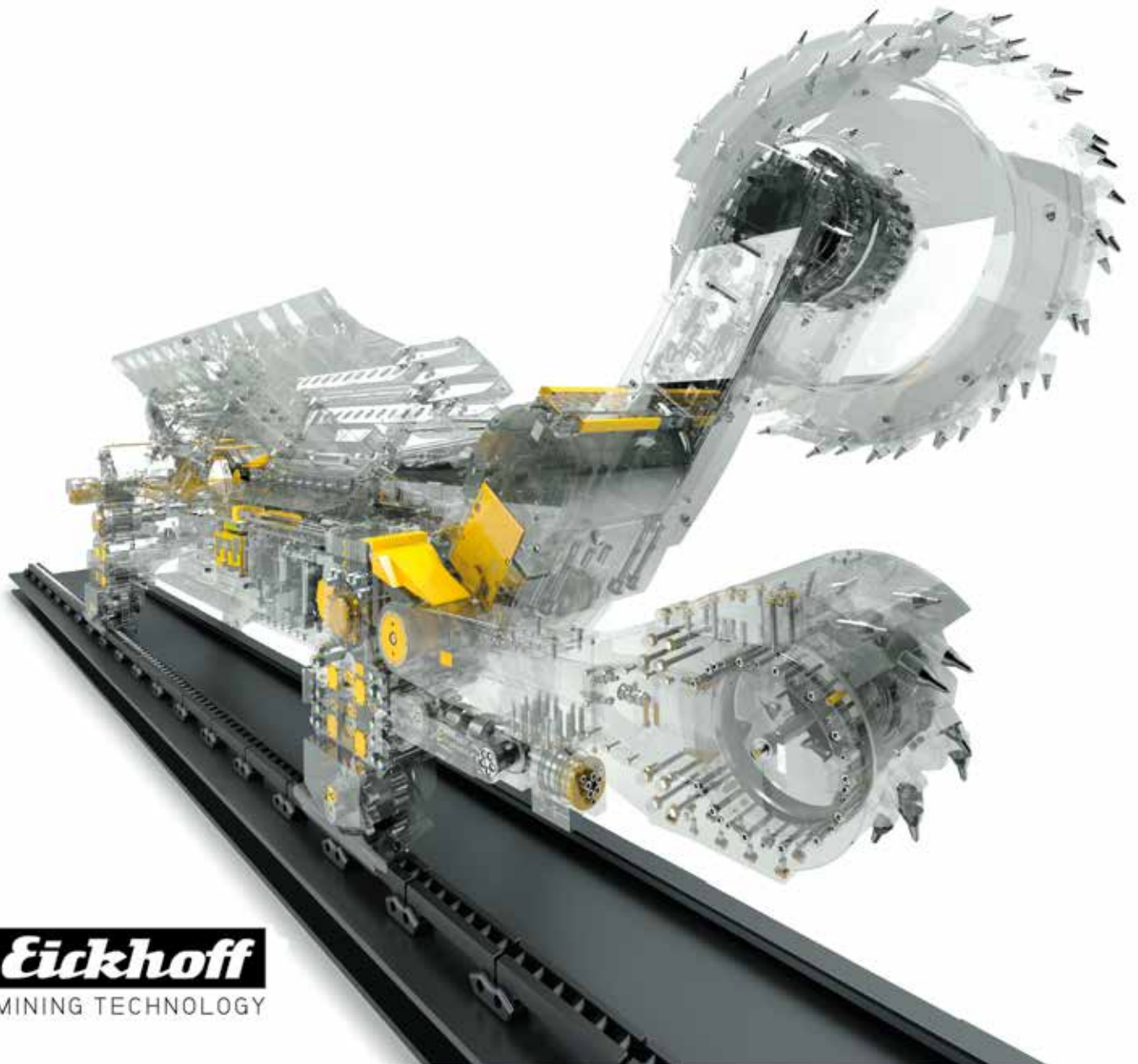


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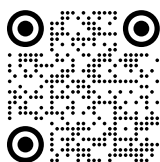
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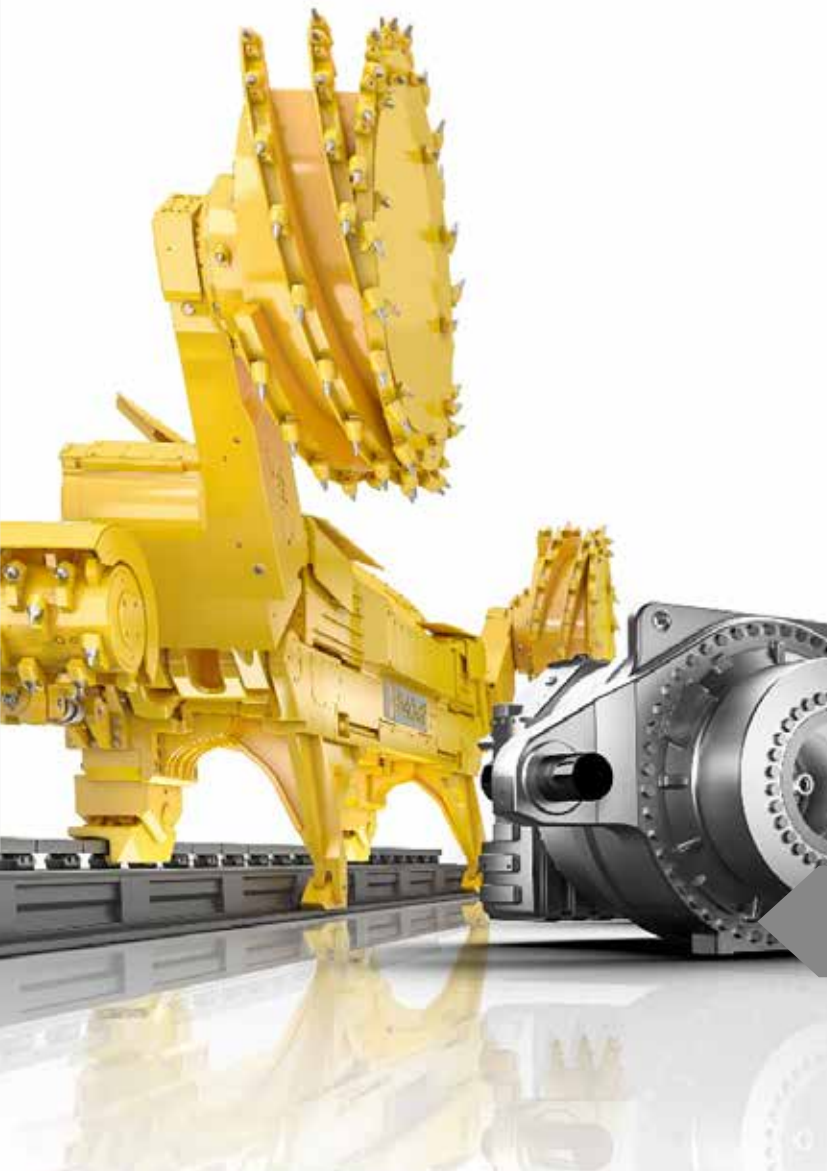
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Where does Thar Coal fit into Pakistan's energy independence pipe dream?

As the missiles rained down on Doha and the rest of the Gulf, Qatar declared force majeure on gas exports. Recently early estimates indicated it may take as long as a month for production volumes to go back to normal.

With another week passing and no end in sight to Iran's aggressions towards its Gulf neighbours that are hosting US military bases, the global energy supply chain is under attack. Perhaps no single region is as vulnerable to the disruption as South Asia. China and India are the single largest buyers of Qatar's Liquefied Natural Gas (LNG) with Taiwan, Pakistan, and South Korea not far behind.

Pakistan's position in this equation is further complicated by the fact that 99% of its imported natural gas comes from the Gulf. The country with the second largest reliance on Gulf gas is Bangladesh, with nearly 60% of their gas imports coming from Qatar and the UAE.

What will the impact of this be in the short term? Pakistan relies on imports for approximately 51.2% of its total energy needs – across electricity generation, home cooking and heating needs, and fuel for vehicles and industrial uses – according to data from the United States Energy Information Administration.

And when it comes to electricity generation, Power Minister Awaiz Leghari claimed in a recent interview with Reuters that 74% of Pakistan's electricity generation comes from local sources, an uptick off the back of rising solarisation. The minister also said that the share of electricity generated through imported LNG in Pakistan was 10%. That much is necessary to meet evening demand peaks and stabilise the grid. In fact, generation from LNG plants has fallen by almost 50% since 2021 according to estimates of the Power Ministry.



Coal generation to drop 7% in 2026, despite Trump's policies

Despite the Trump administration's efforts to boost the coal industry, coal is forecast to generate less electricity this year than last.

The U.S. Department of Energy forecasts a decline in coal generation of 7% this year as renewables, especially solar, gain ground.

It also forecasts the retirement of 4% of U.S. coal generation. The Trump administration has been trying to stop coal plants from shutting down.

Coal plants in Michigan, Indiana, Colorado and Washington state have been ordered to stay on the grid for longer than planned.

Federal officials announced in Louisville last month the rollback of power plant emissions rules.

The Energy Department also approved a federal grant for a pollution control project on a coal plant in Carroll County aimed at extending its operations.

Still, coal is expected to generate 16% of U.S. electricity this year, falling

to 15% next year.

Solar, meanwhile, is expected to increase to 8% of generation this year and 9% next year.

Solar and wind combined are expected to account for 19% this year and 21% next year.

It's been a decade since natural gas displaced coal as the dominant source of fuel for electricity nationwide.

Kentucky is an outlier, with 67% of its electricity still generated by coal.

Coal production and employment in the state, meanwhile, have declined.

Coal generation has become more expensive than other forms of electricity, and electricity customers in Kentucky and other states have been paying the cost.

Customers in Kentucky and other states are also on the hook for the future cost of maintaining coal generation.

Kentucky regulators have recently approved rate increases for electricity customers.



Kazakhstan seeks to meet the rising demand for its new energy projects by increasing mining capacity and upgrading the sector

Kazakhstan seeks to meet the rising coal demand for its new energy projects by increasing mining capacity and upgrading the sector.

These issues were on the agenda of a meeting chaired by Vice Minister of Energy Yerlan Akbarov, with the participation of the country's largest coal-mining companies.

The meeting took place as part of the implementation of the Head of State's directives given at the 5th meeting of the National Qurultay, with a focus on a new national project for the development of coal-based power generation.

As noted by the Ministry of Energy, the project is aimed at strengthening the role of coal as a strategic resource for Kazakhstan,

which has reserves exceeding 33 billion tons. The project involves expansion of generation capacity as well as comprehensive modernization of the sector – from attracting investment and upgrading fuel and logistics infrastructure to introducing environmental solutions and training personnel.

According to the ministry's forecasts, the demand for thermal coal for new projects will exceed 19 million tons per year by 2032. This requires an accelerated increase in production capacity.

In particular, Bogatyr Komir LLP plans to increase coal production from 42.7 million tons in 2024 to 45.2 million tons by 2026, and to reach 56.5 million tons by 2032. By that time, the company



intends to invest 360 billion tenge in the construction of new cyclic-flow technology facilities, the purchase of equipment, and the modernization of production capacities. At the same time, digital solutions are being introduced, including an MES system and freight flow optimization, which will enhance efficiency and safety in mining operations.

Shubarkol Komir JSC also announced plans to increase production. The company expects to raise output to 16.1 million tons by 2026. Its investment program for 2026-2032 is estimated at 95.5 billion tenge and provides for technical re-equipment,

equipment upgrades worth 49.4 billion tenge, the implementation of the second phase of the Cyclic-flow overburden complex-2, and the introduction of digital technologies, including Hovermap 3D mapping systems and robotic dump trucks.

Closing the meeting, Akbarov stressed the need for synchronised development of mining operations, railway infrastructure, and the expansion of the open-top railcar fleet. According to him, this will ensure uninterrupted fuel supplies to the economy and strengthen the country's energy security.



Iran war's gas supply shock pushes top consumers back to coal

Iran's deepening conflict in the Persian Gulf has upended oil and gas markets. It may also have provided coal – with its most significant boost in years.

Climate negotiators have been trying for decades to consign coal to history. That task was already challenging before last month, thanks to expanding energy demand in Asia, a growing focus on domestic self-reliance and faltering programs to wean emerging economies onto greener power.

Now, however, a second gas supply crunch in just over four years is pushing countries across Europe and Asia to fall back on the black stuff, perceived as a readily available alternative. Add in US political support, and coal's long goodbye begins to look even more protracted, a reversal that threatens to undo years of progress on curbing harmful emissions.

Japan, one of the world's largest gas importers, on Friday said it would expand the use of less-efficient coal power plants, as it tries to diversify its generation capabilities. In Bangladesh and India, coal plants are already shouldering the burden of shortfalls elsewhere.

Even in Europe, where plenty of dirty power has been phased out, the Netherlands, Poland and the Czech Republic could all see more coal use if gas prices remain high. Germany is considering reactivating mothballed coal-fired plants as a way to curb electricity prices.

"We are now seeing a second, very large energy supply shock," said Samantha Dart, global co-head of commodities research at Goldman Sachs Group Inc. "If you're sitting in Asia, going through this again, it's possible you change your strategy long term – rely more on coal for longer, build out your renewables faster and reduce your exposure to natural gas."

Gas has long been sold to the emerging world as a bridge fuel – a cleaner alternative to coal that is affordable and reliable, and a step on the path to zero-emissions power generation.

The claim became harder to sustain after the upheaval that followed Russia's invasion of Ukraine, with the price surge and industrial demand destruction that followed. Then came US and Israeli strikes on Iran and a retaliatory attack on

Qatar's giant Ras Laffan plant that could mean years of disruption.

Gas prices in Europe and Asia have yet to reach 2022 levels, but they have already soared – pricing many emerging economies out, with industrial clients already severely impacted across Asia.

"High energy prices will lead governments, industries and households to look at other options," said Fatih Birol, director of the International Energy Agency. "I wouldn't be surprised if there were, at least temporarily, upward pressure on the use of coal both for electricity generation, but also for the industry sector."

Europe's push into renewable energy has helped to reduce the need for fossil fuel generation, cushioning the blow. The number of coal plants has also decreased, limiting the switching option. Indeed, since 2015 coal capacity across Europe decreased by 45%, according to BloombergNEF.

But with renewables unable to meet the full extent of demand, rising gas prices will still push some consumers to turn to coal. Power analysts with the London Stock Exchange Group estimate European

countries could generate around 20% more electricity from coal this summer than last, if the European gas benchmark averages about 50 euros per megawatt-hour. That figure currently stands at around 54 euros.

"This is a bigger disruption than the Russian war," said Tony Knutson, global head of thermal coal markets at consultancy Wood Mackenzie, given the impact on a larger number of countries. Those without enough gas will be forced to pull the coal lever, he added. "I don't think they have a choice."

The biggest swing to coal is likely to be in Asia, where a heavy reliance on oil and gas from the Middle East – and in many cases a limited ability to absorb higher costs – is already causing acute pain. Newcastle coal futures, the benchmark for the power plant fuel in Asia, has climbed by roughly a third this year, hitting the highest level since 2024 earlier this month.

Large economies like Japan, South Korea and Taiwan are major liquefied natural gas importers and also maintain large coal fleets, giving them the ability – and in some cases the incentive – to burn more dirtier fuel as LNG supplies tighten. Japan will allow more coal-fired plants in capacity auctions, and South Korea has also said it is considering moving away from its own curbs on more polluting power.

For top consumers that are also large producers, like India, war-driven fuel shortages strengthen the case for coal – especially as temperatures begin to climb ahead of the summer, lifting demand.

Authorities plan to ask coal plants to defer voluntary



maintenance shutdowns until peak demand passes and have instructed Tata Power Co.'s four-gigawatt plant in Gujarat, which was shut for months, to operate at full capacity until June, when rains usually begin to cover the country.

Coal India, the world's largest producer of the fuel, saw shares rise to the highest since 2024 earlier this month.

"This crisis has given a new leverage to coal in India," said Anandji Prasad, technical director at Western Coalfields, a unit of Coal India. "We have been looking at aggressively developing coal for power generation, but this crisis has brought in focus the need to substitute petroleum products and gas with coal."

The country's cement plants, long reliant on

petcoke, a by-product of oil refining, were among those forced to reconsider when prices began to soar.

"We're stocking up coal for the next 2-3 months, but this can't be a long-term solution," said Hari Mohan Bangur, chairman of Shree Cement, pointing to the lower ash content and higher calorific value of the standard feedstock. "The cement industry needs petcoke."

Neighboring Bangladesh's new government has been forced to seek \$2-billion in loans to be able to import enough fuel to survive the summer. The country is also set to run coal-fired plants at maximum levels in the near-term as LNG prices rise and power shortages deepen, said Shafiqul Alam, lead analyst for the country at the Institute for Energy Economics and Financial

Analysis.

China, as the world's largest consumer, is theoretically vulnerable. In fact, it has been reaping the benefit of a long-standing campaign to diversify energy supply and – after a series of power shortages in 2021 and 2022 – to double down on domestic coal production.

Still, the most insulated major economy appears to be the US. Massive shale production, combined with export capacity that was maxed out even before the war, have kept gas prices little changed since the start of the war, providing little fresh incentive to eye coal.

Even so, political support from President Donald Trump's administration has given the fuel a boost. Earlier this month, Terra Energy Center announced a \$1-billion investment in what

would be the first new coal power project in more than a decade in the country.

Globally, coal demand had been expected to start declining this decade. In December, the IEA said usage in 2025 had edged up to 8.85 billion metric tons and it was forecast to fall 1.4% through 2027.

That now looks far less likely – even if the current setback proves a temporary one, on a path that will ultimately push countries toward more clean energy.

"My gut tells me that in 2026 it's certainly not going to decrease in line with projections that were using pre-war assumptions," said Doug Arent, senior fellow at the WRI Polsky Center for the Global Energy Transition. "The most important thing is to keep the lights on and your productivity moving."

New Hope joins Future Global Alliance

Australian coal producer New Hope Group has joined FutureCoal – the Global Alliance for Sustainable Coal, as the industry body says interest in coal's role in energy security and industrial demand remains strong.

FutureCoal said the new membership reflects growing engagement from Australian coal producers as debate around energy reliability and affordability intensifies.

Australia remains a major player in global coal

markets, holding the world's third-largest coal reserves and generating more than \$90-billion a year in coal exports while supporting about 350 000 jobs across the economy.

FutureCoal CEO Michelle Manook said New Hope's decision to join the alliance highlighted a shift in the national energy discussion.

"Australia is returning to energy realism," Manook said. "As reliability, affordability and system performance move back

to the centre of policy discussions, companies like New Hope are choosing to engage constructively in shaping coal's future."

She said the company would strengthen the organisation's global membership base.

"New Hope Group is an important addition to FutureCoal's membership," she said. "As an Australian coal producer with associated port and agricultural operations, it brings a practical, long-term perspective on how coal continues to operate alongside other energy sources and industries."

FutureCoal said the collaboration would support initiatives under its Sustainable Coal Stewardship roadmap, which focuses on emissions reduction technologies, operational improvements

and environmental standards across the coal value chain.

New Hope CEO Rob Bishop said joining the alliance would help connect Australia's coal industry with international discussions.

"FutureCoal provides an important link between what is happening on the ground in Australia and international discussions on responsible stewardship, technology, and emissions reduction, ensuring practical experience helps shape global outcomes," Bishop said.

Formerly the World Coal Association, FutureCoal represents a body of like-minded coal value chain participants who promote responsible education and transformation across the coal value chain through modernisation and deployment of abatement technologies and processes.



New global dataset puts mining and metals emissions in perspective as demand for energy transition minerals grows

The mining and metals sector accounted for around 11% of global greenhouse gas (GHG) emissions in 2024, as Scope 1 (direct on-site) emissions and Scope 2 (indirect, from purchased power) emissions. This is equivalent to approximately six gigatonnes (Gt) of CO₂. Of this, approximately 3% comes from primary mining activities and 8% from metal production.

Of mining Scope 1 and 2 emissions, 82 per cent are fugitive emissions from coal mining. Fugitive emissions refer to methane and other GHGs naturally present in coal seams that are unintentionally released into the atmosphere during surface disturbance.

Excluding fugitive emissions, Scope 1 and Scope 2 emissions from mining activities contribute 0.54% of global GHG emissions.

Steel production, aluminium production and coal mining were the largest GHG emitters, together accounting for 93% of mining and metals sector Scope 1 and 2 emissions in 2024.

While steel, thermal coal and aluminium are the largest emitters on an absolute basis, this is driven largely by their high production volumes, as they contributed significantly

lower emissions per tonne of product than some other commodities: 1.78 t CO₂ e/t (steel), 0.18 t CO₂ e/t (thermal coal), 12.46 t CO₂ e/t (aluminium) compared to e.g. gold (9,948.48 t CO₂ e/t).

Demand for these commodities, which underpin infrastructure expansion and electricity needs of a growing population, will increase in the coming years, warranting innovation and investment in decarbonising steel and aluminium production and mitigating fugitive emissions.

80% of global mining and metals Scope 1 and 2 emissions are generated in Asia, reflecting the region's role as both a major primary mining centre and the dominant processing hub for most global commodities.

Around 93% of the emissions in the mining and metals sector are direct Scope 1 emissions, generated on site, while the remaining seven% are indirect emissions from purchased electricity (Scope 2 emissions).

The past decade has been the hottest in recorded history. Rising global temperatures are not just numbers on a chart – they are fuelling stronger storms, deeper droughts, devastating floods, and record-breaking wildfires. These changes are already reshaping our world, threatening lives, ecosystems, and economies alike. The climate crisis is no longer a distant challenge; it is a present reality, and how



we respond to the transition to a low-carbon economy will define the future for generations to come.

The mining and metals sector is at the heart of this transition. It provides the copper for renewable power grids, the lithium for batteries, and the steel and aluminium that build our clean-energy infrastructure. As the world progresses towards the global goal of tripling renewable energy capacity by 2030 – a vital step to limiting global warming – and to meeting the UN Sustainable Development Goals, demand for minerals and metals is projected to grow significantly. Yet their production is energy-intensive, contributing greatly to the GHG emissions challenge. Understanding the extent of this contribution is just as important as recognising the sector's critical role in enabling a low-carbon future. A clear, accurate picture of the global mining and metals sector is vital for informed public and policy debate. While several studies have examined global GHG emissions at a sector level, few have looked specifically at the Scope 1 (direct, on site) and Scope 2 (indirect, from purchased power) emissions from mining and metals. One study has estimated that, in 2018, mining and metals production accounted for approximately 10% of global GHG emissions, whilst another study estimated that mining-only GHG emissions contributed between four and seven% in 2020. Yet despite the sector's importance to the energy transition, up-to-date, publicly available and industry wide data has been lacking. By analysing Scope 1 and 2 GHG emissions from 1,700 facilities across 14 commodities – representing 87% of global production of these commodities – and estimating emissions to fill the production coverage gap, we have established a data-driven picture of how much the mining and metals sector contributes to global GHG emissions today.

There remain opportunities to improve the resolution of these data-driven insights, including through deriving facility-level data for the full spectrum of greater than 15,000 facilities currently represented in ICMM's Global Mining Dataset. However, by shedding light on the scale, sources, and distribution of GHG emissions as robustly as we can at present, this dataset provides a foundation for more informed dialogue about the mining and metals sector's role in providing the building blocks for sustainable development and enabling the global energy transition. Specifically, this report examines: GHG emissions produced by the mining and metals sector in 2024. The sector's share of total GHG emissions in 2024, and how it compares with other sectors. Differences in GHG emissions across commodities and regions in 2024. This report provides a snapshot view based on the latest available data in 2024. Although focused on one year, we have provided a dataset for 2020-2025 (2025 data forecasted) which suggests that 2024 is not an outlier but rather is representative.

Like all large-scale datasets, this data will evolve. However, establishing a transparent, industry-wide baseline is a necessary starting point. In line with this intention, we have structured this report to provide data-driven insights separate from the implications we have inferred from the data. We have also made available case studies of ICMM member action on decarbonisation, separately from the dataset itself. It is important to note that this report focuses on the contribution of mining and metals to global GHG emissions via Scope 1 and Scope 2 emissions only. When we refer to sector GHG emissions in this report we mean Scope 1 and Scope 2 emissions. In every sector there are also indirect emissions that occur in the value chain, which are called Scope 3 emissions. ICMM has recently produced guidance

EXTRACTS AND KEY FINDINGS FROM ICMM REPORT

on calculating Scope 3 emissions. As Scope 3 accounting and reporting becomes more common in the industry, exploring industry-wide emissions, including Scope 3 emissions may be a future opportunity. We hope this work sparks curiosity about the data, encourages others to scrutinise it and make their own judgements, and inspires collaboration with us in building a data-driven picture of the mining and metals sector and its role in sustainable development. We invite all interested stakeholders to join us on this journey.

INSIGHTS FROM THE GLOBAL MINING DATASET

Insight 1: The global mining and metals sector accounted for 11% of total global GHG emissions in 2024, 3% from mining activities, 8% from metal production.

Total global GHG emissions in 2024 were 53.2 Gt CO₂ e according to the Emissions Database for Global Atmospheric Research (EDGAR9). Mining activities contributed 1.6 Gt CO₂ e (three% of global GHG emissions) and metal production contributed 4.4 Gt CO₂ e (eight%).

The power industry was the largest source of global GHG emissions in 2024 (15.6 Gt CO₂ e) followed by transport (8.4 Gt CO₂ e) and agriculture (6.2 Gt CO₂ e). Mining and metals together were the 6th largest contributor to global GHG emissions in 2024.

Absolute Emissions (Gt CO₂) 16.0 14.0 12.0 10.0 8.0 6.0 4.0 2.0 Other Sectors » Power industry GHG emissions are those associated with heat or electricity generation from plants (e.g., fossil fuels, biofuels and renewable sources), and therefore, GHG emissions from purchased power are the Scope 2 emissions of other sectors.

Of all mining and metals emissions, 5.5 Gt CO₂ e (93%) were Scope 1, while 0.4 Gt CO₂ e (seven%) were Scope 2

emissions. » These Scope 2 emissions represent roughly 2.6% of the total global power industry's emissions. We have not estimated Scope 2 emissions for other sectors to compare.

Insight 2: In 2024, the largest contributors to Scope 1 and 2 emissions for the mining and metals sector globally were steel production (55%), coal mining (23%) and aluminium production (15%).

Steel production is the largest single source of GHG emissions for the mining and metals sector at 3.3 Gt CO₂ e, comprising mostly (3.2Gt CO₂ e) Scope 1 emissions.

About 70% of the world's steel is presently produced by blast furnace-based processes which are highly carbon-intensive, as carbon from metallurgical coal is used to drive the chemical transformation of iron oxide to steel.

Alumina refining and aluminium smelting together contribute 0.9 Gt CO₂ e (including 0.8 Gt CO₂ e Scope 1 emissions). While refining bauxite to alumina requires high temperature steam and heat, the most significant source of GHG emissions from aluminium production is smelting alumina to aluminium. It originates from two major sources: the consumption of carbon anodes in aluminium electrolysis, which releases CO₂ during use, and the large amounts of electricity required for electrolysis.

Of mining activities, coal extraction represents the largest share of GHG emissions with thermal coal contributing 18% of mining and metals emissions (1.08 Gt CO₂ e) and metallurgical coal 5% of mining and metals emissions (0.29 Gt CO₂ e).

Almost all (97%, 1.33 Gt CO₂ e) of coal mining emissions are Scope 1 emissions, and 96% of those (1.28 Gt CO₂ e) are fugitive emissions. All coal seams naturally contain methane and carbon dioxide trapped in the seam from the process

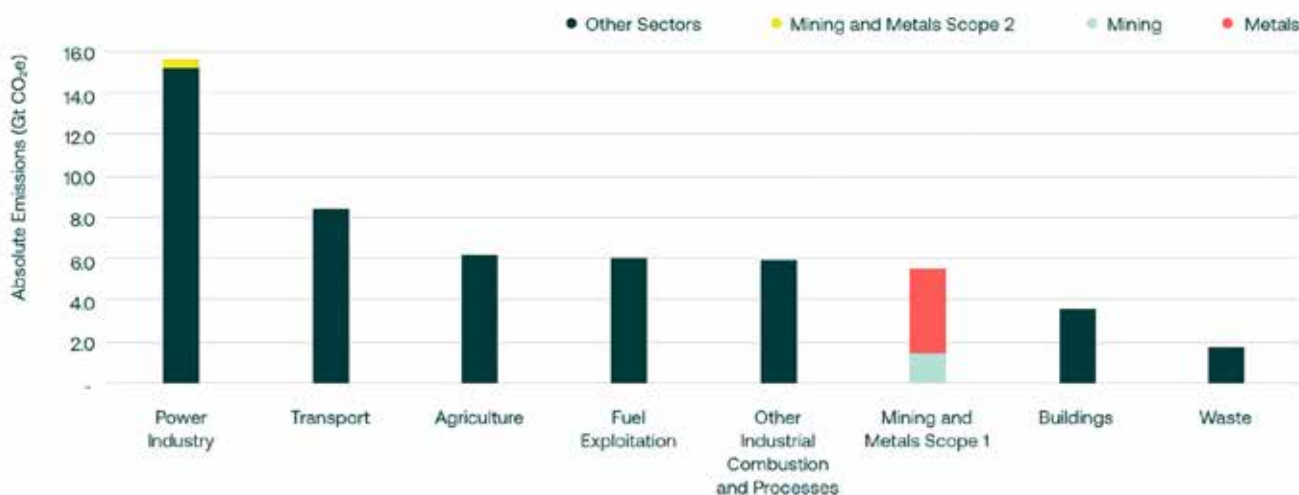


Figure 1: Contribution of global mining and metals sector emissions compared to other sector emissions in 2024. Emissions are scope 1 emissions by sector. Mining and metals scope 1 emissions (10%) are shown in the mining and metals bar. Mining and metals scope 2 (1%) are reflected as part of the power industry scope 1 emissions. Mining and metals sector emissions were derived as described in Appendix: Methodology for the Global Mining Dataset. Please see Approach to calculating global mining and metals emissions for which commodities were included in the analysis and their grouping as either metals or mining. Other industry data were drawn from EDGAR, 2025 and their industry categories are described in the Appendix. EDGAR does not have a sector category called mining and metals; emissions from mining and metals fall under EDGAR's 'Industrial combustion and processes' category which includes combustion for industrial manufacturing and industrial process emissions (e.g., non-metallic minerals, non-ferrous metals, solvents and other product use, chemicals). In this graph, 'Other industrial combustion and processes' category is EDGAR's industrial combustion and processes minus

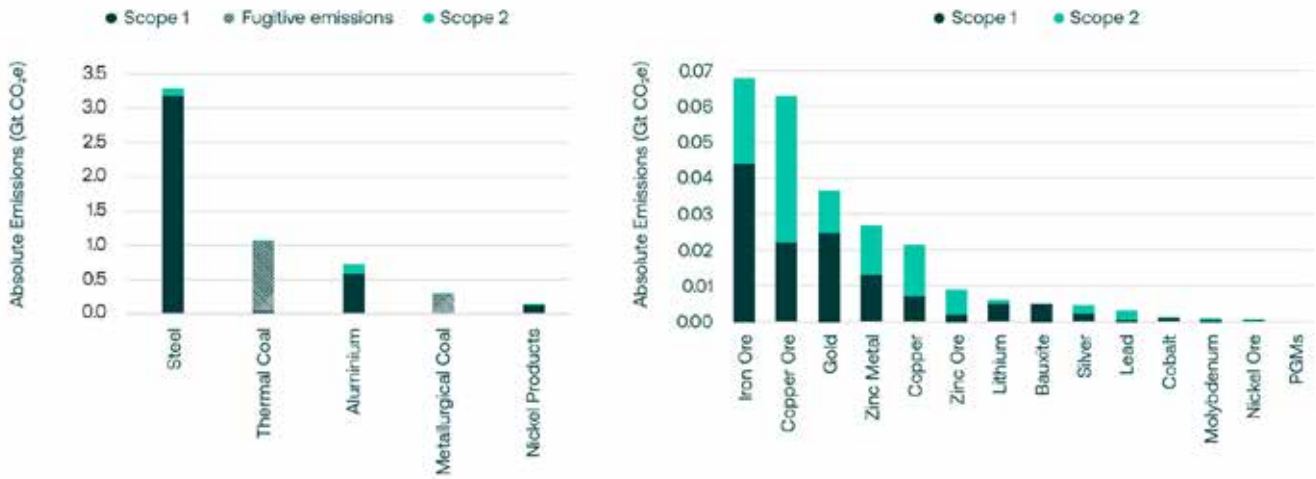


Figure 2: Scope 1 and 2 emissions from mining and meals commodities in 2024. Please note differing scales for the vertical axes. PGMs refer to Platinum Group Metals: platinum, palladium, rhodium, iridium, osmium, and ruthenium.

of coal formation. When a coal seam is disturbed during mining, these gases escape (i.e., become fugitive) to the atmosphere. Fugitive emissions from coal mining contributed approximately 2% of overall global GHG emissions in 2024.

Insight 3: GHG emissions from mining and metal production have increased by three% between 2020 and 2024 – a factor of both the intensity of mining or mineral processing as well as total global demand for the commodities.

While steel, thermal coal and aluminium were the largest contributors to GHG emissions on an absolute basis in 2024, emissions intensities from these commodities (steel

1.78 t CO₂ e/t product, thermal coal 0.18 t CO₂ e/t product, aluminium 12.46 t CO₂ e/t product) are significantly lower than for precious metals.

Gold has the highest emissions intensity of any commodity in our dataset at 9,948.48 t CO₂ e/t product, and silver has emissions at 139.15 t CO₂ e/t product (see Figure 3). The high emissions intensity for these precious metals is primarily driven by the extremely low concentrations of these metals within host rock. This necessitates massive amounts of energy to move, crush and process large volumes of material for a small amount of final product. However, the contribution of these precious metals to total industry emissions is low

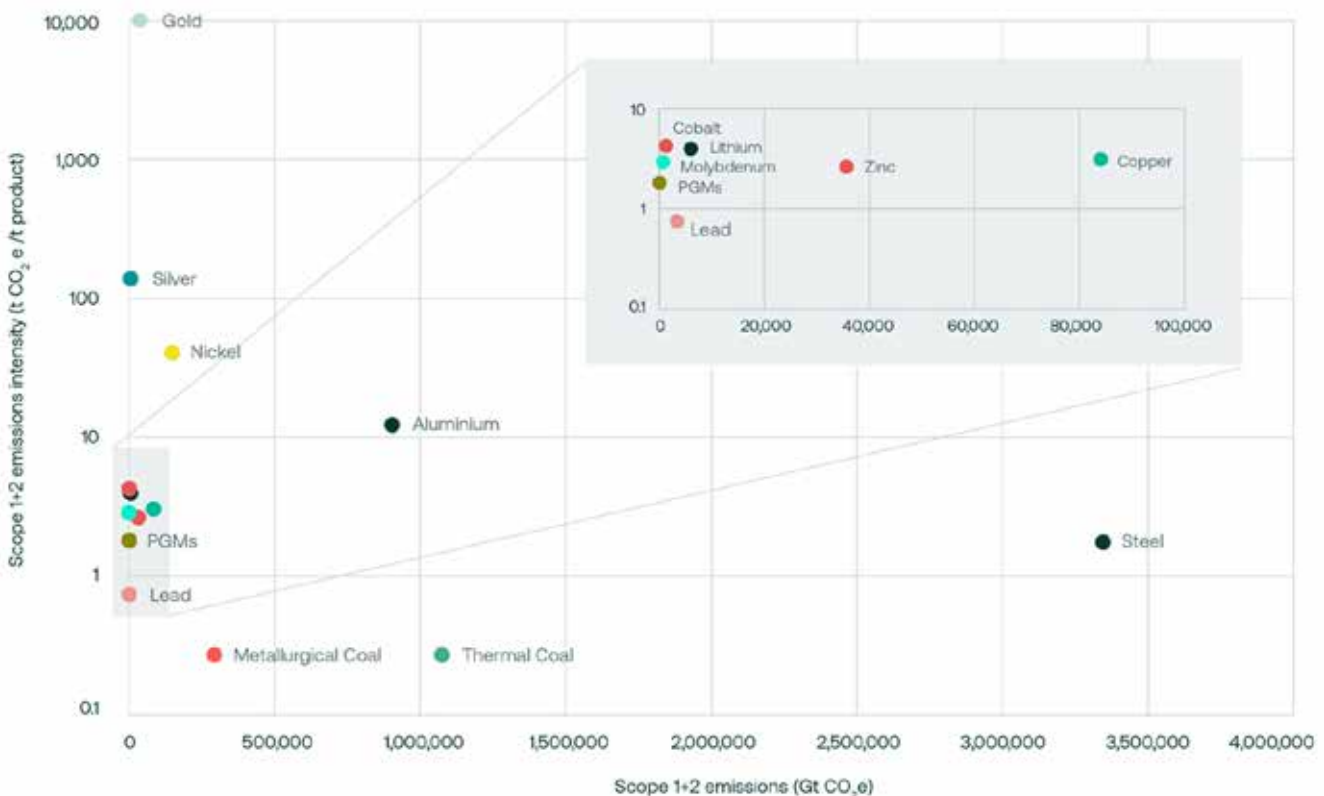
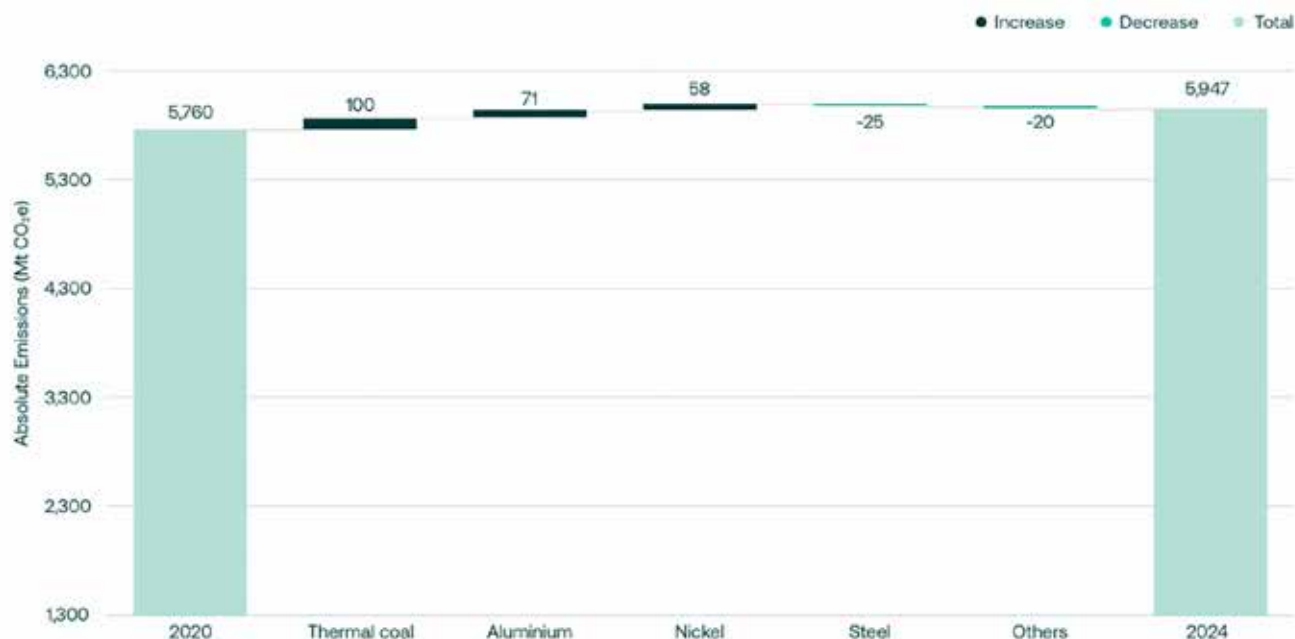


Figure 3: Emissions intensity (t CO₂ e/t product) vs absolute GHG emissions (Gt CO₂ e) for all commodities in 2024.



Production and emissions intensity changes 2020-2024 for commodities contributing most to mining and metals sector GHG emissions

	Thermal coal	Aluminium	Nickel	Steel
Production change 2020-2024 (%)	+10	+12	+45	-0.2
Emissions intensity change 2020-2024 (%)	+1	-3	+13	-1

Figure 4: Changes in absolute emissions (Mt CO₂e), emissions intensity (per cent) and production (per cent) between 2020 to 2024.

because global production of gold (4 kt in 2024) and silver (32 kt in 2024) is low compared to aluminium, steel and coal, which are materials in high demand because of their use in infrastructure, manufacturing and power generation. From the perspective of emissions per unit of economic value, gold traded at US\$77m/tonne in 2024, thus its carbon intensity per dollar of economic value is 0.13 Mt CO₂e /\$B in 2024, lower than other commodities such as aluminium at around 4 Mt CO₂e /\$B. Data for emissions per unit of economic value for other commodities is available in the dataset.

GHG emissions from mining and metals activities have increased by three% from 5.76 Gt CO₂e in 2020 to 5.95 Gt CO₂e in 2024, primarily driven by increases in both the production and emissions intensity of thermal coal and nickel (see **Figure 4**). Nickel is a key component of stainless steel and batteries, which power electric vehicles and is used for other clean energy technologies like wind turbines. Production of aluminium, which is used widely in construction and increasingly in renewable energy infrastructure, has also increased. Notably, emissions intensity of aluminium reduced by three%, driven by shifts toward hydropower and renewable electricity sources.

Insight 4: The distribution of GHG emissions from mining and metals is regionally uneven, but consistent with the distribution of mining and metals processing facilities.

80% of global mining and metals GHG emissions are generated in Asia, reflecting the region's role as both a major primary mining centre and the dominant processing hub for most global commodities (**Figure 5**).

While steel production dominates mining and metals GHG emissions in most regions, notably Europe (93%), coal production is the major source of GHG emissions in North America (41%) and Oceania (37%), see **Figure 6**.

Africa and the Middle East have low total emissions (**Figure 5**) however the major emissions source is kt CO₂, 500,000 50,000 aluminium production contributing 40% of the region's mining and metals GHG emissions, see **Figure 6**. Africa and the Middle East account for only six% of global aluminium production, thus the proportionally high contribution from aluminium in this region is a reflection of the comparatively small steel and coal industries.

After steel (59%), copper ore and aluminium are the next largest contributors of mining and metals GHG emissions in South and Central America (both at 11%)

Aluminium emissions are those from smelting and refining. Steel emissions are those from steel production. Copper ore, iron ore, thermal coal and metallurgical coal emissions are related to mining activities. These represented the main contributing activities in all regions. The 'all others' category includes all other mining or metal processing activities captured in this report.

As the world strives to meet its global climate commitments, the mining and metals sector will continue to play an important role in providing the minerals and metals needed for the energy transition and global sustainable development goals. More steel will be needed for infrastructure to support an

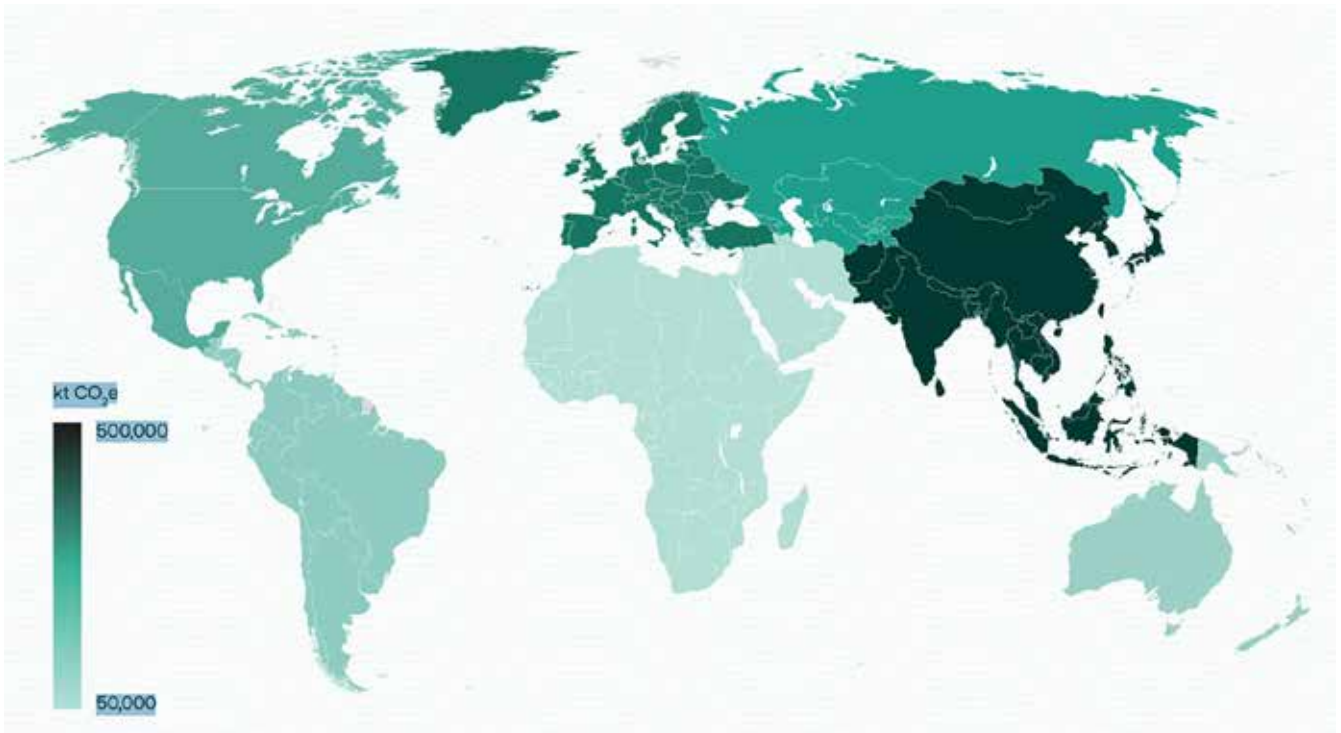


Figure 5: Absolute GHG emissions from mining and metals processing activities across the world in 2024.

urbanising and growing population; aluminium consumption is set to rise with the need for lightweight infrastructure in electric vehicles, solar and wind turbines; and thermal coal consumption is expected to increase in the short term as electricity consumption rises, before plateauing in 2027

However, data confirms that production of these three commodities contributes the most to the mining and metals sector’s GHG emissions presently. To meet the increasing demand required to achieve global sustainable development goals, we, as a sector, must dramatically decouple the necessary growth in production from the growth in GHG emissions.

Medium-term decarbonisation opportunities For steel, global decarbonisation efforts are being driven by a shift away from energy-intensive blast furnace-basic oxygen furnace (BF-BOF) crude steel production towards lower emission direct reduced iron (DRI) with electric arc furnace (EAF) methods, which utilise higher scrap volumes and reduced coal consumption. However, scrap supply is limited and often contains contaminants, such as copper, which can compromise steel quality. Although DRI-EAF production is scaling up, the main constraint for DRI growth is the availability of high-grade iron ore (iron content greater than 67%).

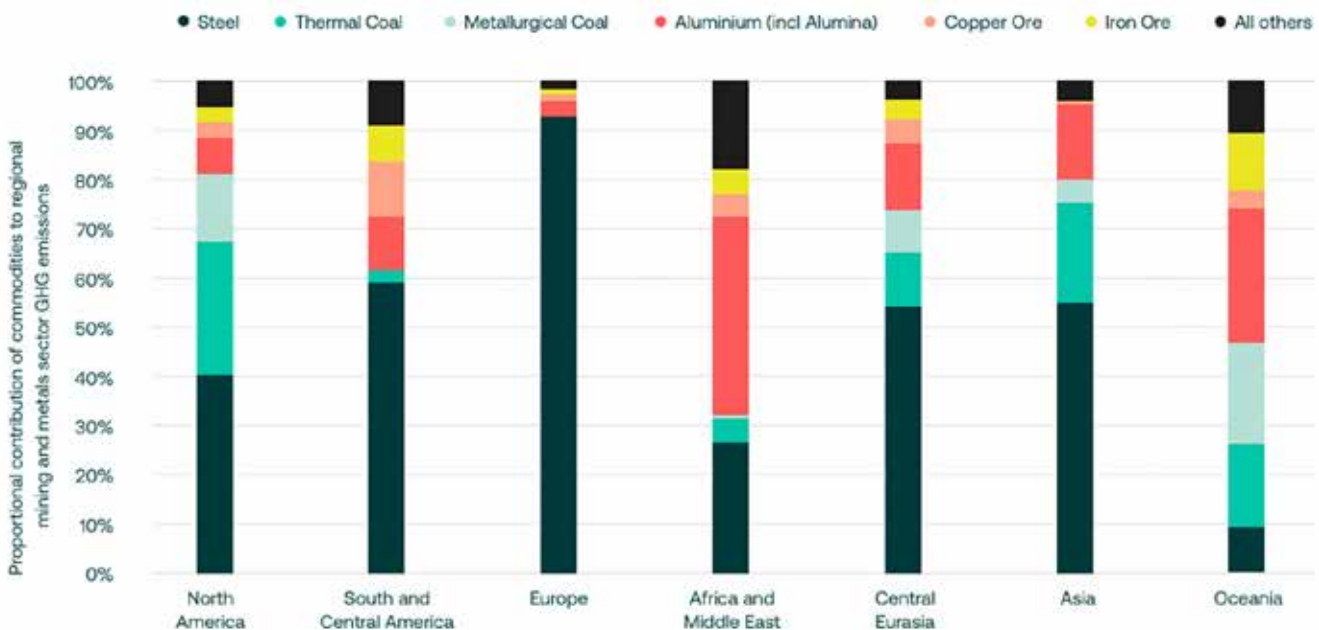


Figure 6: Relative contribution of mining or metal processing activities to regional mining and metals sector GHG emissions in 2024.



Other emerging solutions include Carbon Capture, Utilisation, and Storage (CCUS) which is crucial for mitigating emissions from existing BF-BOF plants that cannot be immediately replaced. This method captures carbon emissions from blast furnace gases and stores them underground or directs them towards production of synthetic fuels/chemicals. In the case of aluminium, the biggest near-term lever is decarbonising the electricity supply as aluminium smelting is extremely electricity-intensive, and the emissions profile depends heavily on the source of power. However, alternatives to carbon-based anodes used in smelting also offer promise.

For coal, fugitive emissions are challenging to mitigate but can be addressed through changes in operational practices to capture methane from mine ventilation before it escapes, or pre-drain it before mining starts, and to utilise it as an energy source.

Beyond these examples, the transition to renewable energy more generally across the industry will also be an important element in decarbonisation for the mining and metals sector. At a typical mine, diesel combustion in haul trucks and loaders is the largest source of direct (Scope 1) emissions, contributing approximately 50% of total CO₂ e output. This represents a significant opportunity for vehicle electrification. Many mines and metallurgical facilities operate their own conventional gas or diesel power stations on site to ensure a steady power supply for crushers, ventilation systems and processing equipment. Those on-site power-generation emissions represent around 30% of Scope 1 emissions.

Transitioning to renewable energies on sites will be part of the solution. Other facilities still depend on coal- or gas-

fired grids, which form a part of the purchased power that represents seven% of total emissions in the mining and metals sector as Scope 2 emissions. As countries and regions transition their grids to renewable energy sources, Scope 2 emissions will decrease, further supporting sector-wide decarbonisation. However, ensuring stable and affordable access to green energy will be essential – particularly for mining and metals companies that rely on purchased power – especially as competition for clean energy grows across other industries. Within mining and metals facilities, companies can also take steps to use energy more efficiently in addition to investing in electrification to drive down emissions. But these efforts only work if there is access to clean energy and low-carbon fuels, and commercial and technical readiness of new technologies are supported by operational readiness and supporting infrastructure. Without strong collaboration, aligning timelines, risk appetites and partnership models between energy providers, governments, investors, technology developers, communities and other key stakeholders, the rising demand for minerals could lead to even higher emissions. This requires coordinated action across sectors to build enabling ecosystems that move beyond transactional models towards more strategic, long-term collaboration to develop supportive policy frameworks, access to finance, and right-fit solutions. This is particularly acute with the extreme regional unevenness of GHG emissions from the mining and metals sector. While this regional GHG emissions profile matches the uneven global distribution of metal processing hubs, demand for the produced metals is global, warranting policy debates that focus on inter-regional collaboration and collective action across investment, infrastructure, technology, and policy arenas to support decarbonisation.



Significant shifts in equipment maintenance

Across the global mining and quarrying landscape, we are witnessing one of the most significant shifts in equipment maintenance philosophy in decades. Lubrication – long regarded as a routine, almost background task – is rapidly becoming a strategic pillar of asset reliability. What was once a manual, schedule-driven activity is now being transformed by digital monitoring, automation, and advanced lubricant formulations designed to withstand the extreme mechanical and environmental stresses of modern mining operations.

The convergence of smart sensors, real-time data analytics, automated delivery systems, and high-performance lubricants is redefining how operators manage wear, friction, and machine health. These technologies are not simply incremental improvements; they represent a fundamental evolution in how the industry approaches reliability engineering. Mines that once relied on periodic inspections and manual greasing are now integrating IoT-enabled condition monitoring, predictive maintenance platforms, and centralised automated lubrication systems capable of delivering precise volumes at optimal intervals.

This shift is driven by necessity. As equipment grows larger, production targets rise, and operations push deeper into remote and harsh environments, the cost of unplanned downtime becomes increasingly severe. Modern lubrication technologies offer a pathway to greater uptime, reduced energy consumption, and longer component life – while also supporting the industry's broader goals of safety, sustainability, and operational efficiency.

Gordon Barratt of Mining & Quarry World explores how these innovations are reshaping lubrication practices across the mining and quarrying sectors, and why the integration of digital intelligence into lubrication management is becoming indispensable for the mines of tomorrow.

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The mining industry continues to operate under significant pressure to improve profitability, a requirement that depends heavily on the reliability and availability of critical machinery and equipment. In this context, lubrication is not a peripheral consideration but a core engineering function that directly influences asset performance, maintenance costs, and overall operational efficiency.

The technical importance of lubrication within mining operations, the challenges associated with selecting appropriate lubricant systems – including energy-efficient, synthetic, and biodegradable formulations – and the ways in which modern lubrication technologies, supported by digital monitoring and automation, are evolving to meet the sector’s demanding conditions. Across the mining value chain, from ultra-class haul trucks to rotary drills and continuous miners, effective lubrication remains one of the most influential yet often under-recognised contributors to equipment reliability.

Mining is fundamental to global resource supply, and the sector’s economic performance is tightly linked to equipment uptime. Lubrication plays a decisive role in maintaining mechanical integrity, reducing component wear, and preventing unplanned downtime. Reflecting this importance, the global mining lubricants market was valued at USD 2,255.3 million in 2023 and is projected to grow 4.7% year-on-year in 2024, reaching USD 2,340.5 million. With a forecast CAGR of 5.4% from 2024 to 2034, demand is expected to rise to approximately USD 3,960.2 million by 2034.

Mining operations frequently take place in remote, abrasive, and thermally extreme environments. Equipment

used in underground development, surface extraction, and material transport is routinely exposed to high loads, shock events, elevated temperatures, and pervasive dust contamination. Under these conditions, equipment reliability and energy efficiency are critical to sustaining production and maintaining safe working environments. Proper lubrication mitigates wear, reduces failure rates, lowers maintenance expenditure, and enhances operational safety.

Energy consumption presents another major challenge. Global mining activities – across both mineral and rock extraction – account for an estimated 6.2% of total worldwide energy use. Approximately 40% of the energy consumed in mineral mining, equivalent to 46 EJ annually, is expended simply to overcome friction. An additional 2 EJ is required to remanufacture or replace components that fail due to wear. Grinding alone represents 52% of mining’s energy demand, followed by haulage (24%), ventilation (9%), and digging (8%).

The economic impact of friction and wear in mineral mining is estimated at 210 billion euros per year. This includes 40% for frictional losses, 27% for replacement parts, 26% for maintenance activities, and 7% for lost production. Adoption of advanced friction-reducing and wear-protection technologies could reduce these losses by 15% over the next decade and by up to 30% over a 20-year horizon. Short-term improvements would yield annual global savings of 31.1 billion euros, reduce energy consumption by 280 TWh, and cut CO₂ emissions by 145 million tonnes. Long-term improvements could double these benefits.

One of the most effective pathways to reducing friction and wear is the deployment of high-performance lubrication solutions, including energy-efficient lubricants and advanced

synthetic or specialty formulations. These solutions complement parallel advances in metallurgy, surface engineering, protective coatings, and component design across gearboxes, engines, shovels, shields, crushers, seals, bearings, conveyors, pumps, fans, hoppers, and feeders. Each subsystem presents unique tribological challenges, and incremental improvements across these areas collectively reduce wear, extend component life, and lower maintenance costs – an important consideration given that maintenance represents a substantial portion of total mining operating expenditure.



Lubrication has long been a critical engineering challenge in mining due to the heavy-duty nature of the equipment involved. Draglines, hydraulic excavators, electric rope shovels, haul trucks, loaders, drilling rigs, and processing machinery all rely on robust lubrication strategies to maintain performance under severe operating conditions.

Mining operations depend on a diverse fleet of equipment across exploration, extraction, haulage, processing, and reclamation. The following sections outline the primary categories of machinery used in the industry and the lubrication requirements associated with each.

Exploration and drilling activities rely on a range of specialised equipment. Core drilling rigs are deployed to obtain subsurface geological samples, while rotary drills are essential for creating large-diameter holes in hard rock formations. Percussion drills are commonly used for drilling blast holes, and sonic drills support geotechnical investigations and environmental assessments. Mud pumps circulate drilling fluids throughout the drilling process, and blast-hole drills prepare the ground for blasting operations. As the mining sector has long demonstrated, lubrication remains a persistent engineering challenge across these systems, as proper lubrication is fundamental not only to performance but also to the reliability and efficiency of drilling machinery.

Excavation operations depend on machines designed to move large volumes of earth and rock. Excavators perform the bulk of digging and material removal, complemented by backhoes for smaller-scale excavation, lifting, and handling tasks. Front-end loaders transport and load bulk materials, while large electric or diesel-powered shovels handle heavy digging and scooping duties. Draglines remove overburden in surface mines, and bucket-wheel excavators provide continuous excavation capability in large open-pit operations.

Crushing and screening processes utilise several types of equipment. Jaw crushers perform primary reduction of large rock, followed by cone crushers for secondary and tertiary size reduction. Impact crushers handle softer materials requiring less force, while gyratory crushers support large-scale ore processing. Roll crushers are used for softer to medium-hard minerals. Vibrating screens classify crushed material by size, and grizzly feeders separate coarse material from finer fractions.

Material transport within mines is supported by conveying systems. Conveyor belts move mined material efficiently across distances, bucket elevators lift material vertically, and radial stackers build stockpiles in controlled formations. Additional material handling relies on forklifts for short-distance transport, cranes for lifting heavy equipment, and hoists for vertical load movement.

Blasting operations require a suite of specialised tools. Explosives break rock, blasting machines ensure safe detonation, and detonators initiate explosions within blast holes. Blast mats control fly rock, while trained shotfirers oversee the entire blasting process. Drilling and blasting systems also include down-the-hole drills for penetrating hard rock and hydraulic drills commonly used in blast-hole drilling in hard-rock mines.

Haulage and transportation systems form the backbone of material movement. Dump trucks transport large volumes of material, articulated haulers operate effectively on rough terrain, and loaders transfer material into haulage units. Haul trucks carry ore and overburden, rail haulage systems support long-distance movement in certain operations, and tippers handle loose materials efficiently.

Processing plants rely on equipment designed to liberate, separate, and refine minerals. Ball mills grind ore into fine powder, while rod mills reduce material to smaller sizes. Flotation cells separate minerals based on surface chemistry, and thickeners remove water from slurry streams. Leaching equipment extracts metals using chemical solutions, gravity separators classify material by density, and magnetic separators isolate magnetic minerals. Hydro-cyclones perform classification and separation, and shaking tables further refine material based on density and particle size.

Ventilation systems are essential for underground operations. Ventilation fans circulate fresh air and remove harmful gases, air scrubbers clean dust-laden or contaminated air, and integrated underground ventilation networks maintain safe airflow throughout mine workings.

Pumping systems manage water and slurry movement. Water pumps support dewatering, slurry pumps handle mixtures of water and ore, sump pumps remove accumulated water from shafts, and pneumatic pumps serve various fluid-handling applications.



Mining support and auxiliary systems enhance safety and structural stability. Bolting machines secure mine roofs, roof support systems prevent collapses, and ground support systems stabilise excavated areas. Exploration samplers collect geological samples, grout plants inject stabilising grout into tunnels, and underground mining carts transport ore and waste through confined spaces.

Underground mining relies on specialised machinery. Continuous miners cut rock and ore continuously, longwall miners extract material from extensive horizontal panels, and room-and-pillar equipment supports operations in mines using this layout. Load-haul-dump (LHD) machines perform loading, hauling, and dumping tasks in confined underground environments.

Safety and health systems are integral to mining operations. Gas detectors monitor air quality, personal protective equipment safeguards workers, and escape chambers provide refuge during emergencies. Fire suppression systems protect vehicles and equipment, first aid kits support medical response, and CCTV systems enhance operational monitoring and safety oversight.

Waste management infrastructure includes tailings dams for storing processing by-products, sludge tanks for handling waste streams, and equipment dedicated to managing waste rock removed during mining.

Reclamation and rehabilitation activities employ dozers to reshape landforms, compactors to stabilise soil, hydro-seeders to establish vegetation, and topsoil spreaders to restore soil layers across reclaimed areas.

Effective lubrication sits at the core of reliable mining operations. It is the mechanism that reduces friction, limits wear and protects critical machine components from premature failure. In an industry where equipment is routinely exposed to extreme temperatures, high pressures, heavy mechanical loads, and pervasive dust contamination, maintaining proper lubrication is essential for minimizing downtime, sustaining performance, and extending asset life – particularly in remote mining locations where maintenance access is limited.

LUBRICANT TYPES, ADDITIVE CONCENTRATIONS AND TYPICAL APPLICATIONS.

Achieving optimal performance requires far more than simply applying a generic lubricant. Lubrication strategies

in mining must be engineered to match the specific operating conditions of each machine. This demands careful consideration of viscosity behaviour, load-carrying capability, thermal stability, resistance to oxidation, and the ability to control contamination. Understanding these parameters is fundamental to maximizing equipment efficiency, reliability, and safety. The combination of heavy loads, elevated temperatures, and abrasive environments means that only high-performance, purpose-designed lubricants can deliver the durability and operational effectiveness required in modern mining systems.

Selecting the correct lubricant is only part of the challenge. Application techniques must also be appropriate for the equipment and its operating environment. Many lubrication points on large machines – such as draglines, shovels, and large excavators – are difficult to access, making consistent and timely lubrication difficult. In addition, formulations must increasingly meet human-health and environmental expectations. Lubricant developers are therefore under pressure to eliminate carcinogenic or toxic components while still delivering the performance demanded by mining equipment. As a result, environmentally responsible formulations are becoming more common, balancing operational requirements with reduced ecological impact.

The challenges associated with lubrication in mining are extensive. Mining environments, whether in coal, iron ore, or other commodities, are heavily contaminated with dust and particulates that rapidly degrade lubricants. Equipment is subjected to extreme mechanical loads, requiring lubricants and greases with high load-bearing capacity and strong resistance to welding or scuffing under severe pressure. Moisture is another persistent threat, as water ingress accelerates lubricant degradation and promotes corrosion. Temperature fluctuations – ranging from sub-zero conditions to high thermal loads – further complicate lubricant performance, demanding formulations capable of maintaining stability across wide temperature ranges.

Monitoring and conditioning lubricants is also difficult due to the remote and dispersed nature of many mining operations. Large fleets of draglines, shovels, excavators, dump trucks, and support equipment often operate across vast areas, making regular inspection and maintenance logistically challenging. For example, operations such as those managed by BCCL in India span dozens of underground, open-cast, and mixed mines, along with multiple washeries, illustrating

Application Type	Typical Additive Type	Additive % Used in Oil
Circulation Oil (Turbine, Compressor)	R&O Classification Antioxidants, Corrosion Inhibitors, Defoamant, Demulsifier	0.5 to 5%
Hydraulic Oil (Non FR Hydraulic)	AW Classification Antiwear Agents Antioxidants, Defoamant, Demulsifier, Corrosion Inhibitors, Pour Point & VI Improvers	2.0 to 5.0%
Gear Oils (Automotive and Industrial Torque Reducer/increaser, Geared Drive)	EP Classification Antiwear Agents Antiseizure Agents, Antioxidants, Defoamant, Demulsifier, Corrosion Inhibitors, Pour Point and VI Improvers	2.0 to 10.0%
Engine Oils (Gasoline, Diesel, Natural Gas)	PCMO/DEO Classification Antiwear Agents, Antioxidants, Defoamant, Corrosion Inhibitors, Dispersants, Alkaline Reserve, Pour Point & VI Improvers	10.0 to 30.0%

the complexity of maintaining consistent lubrication practices across geographically distributed assets. Administrative challenges arise as well, since centralised control of lubrication programs becomes difficult when equipment is spread across remote regions with limited accessibility.

Health and environmental considerations add another layer of complexity. Modern mining operations place significant emphasis on reducing worker exposure to hazardous substances and minimizing environmental impact. Lubricant suppliers must therefore develop formulations that avoid harmful additives while still providing the necessary protection against friction, wear, and thermal degradation. Eco-friendly lubricants are increasingly important as the industry seeks to balance operational performance with sustainability goals.

As mining operations grow more demanding, lubricant manufacturers face increasing pressure to deliver solutions that not only meet OEM performance specifications but also help reduce maintenance costs, extend component life, and support broader health, safety, and environmental objectives. The development of advanced lubrication technologies is therefore becoming a critical enabler of reliability and efficiency across the mining sector.

Mineral-oil-based lubricants continue to dominate mining applications because they are widely available, cost-effective, and suitable for high-volume use in hydraulic systems, engines, and gearboxes across heavy-duty equipment such as excavators, dump trucks, backhoe loaders, draglines, and drilling rigs. The mining sector remains highly price-sensitive, which slows the transition to more advanced formulations. However, the shift toward specialty and synthetic lubricants has already begun as tribological challenges become more apparent and engineers increasingly recognise the performance limitations of conventional mineral oils.

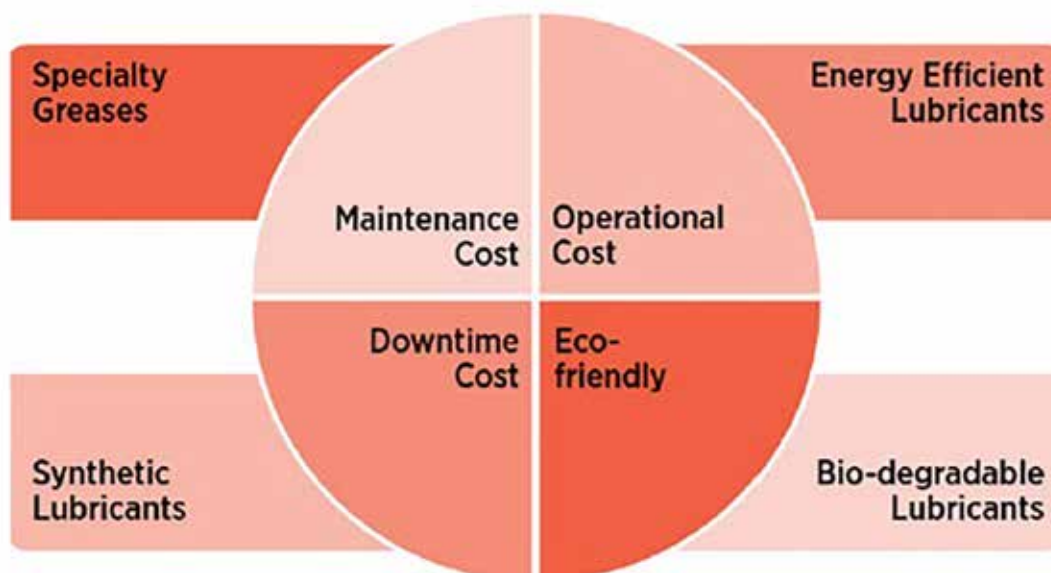
Greases remain essential across many mining machines, including dump trucks, excavators, crushers, and draglines. These components operate under severe mechanical loads, making high load-carrying capacity a critical requirement. Greases must withstand high Timken and weld loads, resist

impact loading, and maintain structural integrity under shock conditions – characteristics that standard greases cannot reliably provide. Moisture and dust contamination further complicate lubrication, necessitating greases with strong water resistance, dust resistance, and robust tackifier and additive systems to protect bearings, pins, bushings, and other exposed components.

Certain applications demand high-temperature greases, typically based on bentonite or clay thickeners, which offer high drop points or non-dropping behaviour to ensure stability in thermally extreme environments. In areas where lubricated components are exposed to chemicals – such as bearings, shafts, and axles – chemical-resistant greases are required to maintain film strength and prevent degradation.

Energy-efficient lubricants have become increasingly important as mining operations pursue higher productivity, lower operating costs, and reduced environmental impact. These lubricants minimise friction more effectively than conventional formulations, improving mechanical efficiency in equipment such as drills, haul trucks, and crushers. Reduced friction translates directly into lower fuel consumption and measurable energy savings. Modern energy-efficient lubricants are often synthetic or semi-synthetic and incorporate advanced additive technologies, including nanomaterials designed to enhance boundary and mixed-regime lubrication where metal-to-metal contact is most likely.

The growing emphasis on sustainability places additional pressure on formulators to develop biodegradable oils and greases capable of withstanding the severe operating conditions typical of mining. Synthetic lubricants, particularly those based on API Group IV (PAO) and Group V (esters), are increasingly adopted because they offer superior performance under extreme temperatures, pressures, loads, and moisture exposure. Although more expensive, synthetic lubricants provide significantly longer service intervals than mineral oils, reducing both lubricant consumption and waste generation. Their extended life cycles contribute indirectly to environmental stewardship by lowering the volume of used oil requiring disposal.





Biodegradable lubricants are gaining support from both mining companies and regulatory bodies seeking to reduce environmental impact. Esters from API Group V are especially suitable because they are inherently biodegradable while still delivering high performance under demanding conditions. Developing biodegradable lubricants that can endure the mechanical and thermal stresses of mining remains a significant engineering challenge, but progress continues as sustainability becomes a core operational priority.

Selecting and applying the correct lubricant has a direct influence on maintenance costs, equipment uptime, and overall profitability. Proper lubrication reduces wear, prevents premature component failure, and minimises unplanned downtime. In parallel, the adoption of advanced lubrication practices – such as automated lubrication systems, condition monitoring, and data-driven maintenance strategies – further enhances equipment reliability and reduces operating costs. Together, high-performance lubricants and modern lubrication management practices form a critical foundation for improving the efficiency, durability, and sustainability of mining operations.

Best practices for lubrication in the mining sector increasingly revolve around monitoring, precision, and data-driven maintenance. Lubrication monitoring and condition-based maintenance have become central to reliability engineering, with oil analysis serving as one of the most effective tools for detecting contamination, degradation, and wear metals. Regular analysis of used oils provides early insight into component health, enabling proactive interventions that preserve lubricant integrity and extend equipment life. Alongside laboratory analysis, condition-monitoring systems equipped with IoT-based sensors now provide real-time data on lubricant condition, temperature, viscosity changes, and contamination levels.

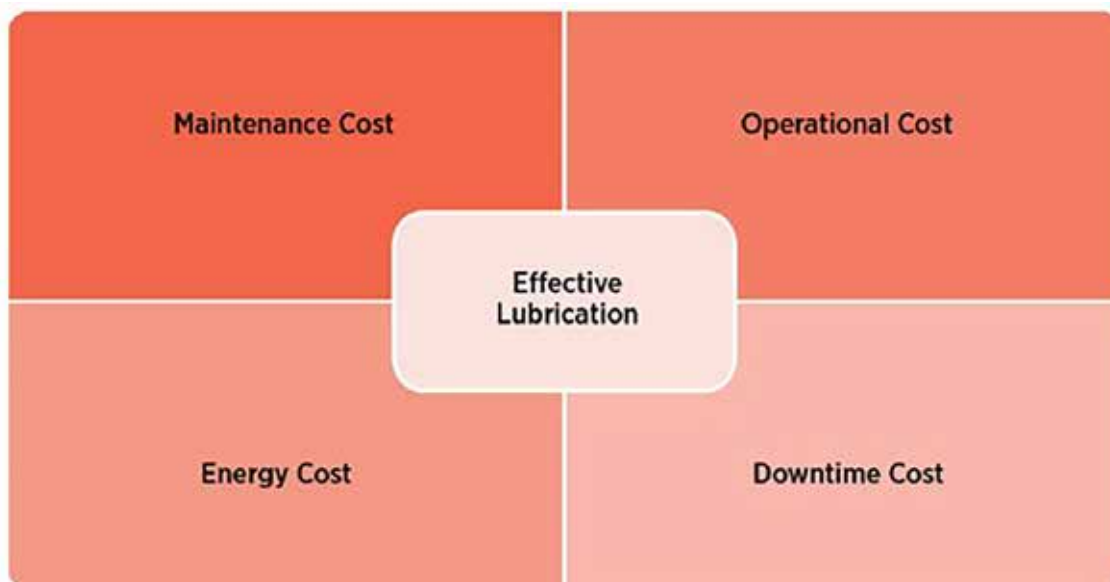
These systems allow engineers to predict potential failures before they occur, reducing unplanned downtime and significantly improving system reliability across mining operations.

Automated lubrication systems further enhance reliability by ensuring that critical components receive the correct amount of lubricant at the right intervals without relying on manual intervention. Centralised lubrication systems are now common on crushers, conveyors, and other high-duty equipment, where consistent lubrication is essential for maintaining uptime and reducing wear. These systems minimise human error, improve lubrication accuracy, and reduce maintenance labour requirements.

Proper storage and handling of lubricants remain equally important. Contamination introduced during storage, transfer, or handling can compromise lubricant performance long before it reaches the equipment. Mining operations must therefore maintain strict adherence to manufacturer guidelines for storage conditions, filtration, and dispensing practices to ensure that lubricants retain their designed properties.

Training is another critical component of effective lubrication management. Many lubricant suppliers conduct technical workshops and seminars for frontline managers, supervisors, and operators to ensure that personnel understand lubrication fundamentals, application techniques, and the consequences of improper practices. Ongoing training programs have a measurable impact on equipment longevity and operational reliability, particularly in large mining operations where staff turnover and varying skill levels can affect maintenance consistency.

Digitalisation and the integration of IoT technologies have transformed lubrication practices across the industrial sector, and mining is no exception. As equipment operates under



extreme loads, temperatures, and environmental stressors, the need for precise and reliable lubrication becomes even more pronounced. Traditional lubrication methods often suffer from inefficiencies, inconsistent application, and a lack of real-time visibility. Digital tools now address these limitations by enabling continuous monitoring, automated alerts, and predictive maintenance strategies.

IoT devices embedded in mining equipment monitor lubrication levels, contamination, and operating conditions, allowing maintenance teams to predict lubrication needs before failures occur. This shift from reactive to predictive maintenance reduces breakdowns and extends component life. Data analytics further enhances lubrication management by enabling mining companies to optimise lubricant consumption, improve operational efficiency, and reduce overall maintenance costs. Machine learning and artificial intelligence are beginning to play a role as well, analysing large datasets to determine optimal lubrication intervals and predict when replenishment or replacement is required. Although widespread adoption in mining is still developing – largely due to the remote and dispersed nature of mining operations – these technologies represent the future of lubrication management.

In the mining industry, where operational efficiency and equipment reliability are essential, lubrication solutions directly influence productivity, safety, and maintenance expenditure. Continuous research and innovation are required to meet the increasing demands of modern mining while addressing environmental and operational challenges. The industry must continue to embrace digitalisation and advanced lubricant technologies, including energy-efficient formulations, which reduce frictional losses, lower energy consumption, and improve system reliability.

Extreme operating conditions, abrasive environments, and the growing emphasis on sustainability demand lubrication strategies that are both robust and adaptable. Automated lubrication systems, IoT-enabled sensors, and predictive analytics provide significant advantages by enabling precise application, real-time monitoring, and informed decision-making. These innovations enhance the overall effectiveness of lubrication practices and support the long-term reliability of mining equipment.

Looking ahead, the future of lubrication in mining will be shaped by continued advancements in digitalisation, predictive maintenance, and environmentally responsible formulations. As mining companies adopt these technologies, they will be better positioned to meet evolving operational demands while improving both efficiency and environmental performance. Ultimately, investing in the right lubrication solutions is not merely a maintenance decision – it is a strategic investment in the long-term resilience and success of the mining industry.



Are conveyor belt returns the solution to efficiency?

The return side of this belt is completely encapsulated by dust and spillage.

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any experts will attest to the fact that efficiency and safety are inextricably linked. Thus, an emphasis on safety translates into reduced operating costs and increased production. Clean return systems using modern equipment mean less spillage and

cleanup under and around the belt, which mitigates labor costs, downtime and exposure to work hazards. A well-maintained belt return also yields less dust, fewer fouled rolling components, and a centered belt entry from the tail pulley into the loading zone.

FUGITIVE MATERIAL

The fugitive material hazards posed around the belt return begin with the discharge at the head pulley. An insufficiently cleaned belt can cause carryback to drop along the entire belt path and spill into walkways or on the return belt. This produces a trip hazard and a possible violation. In addition, dust can get into cracks and divots in the belt, release along the belt path, and foul gears and bearings of rolling components, causing them to seize and creating a possible fire hazard.

Inadequate cleaning technology and tensioning systems allow carryback to collect directly beneath the discharge

zone. If not addressed, material accumulates quickly until the belt runs along the top of the pile, creating carryback across the entire profile while abrasion degrades the belt face and frays the edges. In extreme cases, encapsulation can move carryback to the inside of the belt, fouling pulley faces and causing them to slip, leading to mistracking and component wear.

EQUIPMENT HAZARDS

Many operators focus on cargo-side issues and neglect the return side, where belt tracking should be a pivotal concern. When left unchecked, the belt can drift into the structure, causing fraying and potentially creating a fire hazard. Moreover, if the belt is off-center on the tail pulley, it will likely enter the loading zone unevenly, resulting in off-center cargo loading and exacerbating cargo-side belt tracking issues.

While issues from fugitive material to belt tracking can cause a number of mechanical problems, each one also represents a safety hazard. If components are not functioning at 100%, there is an increased likelihood of a situation that may put a worker in danger while trying to fix the problem. An operation's interests are best served by taking actions intended to prevent the mechanical problems and the accompanying potential for injury, rather



Figure 1: Innovative belt cleaning technology can improve cleaning, safety, and the cost of operation.

than just protecting the worker from hazards that will likely be present with guarding.

SAFE AND EFFICIENT CLEANING

In the past, *belt cleaners* were rigid, linear pieces of hardware made out of various materials from brick to plastic that earned the name “scrapers” or “wipers” because that’s what they did. They had a low operational life, broke or cracked often, and significantly contributed to belt wear.

Modern primary cleaners are usually mounted at the head pulley, made from engineered polyurethane, which is forgiving to the belt and splice, but still highly effective for dislodging cargo. Typically supported by mechanical or

pneumatic tensioners designed to meet the needs of the application, the designs require significantly less monitoring and maintenance of blade tension. At least one modern primary cleaner design requires no tensioning at all after initial installation. Featuring a matrix of tungsten carbide scrapers installed diagonally to form a 3-dimensional curve around the head pulley, it typically delivers up to 4x the service life of urethane cleaners without ever needing re-tensioning. (Figure 1)

As conveyor speeds and cargo volumes increase to meet production demands, *secondary belt scrapers* are often installed immediately after the belt leaves the head pulley to address dust and fines that escape the primary cleaner. Generally equipped with spring or air tensioners that easily adjust to fluctuations in the belt, secondary cleaners are particularly efficient for applications that produce wet, tacky or dusty carryback.

In most applications, normal belt wear can yield valleys and depressions in the belt. Dust and fines that get into these blemishes often remain even after passing under primary and secondary belt cleaning blades, becoming dislodged by the impact of any return idler the belt meets. This causes dust and spillage in areas away from the head pulley. (Figure 2)

In such cases, operations may choose to install a Washbox Cleaning System, which combines secondary cleaners with water spray bars enclosed in a self-contained unit that captures residue and drains wastewater safely away from the work area. (Figure 3)

Even on a clean belt, mistracking is another concern, especially for operators of long conveyors. Previous *belt tracking systems* were reactionary pieces of equipment

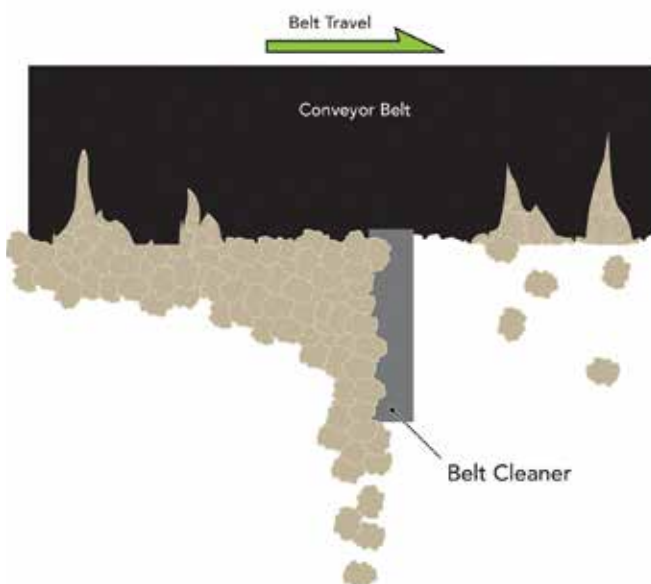


Figure 2: Cleaning a damaged belt with a scraper blade



Figure 3: Thoroughly clean a damaged belt with a washbox.

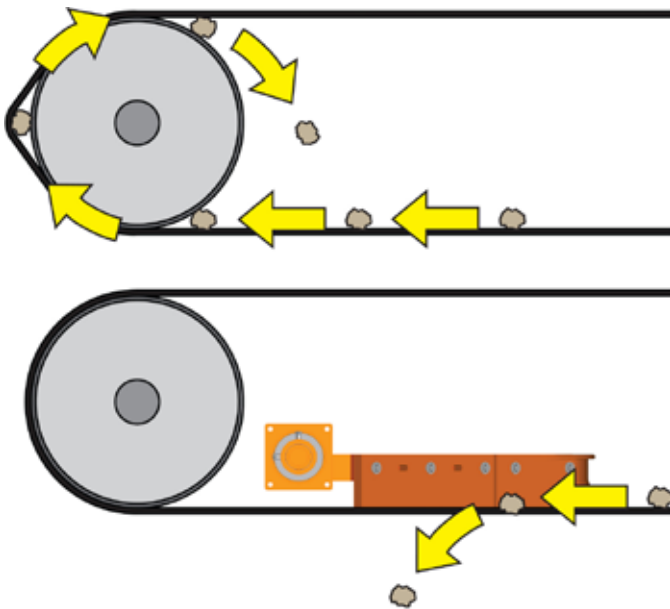


Figure 4: A V-Plow helps prevent repeated entrapment of material between the belt and tail pulley.



Figure 5: The workhorse of tail pulley protection, the V-plow safely clears debris without harming the belt.

designed to help prevent belt contact with the mainframe, however these designs have historically experienced problems with friction heat, edge degradation and belt curling. To avoid these expensive and hazardous consequences, operators can now specify modern tracking equipment designed for the belt return. Shorter single-direction or reversing conveyor systems may only require a crowned roller that uses a ribbed lagging made of durable polyurethane. The moment the belt wanders off-center, the assembly tilts to the opposing side and steers it back toward the center.

Some longer systems may require a series of modern upper and lower trackers hung from the mainframe every 70 to 150 feet (21 to 50 m) and on the return run directly prior to the tail pulley. These designs utilise innovative multiple-pivot, torque-multiplying technology with a sensing arm assembly that detects slight variations in the belt path and immediately adjusts a single flat rubber idler to bring the belt back into alignment.

TAIL PULLEY PROTECTION

Fugitive debris on the return side of the belt can rapidly reach the tail pulley. Once caught between the belt and the pulley, these material chunks can recycle through over and over again, each time putting a new divot in the belt, as well as gouging and fouling the pulley face. This material can become ground into fine dust or ejected from the pulley. Plows are often used to clean the inside of the belt and protect the tail pulley and belt from damage. (Figure 4)

A V-Plow or diagonal plow can extend the life of the entire system by minimizing fouling of the pulley face that can lead to mistracking. Attached to dual steel crossbars bolted to the conveyor frame ahead of the tail pulley, the units employ a unique torsion-arm suspension system that adjusts to fluctuations in belt tension to maintain consistent pressure for effective cleaning at all stages of wear. Lightly riding on the belt, the diagonal design deflects debris away in a specific direction, while the V-plow design deflects debris to either side. Where large lumps or broken idlers are getting on the return side of the belt, a tail protection plow designed for high impact is used, often in addition to or in combination with a return belt cleaning plow. (Figure 5)

GUARDING

Installing adequate *guarding* that encloses the system and has the correct mesh size and mounting distance from the hazard also helps protect workers from fugitive material and reach-in injuries. For systems that are considered “guarded by location” (too high to reach), gates may not be required, although most countries have standards that require guarding against falling bulk materials. (Figure 6)

Return roller guards -- though seldom seen except over roads and walkways -- improve safety and meet the growing demands of government regulations. Build-up under the conveyor or on work platforms can negate the guarded by location “too high to reach”



Figure 6: Conveyor guarding prevents reach-in, but also constrains fugitive debris to under the system.

criteria, so best practice is to guard all known hazards or eliminate the hazard by design.

CONCLUSION

From head pulley to tail pulley, return side belt care is essential to maintaining an efficient and productive system. By installing modern equipment that helps remedy common return side problems, operators reduce the time workers spend near the system servicing and cleaning it. This mitigates hazards, reduces downtime and improves compliance.

In addition to resolving many mechanical problems, these improvements will help prevent injuries caused by incidental contact with a moving belt that can pull a worker into pinch and shear points, some of the most prevalent workplace hazards in bulk handling operations. Over hundreds of projects that directly address return side issues using modern equipment, operators have reported a quantifiable return on investment. Decreased man-hours for system cleaning and downtime for maintenance enable a lower cost of operation, translating into a return on investment in as little as 12–24 months. If an injury is prevented, the payback is instantaneous, but even without considering the cost of an injury, the improvements actually pay for themselves over time.

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Daniel Marshall

Process Engineer, Martin Engineering

Daniel Marshall received his Bachelor of Science degree in Mechanical Engineering from Northern Arizona University. With nearly 20 years at Martin Engineering, Dan has been instrumental in the development and promotion of multiple belt conveyor products. He is widely known for his work in dust suppression and considered a leading expert in this area. A prolific writer, Dan has published over two dozen articles covering various topics for the belt conveyor industry; he has presented at more than fifteen conferences and is sought after for his expertise and advice. He was also one of the principal authors of Martin’s FOUNDATIONS™ The Practical Resource for Cleaner, Safer, and More Productive Dust & Material Control, Fourth Edition, widely used as one of the main learning textbooks for conveyor operation and maintenance.



Skills to meet new requirements in the mining industry – Training and Development

By Trevor Barratt MD

Coal International and Mining and Quarry World

I want this article to have but two virtues: brevity and fundamental relevance. I want it to be brief since over-elaboration draws attention away from central issues. relevant to the extent that it isolates these central issues from the temptingly easy detail and concerns itself more with the 'what' rather than the 'how' of training and development.

I have spent more than five decades immersed in the mining industry, beginning my career as an apprentice electrician in 1965 in the UK. under the then National Coal Board, a system that demanded commitment but gave far more in return. It was a wonderful period, rich with learning, mentorship, and the kind of camaraderie that only mining can produce. The NCB didn't just train apprentices; it shaped them. It taught discipline, respect for the craft, pride in doing things properly, and the quiet confidence that comes from earning your place underground. Those years were not simply preparation for a career; they were an education in life, work, and community.

The five-year apprenticeship before qualification provided a foundation of skill and character that shaped the rest of my mining career long before moving into publishing.

NWARDS

Today's mining industry is shifting faster than at any point since mechanisation arrived in the 1960s – automation, digitalisation, ESG pressures, and new safety expectations are reshaping what

"skilled" means underground and at the surface. Training and development aren't just HR tick boxes anymore; they're strategic survival tools. First then, do we fully recognise the

extent of the change taking place? Those who live through a period of radical change and are active participants in it often cannot see the extent of change as clearly as the bystander- ask any occasionally visiting grandparent!

Have we as professionals and as people yet come to terms with the change and are we fully equipped by education, training, development and experience to respond to the opportunity and the challenges now presented. Are we equipped and in the right frame of mind to attack the future

rather than-as for so many years- to defend ourselves against it. That must be the fundamental question asked when treating the subject of this article.

In this article, I will argue that training and development must evolve from administrative obligations into strategic assets. My call is simple: keep it brief, keep it relevant, and focus on the fundamentals.

RECOGNISING THE NEW SKILL LANDSCAPE

If we accept that the industry is changing, we must then define the skills that matter most in this new environment. The temptation is to produce long lists – competencies, frameworks, matrices – but these often obscure more than they reveal. What matters is clarity around the domains of capability that determine whether a workforce can thrive in a modern mine.

Four stand out as fundamental.

1. Digital Fluency, Not Digital Specialism

Mining no longer needs every worker to be a data scientist, but it does require a workforce that is comfortable with data enabled decision making. Sensors, dashboards, autonomous systems, and predictive maintenance tools are now part of daily operations. The essential skill is not coding; it is the ability to interpret information, trust it, and act on it.

2. Systems Thinking Over Task Thinking

Modern mines are integrated ecosystems. A change in one area – ventilation, haulage, scheduling, energy use – ripples across the whole operation. Workers who understand how their role fits into the wider system

make better decisions, reduce downtime, and improve safety. This is a shift from “my job” to “our process”.

3. Adaptability as a Core Competence

For decades, mining rewarded mastery of a stable craft. Today, the craft evolves continuously. Equipment updates, regulatory shifts, ESG expectations, and automation cycles demand a workforce that can learn, unlearn, and relearn. Adaptability is no longer a personality trait; it is a professional requirement.

4. A Modern Safety Mindset

Safety has moved from compliance to culture. The new skill is not simply following rules but recognising risk, communicating it, and intervening early. Psychological safety – speaking up without fear – has become as important as physical safety. Mines that fail to cultivate this mindset will struggle to meet both regulatory and societal expectations.

THE REAL QUESTION: ARE WE PREPARING PEOPLE FOR THIS?

If these are the skills the industry now requires, the uncomfortable question becomes unavoidable: **are our training and development systems aligned with them?** Too often, training remains reactive, compliance driven, or anchored in yesterday’s job descriptions. Development programmes still assume a static industry rather than a dynamic one.

The challenge is not simply to update courses or buy new simulators. It is to reshape the mindset of the organisation so that learning becomes continuous, strategic, and valued. The mines that succeed will be those that treat training not as a cost but as an investment in resilience.





WHAT A FUTURE READY TRAINING STRATEGY MUST LOOK LIKE

If the industry is to meet its new skill requirements, training and development must shift from event based instruction to a continuous, strategic capability. Three principles define this shift.

1. Training Must Be Integrated, Not Isolated

For too long, training has been treated as a separate activity – scheduled, delivered, signed off, and forgotten. Modern mining demands the opposite. Learning must be embedded into daily operations:

- real time feedback from digital systems,
- on shift coaching,
- simulation based practice before equipment changes,
- and structured reflection after incidents or near misses.

Training becomes effective when it is part of the workflow, not an interruption to it.

2. Development Must Be Forward Looking, Not Backward Facing

Traditional development models reward tenure and past performance. The new environment rewards potential, adaptability, and the willingness to learn. Mines must identify and nurture people who can grow into new roles – automation technicians, data enabled supervisors, ESG coordinators, remote operations specialists.

The question is no longer “What can this person do today?” but “What could this person become with the right development?”

3. Leadership Must Champion Learning as a Strategic Asset

No training programme succeeds without leadership commitment. Supervisors and managers must model the behaviours they expect curiosity, openness to

change, and a willingness to admit when they need to learn something new.

A mine that encourages questions, experimentation, and constructive challenge will outperform one that clings to hierarchy and habit. Culture, not curriculum, is the decisive factor.

THE COST OF INACTION

It is tempting to believe that the industry can adapt gradually, that incremental improvements will be enough. They will not. Mines that fail to modernise their training and development approach will face:

- widening skills gaps,
- reduced productivity,
- increased safety risks,
- and difficulty attracting the next generation of workers.

The industry is already competing with technology, energy, and engineering sectors for talent. Without a compelling development pathway, mining will lose that competition.

CONCLUSION: PREPARING PEOPLE TO SHAPE THE FUTURE, NOT SURVIVE IT

The mining industry stands at a point of inflection. Technology, regulation, and societal expectations are rewriting the definition of a skilled workforce. The question is not whether we can keep up with this change, but whether we can get ahead of it.

Training and development must therefore be treated not as administrative necessities but as strategic investments – investments in resilience, innovation, and long term competitiveness.

If we equip our people with the right skills, mindset, and confidence, they will not merely adapt to the future of mining. They will shape it.

Coal International

Proposed subjects for Coal International

Every issue of **Coal International** contains the latest news, new plant and equipment, health, safety and sustainability and digitisation issues affecting the industry. Site visits plus a one on one interview with top executives and engineers within the industry. All year round focused articles from exploration through to production. A major feature throughout each issue will be: Reducing your carbon footprint, Sustainability and Mining Innovation.



January

Feature: "Beyond Bolting: The Next Frontier in Roof Support"

- Machine monitoring The IoT
- Carbon capture and storage
- Shearers
- Ventilation systems
- Conveying underground
- Dust suppression

Case Studies: Mine water heat networks in former coalfields

Deadline date for all materials: 18/01/2026

Copy Date: 31/01/2026

March

Feature: Automation, AI, and unmanned mining systems

- Underground mining trucks
- Gas monitoring
- Shearers
- Sustainable mining practices
- Conveying: Belt technology
- Online training solutions

Deadline date for all materials: 22/03/2026

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May

Feature: Global regulatory shifts and ESG alignment

- Machine monitoring The IoT
- Transitioning mines to sustainable future
- Dewatering pumps
- Health and Safety innovations
- Machine monitoring The IoT
- Conveying Technology...Scrapers and Cleaners
- Longwall systems
- Conveying Technology

Case Studies: Auxiliary Fleet Utilisation

Deadline date for all materials: 17/05/2026

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July

Feature: Critical minerals and decarbonization pathway

- Hybrid mining machines
- Underground shuttle cars
- Autonomous mining
- Underground/Surface conveyor dust suppression
- Carbon capture and storage
- Shearers

Deadline date for all materials: 19/07/2026

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September

Feature: Supplier profiles and market access strategies

- Pumps and water management
- Rock reinforcement and ground support
- Wheel loaders
- Transitioning to an electric mine
- Conveying
- AFC Stage loader review

Case Studies: Coal Mine Innovation

Deadline date for all materials: 20/09/2026

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November

Feature: Clean coal technologies and energy transition strategies

- Open Pit mining
- Conveying Technology
- Crushing and Screening
- Explosives technology
- Lubrication
- Sustainable mining practices

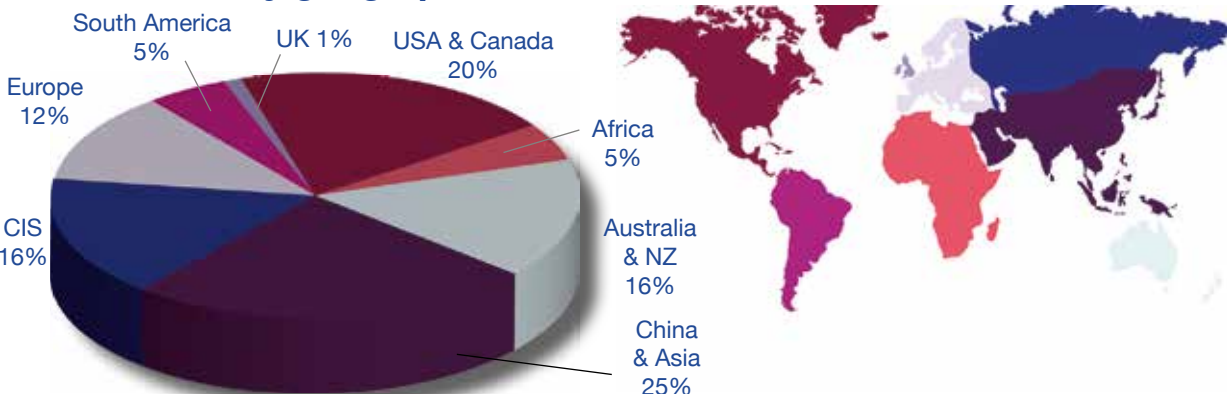
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What sustainability means in a mining context



M

ining remains fundamental to modern society, supplying the critical minerals and metals that underpin infrastructure development, manufacturing, and advanced technologies. At the same time, the inherently extractive nature of the industry can create significant environmental and social challenges if not managed effectively. As expectations from regulators, investors, and communities continue to rise, mining companies are placing greater emphasis on sustainable operating models that reduce impacts and support long-term project viability.

In mining, sustainability refers to the integrated management of environmental performance, social responsibility, and economic value throughout the life of an operation. It encompasses:

- Efficient resource extraction that maximises ore recovery while minimising waste generation and energy consumption.
- Responsible sourcing and supply-chain transparency, ensuring materials are produced in line with global ESG standards.
- Protection of biodiversity and ecosystems, including land stewardship, water management, and progressive rehabilitation.
- Safe, healthy, and equitable working conditions for employees and contractors.
- Constructive engagement with host communities, ensuring that mining contributes to local development and minimises adverse impacts.

Stakeholders across the sector – regulators, NGOs, investors, and community groups – are increasingly demanding stronger sustainability performance. Concerns range from mining’s contribution to greenhouse-gas emissions and long-term resource depletion to the safety and well-being of workers and nearby residents. As a result, implementing robust sustainable mining practices is no longer optional; it is essential for maintaining social licence, reducing operational risk, and ensuring the longevity of mining operations.

CHALLENGES TO SUSTAINABILITY IN MINING

A major constraint on sustainable mining is the accelerating global demand for minerals. Population growth, electrification, and the expansion of low-carbon technologies are driving unprecedented consumption of metals. Meeting this demand while maintaining environmental performance and social licence requires new extraction methods, improved process efficiency, and smarter resource management.

Resource depletion adds another layer of complexity. Many high-grade deposits are already exhausted or in decline, pushing operations toward lower-grade ores, deeper deposits, and more complex geologies. This shift increases energy intensity, water use, waste volumes, and overall operating costs. Without long-term planning and responsible resource stewardship, depletion can trigger supply instability, economic disruption, and additional environmental pressure.

Environmental impacts remain a central challenge. Mining can alter landscapes, disturb ecosystems, and generate air and water pollution if not properly controlled.

Tailings storage, acid rock drainage, dust emissions, and water consumption are particularly scrutinised. In many regions, mining competes with agriculture, communities, and industry for limited water resources, making water efficiency and recycling essential.

IMPROVING SUSTAINABILITY IN MINING

Mining companies can strengthen sustainability performance through a range of operational and strategic measures.

RESPONSIBLE SOURCING

Responsible sourcing frameworks help ensure that extracted materials are not linked to environmental harm or human rights violations. This includes:

- Rigorous supply-chain due diligence
- Verification of contractor and supplier compliance
- Alignment with international ESG standards and reporting frameworks

These practices support transparency and reduce reputational and regulatory risk.

Improving resource efficiency is central to sustainable mining. Key approaches include:

- Optimising mine planning to maximise ore recovery and reduce dilution
- Deploying energy-efficient equipment and electrified fleets
- Enhancing water recycling and reducing freshwater intake
- Implementing advanced process control to improve throughput and reduce reagent use
- Reducing waste generation through better ore sorting, pre-concentration, and tailings reprocessing

These strategies lower operating costs while reducing environmental footprint.

Optimising the use of natural resources and reducing waste is central to sustainable mining. Improving ore recovery, minimising dilution, enhancing process efficiency, and reducing energy and water consumption all contribute to lower operating costs and a smaller environmental footprint.

Mining activities can significantly alter local ecosystems. Engineers can help mitigate these impacts by supporting detailed baseline biodiversity assessments, integrating avoidance and minimisation

measures into mine design, and planning progressive rehabilitation and post-closure landform stability. Effective water management, erosion control, and habitat restoration are key components of this work.

Worker safety remains a core pillar of sustainable operations. Maintaining safe working conditions requires robust training programs, proper equipment selection, effective ventilation and ground-control systems, and continuous monitoring of occupational hazards. A strong safety culture reduces incidents and supports long-term workforce well-being.

Sustainable mining also depends on constructive engagement with host communities, regulators, and NGOs. Transparent communication helps build trust, identify potential impacts early, and develop mitigation strategies that align with community expectations and regulatory requirements. This engagement is essential for maintaining social licence to operate.

Integrating renewable energy sources – such as solar, wind, or hybrid microgrids – can reduce greenhouse-gas emissions and lower long-term energy costs. For remote operations, renewables can also improve energy security and reduce reliance on diesel generation.

Advances in technology offer powerful tools for improving sustainability performance. Artificial intelligence, automation, drones, and sensor networks can enhance orebody knowledge, optimise haulage and processing, reduce waste, and improve predictive maintenance. These technologies also strengthen safety by reducing worker exposure to hazardous environments.

CONCLUSION

Sustainable mining practices are essential for the long-term viability of the industry, the protection of the environment, and the well-being of workers and communities. Although the challenges are substantial, mining companies are increasingly adopting integrated sustainability strategies that involve engineering innovation, operational efficiency, and active stakeholder participation. By embedding these practices across the mine life cycle, the industry can reduce its environmental and social impacts while positioning itself for long-term success.



Resource Efficiency

Optimizing the use of natural resources and reducing waste



Health and Safety

Ensuring safe and healthy working conditions



Stakeholder Engagement



Use of Renewable Energy



Innovation and Technology

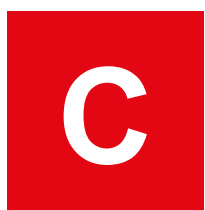


Biodiversity Protection

Conducting biodiversity assessments and protecting ecosystems

A novel cognitive opportunistic communication framework for coal mines

The dynamic advancement and harsh environment of coal mines often result in intermittent or regional wireless connection between sending nodes and receiving nodes and then lead to the decrease of transmission success ratio and even failure. To solve this problem, the environmental cognition and best-effort transmission are both demanded. Here we proposed a novel communication framework for coal mines based on a cognitive opportunistic concept to address the wireless network communication problems in coal mines, which consists of the node mobility model in coal mines, cooperative cognition of the time-varying communication environment, and the opportunistic routing of intermittent or regional connection scenarios. To realize this framework, real time neighbour discovering mechanisms and mobility perceiving strategies, called environment cognition, must be deeply investigated to predict the trends of node movement. The obtained results of environment cognition are then used to analyse current channel characteristics to determine and set optimum communication system parameters and reduce the probability of intermittent or regional connection. To address those unavoidable situations of the intermittent or regional connection, the opportunistic routing mechanism is brought forward to provide relatively stable data transmission. Finally, as an example of cognitive opportunistic mine communication of this framework, personnel evacuation under an emergency is discussed.



Coal production and consumption has been playing an important role in the energy industry of China. It is crucial for the safe and efficient production to monitor environmental parameters, equipment status, personnel information, production situations, and security status and send these parameters to the ground monitoring center in real time via the ubiquitous mine internet of things (MIoT). A mine roadway, comprised of rough coal,

rock, and bolt-beam mesh, has extensive branches and bending with narrow and long space. At the same time, a mine roadway is full of metal supports, large production equipment, transportation vehicles, and steel rails, resulting in strong multipath effects, serious fading, and significant interferences of radio wave propagation.

Particularly, all equipment in a coalface must keep advancing throughout the mining process, which causes dynamic changes of the communication space.

1. Due to the mine roadway characteristics, wireless communication systems used in mines face unique difficulties compared to those used on the surface, such as the following:
2. Communication nodes may be damaged by coal, rocks, or humans, resulting in intermittent or regional network connections.
3. The time-varying physical communication space forces wireless channels into a time-varying state, resulting in intermittent network connections; and
4. The great amount of dust produced during the coal cutting process and the presence of large, moving metal equipment result in poor adaptation to wireless communication systems, whose main effect on communication systems is also regional or intermittent node connection.

To address the wireless communication problem of intermittent or regional connection in mine roadways, two critical difficulties must be resolved: adaptation ability of communication systems to the changing environmental parameters and the relatively stable transmission ability under an inevitable unstable condition of intermittent or regional connection. This article proposes a novel cognitive opportunistic communication framework for coal mines to enhance the ability of the MIoT to adapt to the mine roadway environment and ensure that monitoring signal will not be interrupted by the harsh time-varying transmission environment, supporting, and guaranteeing the construction of digital and intelligent mines.

Compared to existing communication frameworks for ground applications, our framework includes components specific to coal mines to address the special communication difficulties met by the roadway. Compared to existing communication frameworks for coal mines, this framework includes models specific to special roadway sites and emergency situations based on opportunistic and cognitive technologies to deal with communication problems introduced by regional or intermittent connection.

Our major contributions are summarised as follows:

1. We reviewed the state of the art of the wireless communication technologies in coal mines and revealed

their characteristics and key challenges. Besides, we also analysed the reasons why communications systems used in surface environments cannot be directly utilised in coal mines.

2. We proposed a cognitive opportunistic mine communication framework, which can adapt to the dynamic advancement and vulnerability of mining nodes and is thus of great significance to guarantee the successful communication
3. Some key technologies were deeply investigated, such as the node mobility model in coal mines, cooperative cognition of the time-varying communication environment, and the opportunistic routing of intermittent or regional connection scenarios
4. An application example of personnel evacuation under an emergency scenario was explored to demonstrate the effectiveness of the framework

The remainder of this paper is organised as follows.

Section 2 surveys some typical wireless communication systems and their challenges in mines and proposes a cognitive opportunistic mine communication framework.

Section 3 details the three key technologies involved in the proposed framework, namely, the construction of the node mobility model, cooperative cognition of the time-varying communication in the mine roadway, and the opportunistic routing of intermittent or regional connection scenarios. As an exemplary application scenario.

Section 4 discusses the application of cognitive opportunistic mine communication for personnel evacuation in an emergency.

COGNITIVE OPPORTUNISTIC MINE COMMUNICATION FRAMEWORK

State of the Art of Wireless Communication in Mines.

Existing investigations into wireless mine communication have generally focused on the propagation characteristics of a wireless signal, network models, network protocols, and communication system development.





Examples of wireless nodes

Propagation Characteristics of a Wireless Signal

Typical research methods in this field are ray tracing, waveguide theory, and experimental testing. Ray tracing is a method to investigate the transmission characteristics of a wireless signal by tracing the path of rays², which is often inefficient because of the strong multipath characteristics present in most mines. The fourteen-waveguide method regards a mine roadway as a waveguide to study the transmission characteristics of a wireless signal³; however, the complex mine environment often produces significant differences between results obtained by a waveguide theoretical model and those obtained by practical testing. Experimental testing is a method often used to obtain such statistical characteristics as path loss and delay spread of roadways by conducting field investigations⁴; experimental conclusions are often closely related to the experiment locations and signal frequencies.

Network Models

Typical mine network models include chain models and mesh models. The chain model deploys wireless nodes linearly along a roadway corresponding to its linear characteristics⁵, but it is more likely to form energy holes. In a mesh model, some nodes such as access points act as backbone nodes, interconnecting with each other to form a mesh network⁶; some access points which have accessibility to the wireless sensor networks are referred to as gateways. Thus, this type of network is essentially a mixed network composed of wireless and wired components which requires support from transmission cables⁷.

Network Protocols

The purpose of protocol design is typically to expand network coverage, improve success ratio of message transmission, and reduce energy consumption or transmission delay. Network coverage is primarily implemented by studying different node deployment methods⁸, which must consider the relationships among the coverage model, the roadway width limit, and node redundancy. Success ratio of transmission and network energy consumption are often the greatest challenges to successful wireless network communication⁹. Some nodes in a chain network model will not work any longer once their energy becomes depleted¹⁰. Finally, transmission delay is related to the type of data and the method of relay node selection¹¹.

System Development

Primary types of wireless communication systems in mines include ultra-low-frequency, through-the-

earth communication, medium-frequency induction communication, leaky feeder communication, personal handy-phone, ZigBee, and Wi-Fi systems¹². These systems are typically transplanted from ground systems without consideration of the special difficulties presented by the mining environment. Many systems are unable to adapt to the complex, changing communication environment of mines and may only prove to be effective in a part of a mine or roadway, but ineffective in the overall mining environment¹³.

The reason wireless communication technologies on ground cannot be directly applied to mine roadways is that communication systems must be able to perceive the complex and changing environmental characteristics around them and tell these results to their communication partners in a timely manner, to increase the cooperative communication abilities.

Traditional wireless communication systems which utilise relatively fixed parameters such as communication frequency, modulation method, and bandwidth are often unable to adapt to the dynamic and various changes in a mining environment. Additionally, in a complex environment like the mine roadway which contains many devices as well as various geological structures and roadway interconnections, data transmission and reception between wireless communication nodes must follow a suitable routing protocol to be dynamically adaptive to the environment.

Take the coalface, the forefront of coal production, as an example. To enable the coal cutting, roof supporting, and coal transporting, all miners and mining equipment (such as the

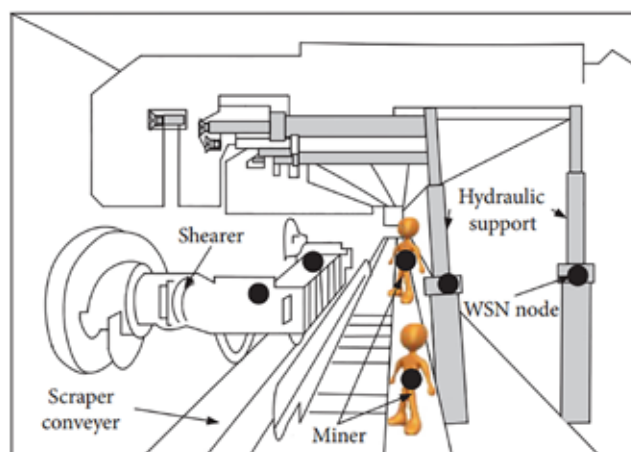


Figure 1: Coalface and its WSN deployment

shearer, hydraulic support operator, and scraper conveyor operator) must cooperate closely. The dynamic advancement of the equipment at the coalface forces the communication space into a time-varying state, making it impossible to lay additional wired communication cables in a timely manner. Under these conditions, wireless communication must be flexible to deploy and easy to extend as the mining face advances. For this purpose, wireless sensor network (WSN) nodes can be deployed on the hydraulic supports, shearer, and miners (**Figure 1**) [14]. Test nodes move along with the equipment and miners, leading to a linear (chock type support) or bilinear (chock-shield support) topology based on the linking conditions. Because of the extensive existence of the reliable wired/wireless networks in tailgates or headgates, the wireless sensor network at the coalface can easily transmit its messages to access points in gateways and then to other regions of the mine or ground information center. That is, these access points will be the sink nodes of the WSN in a coal mine.

Unfortunately, the information at the coalface cannot always be transmitted to the sink node due to the intermittent or regional connections, which is a frequent situation encountered in mine roadways. For example, coal production may make some network nodes occasionally damaged and sudden accidents can also induce network coverage failure in some areas. The most common method to maximise the network coverage in mine roadways is to increase node density, which can not only result in increased costs of system construction and operation, but also lead to increased network management complexity. Therefore, it is imperative to investigate new paradigms of wireless network design for use in mines.

Intermittent or regional connection does not mean absolute or permanent failure of communication between the transmitting and receiving nodes¹⁵. The negative effects of unstable link quality will be substantially offset by a communication system with the ability to dynamically cognise environmental features and self-adaptively adjust communication parameters based on the results of cognition¹⁶, reducing the probability of intermittent or regional connection. Considering that node movement creates a meeting opportunity for nodes located in different regions, data can be transmitted to other nodes that are more likely to meet the target node even in the case of intermittent or regional connection; such information can then be stored, transported, and forwarded for delivery to the target node¹⁷. An opportunistic communication network based on cognition of the mine environment can adapt to the dynamic advancement and vulnerability of mining nodes and is thus of great significance to improve successful communication.

At present, few studies have been reported which investigated self-adaptive mine communication based on opportunistic communication. Ji Luo conducted a study on delay tolerant communication in coal roadways¹¹, in which the tramcar in the mine roadway was used as a mobile sink node, and the sensors deployed in the roadway remained stationary; the tramcar moved along the deterministic path in the roadway to directly collect data from sensor nodes, thus avoiding multi-hop transmission. However,

this study only considered the specific circumstances of a moving tramcar and stationary nodes, while practical applications must also consider the moving nodes which represent underground miners. The reported study also failed to consider the effects of dynamic changes in the physical communication space and did not address the environmental self-adaptation problem in mine roadways, thus failing to address the challenges posed by intermittent or regional connection.

Three key problems must be addressed to implement cognitive opportunistic mine communication:

1. The establishment of the node mobility model based on the node movement characteristics and spatial constraints of mines: this model will serve as the basis for cognition of the mine environment and the implementation of opportunistic communication. The difficulties implementing this model include the state transition mechanism and performance bounds of the model, its concordance with actual motion, influential factors, and their interaction mechanism of the model
2. The dynamic determination of optimum parameters for communication links to reconfigure the communication system automatically: this is essential to the environmental self-adaptation of wireless communication systems for mines and to the reduction of intermittent or regional connection. The main challenges are the modelling of the joint optimisation to dynamically determine and configure the optimum communication parameters.
3. The design of opportunistic routing algorithms accurately reflecting the characteristics and requirements of mines based on the influential factors of transmission performance and their operational mechanisms: this is necessary to relatively stable data transmission of wireless communication systems for mines under intermittent or regional communication conditions. The challenge presented by this problem is that there are too many factors which must be considered when designing such type of algorithms.

Here an opportunistic mine communication framework is proposed; see **Figure 2**. First, historical data of node movement achieved by positioning systems are used to determine and analyse node meeting characteristics such as the interval and duration of node meetings. The work arrangement of mining crews is utilised to investigate the groups to which different personnel belong. The fourteen cognition results of environmental parameters are exploited to obtain contextual information regarding the node circumstances. The analyses described above as well as the physical roadway structure make it possible to construct the node mobility model. Second, a node timely determines the available channels between itself and its neighbour nodes according to the perceived environmental parameters. Based on the monitoring requirements of the ground monitoring center and channel estimation results of mine roadway, the communication system parameters are adjusted to implement its self-adaptation to the mine environment. Finally, based on the established node mobility model and the results of

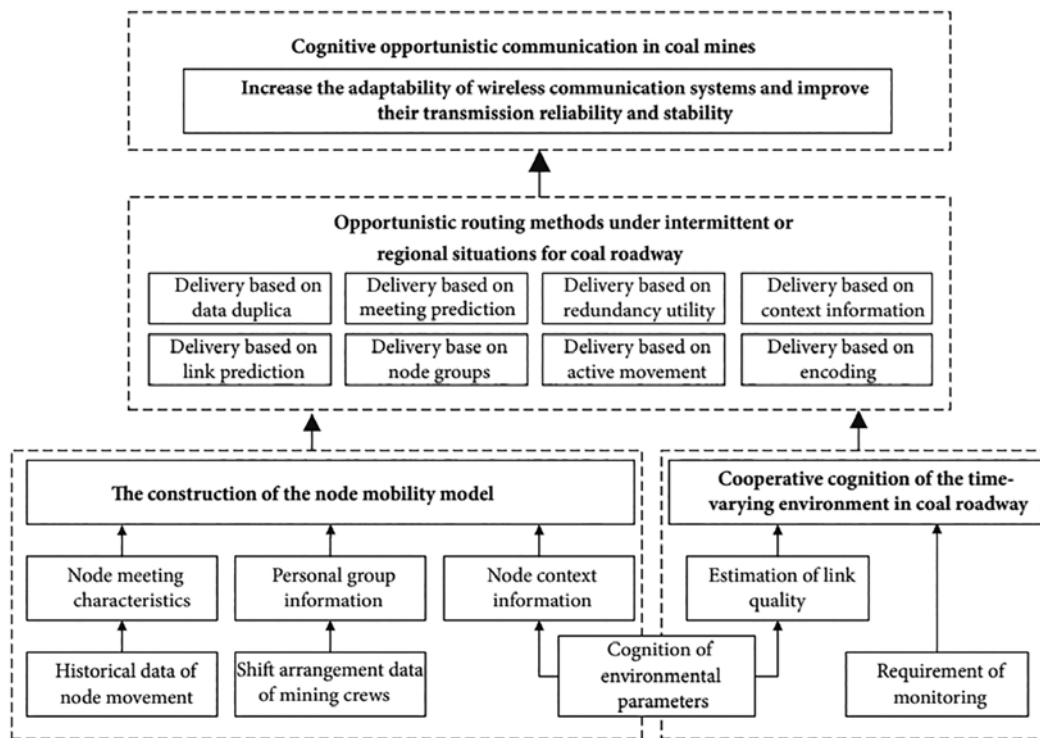


Figure 2: Cognitive opportunistic communication framework for coal mines.

communication environment cognition, the opportunistic communication mechanism of mine roadways can be investigated, and effective opportunistic routing algorithms can be designed to implement stable data transmission under regional or intermittent connection conditions.

To address the challenges faced by the proposed architecture, Section 3 will discuss the construction of the mobility model for moving nodes in mine roadways, as well as cooperative cognition of the time-varying communication environment and the opportunistic routing of intermittent or regional connection scenarios.

Construction of the Mobility Model for Mobile Nodes in Mine Roadways.

Data transmission in a mine roadway is primarily affected by transmission distance, the node mobility model, and neighbour scanning frequency¹⁸. Additionally, much data is closely related to the contextual information of nodes and demonstrates strong temporal or spatial characteristics¹⁹. Therefore, discovery of neighbours, the perception of node mobility, and construction of a mobility model serve as the foundations for environmental cognition. The fourteen synchronous neighbour discovery methods are not appropriate for a mine roadway because the assumption of one node transmitting and one node receiving does not necessarily hold true, particularly in a coalface. It is essential to carefully investigate the scanning frequency of neighbours to make a trade-off between energy consumption and information timelines.

Mobility models are the basis for movement perception and the design of a routing algorithm. Current studies of mobility models have primarily focused on discovering the distribution characteristics of meeting intervals and durations²⁰ and the establishment of network sequential diagrams reflecting changes of network topology²¹. Experimental data have also been used to study the characteristics of information

transmission paths to determine the temporal-spatial correlation between nodes²².

Traditional mobility models based on random movement assume that both destination and velocity are random; this is characterised as Brownian motion, such as that employed by the random waypoint model (RWP) and random walk model (RWM). This type of mobility model facilitates the theoretical derivation of performance bounds; it is very flexible and its movement characteristics can be extended by making changes to the model parameters. However, this type of model cannot capture the actual movement patterns of moving objects in mine roadways. The fourteen tramcar, shearer, and hydraulic support in a mine roadway move according to a highly regular pattern, but the movement of a miner is both regular and random due to the constraints of their job types and working hours. Existing mobility models cannot fully reflect these characteristics, and further study must be conducted to explore the mobility models of nodes based on the characteristics of mine roadways to provide guidance for the design of opportunistic routing algorithms.

First, the existing positioning system is used to collect the location and time information of the moving nodes in the mine roadway to obtain historical datasets of node movement (Figure 3). The status distribution and meeting intervals and durations of nodes at a given moment reflect the temporal and spatial characteristics of opportunistic networks, which are of great significance to data transmission. These studies help solve^{23,24} (1) which nodes frequently meet the current node and are thus candidates for relay selection; (2) which nodes have social and group connections which may indicate a greater willingness to communicate cooperatively; and (3) how long a meeting lasts, in which an optimal time value will allow complete yet efficient communication. A mobility model can then be designed based on the obtained statistical characteristics.



For example, the movement of nodes in a mine roadway can be modelled as a temporally correlated Markov process, which is then validated by experimental data. If the states of a message located at node and node are called current state and next state, respectively, then its transition from the current state to the next state corresponds to a data transmission scenario. The period spent awaiting the transition from one state to another represents the meeting interval, and the period spent in the designated state represents the meeting duration. Different states correspond to different mine locations, and state transitions correspond to location migration. Transitions into and out of the same state demonstrate identical movement characteristics,

while transitions between different states demonstrate different movement characteristics. A feedback mechanism can be introduced to the state transition process to mitigate the fluctuation of motion patterns in different locations. Node mobility can thus be perceived, and node movement can be predicted based on the node mobility model and node discovery mechanism.

Cooperative Cognition of the Time-Varying Communication Environment of Mine Roadways

Due to the dynamic changes in the physical space and the harsh working conditions of mines, the wireless links in mine roadways are subject to sudden, significant changes, which

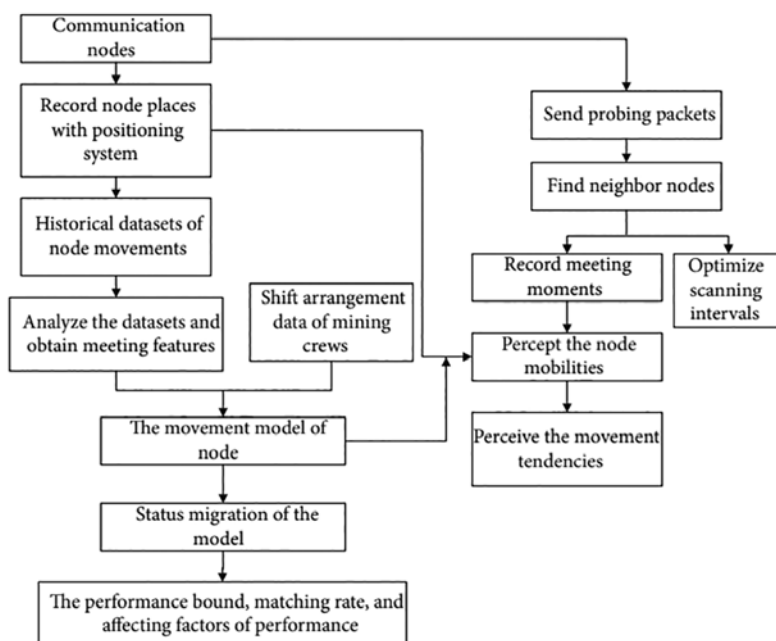


Figure 3: Construction of the mobility model for model for mobile nodes in mine roadways.

can result in the loss or increased delay of data. Environmental cognition helps enhance the adaptation of communication systems to environmental changes. Once link quality reduces, the communication system can adjust its parameters to adapt to the current surroundings to avoid intermittent connection. For this purpose, it is essential to estimate the link quality in real time²⁵ to adjust the communication parameters to optimum values in a timely manner. For example, the power of transmission systems can be improved to increase the one-hop transmission distance to improve the success ratio of data transmission under poor link quality or relay failure conditions.

However, higher transmission power also results in greater energy consumption and leads to greater interference to neighbours on the same frequency²⁶. A self-adaptive power control algorithm may be designed to reduce energy consumption (**Figure 4**) and to enable nodes to establish and maintain connection using minimum power requirements. Power control and channel selection must be jointly optimised to reduce interference²⁷ and must be designed as a distributive, dynamic algorithm which may employ game theory, or the machine learning method based on local node information such as local signal-to-noise ratio. Both environmental cognition and parameter adjustment require that nodes engage in explicit or implicit information exchange when they meet²⁸, leading to a cooperative mode based opportunistic cognition and adjustment. To implement environmental parameter cognition, nodes must effectively perceive the communication environment and adjust parameters based on the environment, user goals, and node capabilities²⁹.

However, it must be noted that environmental cognition cannot be equated with environmental perception; the latter simply involves parameter acquisition, while the former involves decision-making based on perceived information³⁰, even in situations in which the acquired environmental information is incomplete.

Opportunistic Routings of Intermittent or Regional Connection Scenarios in Mine Roadways.

If the decline of data transmission performance does not result from the link degradation but from link interruption, the studies described above will not be enough to ensure data transmission. As a possible solution, node movement characteristics and the spatial constraints of mine roadways must be explored to design an efficient opportunistic routing method. In the field of opportunistic routing, existing studies have extensively focused on the forwarding mechanism based on a message replica. This forwarding mechanism creates a balance between transmission delay and resource consumption by controlling the number of copies³¹ or calculates the probability of node meeting based on historical information and link prediction before forwarding the data to the nodes that are more likely to meet the destination node³².

Node movement in a coal mine consists of highly correlated cooperative movement that seeks to accomplish production goals. In the coalface, a shearer driver operates the shearer to cut coal, and the hydraulic supports advance to support the roof during the mining process. The mined coal is then transported to the belt via the scraper conveyor and then

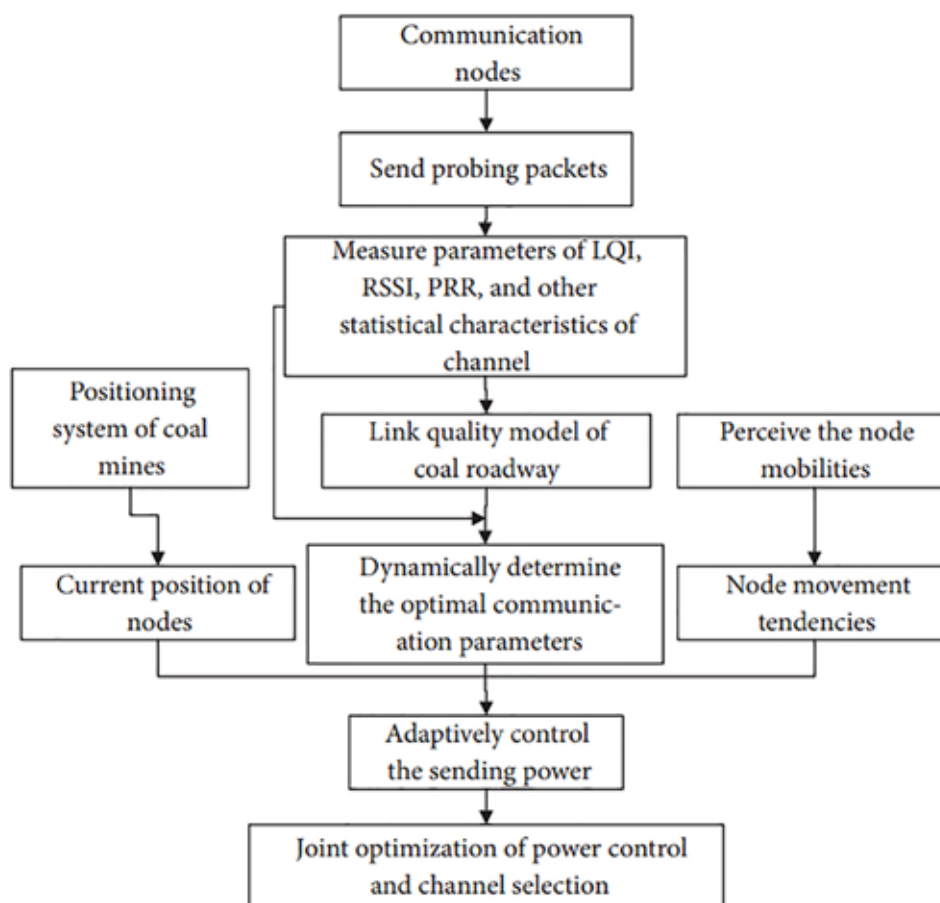


Figure 4: Cooperative cognition of the time-varying communication environment of mine roadways.

lifted onto the ground after transportation via the belts or tramcars. This overall process involves driving, mining, transportation, ventilation, and drainage and thus requires a great number of personnel and lots of equipment. The movement of the equipment and personnel includes both regular movement (such as that exhibited by the shearer, hydraulic support, and tramcar) and mixed regular and random movement, such as the movement of the operators. Overall, most node movements in mine roadways are characterised as regular movement. With the help of mobility models, opportunistic routing algorithms can be designed based on meeting prediction, copy distribution, and context distribution mechanisms; see **Figure 5**.

Additionally, nodes in a mine roadway often transmit data in a linear, directional manner. For example, the data transmission of the coalface always heads to the sink node in the headgate or tailgate. Therefore, it is appropriate to design an opportunistic routing algorithm based on geographic locations. The fourteen tramcars and personnel which partake in cyclic reciprocating motion provide opportunities for data transmission between nonadjacent equipment and personnel which can serve as the ferry node between disconnected nodes. Furthermore, the established node mobility model incorporates historical meeting information and node meeting characteristics. Based on these various characteristics, different utility indicators can be designed for opportunistic transmission. According to the results of communication environment cognition, a set of relay candidates can be determined for the current node in order to implement opportunistic transmission based on link prediction's success of message transmission as well as the energy consumed by transmission is greatly affected by the number of nodes in a mine roadway, the number of messages to be transmitted, and message size. Finally, the parameters of the physical layer, link layer, and network layer can be combined³³ to design cross-layer opportunistic routing algorithms.

AN EXEMPLARY APPLICATION: PERSONNEL EVACUATION BASED ON COGNITIVE OPPORTUNISTIC COMMUNICATION IN AN EMERGENCY

Cognitive opportunistic communication is of great significance to the mobile acquisition of mine environmental information as

well as the continuous monitoring of miners' health information, particularly to disaster prevention and reconstruction of a mine internet of things designed for ordinary activities. As an example, this section discusses the application of cognitive opportunistic communication to the transmission process of disaster information in an emergency, such as a coal mine flood, the presence of excessive gas, and production accidents. In case of an emergency, the sensor node (carried by a person) which first perceives the emergency must quickly transmit the information about when and where the accident took place and the urgency degree of the accident to nearby personnel and instruct personnel to evacuate as quickly as possible, as shown in **Figure 6**.

However, some nodes in the accident region may not be in normal working status because of the emergency, making the accident information incapable of being transmitted. However, the sensor nodes carried by moving objects (e.g., personnel or vehicles) can detect the accident information and subsequently transmit the information through cognitive opportunistic communication during evacuation.

1. The first person who perceived the emergency will first evacuate from the area of danger. As more people are met during the evacuation and information is exchanged, more people will evacuate. In this way, information is diffused during the evacuation process
2. A vehicle typically moves in a periodic motion along a determined path at a determined rate to transport goods or personnel. If no person is in the vehicle, the vehicle will continue to move until it meets a person to which it will forward information regarding the accident. If a person is present in the vehicle, the person can choose to evacuate by the vehicle continuously or get off and evacuate on foot.

Emergencies that occur in a mine roadway often affect one or more areas of the roadway rather than a single place, such as in the case of a coal mine flood or the presence of excessive gas. Therefore, personnel must move toward a designated safe area. For example, as shown in Figure 6, there are four designated evacuation routes. Following route 1, a person can evacuate directly along the upper oblique

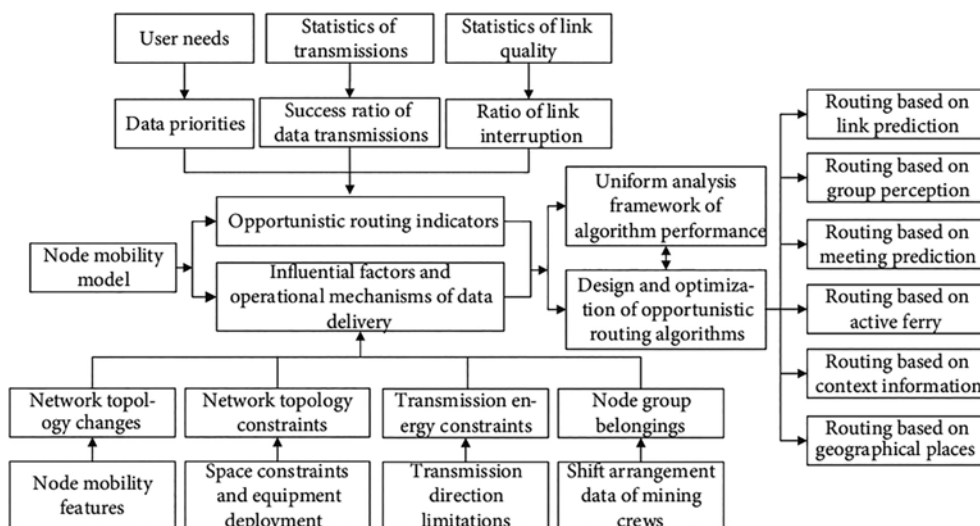


Figure 5: Opportunistic routings of intermittent or regional connection scenarios in mine roadways.

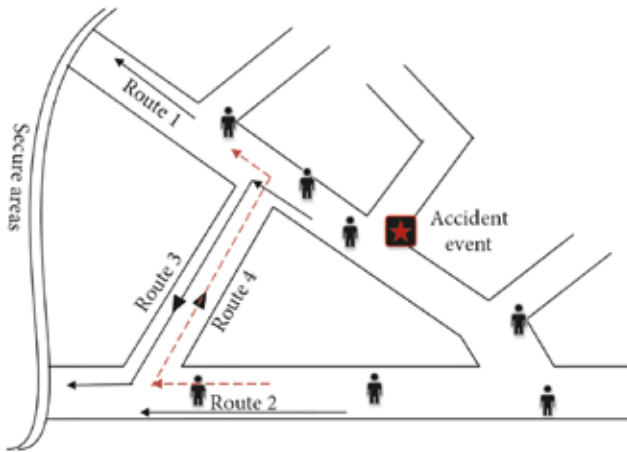


Figure 6: Personnel evacuation under emergency scenarios.

straight roadway; following route 2, a person can evacuate directly along the lower long straight roadway; following route 3, a person can evacuate along the lower roadway after passing through the upper roadway and the middle roadway; following route 4, a person can evacuate along the upper oblique straight roadway after passing through the lower roadway and the middle roadway. In an actual mine roadway, different roadway combinations may generate many escape routes; a person can evacuate quickly and safely only by following a designated optimum path.

As the popularity of the mine internet of things increases, personal terminals used for perception in mines have developed increasingly diverse functions and strong computing capabilities. A roadway map can be stored in personal terminals and advice about best escape routes can be offered in case of an accident, based on the perceived information of the accident scenario. A circumstance in which all personnel evacuate along the same route should be avoided to avert congestion or collision, and the cognitive opportunistic abilities of the communication system can recognise the mine environment in real time to plan, guide, and proactively evaluate optimum escape routes and to ensure balanced traffic distribution. This indicates that cognitive opportunistic mine communication is of great importance to accident information spread and evacuation path optimization in an emergency.

It must be noted that all personnel who follow the feasible escape routes from the accident location to the pithead must receive information about the accident. However, personnel in roadways that are positioned directly opposite the escape paths cannot receive information about the accident because they cannot encounter any moving objects with the event information. This problem can be addressed from the following perspectives:

1. Mine trunk roadways are typically covered by wired industrial networks, while some of these roadways are also covered by Wi-Fi wireless networks and opportunistic communication is typically implemented at the endpoint of a coal mine such as the coalface. If an accident occurs at the endpoint of a coal mine, personnel nearby will see or hear the accident, prompting themselves to shout to warn others of the

accident. As a result, all personnel in this region can quickly evacuate, prohibiting a circumstance in which the location of the accident cannot be communicated

2. If an accident occurs in an area covered by a traditional wireless network (such as a Wi-Fi, 3G, or 4G network) resulting in damage to some aspects of the wireless network, personnel in the underground coal mine will form an opportunistic network during evacuation, while personnel located behind the accident location can receive accident information via the mixed network
3. If a person is evacuated to a region effectively covered by a network, the accident message can be transmitted to the ground control center via the backbone network, which then notifies all underground personnel of the accident situation via voice broadcast or direct transmission of the message to personal terminals. Of course, if an area of a roadway collapses, the miners behind the area of the roadway cannot evacuate and must wait for rescue no matter whether they have perceived the accident situation or not.

CONCLUSIONS

The communication parameters of wireless mine communication systems, such as communication participants, signal transmission environment, and node mobility model, greatly differ from those of ground wireless communication systems. Cognitive opportunistic means, therefore, play crucial roles there, because their self-adaptive recognition mechanisms for mine environments and the opportunistic communication abilities keep communication systems informed about the time-changing environmental or communicational parameters. Keeping this issue in mind, we proposed a novel wireless communication framework for coal mines based on the cognitive opportunistic communication of the internet of things, which includes three key elements, namely, the node movement model constructing, the cooperative cognition of time-varying communication environments, and the opportunistic routing of intermittent or regional connection scenarios. Eventually, an example of personnel evacuation under an emergency scenario was explored to validate the usage of this framework. Subsequent studies will involve the theoretical investigation and field experiments based on the movement data collected from mine nodes, as well as the design of practical node mobility models, routing methods, and the system prototype of the cognitive opportunistic communication system for mines.

REFERENCES

For further references and reading please use the link acknowledged. ???

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The publisher has added all additional images.

Cutting through darkness



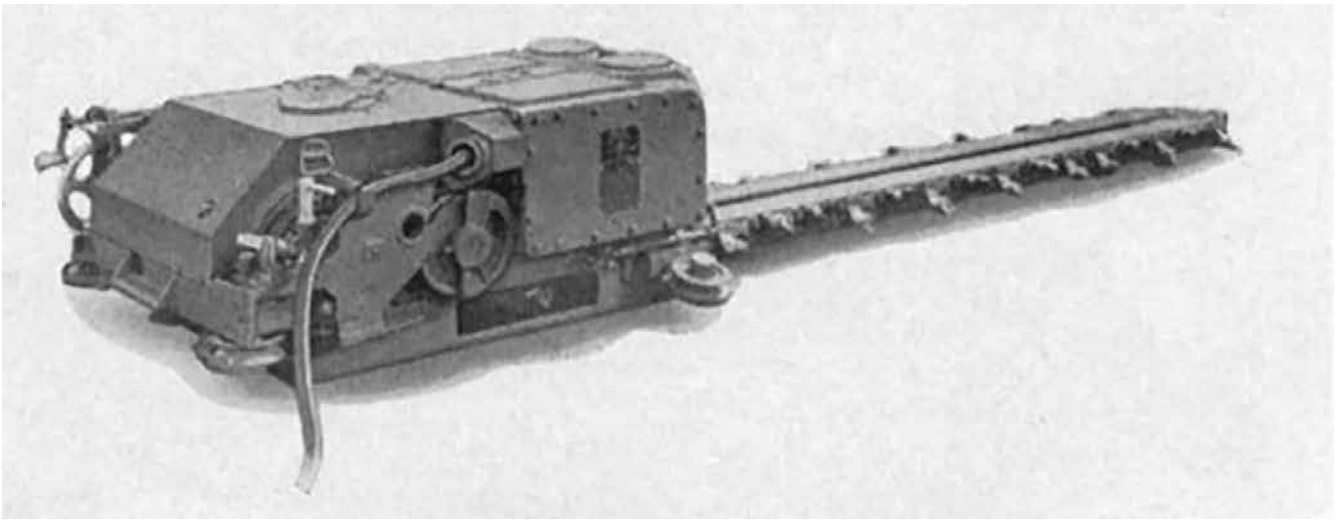
Cutting through the coal seam with mechanical precision, the modern underground shearer stands as the mine's most formidable expression of engineered power. **Cutting Through Darkness: The Shearer's Orchestrated Fury** captures the essence of this machine – an intricate blend of brute force, automation, and finely tuned co-ordination that transforms raw geology into controlled production. In the confined, dust-laden corridors of a longwall face, the shearer becomes both conductor and engine, synchronising its rotating drums, hydraulic haulage, and real-time sensing systems into a single, continuous rhythm of extraction.

Underground coal mining has evolved around this capability. The shearer not only dictates the pace of the longwall but also shapes the safety, efficiency, and environmental footprint of the entire operation. Its design reflects decades of innovation: stronger cutting systems to handle harder seams, smarter monitoring to anticipate geological shifts, and integrated control platforms that allow operators to manage complexity with greater confidence. Each pass along the face is a choreography of movement – advancing supports, clearing debris, and maintaining roof stability – while the machine relentlessly carves through the strata. *Gordon Barratt of Coal International dives into the evolution of the underground shearer, charting its journey from early brute-force cutter to today's precision-driven powerhouse.*

ISTORICAL CONTEXT OF THE LONGWALL SHEARER

The history of longwall shearers is closely tied to the broader evolution of underground coal mining, reflecting a steady shift from manual labour to mechanised, high-capacity

production. Early longwall mining in the nineteenth and early twentieth centuries relied almost entirely on hand tools. Miners undercut the seam with picks, wedged coal from the face, and loaded it by hand. Although the longwall layout itself was efficient, the lack of mechanisation meant that productivity remained limited and working conditions were harsh. The idea of a machine that could cut coal



Mining equipment from the 1940s

continuously along the face emerged gradually as engineers sought ways to reduce physical labour and increase output.

The first major step toward the modern shearer came in the 1930's and 1940's, when early mechanised cutters – often simple chain-based machines – were introduced. These devices could undercut or slot the seam, but they lacked the ability to perform full-height cutting. It was not until the 1950's that the first true shearer loaders appeared, equipped with rotating drums fitted with picks. These early shearers were relatively small and lacked the power and control systems of modern machines, yet they represented a breakthrough: for the first time, a single machine could cut coal, load it onto a conveyor, and move along the face in a continuous cycle.

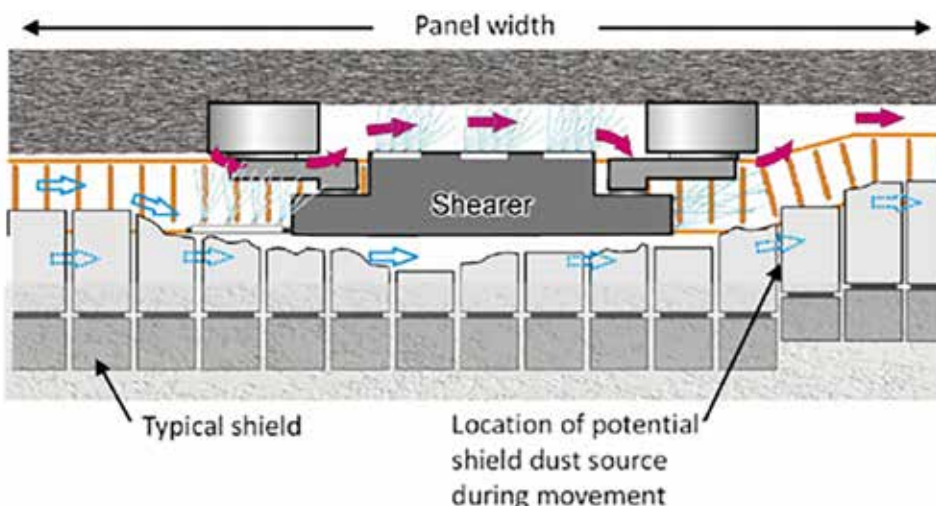
As longwall mining expanded in the latter half of the twentieth century, shearers evolved rapidly. The introduction of double-ended ranging-drum designs in the 1960's and 1970's transformed the industry by allowing bi-directional cutting and precise control over cutting height. At the same time, improvements in hydraulic roof supports and armoured face conveyors created a fully integrated longwall system, enabling shearers to operate safely and efficiently in increasingly challenging geological conditions. Mines in Europe, the United States, and later China and Australia

adopted these systems widely, recognising their potential to deliver unprecedented levels of productivity.

By the late twentieth and early twenty-first centuries, the focus shifted from mechanical power to automation and control. Electronic monitoring, variable-speed drives, and horizon-control systems allowed shearers to maintain optimal cutting conditions with far less human intervention. In some regions, particularly China, semi-autonomous longwall faces became common, with operators overseeing the process from remote control rooms rather than working directly at the face. This technological leap not only improved efficiency but also significantly enhanced safety by reducing workers' exposure to hazardous environments.

Today's longwall shearers are the product of nearly a century of engineering refinement. They embody the transition from manual mining to a highly mechanised, data-driven process that can extract thousands of tonnes of coal per shift. Their historical development mirrors the broader industrial story of mining: a relentless pursuit of greater productivity, improved safety, and more sophisticated technology.

The shearer's design reflects decades of engineering refinement. Its cutting drums can be adjusted to match seam height, while onboard sensors and control systems help maintain precise positioning along the armoured face conveyor. Modern shearers often integrate advanced monitoring, allowing operators to optimise cutting speed, manage geological variations, and improve safety. In many operations, the machine's movement is partially or fully automated, reducing human exposure to hazardous conditions.



As a result, the longwall shearer has become a symbol of efficiency in deep mining. It enables mines to extract large volumes of coal with consistent quality, while also

supporting improved safety standards. Its evolution continues as digital technologies, automation, and data analytics push the boundaries of what longwall systems can achieve.

A shearer works through a continuous, carefully choreographed process that brings together cutting, loading, and roof control in one moving system. At its core, the machine carries two large rotating drums, each fitted with rows of hardened picks. As the drums spin, the picks bite into the coal seam and fracture the material from the face. The drums are mounted on ranging arms that can be raised or lowered, allowing the shearer to follow the natural variations in seam height and maintain a clean, consistent cut.

The machine travels along the armoured face conveyor, which acts as both a track and a transport system. A haulage mechanism – usually a rack-and-pinion or chain drive – pulls the shearer steadily along the face at a controlled speed. As coal is cut, it falls directly onto the conveyor, which carries it away from the face and into the mine's main haulage system. This immediate removal of material keeps the cutting zone clear and prevents the machine from becoming bogged down.

Behind the shearer, hydraulic roof supports advance in sequence. These shields hold up the roof while the machine works in front of them, creating a protected corridor for the shearer and any personnel. Once the supports move forward, the area behind them is allowed to collapse in a controlled manner, following the natural behaviour of the rock strata. This cycle of cutting, conveying, and support movement continues without interruption as the shearer travels from one end of the longwall face to the other.

Modern shearers incorporate sophisticated control systems that monitor drum position, cutting forces, and geological conditions. Operators can adjust cutting height, speed, and

other parameters from a remote station, and in many mines the machine operates semi-autonomously. Sensors and navigation systems help maintain the correct horizon, ensuring the shearer stays within the coal seam even when the geology becomes complex. The result is a highly efficient, continuous mining process that maximises output while minimizing human exposure to hazardous underground conditions.

Several of the world's highest-capacity underground coal operations rely on longwall systems equipped with shearers, and a few stand out for their scale, output, and technological sophistication.

The North Antelope Rochelle Mine in Wyoming's Powder River Basin is often cited as the largest coal mine in the United States. While much of its production comes from surface operations, its longwall sections have historically used high-capacity shearers to extract thick, consistent seams that support enormous annual output. In the same region, the Black Thunder Mine has also operated longwall units with shearers during periods when underground extraction complemented its vast surface pits.

China hosts some of the most advanced and heavily mechanised longwall operations in the world. Mines such as Shenhua's Shendong Coalfield deploy fleets of modern shearers capable of cutting extremely long faces – often exceeding 300 metres. These operations are known for integrating automation, remote monitoring, and high-powered shearers that can handle demanding geological conditions while maintaining exceptional production rates.

Australia's longwall sector is similarly dominated by shearer-based systems. The Broadmeadow Mine in Queensland's Bowen Basin is a notable example; operating longwall faces that have set production records using state-of-the-art shearers and horizon-control systems.



North Antelope Rochelle Mine in Wyoming's Powder River Basin



Other major Australian longwall mines, such as Moranbah North and Grosvenor, also rely on shearers to extract high-quality metallurgical coal for export.

In Europe, the Bogdanka Mine in Poland stands out as one of the continent's most productive underground operations. Its longwall panels use shearers to mine relatively thick seams with high efficiency, contributing to the mine's reputation for reliability and modernisation.

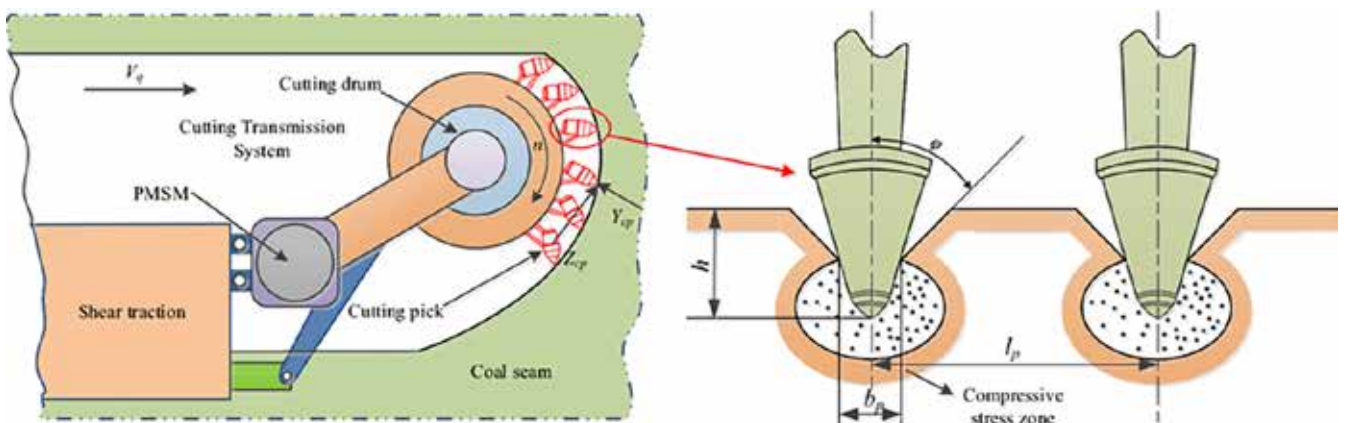
These operations illustrate how shearers underpin some of the world's most productive longwall systems, combining heavy engineering with increasingly sophisticated automation to sustain high output in challenging underground environments.

Longwall shearers have reshaped the economics and rhythm of underground coal mining by bringing a level of efficiency and consistency that earlier methods simply could not match. Their impact begins with the way they streamline the entire extraction process. Instead of relying on multiple machines and large teams of workers performing separate tasks, the shearer integrates cutting and loading into one continuous motion. As it traverses the longwall face, it removes coal at a steady rate, drops it directly onto the conveyor, and allows the roof supports to advance behind it in a seamless cycle. This uninterrupted flow eliminates many of the pauses and inefficiencies that once defined underground mining, turning the longwall face into a highly controlled production line.

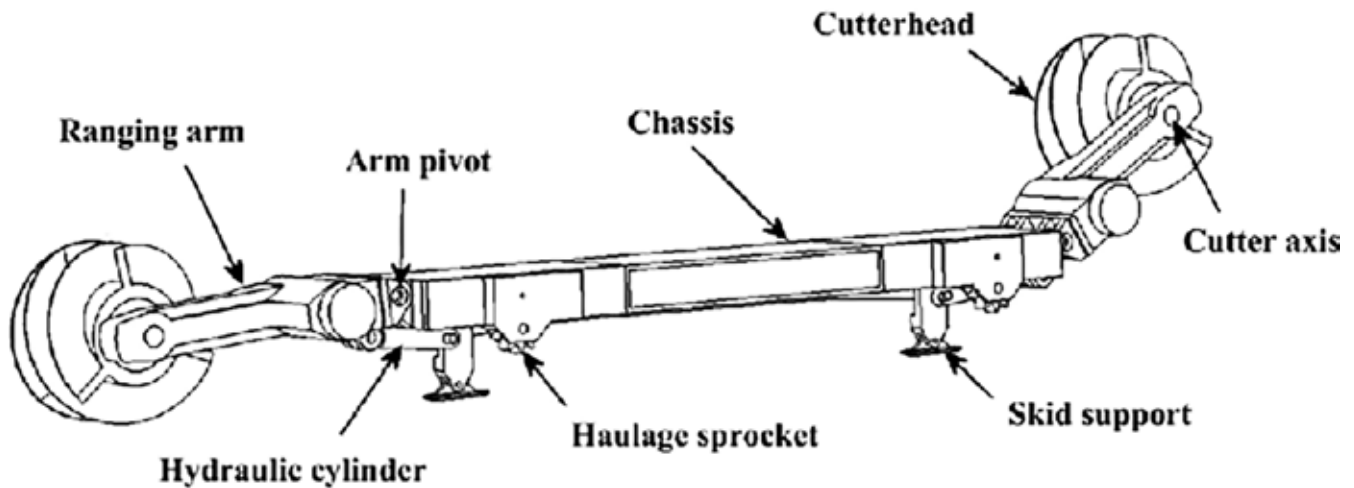
The productivity gains are equally striking. A single modern shearer can cut thousands of tonnes of coal per shift, far surpassing the output of older room-and-pillar systems. Its ability to operate bi-directionally means that production continues as it moves in either direction along the face, and its adjustable ranging arms allow it to maintain optimal cutting height even when the geology becomes unpredictable. Automation has amplified these advantages. With sensors, horizon-control systems, and remote operation, shearers can maintain ideal cutting conditions with minimal intervention, reducing downtime and ensuring that the machine stays within the coal seam. This consistency translates directly into higher yields, fewer interruptions, and more predictable production schedules.

The broader impact on coal mines extends beyond raw output. By mechanising the most hazardous parts of underground work, shearers have significantly improved safety. Workers spend less time at the face, shielded instead by hydraulic supports and remote-operation systems. Mines that adopt longwall shearers often see reductions in exposure to dust, roof falls, and other risks inherent to manual cutting. At the same time, the reliability of shearer-based systems allows mines to plan longwall panels more strategically, optimise ventilation and haulage, and reduce the overall cost per tonne of coal produced.

In many regions, the introduction of shearers has been the decisive factor that kept underground mining economically viable. Their combination of efficiency, productivity, and



Schematic diagram of the cutting process of a shearer drum



Double-ended ranging-drum shearer.

enhanced safety has turned longwall operations into some of the most sophisticated industrial systems in the mining sector. Even as the global energy landscape evolves, the engineering behind shearers remains a benchmark for how mechanisation can transform a traditionally labour-intensive industry into one driven by precision, automation, and high-volume output.

Modern longwall mining relies on a small family of shearer types, each shaped by the geological demands of the seam and the production goals of the operation. Although all shearers share the same fundamental purpose – cutting coal with rotating drums while travelling along the longwall face – their designs have diverged into distinct categories that reflect different engineering priorities. These variations allow mines to match the machine to the seam rather than forcing the seam to fit the machine, which is one of the reasons longwall mining has become so adaptable and efficient.

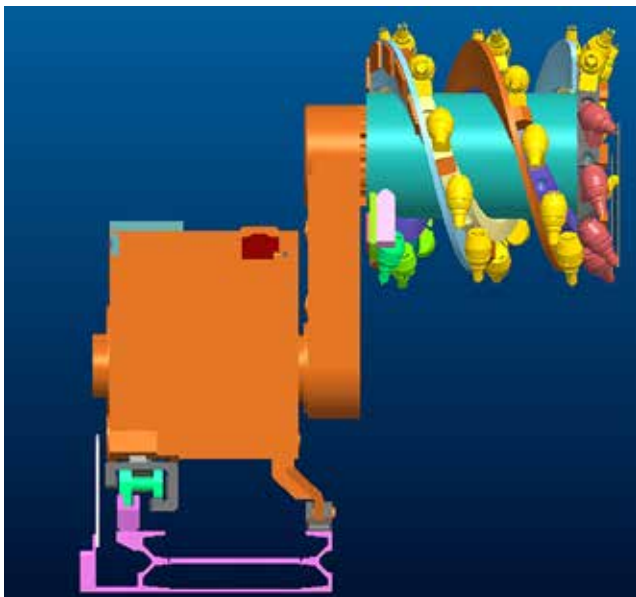
The most common type in use today is the double-ended ranging-drum shearer, a machine equipped with a cutting

drum at each end mounted on independently adjustable arms. This configuration allows the shearer to cut in both directions, maintaining continuous production as it moves up and down the face. The ability to raise and lower each arm gives operators precise control over cutting height, making this design ideal for seams with variable thickness. Its versatility has made it the dominant shearer type in high-capacity longwall operations across the world.

DOUBLE-ENDED RANGING-DRUM SHEARER

A second category is the single-ended ranging-drum shearer, which carries only one cutting drum. These machines are less common today but still valuable in certain geological settings. Their simpler design can be advantageous in thinner seams or in operations where bi-directional cutting is not essential. By focusing power and structural strength on a single drum, these shearers can be more compact and easier to maintain, though they typically cannot match the productivity of double-ended models.

Another important distinction lies in the power class of the shearer. High-power shearers – often exceeding a thousand kilowatts of installed cutting power – are built for thick, hard seams and long faces where production demands are extreme. They feature reinforced frames, heavy-duty haulage systems, and advanced automation to maintain stability and cutting accuracy under intense loads. Medium-power shearers, by contrast, serve mines with moderate seam conditions, offering a balance between capability and cost. Their lighter construction and lower energy requirements make them suitable for operations where geological constraints limit the use of the largest machines.



Single-ended ranging-drum shearer



Shearer Pick

Automated and semi-automated shearers have emerged as a distinct class of longwall equipment, defined not by changes in mechanical architecture but by the sophistication of their control and sensing systems. Modern units integrate horizon-control algorithms, inertial navigation, and real-time condition monitoring, enabling the machine to hold cutting height, maintain face alignment, and manage load with far less operator input. In practice, automation has created a new operational category of shearer – one engineered for precision, repeatability, and risk reduction, not just cutting capacity.

KEY AUTOMATION TECHNOLOGIES USED IN CURRENT LONGWALL SHEARERS.

Longwall Command and Control (LCC) – Provides remote operation, diagnostics, and supervisory control of the shearer and associated longwall systems. By removing personnel from the face, it reduces exposure to geotechnical hazards and improves situational awareness through integrated data streams.

HBT Longwall Shearer Automation – Implements tiered automation modes, ranging from assisted operation to fully automated cutting sequences. Capabilities include radio-remote operation, automated travel and cutting routines, and embedded safety interlocks that manage abnormal conditions.

Inertial Navigation Systems (INS) – Supplies high-resolution positional data (centimetre-scale accuracy) for shearer localisation along the face. This accuracy is essential for maintaining consistent web depth, controlling drum horizon, and coordinating with AFC and shield automation.

Automatic Cutting Technologies – Incorporates coal-rock interface detection, adaptive cutting control, and pattern-based (mnemonic) cutting logic. These systems adjust drum height, speed, and load in real time based on material characteristics, improving both productivity and equipment protection.

WHY THESE DEVELOPMENTS MATTER FOR ENGINEERS.

Automation is reshaping longwall operations from reactive, operator-driven processes into data-rich, closed-loop

control systems. The result is:

- More stable cutting conditions and reduced equipment wear
- Improved face alignment and reduced geological deviation
- Lower operator exposure to hazardous environments
- Higher consistency across shifts and crews
- A platform for further integration with shield, AFC, and ventilation automation

As automation levels increase, shearers are evolving into coordinated nodes within a fully instrumented longwall system rather than standalone cutting machines.

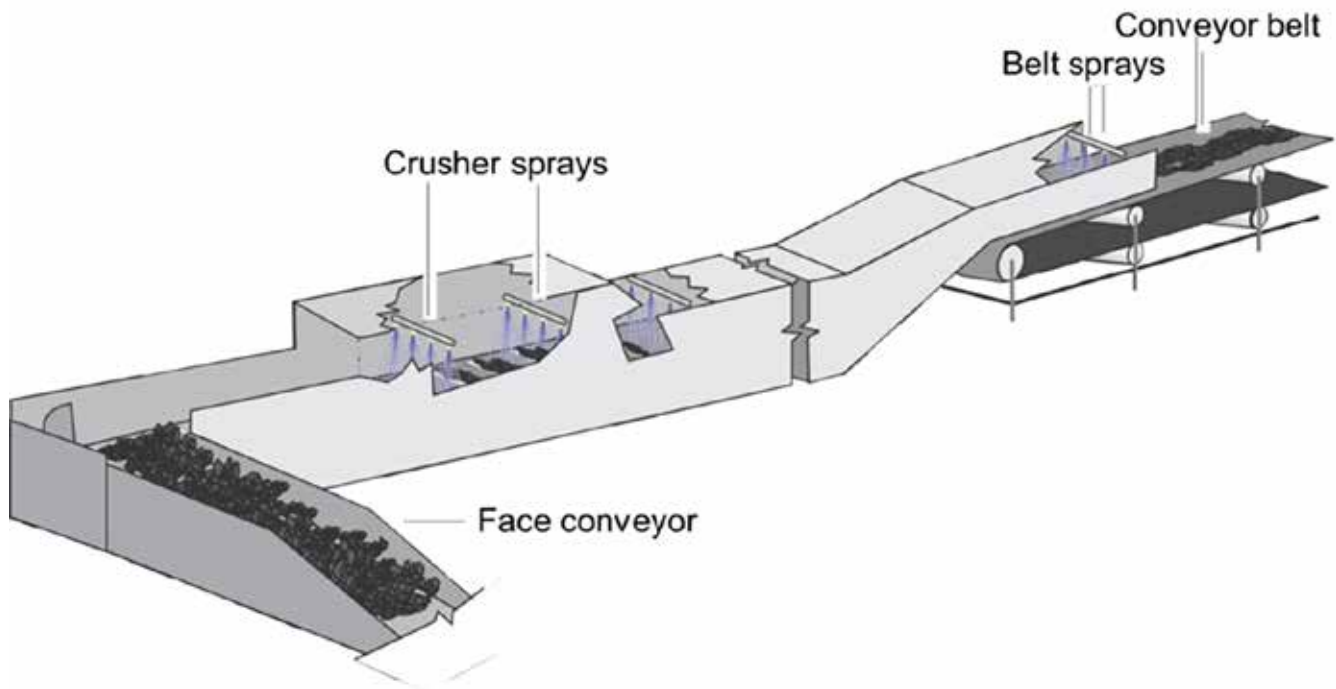
Together, these categories illustrate how shearers have evolved into a diverse set of machines tailored to the complexities of underground coal mining. Whether designed for maximum output, adaptability to challenging geology, or integration with advanced automation, each type plays a role in making longwall mining one of the most productive and technologically sophisticated methods of coal extraction in use today.

ARMoured FACE CONVEYOR (FACE COAL HAULAGE)

The Armoured Face Conveyor is the central transport link in any modern longwall, carrying every tonne of coal cut at the face to the main gate. Its introduction marked a decisive shift away from the limitations of early belt-based systems, which had to be dragged sideways each time the face advanced and therefore could not support the production rates demanded by mechanised longwalling. The AFC, first developed in Germany and long known as the “Panzer” conveyor, provided the robust, flexible haulage path required for continuous cutting and ultimately enabled the high-capacity longwalls that define the industry today.

At its simplest, the AFC is a one-sided scraper conveyor, with the coal face itself forming the second wall of the trough. As the shearer cuts, coal falls into this channel and is dragged along a steel base plate by an endless chain fitted with scraper flights. The return chain runs in an enclosed lower race beneath the base, giving the conveyor its characteristic two-level profile. Early designs





used twin outboard chains, but as face widths increased and production demands rose, these were replaced by centre-chain systems. Modern longwalls typically employ double or triple centre chains to manage higher loads and reduce chain stress. The outer ends of the flights are guided by channel lips along the base, while the lower return path forms the familiar “Sigma Section.”

The conveyor is driven from both the main gate and tailgate by electric motors and sprocket assemblies that must remain aligned with the face. The physical size of these drive units – together with chain strength – often dictates the maximum practical face length. Specially shaped drive pans raise the chain path to accommodate the sprockets and shafts. Along the remainder of the face, the AFC is built from a series of interlinked pans, each typically matching the width of a roof support. Flexible couplings between pans allow both vertical and horizontal articulation, enabling the conveyor to “snake” as the supports advance. The pans are connected by loose-fitting dog-bone bars that provide strength while allowing movement, and inspection pans with removable base sections are spaced along the face to give access to the lower race for cleaning and repair.

Once the shearer completes a web, the AFC must be advanced to the new cutting line. This is achieved using double-acting hydraulic cylinders mounted on the supports and attached to the conveyor’s back plate. These cylinders push the conveyor forward and then pull the supports up to the face once they are lowered. Because the drive units sit on rigid base structures, several supports must push them forward simultaneously to maintain alignment and stability.

Coal loading is a critical part of this process. Because the shearer cuts ahead of the conveyor, much of the coal initially lies on the floor of the cut rather than falling directly into the trough. As the AFC advances, its wedge-shaped toe plates lift this coal onto the conveyor. Effective loading is essential: any coal left behind prevents the conveyor

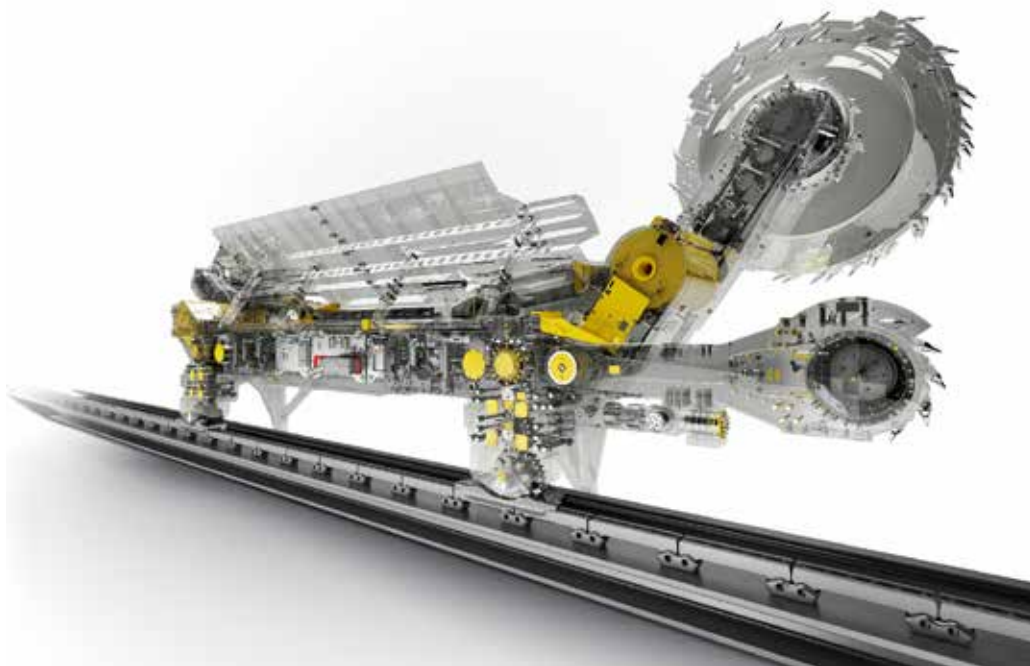
from being pushed fully to the solid face. Earlier systems sometimes used small ploughs – “activated ramp plates” – to improve loading, but modern toe-plate designs have largely removed the need for these additions.

Beyond its primary haulage role, the AFC also serves as the structural backbone of the longwall. The shearer runs on tracks formed by the edges of the base, and its haulage system – whether chain or rack-and-pinion – is mounted directly on the conveyor. The back plate carries the trays, brackets, and channels that support fixed and trailing cables, hydraulic hoses, and other face services. In effect, the AFC becomes the physical and functional spine of the entire longwall system, integrating coal clearance, machine guidance, and service management into a single continuous structure.

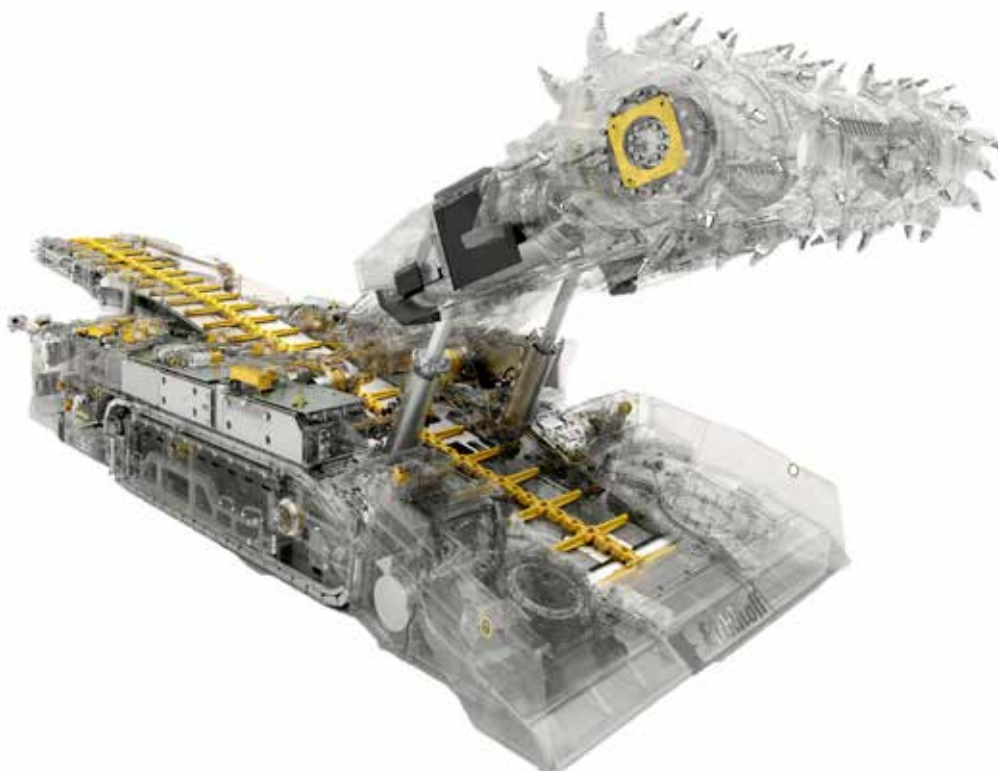
OVERVIEW OF THE LONGWALL SYSTEMS MARKET

The longwall systems market has evolved into one of the most technologically advanced segments of the global mining industry, driven by rising productivity expectations, increasingly stringent safety standards, and accelerating automation. At the centre of this transformation is the integration of three core components – shearers, armoured face conveyors, and hydraulic roof supports – into a single, highly coordinated production system. Longwall mining’s ability to deliver exceptional output with a comparatively small workforce continues to attract investment, even as the broader coal sector undergoes long-term structural change.

In recent years, the market has shifted decisively toward larger, more powerful systems capable of operating on longer faces and in more complex geological conditions. Manufacturers have responded by increasing cutting power, boosting conveyor capacity, and strengthening roof supports to handle higher loads. At the same time, digitalisation has become a defining theme. Modern longwall systems now rely on real-time monitoring, automated horizon control, and



Eickhoff SL1000



remote operation – capabilities that have paved the way for semi-autonomous and, in some regions, fully automated longwall panels. China and Australia, with their large-scale operations, remain at the forefront of this transition.

Geographically, the market is dominated by countries with extensive underground coal reserves and strong demand for high-productivity mining methods. China remains the largest adopter, followed by Australia's export-driven metallurgical coal sector. The United States, Poland, and Russia also represent important markets, though investment patterns vary with regulatory and energy policy trends.

Despite the global shift toward renewable energy, longwall technology continues to advance because coal – particularly metallurgical coal – remains essential to industrial processes such as steelmaking. As a result, the industry's focus has turned toward making longwall operations safer, more efficient, and more environmentally responsible. Automation, data analytics, and advanced machine design have transformed longwall mining into a highly engineered, precision-driven production system. Within this landscape, industry leaders such as Eickhoff play a pivotal role in shaping the next generation of longwall performance, reliability, and automation.

Eickhoff has re-entered the US longwall market with renewed momentum, marked by the successful placement of ten SL750 shearer loaders into high-performance operations. This achievement represents more than a commercial milestone; it reflects the confidence leading US producers place in Eickhoff's technology and long-term commitment to the industry. To support this growth and ensure that service quality matches machine performance, Eickhoff has established a dedicated Life Cycle Management Center in the United States. This local presence strengthens responsiveness, improves spare-parts availability, and provides the long-term operational support that modern mines increasingly rely on.

Beyond shearers, Eickhoff continues to expand its global footprint through a broader portfolio that includes the new generation CM2E continuous miner and high-performance AFC gearboxes from the EKP and EP product ranges. As a family-owned company guided by the principle of "Last Man Serving," Eickhoff maintains a long-term perspective, investing consistently in mining technology and customer support to remain a reliable partner to the coal and potash industries.

Eickhoff shearers are engineered to deliver strong cutting performance across a wide range of geological conditions. Cutting capacity depends on installed power, seam characteristics, and operational setup, while drum design and pick selection are tailored to coal hardness and local geology to maximise productivity and tool life. The product portfolio spans seam heights from 1.2 metres to more than 10 metres, with specialised solutions such as the SL300L for ultra-low seams and the new SLX for extraction heights above ten metres. Even under variable geological conditions, advanced control systems and optimised mechanical design ensure consistent cutting performance.

Automation has become a defining force in modern longwall mining, evolving from basic mechanisation into fully integrated, sensor-driven, data-rich operation. Today, Eickhoff shearers operate as part of highly coordinated longwall systems in which the shearer, roof supports, and AFC work together with increasing autonomy. Horizon control, face alignment, and remote operation from surface control rooms are now standard capabilities, and in the technically leading Australian market, several Eickhoff shearer operations are approaching near-fully automated performance.

A key element of this progress is the adoption of state-based control systems that divide the cutting process into configurable steps, allowing operations to be tailored to site-specific conditions. Inertial navigation systems embedded within the shearer provide continuous tracking of position, horizon, and alignment, ensuring precise and repeatable cutting. Real-time monitoring, enabled by a network of sensors and high-speed communication systems, integrates machine condition, geotechnical feedback, and environmental data into centralised platforms. This transparency allows operators to supervise production remotely with confidence. At the same time, advanced diagnostics and AI-supported systems are enabling predictive maintenance, anomaly detection, and continuous

optimisation, improving productivity while enhancing safety by removing personnel from hazardous areas.

Reliability and durability remain core design principles across all Eickhoff equipment. Major components – including gearboxes, haulage systems, and cutting units – are engineered for long service life and predictable maintenance intervals. Underground accessibility is a central focus, ensuring that maintenance can be carried out efficiently even in challenging conditions. Continuous improvements in component design reduce wear, extend service intervals, and increase overall equipment availability. In line with the "Last Man Serving" philosophy, Eickhoff continues to supply spare parts for machines that have been in operation for decades.

Safety is embedded in every aspect of Eickhoff machine design. Modern systems incorporate multiple safety layers, including automated interaction between the shearer, roof supports, and AFC to prevent collisions and unsafe conditions. Automation further enhances safety by enabling remote operation from surface control rooms, significantly reducing personnel exposure to dust, noise, and moving machinery. All equipment is designed to meet the relevant regional safety standards and certifications.

Eickhoff offers a range of installed power configurations tailored to operational requirements, with efficiency gains achieved through optimised drive systems and intelligent control strategies that maintain consistent cutting performance while minimising mechanical stress. The company's shearers are fully integrated into the longwall system, communicating continuously with roof supports and other infrastructure through high-speed networks and open interfaces. This approach ensures synchronised operation across the entire face and allows seamless adaptation to both new installations and existing systems, even across different OEM environments.

Supporting this technology is a comprehensive suite of training and lifecycle services. Eickhoff provides structured training for operators, maintenance teams, and automation specialists, recognising that the shift toward automation requires continuous upskilling. Training is delivered through a combination of on-site instruction, simulation tools, and digital learning platforms. Remote diagnostics and assistance tools further enhance operational support, helping to minimise downtime. With a strengthened presence in key markets such as the United States, Eickhoff continues to improve spare-parts availability and service responsiveness, backed by a globally experienced team.

Looking ahead, Eickhoff is actively developing new machine concepts and technologies to meet future market requirements. While details remain confidential, these efforts focus on expanding capabilities in specialised applications and advancing automation and system integration even further. The company's long-term strategy ensures that innovation remains continuous, purposeful, and aligned with the evolving needs of the mining industry.

EMERGING TRENDS, INNOVATIONS AND CONCLUSIONS

The longwall systems market is entering a new era defined

by automation, digital intelligence, and a heightened focus on operational safety. Within this shifting landscape, Eickhoff stands out as one of the industry's most influential players, shaping not only the performance expectations of modern shearers but also the technological direction of the sector as a whole. The company's longwall equipment has become emblematic of the transition from traditional mechanical cutting to integrated, data-rich mining systems capable of delivering unprecedented levels of precision and reliability.

Across the industry, automation is emerging as a transformative force. Advanced horizon-control systems, inertial navigation, and real-time geotechnical sensing now enable shearers to maintain cutting accuracy with minimal human intervention. In many operations, the operator has moved from the face to a remote-control room, reducing exposure to dust, noise, and geotechnical hazards. This shift is steadily guiding the sector toward fully automated longwall panels, where human involvement is limited to oversight and strategic decision-making.

Digital integration is accelerating this evolution. Modern shearers generate extensive streams of operational and geological data, which – when connected to mine-wide monitoring platforms – allow engineers to optimise cutting parameters, anticipate maintenance requirements, and respond quickly to changing ground conditions. Predictive maintenance supported by machine-learning algorithms is becoming increasingly common, reducing unplanned downtime, and extending component life.

Mechanical innovation continues to advance alongside digital progress. Higher power ratings reinforced ranging arms, and more durable picks are enabling operators to tackle longer faces and harder seams with greater efficiency. Energy-efficient motors and variable-speed drives are improving performance while reducing power consumption, and manufacturers are experimenting with lighter yet stronger materials to reduce machine weight without compromising structural integrity.

Environmental and safety considerations are also reshaping design priorities. Dust-suppression systems are becoming more sophisticated, noise-reduction technologies are improving working conditions, and enhanced fire-suppression and cable-management solutions reflect a broader industry commitment to safer, cleaner, and more sustainable longwall operations.

Taken together, these developments illustrate a sector in the midst of profound transformation. The longwall shearer – once defined primarily by brute mechanical force – is evolving into a highly automated, sensor-rich, digitally integrated system. Companies like Eickhoff are not simply responding to this shift; they are actively driving it, setting new benchmarks for performance, reliability, and technological sophistication. The future of longwall mining will be shaped by those who can combine mechanical strength with digital intelligence, and Eickhoff is firmly positioned among the leaders defining that future.

Emerging trends and innovations around longwall shearers reflect a mining industry that is becoming more automated, more data-driven, and more focused on safety and precision than ever before. The modern shearer is no longer just a powerful cutting machine; it is increasingly a platform for digital technologies that reshape how longwall operations are planned, monitored, and executed.

One of the most significant developments is the rise of automation and autonomous control. Shearers equipped with advanced horizon-control systems, inertial navigation, and real-time geotechnical sensing can maintain cutting height and position with minimal human intervention. In some mines, operators supervise the shearer from remote control rooms rather than working at the face, reducing exposure to dust, noise, and roof-fall hazards. This shift toward remote and semi-autonomous operation is steadily moving the industry toward fully automated longwall panels, where human involvement is limited to oversight and maintenance.

Digital integration is another defining trend. Modern shearers generate vast amounts of data – from cutting forces and motor loads to geological feedback and conveyor performance. When this information is fed into mine-wide monitoring platforms, it allows engineers to optimise cutting parameters, predict maintenance needs, and respond quickly to geological anomalies. Predictive maintenance, supported by machine-learning algorithms, is becoming increasingly common, helping mines reduce downtime by identifying component wear or performance issues before they escalate into failures.

Mechanical innovation continues alongside digital advances. Shearers are being built with higher power ratings, stronger ranging arms, and more durable picks to handle longer faces and harder seams. Energy-efficient motors and variable-speed drives are improving performance while reducing power consumption. At the same time, manufacturers are experimenting with lighter but stronger materials to reduce machine weight without compromising structural integrity, which can improve manoeuvrability and reduce stress on haulage systems.

Environmental and safety considerations are also shaping new designs. Dust-suppression systems are becoming more sophisticated, using targeted sprays and airflow modelling to reduce airborne particulates at the source. Noise-reduction technologies, improved cable management, and enhanced fire-suppression systems reflect a broader push to make longwall operations safer and more sustainable.

Together, these innovations signal a future in which the longwall shearer becomes increasingly intelligent, efficient, and integrated into a broader digital ecosystem. The machine that once symbolised brute mechanical power is evolving into a highly automated, sensor-rich system that embodies the next generation of underground mining technology.



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