectively, these changes reflect an evolution in the mining operating model, where integrated data, digital platforms and artificial intelligence enable coordinated, resilient and value-oriented performance across the mining value chain.

Global perspectives on Mining 5.0

Building on the global shift towards Mining 5.0, the focus moves from intent to execution. Decarbonisation, workforce upskilling, compliance and community impact are built into operational workflows, with automation governed by clear human accountability to deliver safer, cleaner and more resilient mining ecosystems worldwide.

Technology adoption of mining players for leading global economies and key enablers

Region/Countries	Technology adoption in mining	Key enablers	Indicative impact
Australia	Large-scale autonomous haulage, drilling and rail, integrated operations centres, AI-driven pit to port optimisation	Scale of Tier-1 miners, strong OEM ecosystem, private LTE/5G, favourable safety regulation	**15–20 percent** productivity uplift per autonomous truck; ~**15 percent** lower operating costs; improved asset utilisation over 24x7 operations[9]
Canada	Electrified underground fleets, ventilation-on-demand, advanced geoscience analytics	Carbon pricing, deep underground mining expertise and strong mining innovation networks	**30–50 percent** ventilation energy reduction; ~**40–50 percent** reduction in underground energy cost, translating to millions of US$ per mine annually[10]
US	IIoT platforms, predictive maintenance, semi-autonomous equipment (e.g., MineStar)	Mature OEM and digital ecosystem, focus on reliability and ROIC	**5–10 percent** improvement in equipment utilisation, **5–8 percent** reduction in maintenance cost[11]
Chile	Autonomous fleets in copper, AI-enabled leaching, water-efficient digital control systems	Water scarcity pressure, copper-centric R&D investments	**10–15 percent** productivity improvement in large copper operations; improved resilience to water supply constraints[12]
China	5G-enabled smart coal mines, AI surveillance, robotics and centrally mandated digital platforms	State-driven mandates, strong domestic tech and 5G ecosystem	Rapid scale-up; productivity and safety gains at national scale, though ROI varies widely across mine classes[13]
Nordics (Sweden, Finland)	Fully autonomous underground trials, electric and fossil-free mining pilots	Tight OEM-miner collaboration, strong ESG regulation	Long-term cost reduction via electrification; leadership in next-gen underground productivity and safety[14]

9. Autonomous haul trucks productivity gains
10. Optimizing ventilation in underground mines in Canada
11. CAT: Minestar solutions productivity
12. MinerMundo-Autonomous haul trucks productivity
13. Autonomous haulage systems the future-of-mine transportation
14. Rio-Mining innovation/automation

Region/Countries	Technology adoption in mining	Key enablers	Indicative impact
Latin America (Brazil, Peru)	Fleet management systems, AI-assisted grade control and drones for surveying	Presence of global majors, large open-pit assets	**20-70 percent** reduction in surveying costs using drones vs traditional methods; faster planning cycles[15]
Africa	Digital safety monitoring, selective mechanisation	Safety imperatives, labour-intensive deep mines	Targeted safety and cost benefits; limited full autonomy due to energy and infrastructure constraints
Middle East	Born-digital greenfield mines, integrated digital planning, automated labs and renewable integration	Government-led capital investment (Vision programmes)	Faster time-to-value and ESG-linked cost advantages through digital-first design
India	Digital mine management, drone surveys, GPS tracking and early automation pilots in coal and iron ore mines	Regulatory digitisation push, cost sensitivity, brownfield mine base	Efficiency and compliance-led benefits; drones enable up to ~**50-70 percent** survey cost savings and faster approvals, while full autonomy ROI remains selective

Across leading mining economies, technology adoption is directly linked to scale, infrastructure readiness and regulatory alignment. Where these conditions converge, miners are realising double-digit productivity gains and multi-million-dollar cost benefits. This is also setting the foundation for broader automation and AI-led gains towards Mining 5.0.

15. Sph Engineering-drones in mining

a. Evolution to Mining 5.0: From volume optimisation to value realisation

Having established the strategic rationale for Mining 5.0, the transition from Mining 4.0 may be understood as a fundamental shift in value creation. Declining ore grades, rising expectations for low-carbon traceability and continuous regulatory scrutiny require capabilities that extend beyond conventional volume optimisation. While Mining 4.0 primarily focused on improving discrete processes and functional efficiencies, Mining 5.0 redefines performance by integrating productivity and sustainability within a unified operating model.

Figure 6: Tech value realisation framework to thrive in tomorrow's worlds

This shift is characterised by four structural changes that distinguish Mining 5.0 from earlier digitalisation efforts:

Figure 7: Themes that will help mining industry to shift from Mining 4.0 to Mining 5.0

From digital dashboards to autonomous engines

Mining 5.0 uses AI for real-time decisions, reducing variability while keeping humans in control.

From automation islands to end-to-end digital twins

Mining 5.0 unifies systems through AI-driven digital twins to optimise end-to-end processes.

From reactive safety to predictive-zero harm

Mining 5.0 enables AI-driven, real-time risk detection and intervention, embedding safety within production control.

Next-gen analytics and decision support

Mining 5.0 enables circularity, converting waste into resources and unlocking new value streams.

Key technolog enablers

- Advanced analytics, AI and optimisation engines
- Intelligent automation and closed-loop control systems
- Real-time data platforms with Edge-Cloud architecture
- Digital twin models and simulation engines
- Sensing and connected worker technologies
- Predictive analytics and AI-driven risk intelligence
- Integrated decision systems
- Digital traceability
- Circular optimisation engines
- Ecosystem integration and collaborative digital platforms

IT/OT convergence

Unified data foundation and interoperability

Cybersecurity and governance

From digital dashboards to autonomous decision engines

Mining 4.0 relied on dashboards to inform human decisions. Mining 5.0 embeds AI within operational control layers, enabling insights to be translated into timely, context-aware actions, while retaining defined human oversight.

At a leading global resource company's copper mine in Chile, AI has transitioned operations from dashboard-based monitoring to autonomous decision execution. ML models generate real-time recommendations and closed-loop control for concentrator circuits and autonomous fleets. The fully autonomous open pit mine now operates trucks and drills coordinated by AI decision engines with defined human-oversight – embedding intelligence directly into execution rather than post-hoc reporting.[16]

From automation islands to end-to-end digital twins

Isolated automation is replaced by integrated digital twins that connect geology, operations, maintenance, energy and safety, enabling system-level optimisation and scenario-based decision-making.

A global resources company's collaboration with a leading software and technology company committed up to 17,500 TB of operational data to Azure beginning in 2021,[17] which now runs hourly predictive-recovery insights on Azure Machine Learning and Synapse Analytics, an early demonstration that cloud-native twins can close the loop on a live copper concentrator.[18]

From reactive safety to predictive-zero harm

Safety shifts from lagging indicators and audits to predictive, AI-driven risk identification with real-time intervention capabilities embedded into production workflows.

The predictive-fatigue platform at a major polymetallic open pit mine in Mexico covers more than 1,000 workers, with alerts routed directly to operators, supervisors, and the fleet-dispatch system, transforming zero harm from an aspiration into a design property of the operation.[19]

From linear value chains to circular eco-systems

Waste and byproducts are reimagined as secondary resources, enabling circular material flows, reduced environmental liabilities and new value streams throughout the mine lifecycle.

A leading Anglo-Swiss trading and mining company's shifts towards Mining 5.0 by integrating circular economy through the acquisition of Li-Cycle and Portovesme recycling hub extends the circular model to end-of-life batteries.[20] A leading US-based mining company's leaching-excellence programme recovered ~214 million pounds of incremental copper in 2024 and is scaling towards a 300-million-pound annual run-rate by the end of 2025, and 400 million pounds by late 2026.[21]

Together, these transitions reposition Mining 5.0 as an operating model focused not only on how efficiently mining is performed, but on the long-term value it delivers to enterprises, ecosystems and society.

16. Microsoft News: BHP unleashes the power of digital at world's largest copper mine
17. BHP's partnership with Microsoft:"BHP establishes new cloud agreements," media release, June 2021
18. Escondida: Microsoft News Australia, "BHP unleashes the power of digital at world's largest copper mine".
19. Fatigue Science, "Technology adopted to predict worker fatigue at one of world's largest silver mines."
20. Glencore, "Glencore and Li-Cycle announce joint study to develop a European recycling hub".
21. Mining Weekly, "Freeport targets low-cost copper gains with leaching technologies," 27 January 2025

b. Sensing the emerging mining technologies by 2030

Figure 8: Factors driving the demand for disruptive digital technologies

Technology in mining is a strategic lever for safety, sustainability, resilience, and value creation; integrated analytics, robotics, IIoT, platforms, and cybersecurity drive efficiency and reduce costs across the value chain.

Interventions across major digital technologies implemented by global mining players

Digital technology	Adoption Share (in %)	What is commonly implemented
Cybersecurity	70–80 (high adoption)	OT/IT security, SOCs, network segmentation, identity and access management, ransomware protection (driven by rising cyber risk to mine control systems)[22]
Automation (including autonomous and remote operations)	60–65	Autonomous/semi-autonomous haulage, remote operating centres, automated drilling and process control, especially in large open-pit mines.[23]
Analytics and AI	40–55	Advanced analytics for throughput optimisation, predictive maintenance, and ore recovery; AI adoption is scaling in majors.[24]
IIoT and industrial networks	60–70	Connected equipment, fleet tracking, sensors, mine communication systems, private LTE/early 5G networks.[25]
Robotics	30–40 (selective adoption)	Robotic drilling, inspection robots and automated labs; primarily in underground and high-risk environments.[26]

The technology vectors below, taken together, constitute the architecture of Mining 5.0.

Digital and physical foundations (sense and connect)

Advanced sensing and industrial IoT

Advanced sensing in Mining 5.0 integrates multi-modal technologies with IoT to characterise ore and equipment in real time, shifting sensing upstream to enable early grade decisions, reduce waste, and improve efficiency across in-pit operations and monitoring.

At a lithium mine of a leading miner in Western Australia, a high-capacity sorting installation with a combined throughput of ~1,000 TPH is the world's largest lithium ore-sorting plant. The company reported ~77 percent q-o-q production increase in Q4 FY25 following full commissioning, alongside energy savings of 8–15 GWh per year from rejecting barren material before grinding.[27]

22. Deloitte Africa: Digital Transformation in Mining Report
23. Mining Magazine: Automation and Digitalisation Insights
24. Mining Magazine: Automation and Digitalisation Insights
25. Mine-Site Technology Adoption Survey, 2025
26. Mining Magazine: Automation and Digitalisation Insights
27. TOMRA Mining, 2025; Pilbara Minerals Q4 FY25 quarterly report

Connectivity

Mining 5.0 connectivity, led by private 5G, delivers low-latency, high-bandwidth performance on a unified backbone, enabling autonomy, teleoperation and real-time analytics, while evolving from pilots to an AI-integrated operational backbone.

At a leading gold mining company's operation in Australia, world-first deployment of a 5G tele-remote dozer fleet: a private 5G network supporting up to 12 dozers across ~2.5 km on a single radio, with uplink speeds of up to ~175 Mbps, and productivity gains reported on the tele-remote task.[28]

Cyber resilience and trust

Mining 5.0 embeds cyber resilience across OT and traceability layers using AI-driven security, zero-trust architectures and micro-segmentation. This ensures proactive protection against production, safety and regulatory risks in highly connected operations.

LockerGoga ransomware encrypted systems across ~22,000 computers at ~170 locations in March 2019. A Norwegian aluminium and renewable energy company declined to pay and restored operations from backups, disclosing a financial impact of ~US$70 million across the first half of 2019.[29] Dragos's Q2 2025 industrial-ransomware analysis recorded 11 mining-sector incidents in the quarter, a more than fivefold increase on Q1 2025, evidence that the threat environment is intensifying rapidly.[30]

Data and platform layer (integrate and govern)

Cloud data platform and computing

The transition to cloud data platforms in mining enables centralised, scalable and secure data management across sites. Cloud computing supports real-time analytics, remote operations, and AI deployment, improving agility, collaboration, cost efficiency and enterprise-wide decision-making.

A British multinational company adopted cloud-enabled data platforms, in collaboration with leading software and technology providers, to deploy scalable cloud infrastructure and cloud-computing capabilities for real-time analytics, digital twins and AI-driven optimisation across operations, safety and sustainability.[31]

Digital twins

A mining digital twin is a real-time, spatial model that integrates geology, operations and the environment. In Mining 5.0, it becomes a unified operating system that enables simulation, AI-driven decision-making and lifecycle optimisation from design to closure.

A leading Australia-based mining company's mine in Pilbara designed a full digital replica of the processing plant.[32] In 2025, a leading industrial automation company released GMD Co-pilot, a Gen-AI operator assistant purpose-built for gearless mill drives and among the first such assistants fielded at production scale in mining.[33]

28. Ericsson and Newmont: world-first 5G tele-remote dozer fleet at Cadia, April 2025; Ericsson, press release, April 2025
29. "Hackers hit Norsk Hydro with ransomware": Hydro official cyber-attack page
30. Dragos, "Industrial Ransomware Analysis: Q2 2025
31. AIX Case Stude: Anglo American transforms Mining with AI
32. Rio Tinto, "Rio Tinto opens Gudai-Darri, its most technologically advanced mine," 21 June 2022
33. ABB released GMD Copilot in March 2025 generative-AI operator assistant for gearless mill drives; press release, 19 March 2025

Cognitive intelligence layer (decide and learn)

Artificial Intelligence

AI in mining uses machine learning and foundation models to enable autonomous, human-governed decisions; as Mining 5.0's cognitive backbone, it integrates the value chain – spanning exploration to operation optimisation – shifting from rule-based systems to intelligent, adaptive operations.

A scientific mineral exploration company disclosed the ultra-high-grade copper deposit in Zambia, among the first world-class deposits publicly attributed to AI-assisted targeting. At the processing end, IntelliSense.io reported that AI-based tuning of the rougher and cleaner circuits at a Chilean copper mine lifted overall copper recovery by ~1 percent, generating an annualised value of ~US$38 million.[34]

Large Language Models (LLMs)

LLMs, combined with GenAI and Agentic AI, are emerging as a strategic enabler in mining, supporting knowledge-driven operations through advanced query resolution, predictive insights, scenario analysis and decision support, thereby strengthening human-centric, data-led and resilient Mining 5.0 operating models

A leading Australia-based multinational mining company collaborated with an American-German data processing company to integrate GenAI and advanced language-based models to process data for autonomous truck fleets, improving logistics by interpreting technical logs to reduce operational delays.[35] A leading US-based steel manufacturer leveraged cloud GenAI capability to optimise maintenance strategies across its iron ore mines in North America.[36]

Execution and control layer (act and optimise)

Integrated Remote Operations Centres (IROCs)

Centralised and off-site hubs are integrating real-time operational data to monitor and optimise mining assets across sites, enabling faster decision-making, improved safety and productivity and consistent, cost-efficient operations at scale.

A leading Australia-based mining company operates its Pilbara iron ore system through The Hive, a Perth-based remote operations centre overseeing the pit-to-port value chain. It coordinates autonomous haulage, rail, processing and energy systems using AI-driven control and monitoring tools that analyse real-time data to optimise performance, detect anomalies and support timely operational decisions.[37]

Autonomous operations

In autonomous mining, self-driving fleets are coordinated through edge AI and private networks, enabling safe, continuous operations. In Mining 5.0, multi-agent systems operate as integrated fleets, enhancing system-wide efficiency and resilience.

A Swedish multinational mining equipment manufacturing company's AutoMine Interoperable Access Control System, enables third-party autonomous equipment to share safety-managed zones with drill rigs, breaking the vendor lock-in, that kept mixed underground fleets manual for more than a decade.[38] An autonomous mine-truck entered service at a leading Canadian gold producer company's mine in July 2025 as the site's first driverless haul truck, with automation progressively extending across the broader drill-load-haul cycle.[39]

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34. IntelliSense.io: AI-based tuning of rougher and cleaner circuits at a Chilean copper mine; IntelliSense.io, case study, August 2023
35. Blog/celonis-brings-process-intelligence-to-every-business-user-with-llm-for-pql-generation
36. BuildSteel SFIA report: https://buildsteel.org/why-steel/innovation/u-s-steel-to-build-gen-ai-applications/
37. Fortescue news: The Hive
38. Sandvik's AutoMine Interoperable Access Control System, released June 2024; Sandvik Mining and Rock Solutions, press release, June 2024
39. Epiroc's MT65 MKIII autonomous Minetruck entered service at Agnico Eagle's Odyssey mine in July 2025; International Mining, 24 July 2025

Human-centric interaction layer (engage and augment)

Spatial computing

Spatial computing integrates physical and digital environments through AR and VR, enabling immersive visualisation, precision design, human centric training and intelligent maintenance – key Mining 5.0 enablers for safer operations, enhanced workforce capability and sustainable, technology-augmented productivity.

Digital twin solutions adopted by a leading multinational miner evolved into spatial twins through spatial computing, delivering immersive, real-time 3D plant representations that enable enhanced visualisation, simulation and human-centric interaction with the physical environment.

Sustainability and regeneration

Energy and electrification

Mining 5.0 energy systems integrate electrification, hydrogen fuel cells, renewables and AI-driven optimisation, replacing fossil fuels and positioning energy as a strategic, carbon-sensitive asset with region-specific deployment maturity.

An Australia-based leading mining company's Real Zero programme has committed US$6.2 billion to eliminate operational Scope 1 and 2 emissions by 2030, displacing ~700 million litres of diesel and ~3 million tonnes of CO_2-equivalent emissions annually. It is electrifying a broad fleet of mining equipment, underpinned by new multi-gigawatt-scale Pilbara solar, wind and storage capacity.[40] At a gold mine operated by a leading Swedish mining company, smart ventilation system has delivered 54 percent in energy savings and ~21 percent in air-heating energy reductions.[41]

Nature and climate integration

Mining 5.0 integrates climate and nature stewardship into operations by reprocessing tailings, planning restorations and ensuring ESG traceability. It redefines waste and closure as opportunities for resource recovery and digitally verified landscape regeneration.

A leading Australia-based multinational mining company's blockchain-traceability platform provides the German automobile company with verified sustainability credentials including carbon intensity for low-carbon aluminium from mine to delivered metal, extending Mining 5.0's trust architecture into the customer's Scope 3 accounting.[42]

40. ESG News, "Fortescue announces $6.2 billion to eliminate fossil fuel risk by 2030"; Fortescue Real Zero page
41. Boliden's Kankberg gold mine / ABB SmartVentilation: ABB, news release
42. Rio Tinto partners with BMW Group on premium aluminium car parts, February 2023

Indian perspectives on Mining 5.0

India's mining sector enters the Mining 5.0 era with distinct strengths and constraints. While many organizations have implemented elements of Mining 4.0, digital capabilities remain fragmented. The opportunity lies in orchestration rather than reinvention. Key priorities include:

- Strengthening data governance and interoperability across IT, OT and engineering systems
- Investing in workforce readiness and change management
- Designing hybrid cloud-edge architectures suited to India's operating conditions
- Embedding ESG metrics into routine operational decision-making

Without integration, digital investments risk remaining isolated pilots with limited enterprise value. With effective integration, India can build system-level capabilities aligned to national priorities of energy security, sustainability and inclusive growth.

a. Opportunities for large-scale mine digitalisation

India's mining sector has progressed steadily through Mining 4.0, with widespread adoption of digital tools across exploration, operations, safety and compliance. The next opportunity lies not in deploying additional point technologies, but in orchestrating these capabilities into integrated operating systems. Scale is achieved when data, analytics, AI and governance are aligned across the value chain, enabling faster decisions, reduced variability and system-level performance rather than isolated efficiency gains.

- **Using national digital platforms as public infrastructure**

  India's national platforms – NGDR, NMI, NDAP and Unified Mining Portal – provide a strong digital foundation across geology, production, compliance and environment. Interoperability through common APIs can transform them into a Mining 5.0 intelligence backbone, enabling near-real-time data flows, continuous risk-based regulation, improved planning certainty and trusted public digital infrastructure.

- **Scaling digital operations through command-centre models**

  Existing command centres will evolve into predictive, AI-enabled control hubs. They will support proactive safety, predictive failure analysis, dynamic environmental management and adaptive planning. Networked across sites, they enable cross-mine optimisation, while shifting human roles toward AI-augmented decision-making.

- **Enabling resilience through cloud-edge hybrid architectures**

  Given India's diverse and connectivity-constrained mining landscape, hybrid architectures are essential. Edge systems support low-latency, safety-critical decisions, while cloud platforms enable enterprise analytics. This model ensures resilience, scalability and integration with multi-mine intelligence.

- **Integrating IT, OT and engineering for adaptive planning and execution**

  Mining 5.0 requires convergence of IT, OT and engineering systems to create dynamic digital twins. This enables continuous planning, virtual testing and lifecycle optimisation, reducing risk, improving capital efficiency and augmenting human expertise.

- **Standardisation of data models and interoperability**

  Scalable digitalisation depends on harmonised data models and open standards. Interoperability reduces integration costs, avoids vendor lock-in and fosters ecosystem collaboration. This accelerates innovation across miners, OEMs, technology providers and regulators.

- **Building workforce capability and trust at scale**

  Sustained digital transformation in India will depend on workforce readiness. Technology adoption without parallel investments in skills, change leadership and trust often fails to scale. Opportunities exist to embed AI into decision-making workflows, supported by targeted upskilling, transparent governance and clear accountability, ensuring that digitalisation simultaneously strengthens safety, productivity and inclusion.

Implications for the mining industry

Mining 5.0 is not a technology roadmap; it is a leadership agenda. Success depends on:

- Aligning operating models and incentives with value over volume
- Treating AI and data as enterprise capabilities, not functional tools
- Investing in trust – across the workforce, communities, regulators, and customers
- Embracing collaboration to build systems advantage across ecosystems

India's opportunity for large-scale mine digitalisation is not constrained by technology availability, but by integration and orchestration. By using national platforms, scalable architectures, integrated operating models, and a human-centric approach, the Indian mining sector can move beyond fragmented digital gains towards system-level Mining 5.0 performance – aligned with business priorities and global competitiveness.

b. Sustainability as an operational system

India's mining sector is transitioning from compliance-led sustainability, driven by regulation, PSU mandates, and ESG reporting, towards an integrated, data-driven model. ESG regulations in the Indian mining sector are evolving from voluntary commitments to mandatory, data-driven compliance, led by SEBI's BRSR framework for the top 1,000 listed companies. Key requirements include BRSR core disclosures, mandatory assurance for leading entities, Scope 3 value-chain emissions reporting and digital compliance.

Together, these measures are accelerating focus on carbon reduction, waste management, governance transparency and social accountability across operations. Under Mining 5.0, sustainability is embedded in core operations, enabled by real-time intelligence, shifting from reporting to measurable performance.

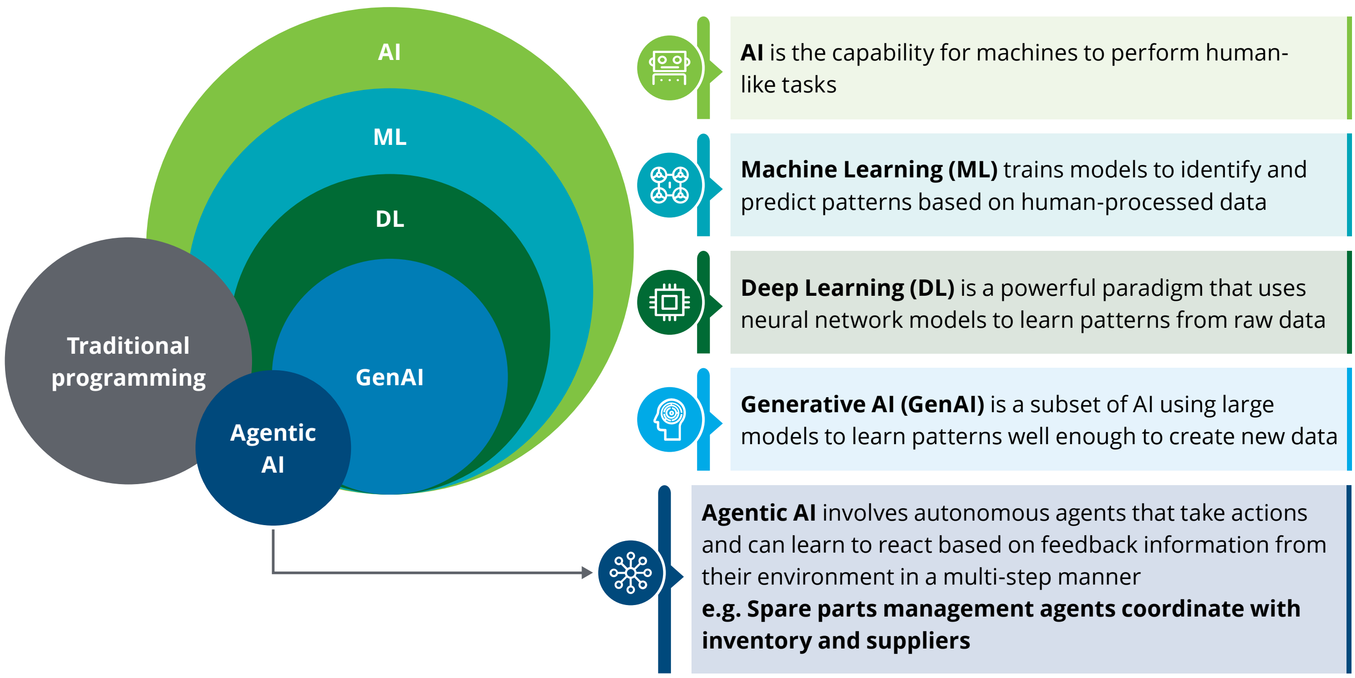
Focus areas	Industry example	Mining 5.0 shift	Actionable levers	Indicative KPIs
Zero harm: Safety remains largely inspection and audit-driven, with limited real-time integration.	A leading iron and steel player adopted AI-based computer vision to detect oversize boulders on dumpers, eliminating manual intervention near crushers, and to monitor AI-based fatigue & proximity for workforce safety.	Predictive, AI-enabled safety systems anticipate risks such as fatigue, geotechnical instability, and equipment anomalies before exposure.	Real-time monitoring, wearables, AI-based risk analytics and integration into shift planning	Predictive vs reactive incidents, LTIFR/AIFR reduction, near-miss frequency, response time
Zero waste: Waste management is compliance-focused, with limited reuse beyond pilots.	A leading coal miner adopted sensorised coal washeries and beneficiation plants with digital yield-optimisation models.	Waste streams are treated as secondary resources, integrated into long-term resource planning and reuse strategies.	Digital waste inventory, sensor-based characterisation, industrial reuse linkages, reprocessing economics	Percentage waste reused, secondary revenue and environmentally liability reduction
Zero emission: Current efforts emphasize efficiency and reporting, with limited real-time control	A leading zinc miner deployed BEVs (Normet SmartDrive and Sandvik Loaders) for underground operations. A leading integrated steel player implemented AI-enabled energy management systems across mining and ferro-alloy plants for real-time energy optimisation.	Emissions become a real-time operational parameter, optimised through intelligent energy systems.	Electrification, renewables with storage, AI-based energy optimisation, carbon-aware production planning	Emissions intensity, renewable share, energy efficiency, real-time carbon variance

Focus areas	Industry example	Mining 5.0 shift	Actionable levers	Indicative KPIs
Water positivity: Water management focuses on recycling and compliance, with fragmented impact assessment	A leading iron ore miner deployed an IoT-based real-time water-monitoring system for withdrawal, recycling and discharge quality, as well as a digital groundwater and surface-water monitoring system.	Integrated, watershed-level water stewardship using digital and hydrological models.	Digital water balance, continuous groundwater and surface water monitoring, community reuse, institutional collaboration	Recycling rate, net water balance, freshwater reduction, community access impact
Circular mining: Circular practices exist, but are not embedded in lifecycle planning	A leading steel player integrated digital platforms, managing steel and mining by-products through the Industrial By-products Management Division (IBMD).	Circularity is designed into the mine lifecycle – from exploration to post-closure regeneration	Circular mining design, early-stage closure planning, asset repurposing, ecosystem integration	Lifecycle material reuse, land restoration, post-closure value

c. Potential application of AI in mining

Globally, AI has advanced from pilot initiatives to production-scale deployment across exploration, operations and automation. Under Mining 5.0, AI is emerging as the enterprise's cognitive backbone, integrating geological, operational, environmental and human inputs to enable real-time risk management, decision augmentation and resilient performance. Early adoption in India reflects this transition.

Figure 9: AI and its subsets



- **AI-supported integrated planning and scheduling**

  AI is increasingly used to integrate short-interval control, shift planning and enterprise scheduling into a unified, dynamic planning environment. Although nascent in India, this approach replaces static plans with scenario-based, near-real-time decision-making, reducing latency and improving operational alignment.

- **Operational optimisation and real-time decision augmentation**

  AI, positioned as decision support rather than operator replacement, analyses live data to highlight constraints and recommend actions for fleet allocation, ore blending, throughput and energy use. "Talk-to-data" capabilities further replace static dashboards by enabling natural-language interaction with operational systems, embedding intelligence directly into daily workflows.

- **Predictive and prescriptive maintenance for asset reliability**

  Machine learning models combine condition-monitoring signals, historical maintenance data and operating parameters to anticipate failures, optimise maintenance schedules and extend asset life. Value is maximised when maintenance insights are integrated with planning, supply chain coordination and financial outcomes.

- **AI-enabled predictive safety and risk intelligence**

  Safety represents the most mature AI application in mining. AI enables early detection of leading risk indicators – such as fatigue, proximity breaches, ground instability and unsafe behaviours – shifting safety management from reactive investigation to predictive prevention and continuous risk mitigation.

- **Knowledge capture and workforce augmentation**

  AI is increasingly used to preserve institutional knowledge and scale scarce expertise through virtual assistants, intelligent SOPs, and real-time decision support, strengthening workforce capability and operational consistency.

- **Enterprise-level AI orchestration rather than isolated pilots**

  Leading organisations are moving beyond isolated pilots towards coordinated, enterprise-level AI strategies aligned with operating models, governance frameworks and data foundations. AI is also reshaping traditional ERP systems, transforming them from transaction-centric platforms into intelligent, predictive systems that enable adaptive workflows and real-time decision support.

  The differentiator is no longer the sophistication of individual AI models but the ability to integrate intelligence across systems, processes and people, turning localised efficiencies into system-level operational excellence.

  GenAI is broadening analytical and productivity applications across organisations; however, the emergence of **Agentic AI** – capable of autonomously coordinating tasks, workflows and decisions – is potentially more transformative. Realising its value will require deliberate redesign of roles, workflows, governance and organisational structures. As these technologies introduce new risks, mining companies are adopting robust responsible-AI frameworks to address governance, regulatory compliance, cybersecurity and enterprise risk management while preserving human oversight, accountability and trust.

Figure 10: Deloitte Trustworthy AI Framework

SAFE AND SECURE

The technology can be protected from risks (including cyberat tacks) that may cause physical, mental, and/or digital harm.

ROBUST/RELIABLE

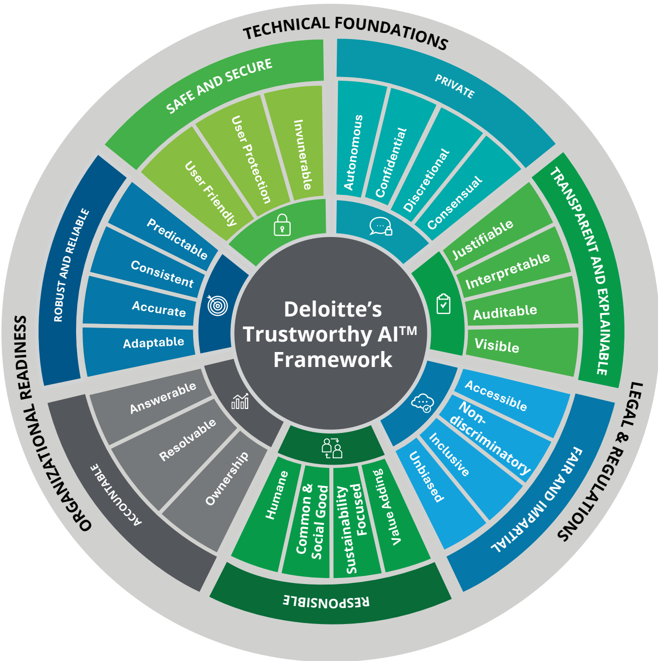
The technology produces consistent, accurate outputs, withstands errors and recovers quickly from unforeseen disruptions and misuse.

ACCOUNTABLE

Policies are in place to determine who is responsible for decisions made or derived using technology.

RESPONSIBLE

The technology is created and operated in a socially responsible manner.



PRIVATE

User privacy is respected, and data is not used or stored beyond its intended and stated use and duration; users can opt in or out of sharing their data.

TRANSPARENT/EXPLAINABLE

Users understand how technology is used, particularly in decision-making; these decisions are easy to understand, auditable and open to inspection.

FAIR/IMPARTIAL

The technology is designed and operated inclusively for non-discriminatory application, access and outcomes.

Focus areas across value chain	ROI	Feasibility	Scalability	Industry example
Exploration: AI enables data-driven prospectivity mapping by integrating geological and remote sensing data, unlocking value from legacy datasets	High (faster discovery cycles, lower exploration cost per target)	Medium-High (data availability exists; quality and integration are the main constraints)	High (national datasets and repeatable models allow reuse across regions)	A leading integrated steel player deployed AI/ML models on geological and geospatial datasets to identify high-grade ore zones and improve targeting accuracy
Mine planning and scheduling: AI supports dynamic, scenario-based planning, optimising decisions in near real-time under uncertainty	High (reduced rework, improved NPV realisation, better asset utilisation)	Medium (requires integration of planning, operations, and other associated functions)	Medium-High (stronger in larger, multi-asset enterprises)	A leading steel manufacturer implemented AI-enabled intelligent mine planning systems, integrating geological models, equipment availability and grade targets
Operations and maintenance: AI-driven models optimise fleet performance, predict failures, and extend asset life	Very High (downtime reduction, asset life extension, fuel and energy savings)	High (sensors and data already widely deployed)	High (repeatable across similar asset classes)	A leading iron ore miner deployed predictive maintenance AI models using vibration, thermal, and operating data from crushers, conveyors and dumpers
Safety and risk intelligence: AI integrates sensors and analytics to anticipate risks and prevent incidents proactively	High (reduction of unsafe incidents, avoided shutdowns, reputational protection)	Medium (requires workforce trust, governance and ethical AI frameworks)	Medium-High (easier in organised, digitally mature operations)	A leading miner implemented AI-enabled wearables and RFID "Suraksha Cards" to monitor worker location, proximity risks and fatigue

Focus areas across value chain	ROI	Feasibility	Scalability	Industry example
Self-optimising processing: AI continuously adjusts plant parameters to maximise recovery and energy efficiency	Very High (recovery improvement, energy and reagent efficiency)	Medium (complex model, self-optimising process parameters)	High (standardised plants enable rapid rollout)	A leading iron ore miner deployed AI-assisted process control for low-grade ore and slime beneficiation
Supply chains: AI enables responsive, end-to-end logistics and demand optimisation across pit-to-port networks	Medium-High (reduced logistics costs, lower inventory, improved fulfilment)	Medium (depends on external data and ecosystem integration)	Medium (stronger at the enterprise or regional level)	A leading miner implemented AI-supported digital logistics management integrated with production and sales forecasts
Workforce of the future: AI-powered assistants and training systems enhance decision-making, safety, and capability building	High (indirect but sustained productivity and safety gains)	Medium (requires cultural change and sustained investment)	Medium (depends on training infrastructure and adoption)	Across Indian mining majors, AI-enabled AR/VR training, personalised safety learning, and skill-gap analytics were adopted

In a Mining 5.0 paradigm, AI shifts from a peripheral tool to the core of the mining enterprise, integrating data, systems and human decision-making into a unified, adaptive framework. The next phase of value creation will depend on embedding AI into decision-making architectures, strengthening data governance and ensuring that human judgment, safety and trust remain central.

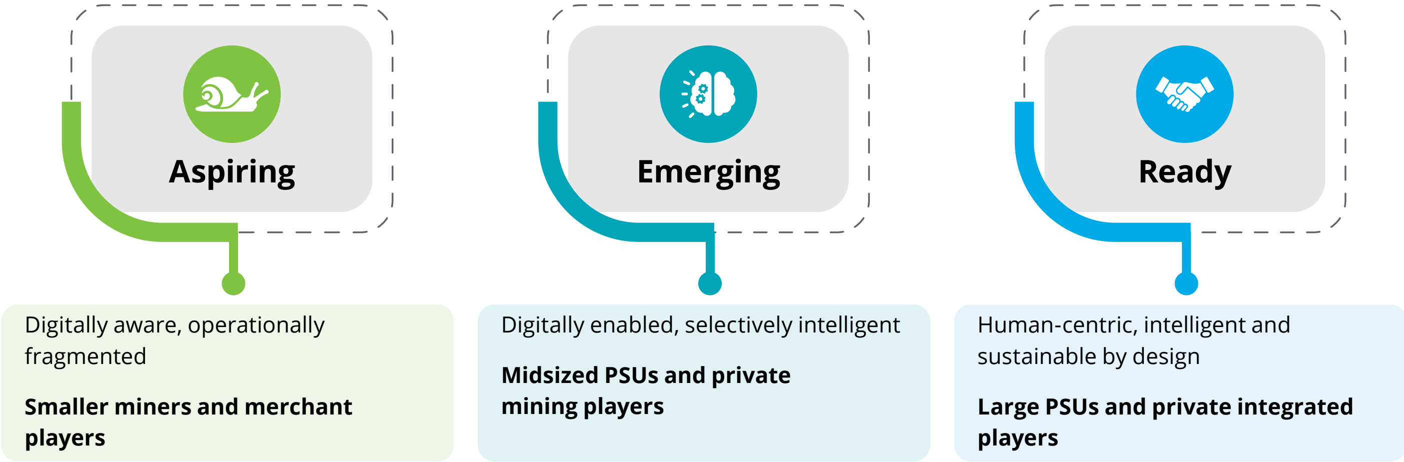
With robust governance and human-governed design, AI can transform mining from a predominantly extractive activity into an intelligent, sustainable and trusted driver of industrial growth – aligned with India's economic, environmental and social priorities. For Indian mining companies, this transition represents an opportunity to leap from isolated digital success stories toward integrated Mining 5.0 operating models.

d. Preparedness of the Indian mining industry for Mining 5.0

Technology preparedness and digital maturity vary significantly across mining organisations, constrained by fragmented digital infrastructure and limited organisational readiness for change. Progressing towards Mining 5.0 therefore requires a phased, leadership-led transformation that aligns technology adoption with strategic business objectives, builds digital culture and enables enterprise-wide scaling beyond isolated initiatives.

Across the Indian mining sector, preparedness for Mining 5.0 can be broadly characterised along three stages.

Figure 11: Category of digital adoption level in the Indian mining industry



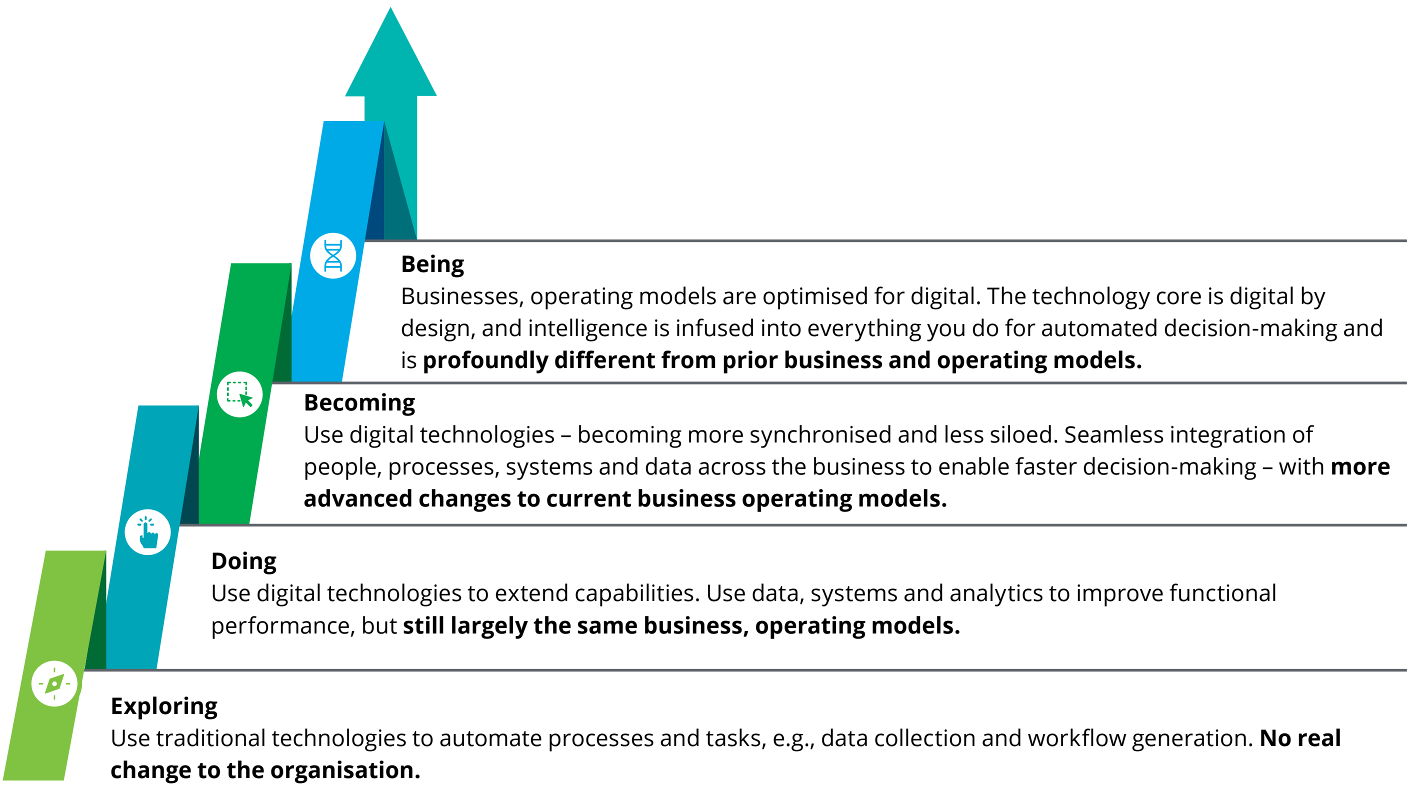
Aspiring: Organisations rely on isolated digital tools with limited integration, remaining reactive and focused on short-term efficiency gains.

Emerging: Miners have advanced beyond pilots by deploying IIoT, analytics and digital safety solutions, but continue to face gaps in integration, governance and workforce enablement.

Ready: Only a select group of large miners demonstrate Mining 5.0 readiness, with integrated digital cores, embedded analytics and human-governed operating models supporting decision intelligence, predictive safety and resilient performance.

Overall, the sector remains in a transitional state. While policy enablers and digital ecosystems are strengthening, accelerating progress from Aspiring to Ready will require more than technology adoption – it demands sustained leadership commitment, robust data governance, workforce capability development and cultural readiness to convert digital investments into long-term, human-centric value creation.

Figure 12: Roadmap towards higher level of digital maturity



e. Potential outlook for disruptive mining technologies by 2030

By 2030, the mining technology landscape will shift from standalone equipment to integrated platforms, intelligence, energy systems and lifecycle solutions. High-growth segments include digital and AI platforms, autonomous systems, mining SaaS, green energy and closure technologies, with business models moving towards service-based, performance-linked collaborations. For India, this creates a dual opportunity: modernising operations while building domestic capability across AI, software, energy and sustainability.

Strategic direction

Digital & AI platforms form the intelligence backbone of modern mining, integrating geology, operations, maintenance and ESG data to enable near-real-time, system-level decisions by orchestrating insight, governance and action across the mine-to-market value chain.

Autonomous systems drive safety, consistency and productivity in Mining 5.0 when embedded in integrated operating models. Combined with digital platforms and human oversight, autonomy reduces hazard exposure while stabilising and optimising end-to-end operations.

Mining SaaS & AI agents embed decision intelligence directly into daily workflows, acting as responsible decision co-pilots that augment human judgment, improve consistency and enable scalable, enterprise-wide performance across the mining value chain.

Green mining energy solutions are becoming strategic assets, combining electrification, renewables and AI-optimised energy management to improve cost predictability, energy security and emissions outcomes. In India, BEVs are moving from pilots to mainstream adoption.

Mine closure & restoration are shifting from end-of-life obligations to lifecycle value levers. Digital closure planning, tailings reprocessing and restoration embedded from project inception enable earlier risk mitigation, better capital outcomes and stronger community trust. By 2030, competitive advantage will depend on integrating these capabilities at scale, transforming mining into a connected, intelligent and sustainable industrial system. Revenue models will shift decisively from one-time equipment sales to service-based, performance-linked collaborations.

For India, this evolution represents a dual opportunity: modernising mining operations while building domestic capability in AI and energy, software and environmental technologies. While global peers operate at greater deployment maturity, their experience provides a clear benchmark, not for replication, but for demonstrating what becomes possible when Mining 5.0 building blocks are integrated at scale.

Indian mining and metals companies currently invest ~INR55,000–65,000 crore annually in mining-focused capex. By 2030, this spend will shift from capacity expansion to Mining 5.0 capabilities. While overall capex is expected to post ~7 percent CAGR, its composition will rebalance from mine development and equipment towards Mining 5.0 – digital intelligence, automation, safety and decarbonisation – with nearly one-fifth (~INR12,500–17,000 crore/~US$1.4-1.9 billion) supporting human-centric, intelligent and sustainable operations.[43]

[43] Deloitte analysis

Focus areas	Select use cases	Market driver	Typical business models	Scalability
Digital and AI platforms	• Integrated mine intelligence platforms • ESG and compliance intelligence layers • Portfolio-wide command centre orchestration	Multi-site optimisation, continuous compliance, predictive decision-making	Core intelligence layer enabling optimisation and compliance; platform-based approach with high scalability through subscription models	Very high across large PSUs and private groups
Autonomous systems	• Autonomous haulage and drilling • Retrofit autonomy kits • Hazard-zone robotics	Safety, labour constraints, productivity volatility	Targeted deployment in high-risk, large-scale operations; shift to autonomy-as-a-service	Medium, strongest where scale and mechanisation are high
Mining SaaS and AI agents	• AI planners, maintenance agents, safety agents • Compliance, procurement and training SaaS	Faster adoption, lower entry barriers and workforce augmentation	Democratised, asset-light solutions extending AI to mid-tier miners; strong scalability	Very high across mine sizes
Cybersecurity and digital governance	• OT cyber protection • Secure networks (5G/LTE, edge computing) • AI governance and data security	Increased connectivity, safety-critical digital operations	Growing thrust on securing the digital core and governing intelligence to scale the business trustfully and resiliently; federated defence model, SOC operations through vendor ecosystem	High with more digital adoption
Green mining energy solutions	• Hybrid renewable microgrids • Battery-electric and hydrogen solutions • AI-driven energy optimisation	Decarbonisation, energy resilience and rising carbon scrutiny	Renewables, electrification and energy optimisation, driven by decarbonisation and energy security	High in energy-intensive scenarios
Closure and restoration	• Digital monitoring of mine closure activities • Water remediation and land restoration • Post-mining land-use optimisation	Regulatory scrutiny, ESG financing, social licence	Growing focus on lifecycle value, ESG compliance and land regeneration, outcome-based restoration contracts	Medium but structurally durable

Navigating the way forward

Indian miners must shift from compliance to value-led transformation. They need to invest in digital foundations, embed AI governance, use ecosystem collaborations, integrate sustainability into core strategy and prepare the workforce for human-AI collaboration. This will help unlock scalable and resilient Mining 5.0 operations.

Shift mindset from compliance to competitive advantage

Short term

Reframe digital, safety and ESG initiatives from regulatory compliance responses to business-value enablers. Leadership must articulate a clear Mining 5.0 vision where productivity, safety, cost resilience and sustainability outcomes are explicitly linked to technology investments.

Medium to long term

Institutionalise technology-led differentiation by embedding digital and sustainability metrics into core performance management and capital allocation decisions, making Mining 5.0 capabilities a source of sustained competitive advantage.

Build AI governance and trust frameworks

Short term

Establish a baseline AI governance covering data quality, model validation, cybersecurity, access control and ethical use, especially for safety-critical and environmentally sensitive applications. Define ownership for AI risk and accountability early.

Medium-to-long term

Mature governance into enterprise-wide, auditable AI frameworks that enable scalable adoption of autonomous and semi-autonomous systems, regulatory confidence and stakeholder trust.

Invest in digital foundations early

Short term

Prioritise core digital enablers, including IIoT sensorisation, IT-OT integration, secure networks, cloud data platforms and cybersecurity. These foundations are critical to avoid fragmented pilots and unlock scalable value from AI, automation and advanced analytics.

Medium-to-long term

Evolve digital foundations into integrated enterprise platforms that support digital twins, autonomous operations, integrated command centres and real-time decision intelligence across the mining value chain.

Embed sustainability and community value in core strategy

Short-term

Integrate digital tools for sustainable practices into operational processes to optimise energy use, monitor carbon and water, reduce waste and support ESG reporting – not as standalone reporting systems.

Medium-to-long term

Embed sustainability into planning and operations, decarbonisation, circular mining, water positivity and community outcomes into mine design, operating models and capital planning, positioning sustainability as a value-creation lever and licence-to-operate enhancer.

Collaborate with start-ups, academia and global ecosystems

Short term

Adopt structured collaboration models – pilots, sandboxes, co-development programmes – with start-ups, technology providers and research institutions to incubate ideas, accelerate innovation and reduce time-to-value.

Medium-to-long term

Build long-term innovation ecosystems through Digital Centres of Excellence (DCoEs), global technology alliances and academic collaborations that localise global best practices for Indian mining conditions.

Prepare the workforce for human-AI collaboration

Short term

Address skill gaps and resistance through targeted upskilling, digital mindset programmes, AR/VR-based safety training and role-based learning to enable effective use of intelligent tools.

Medium-to-long term

Redesign roles and operating models to ensure humans supervise, augment and govern intelligent systems, creating a future-ready, human-centric workforce that is central to Mining 5.0 success. The future is not human vs AI, but human judgement amplified by AI.

In summary, the success of the Indian mining sector in capturing Mining 5.0 value hinges on leadership decisions regarding integration, governance, collaboration and workforce readiness. Organisations that approach digitalisation as a strategic enabler are likely to outperform others. Mining 5.0 will entail a comprehensive transformation across strategy, operating models, capabilities and capital priorities, integrating digital intelligence and sustainability to achieve safer, smarter and more resilient mining operations.

Conclusion

The transition to Mining 5.0 reflects a fundamental shift from volume-centric, compliance-led operations to integrated, intelligent and value-driven mining systems. As technological capabilities mature and sustainability expectations intensify, the differentiator for mining companies will be their ability to orchestrate data, AI, automation and human judgment into coherent operating models, rather than just access to resources. Mining 5.0 redefines how decisions are made, embedding real-time intelligence, predictive safety and sustainability directly into daily operations while preserving human accountability in safety-critical and uncertainty-rich environments.

Capturing this opportunity requires deliberate leadership choices. Indian mining companies must move beyond fragmented digital pilots towards enterprise-scale integration, invest early in digital and governance foundations and prepare the workforce for human-AI collaboration. Equally critical is embedding environmental stewardship and community value into the core strategy, rather than treating them as external obligations. Through ecosystem collaborations, strong governance and a human-centric approach, Mining 5.0 can enable safer operations, resilient supply chains and sustained competitiveness. For the Indian mining industry, Mining 5.0 represents a structural shift in operations, aligning mineral development with national priorities for growth, sustainability and global relevance.

Glossary

Abbreviation	Description	Abbreviation	Description
%	Percent	MQTT	Message Queuing Telemetry Transport
~	Approximately	MT	Million Tonne
AI	Artificial intelligence	MMDR	Mines and Minerals (Development and Regulation) Act
AIFR	All Injury Frequency Rate	MTS	Mining Tenement System
API	Application Programming Interface	NCMM	National Critical Mineral Mission
AR	Augmented Reality	NDAP	National Data and Analytics Platform
BEV	Battery Electric Vehicle	NGDR	National Geoscience Data Repository
BT	Billion Tonne	NMI	National Mineral Inventory
BRSR	Business Responsibility and Sustainability Reporting	OPC-UA	Open Platform Communications Unified Architecture
CSR	Corporate Social Responsibility	OT	Operational Technology
DCoE	Digital Centre of Excellence	OEM	Original Equipment Manufacturer
DCS	Distributed Control System	OEE	Overall Equipment Effectiveness
EV	Electric Vehicle	PLI	Production Linked Incentive
ESG	Environmental, Social and Governance	PLC	Programmable Logic Controller
GenAI	Generative Artificial Intelligence	PSU	Public Sector Undertaking
GPS	Global Positioning System	PSU	Public Sector Undertakings
GHG	Greenhouse Gases	RFID	Radio-Frequency IDentification
GDP	Gross Domestic Product	R&D	Research and Development
GVA	Gross Value Added	ROIC	Return on Invested Capital
INR	Indian Rupee	ROI	Return on Investment
IIoT	Industrial Internet of Things	SEBI	Securities and Exchange Board of India
IT	Information technology	SOC	Security Operations Centre
IOC	Integrated Operation Centre	SIC	Short Interval Control
LTE	Long Term Evolution	SaaS	Software as a Service
LTIFR	Lost Time Injury Frequency Rate	SOP	Standard Operating Procedure
ML	Machine Learning	SCADA	Supervisory Control And Data Acquisition
MES	Manufacturing Execution System	TPH	Tonnes per hour
MTTR	Mean Time to Repair	TAT	Turnaround Time
MWD	Measure while Drill	USD	United States Dollar
M&A	Mergers and Acquisitions	VR	Virtual Reality

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INDIAN CHAMBER OF COMMERCE
A Century of Service to the Nation

About Indian Chamber of Commerce (ICC)

In the heart of the world's largest democracy, ICC stands as a beacon of economic progress, collaboration, and prosperity. As one of the oldest trade associations in the country, it was founded in 1925 by pioneering Indian industrialists based in Kolkata in pre-independent India, led by the visionary leader Mr. Ghanshyam Das Birla. The early years of the Chamber's history show its dedicated commitment to the progressive modernisation of domestic trade, commerce, and industry.

Today, as the world increasingly becomes economically integrated, ICC's efforts have been focused into building a competitive industrial base that can take on the best in the world on equal terms. It has evolved into an illustrious institution that fuels the dreams of visionaries, nurtures entrepreneurship, and shapes the economic destiny of a resurgent India. Presently ICC has 12 Offices across India and 25 International Representative Offices globally. This glorious year, ICC has stepped into its Centenary Year. The Indian Chamber of Commerce headquartered in Kolkata, over the years ICC has truly emerged as a national Chamber of repute, with full-fledged offices in New Delhi, Kolkata, Mumbai, Chennai, Jaipur, Patna, Ranchi, Siliguri, Hyderabad, Bhubaneswar, Guwahati & Agartala functioning efficiently, and building meaningful synergies among Industry and Government by addressing strategic issues of national significance.

Presence of ICC

Domestic presence: ICC has countrywide presence in India, including Kolkata, Mumbai, Delhi, Chennai, Jaipur, Hyderabad, Bhubaneswar, Siliguri, Patna, Ranchi, Guwahati, Agartala, and its presence continues to expand.

International Presence: ICC has 25 offices in foreign countries that includes Argentina, Austria, Brazil, Canada, Chile, France, Germany, Greece, Indonesia, Italy, Kuwait, Mauritius, Mexico, New Zealand, Peru, Romania, Saudi Arabia, South Korea, Switzerland, UAE, UK, USA (East & West Coast) & Vietnam.

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