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Kamet Steel completes major overhaul of some of its pulverised coal injection equipment to reduce energy costs

The Kamet Steel plant, part of the Metinvest mining and metallurgical group, built on the facilities of Dniprovsky Metallurgical Plant (Kamyanske, Dnipropetrovsk region), carried out a major overhaul of part of the pulverised coal injection (PCI) technology equipment in the blast furnace to reduce energy costs.

According to the company, the efficiency of blast furnace production at Kamet Steel is inextricably linked to the reliability of the pulverised coal injection technology. Therefore, to ensure the stable operation of this equipment, grinding circuit No. 2 was overhauled – a key stage in the current modernisation of the pulverised coal injection complex.

As specified, pulverised coal injection is an energy resource that acts as a highly efficient carbon component and allows for a radical reduction in natural gas consumption or its complete elimination in the smelting process. Pulverised coal injection also reduces coke consumption, the coke equivalent of conventional fuel, and contributes to increased blast furnace productivity.

The pulverised coal injection section provides fuel not only for the blast furnace production, but also for the rotary kilns of the lime kiln.

Kametsteel was established based on the Dniprovsky Coke and Chemical Plant and the Dniprovsky Metallurgical Plant. The plant is part of the Metinvest group.

Metinvest is a vertically integrated mining group of companies that manages assets in every link of the production chain from iron ore and coal mining and coke production to the production of semi-finished goods and finished products from steel, pipes and coils, as well as the production of other high value-added goods. The group consists of mining and metallurgical enterprises located in Ukraine, Europe and the United States, has a sales network covering all key global markets.

Colombia pushes Glencore talks on Cerrejon mine closure

Glencore operates the Cerrejon coal mine under a concession agreement and its permit expires in 2034.

Colombia has urged Glencore to engage in discussions with local authorities and community representatives regarding the closure of the Cerrejon coal mine in La Guajira, Colombia.

Glencore runs the Cerrejon mine under a concession agreement, with the operating permit set to expire in 2034.

It comprises an extensive mining area, a 150km railway and a port on Colombia's Caribbean coast.

Minister of Mines and Energy Edwin Palma said: "The president tasked us with inviting Glencore to discuss how the mine will be closed. We don't have to wait until the remaining years of the concession have passed.

"We need to start discussing now what the social and economic strategy will be for La Guajira in relation to the energy transition."

Glencore and the Cerrejon mine are yet to comment on the latest request.

Colombia's President, Gustavo Petro, previously indicated willingness to amend Glencore's concession contract unilaterally if exports to Israel continued. The company complied with Petro's requests.

In 2025, the Cerrejon mine produced 16.8 million tonnes (mt) of coal, a decrease from 19.2mt in 2024.

Petro has prohibited new exploration contracts for hydrocarbons and minerals, including coal, as part of a transition to renewable energy.

Palma added: "I want to invite Glencore to engage in dialogue with the tripartite committee, which is already established as the mechanism for discussing the energy transition. This involves investments in energy but also in workforce retraining, training and new ventures focused on clean energy."

Cerrejon is one of the world's largest open-pit coal export mining operations.

With four decades of expertise, it oversees coal extraction, railway transport and export, providing energy products globally from La Guajira.

These Asian Nations Have Returned to Coal for Energy

Disruptions of oil and natural gas shipments in the Strait of Hormuz are pushing Asian governments to preserve and expand coal capacity as strategic insurance.

In a previous piece written last November, I argued that coal would remain a transition fuel for much of Emerging Asia by the logic of the Four As: availability, affordability, accessibility, and acceptability. That argument rests on structural conditions: the region's coal reserves, the cost gap between coal and alternatives, and the political durability of an energy source that supports jobs and grid reliability across dozens of developing economies. The Russian invasion of Ukraine provided a new live stress test of that thesis, as energy shortages hit Asian countries in 2021 and 2022. Events since have added to the evidence.

The Strait of Hormuz Chokepoint and Its Consequences

The Strait of Hormuz carries roughly 20% of global oil consumption, 27% of seaborne oil trade, and 20% of global liquefied natural gas (LNG) trade. Some 89% of the crude oil that transits the strait is destined for Asian markets, and China alone absorbs 37.7% of total Hormuz crude flows, the largest share of any single nation. On the LNG side, 83% of Hormuz LNG flows to Asia, and Qatar, which declared force majeure on all its export contracts after attacks on the Ras Laffan complex, accounted for roughly 20% of global LNG supply before the crisis.

But the overall numbers hide very different stories at the country level as system dependence and portfolio dependents diverge. Pakistan is in the most vulnerable position: Qatar supplies almost all its LNG and roughly a fifth of its total gas needs, with virtually no alternative suppliers to fall back on. Kuwait and Bangladesh face similarly concentrated risk. India and Singapore are heavily reliant on Qatari LNG within their import mix but at least have some other suppliers in the picture. China, Japan, South Korea, and Italy import large volumes but are less dependent on Qatar specifically and have more options if supply were disrupted. Taiwan is an interesting outlier: it leans heavily on Qatari LNG for its overall gas supply yet has managed to diversify its roster of suppliers more than its exposure level might suggest.

Switching Back to Coal: Who Can and Who Cannot

As I argued before, fuel switching is the primary near-term adjustment mechanism in any gas shortage, and coal is the primary substitute given its characteristics and, often, already existing infrastructure. The current crisis highlights this relationship as India is burning more coal to meet higher summer demand; South Korea has lifted caps on coal-fired electricity generation; Indonesia is prioritising domestic coal supply over exports, while Thailand, the Philippines, and Vietnam are all boosting coal-fired power.

Countries with established coal infrastructure and domestic or regional supply, including India, Indonesia, China, and, to a degree, South Korea, can absorb the shock with relative speed. The situation is fundamentally different for Bangladesh, Pakistan, Singapore, and other economies where domestic gas or coal are either unavailable or insufficient to cover the natural gas shortfalls. For these poorer importers, the crisis is not merely an energy price shock but a genuine supply security emergency. Coal is often the most accessible substitute, but it is not always accessible enough.

But coal resources are essentially present in the region. As such, we may expect countries that lack the generation infrastructure to scale coal quickly or that face additional logistics costs to look to resolve those issues. This does not mean they will completely give up on imports of LNG, but they will focus more on redundancy to support their energy security.

China has gone further than any other country in building an industrial and strategic redundancy around domestic coal, including through its rapidly expanding coal-to-gas (CTG), coal-to-liquids (CTL), and coal-to-chemicals (CTC) sectors. With approximately 380 million tonnes of coal consumed annually as a chemical and fuel feedstock, and a CTL sector that grew 24% in 2023 alone, China has turned domestic coal into a strategic substitute for natural gas (in power generation and beyond) but also for oil, otherwise extremely difficult to substitute.

Energy Security Lessons for Asia's Coal Transition

At the time, as the notion of globalisation retreats, systems that rely too heavily on imported fuels without redundancy remain exposed. The experience of the current crisis is likely to make governments across Asia reluctant to fully retire coal-fired generation capacity even as their renewable buildouts accelerate, and some may even expand it. The logic mirrors the "credible threat" principle familiar from European gas security debates: the mere existence of dispatchable backup capacity confers stability, independent of how often it is used. A country that retains coal as a standby resource, even at low utilisation rates, is in a fundamentally different position from one that has decommissioned it entirely when an unexpected disruption hits. Coal plants that might otherwise have been scheduled for early retirement are being reconsidered, not as the primary generation source of the future, but as insurance against a world where energy supply routes cannot be taken for granted. And some new coal plants will be built to make sure countries have access to reliable energy resources as they develop economically.

By: **Anna Mikulska**

Middle East sulphur supply disruptions give opening for South Africa to reprocess coal waste

One of the hitherto generally unnoticed side effects of the conflict in the Gulf has been a disruption in the global supply of elemental sulphur, which is a by-production of oil production, University of Cape Town (UCT) Department of Chemical Engineering academics Dr Helene-Marie Stander and Professor Jennifer Broadhurst have highlighted. Elemental sulphur is very important because, when converted into sulphuric acid, it is used to produce fertilisers and for the refining of copper and nickel.

Because of this supply disruption, China banned the export of sulphuric acid, with effect from the start of this month. That is how serious an issue this is.

South Africa consumes about 11-million tons per year (Mtpa) of sulphuric acid, of which some 7 Mtpa is produced by burning sulphur. The country imports rather more than 1 Mtpa of elemental sulphur, almost entirely from Gulf countries, particularly Saudi Arabia. A reduction in this sulphur supply and the consequent increase in the sulphur price, could seriously affect the country's agricultural and mining sectors, they warn.

However, there is a local alternative, they highlight. South Africa's significant coal reserves contain both organic sulphur and mineral sulphur, in the form of pyrite. And pyrite can be roasted to produce sulphuric acid.

"The pyrite component in coal is rejected with the coal waste during processing and can be effectively separated from the rest of the waste material, although this is not currently standard practice," they point out. "This means that there is a real opportunity for South Africa to start roasting coal-derived pyrite to replace some of the sulphur currently being imported."

A UCT study has ascertained that the country's current arisings of coal waste could produce up to 800 000 t/y of sulphuric acid. That number could be increased by reprocessing coal waste facilities to retrieve pyrite. In all, South Africa could increase its sulphuric acid production by 1.4-million tonnes a year and so close the supply gap created by the Middle East conflict.

Recovering and burning pyrite would also have a significant environmental benefit, for pyrite is responsible for the problem of acid mine drainage, which threatens water quality in the upper Olifants River catchment area. This, in turn, threatens human and animal health, agriculture, the environment (not least, the Kruger National Park) and tourism, downstream. Pyrite oxidation also generates heat and is an important trigger for spontaneous combustion in coal waste heaps, adding to air pollution in Mpumalanga province.

The additional step in the separation process, to recover pyrite, would also recover some coal, as well as other waste products that could be used for aggregate in the construction sector, and soils for use in mine rehabilitation.

"Recovering pyrite from coal waste to produce sulphuric acid can alleviate some of the economic impacts of tensions in the Middle East, can reduce the environmental impacts associated with coal mining, and can provide additional economic opportunities," they sum up. "This geopolitical moment is an opportunity for the industry to demonstrate its value both to South Africa and the world at large."

South Africa allows 11 private firms to operate trains on its freight rail network

South Africa has allowed 11 private firms to operate trains on the country's freight rail network, the state company that manages the network said on Wednesday, part of a government drive to boost freight volumes and lift economic growth.

- Transnet said in a statement that the private companies would operate on five strategic rail corridors, serving sectors including coal, manganese, containers, fuel and general freight.
- The companies are ARC South Africa, The Railway Corporation, TLD Marine, MENAR, Sharp Logistics, Barberry, Grindrod, Minrail, IRACEMA, Motheo Logistics and Interlinks.
- South Africa is trying to address logistics bottlenecks that have stifled commodities exports in Africa's biggest economy.
- The private companies are expected to introduce an additional 24 million tons of freight capacity to the network, with the potential to scale to 52 million tons over the next five years, Transnet said.
- Some of the companies are aiming to start operations this year and the others next year.
- South Africa's government is pushing to increase annual rail volumes from approximately 180 million metric tons to 250 million tons by 2030

660MW coal-fired powerplant to take off in Enugu July

Enugu State Government has unveiled plans to build a 660MW coal-fired power plant in the state.

The commencement of the project is billed for July, according to the state government.

This part of Governor Peter Mbah's administration's strategy to actualise its vision to grow the state's economy from $4.4bn to $30bn.

This was even as the Organised Private Sector Nigeria (OPSN), an umbrella body for Nigeria Employers' Consultative Association (NECA); Manufacturers Association of Nigeria (MAN); Nigerian Association of Small-Scale Industrialists (NASSI); Nigerian Association of Small and Medium Enterprises (NASME), and the Enugu Chamber of Commerce, Industry, Mines and Agriculture (ECCIMA) endorsed the governor for a second term in office.

They said he had made them proud as a private sector player himself by his outstanding leadership that had "strengthened confidence in Enugu as an emerging destination for investment, commerce, enterprise development, and living."

Governor Mbah spoke during a solidarity visit by OPSN, Enugu State, to him at Government House, Enugu recently.

Mbah recalled that Enugu State, under his leadership, was the first subnational to set up an electricity market following the Constitution and Electricity Act amendments that effectively transferred power from the Exclusive List to the Concurrent List, thus paving the way for states to participate in all the power value chain, namely generation, transmission, and distribution.

"But we have gone beyond just setting up the electricity market to now being interested in producing the electricity here. I am pleased to inform you that in July we are going to be breaking ground for a 660MW coal-fired power plant.

"The outlay in terms of time for building the plant is 24 months. So, our target is to commission that power plant 24 months after the groundbreaking in July.

"What that simply means is that post-2027, you will not have your power go off in Enugu, whether for businesses or for residential. You are also going to have affordable electricity because it is going to be by far the cheapest in the country."

The governor allayed concerns normally associated with coal, citing the low sulphur content and high calorific value of Enugu coal, standing at about 7,000 kilocalories per kilogramme.

"The interesting thing about our coal is that we have the best quality of coal in the world. Our sulphur content is less than 0.5 . With 1% you are happy, but this one is 0.5%. The only country that comes close is Japan.

"So, instead of just exporting our coal, we are going to be benefiting from it by adding value, generating electricity with it," he said.

He said the project was not a knee-jerk decision, as his administration had taken about two years to undertake the necessary studies and also secure coal assets to guarantee unhindered supplies to the plant.

Mbah equally listed investment in security, establishment of a one-stop shop for prospective investors, the ongoing construction of a technology incubation centre, and partnership with the Nigerian Communications Commission to build an Artificial Intelligence Institute as part of his administration's strategy to further improve the Enugu business environment and prepare for the future.

"In four years from now, AI will contribute $20trn to the global economy. We just do not want Enugu State to miss out on such huge funds. We want to be at the epicentre, not just as consumers, but as producers," he stated.

OPSN had earlier endorsed Mbah and called for improved power supply, expressing the need for the sustained implementation of harmonised taxes and levies, continuous improvement in access to land, affordable financing, and technical support for SMEs, among others.

Speaking, the Convener, OPSN, Enugu, and Chairman, NECA South East Zone, Dr. Ugochukwu Chime, expressed the group's satisfaction with the Mbah administration, citing security, improved infrastructure, transportation, hospitality, social services, and other enablers of business and investment.

"We particularly commend your administration's significant investments in security because we all know that business only goes to secure and peaceful destinations, urban renewal, and city expansion developments.

"The construction and rehabilitation of strategic road networks have improved mobility, enhanced access to commercial centres, and stimulated economic activities across the state," Chime stated.

Chime said Mbah, by his exploits, had made it imperative for more private sector players to join politics.

"Organised Private Sector is particularly proud that you are one of its distinguished products. Your private sector background, where practical and common-sense decisions prevail, has enabled you to appreciate the critical role of businesses in economic growth, job creation, and improved welfare of the people," he said.

Other speakers, including Dr. Ifeanyi Okoye of NECA; founder of Peace Group of Companies, Dr. Maduka Onyishi; ECCIMA President, Engr. Nnanyelugo Onyemelukwe; ECCIMA Vice President, Princess Egbo; and Chairman of Wilson Group, Chief William Agbo, lauded Mbah for turning the state's fortunes around as a centre for business and investment.

Some of the members used the opportunity to present several made in Enugu products to the governor.

End of Norwegian mining on Svalbard as Norway's last mine closes

Norway's coal production on Svalbard is over. The company Store Norske is closing Mine 7, the last Norwegian coal mine.

Mining operations have played a significant role on the Arctic archipelago for over 100 years and has long been central to the settlement in Longyearbyen.

The end of this chapter is officially marked on Svalbard.

"An ending marked with respect," says General Manager Gudmund Løvli of Mine 7 to High North News recently.

General manager Gudmund Løvli started as a miner with the company Store Norske 35 years ago. In recent years, he has led the cleanup work in Svea and been the general manager for Mine 7. After the closure, he will be in charge of the cleanup in the mine.

"We wanted to mark that we are now officially closing the mine shaft in Mine 7. Initially, it was supposed to be quite an anonymous event, but it has suddenly gained more attention," says Løvli.

"We see media from all over the world here now. It has become bigger than we had expected ourselves."

A dignified conclusion

"It will be a simple symbolic act. Not a celebration, but a dignified ending," Løvli emphasises.

How is the atmosphere like today?

"The atmosphere is fine. This is something people have been prepared for for a long time. But of course, now it is over. I do not think we will fully process this until tomorrow."

Cleanup of the mine

Until now, the focus has been on cleanup inside the mine, removing things like power and clearing it completely before the water arrives in the summer.

"The plan was to be finished in May, and we are. Now the work begins to clear the outside areas, but with significantly less staffing," he concludes.

Extended operations

The closing of the mine follows the decision from 2021 to phase out Longyearbyen's coal power plant, which supplies the city with energy.

When Longyearbyen Community terminated the agreement to purchase coal from Mine 7 for energy production, Store Norske decided to close the mine in the autumn of 2023.

Following the war in Ukraine, high demand and high prices of coal, led to the decision to extend operations two more years.

From the coal quay in Longyearbyen.

India clears $3.9 billion push to turn coal into gas to reduce imported fuel reliance

India's cabinet approved a 375 billion rupee ($3.92 billion) scheme to boost coal gasification projects, reducing reliance on imported fuels and channelling domestic coal into cleaner industrial uses, Information Minister Ashwini Vaishnaw said

The cabinet decision seeks to encourage the conversion of coal into synthetic gas that can be used to produce power, fertiliser, petrochemical among other industrial applications.

That, in turn, would help reduce India's imports of liquefied natural gas (LNG), urea, ammonia and methanol, Vaishnaw said.

The scheme comes as India's gas imports have been impacted by the Middle East crisis.

Several countries, including the United States and China, are also exploring coal gasification technologies as part of efforts to cut emissions while continuing to rely on coal for energy security.

India, which has one of the world's largest coal reserves of 401 billion tons and 47 billion tons of lignite, aims to gasify about 75 million metric tons of coal annually, Vaishnaw said, with the scheme expected to bring investments of about 3 trillion rupees.

Under the plan, the government will provide financial assistance of around 20% of the cost of plant and machinery.

Interest in the sector is expanding among power producers. State-run power producer NTPC is looking to enter the coal gasification business, with plans to produce between 5 million and 10 million tonnes per annum of synthetic gas over the next three to four years, Reuters reported last year.

India had in 2024 approved an 85-billion-rupee coal gasification incentive scheme. ($1 = 95.7700 Indian rupees)

Leader visits mine on election day

The election to the 15th Supreme People's Assembly of the DPRK took place on March 15, marking an occasion for further consolidating the people-centred socialist system of the Korean style and providing a powerful sovereign guarantee for the comprehensive development of the state.

That day the respected Comrade Kim Jong Un visited the Chonsong Youth Coal Mine under the Sunchon Area Youth Coal-mining Complex to vote for the manager of the coal mine, a candidate for deputy to the SPA, and encourage the miners there.

This shows that he sets great store by coal-mining sector and intends to value and put forward the working class in this sector.

During the period of the five-year plan for the national economic development set forth by the Eighth Congress of the Workers' Party of Korea in January 2021, the coal-mining industry enhanced the productivity of each pit as part of its efforts to put production on a normal track, playing its part in ensuring the sustainable development of the national economy as a whole. The Ninth Party Congress held in February this year decided to set it as a target of the new five-year plan to boost the coal output by 1.2 times.

Coal is the food of industry and powers the development of a self-reliant economy. Without coal, the production growth of electric power, metal, chemical and other industries is inconceivable.

Moreover, during the term of the Eighth Party Central Committee, metal, chemical and electric power industries readjusted and reinforced their Juche-oriented production lines based on coal abundant at home. Given this, it is necessary to increase the coal output in order to fully guarantee the growth of the overall economy.

Comrade Kim Jong Un bestowed utmost trust on the coal miners, calling them the hard core of the country performing the most valuable feats in the vanguard of state building. He expected that the miners would play the active role of a powerful engine in the lead of the struggle to attain the targets of the new five-year plan.

He set it as one of the important tasks to build up the Chonsong Youth Coal Mine into a standard one, where mechanisation and informatisation of the work inside its pits are realised and to transform all the mine villages into modern and cultured villages and towns within the term of the Ninth Party Central Committee.

This task is a gigantic undertaking of historic significance to give the country another facelift.

Once it is carried out, a new life and new culture of the advanced working class will take its undisputed position in the centre of our times.

His visit to the Chonsong Youth Coal Mine marked a historic occasion that declared a fresh start for civilisation and modernisation of the coal-mining industry, and an important political occasion that injected great vitality into the dynamic advance of the state towards its comprehensive development.

Breathing life into the mine: modern ventilation for safer, smarter operations

Gordon Barratt of Coal International and Mining & Quarry World looks at the fundamentals of mining ventilation. Effective ventilation remains one of the most critical determinants of health, safety, and productivity in underground mining. Well designed systems not only dilutes and removes toxic and explosive gases but also delivers the fresh air required to sustain efficient working conditions at the face. For modern mines – whether deep hard rock operations or extensive coal workings – ventilation is not simply an engineering requirement; it is the backbone of safe production.

Underground mining has always been a battle against the invisible. Long before mechanisation or modern safety systems, miners understood that stale, foul, or explosive air could kill as surely as a roof fall. The story of ventilation is therefore the story of how underground coal mining became possible at scale.

AIRFLOW UNDERGROUND: THE ORIGINS OF MINE VENTILATION

The story of how miners have understood and controlled the movement of air underground stretches back thousands of years. Long before ventilation became a science, working miners were making practical observations that shaped the foundations of modern mine airflow.

As early as 4000–1200 BC, European miners were driving tunnels into chalk to extract flint. Excavations at Grimes Graves in southern England show that these Neolithic workers used brushwood fires at the face – likely to fracture the rock. In doing so, they would have seen first-hand how fire draws air through confined spaces. That simple observation, made at the working face, became a principle rediscovered repeatedly by the Greeks, the Romans, medieval miners, and later during Britain's Industrial Revolution.

By 600 BC, the Laurium silver mines of Greece were already demonstrating a deliberate approach to ventilation. Their layouts show that Greek miners understood the need for a connected circuit, with at least two airways serving each major working area. Evidence also suggests they used divided shafts to separate intake and return air – an early form of controlled ventilation.

Roman metal mines continued this practice. Many had twin shafts, and Pliny the Elder (AD 23–79) recorded how workers used palm fronds to push air along headings – primitive, but unmistakably a ventilation technique.

For the next 1,500 years, European metal mining left few written records, but the first comprehensive technical text arrived in 1556 with Georgius Agricola's De Re Metallica. Working in the mining districts of Bohemia, Agricola documented the methods of his time with remarkable detail. His illustrations show miners diverting surface winds into shafts, operating wooden centrifugal fans driven by men or horses, using bellows for auxiliary ventilation, and installing air doors to control flow. He also recognised the dangers of "blackdamp" – oxygen-depleted air – and the explosive threat of "firedamp," which he compared to a dragon's fiery breath. The English translation, completed in 1912 by Herbert and Lou Hoover, remains a cornerstone of mining literature.

From the seventeenth century onward, papers presented to the Royal Society began to examine the explosive and toxic nature of mine atmospheres. As the Industrial Revolution accelerated coal demand, conditions in many British coal mines became increasingly hazardous. Ventilation relied either on natural draught – often ineffective when surface and underground temperatures equalised – or on fire. Early ventilating furnaces were built at surface, but miners soon discovered that lowering burning coals in a wire basket down the upcast shaft produced a stronger draught. This insight led directly to the development of shaft-bottom furnaces.

Throughout this period, the only source of underground light was the candle – an ever-present ignition risk in an atmosphere where firedamp and poor ventilation were constant threats.

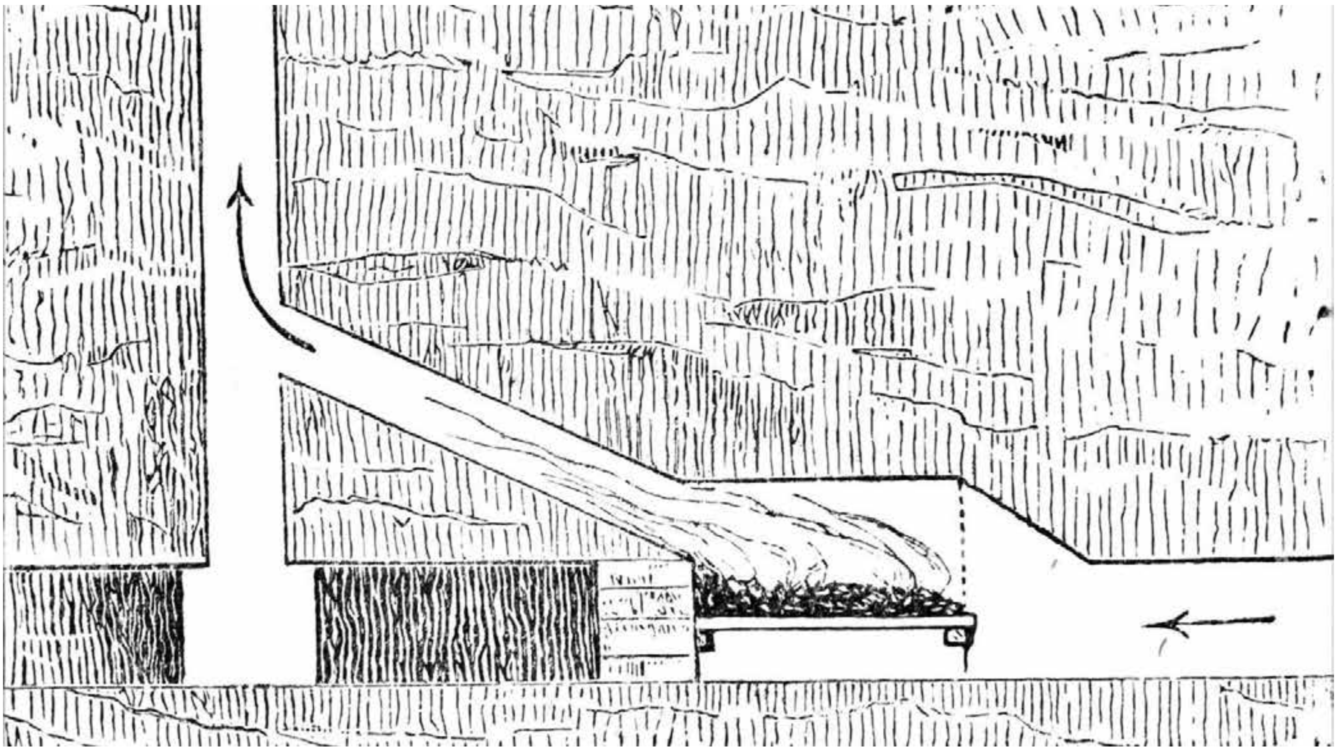
The earliest coal workings In Britain and Europe were shallow bell pits and adits where air moved only because the openings were close to the surface. Ventilation was little more than a natural draught created by differences in temperature and elevation. As workings deepened in the 17th and early 18th centuries, this passive airflow became dangerously inadequate. Blackdamp (oxygen-poor air) and firedamp (methane) accumulated, and explosions became common.

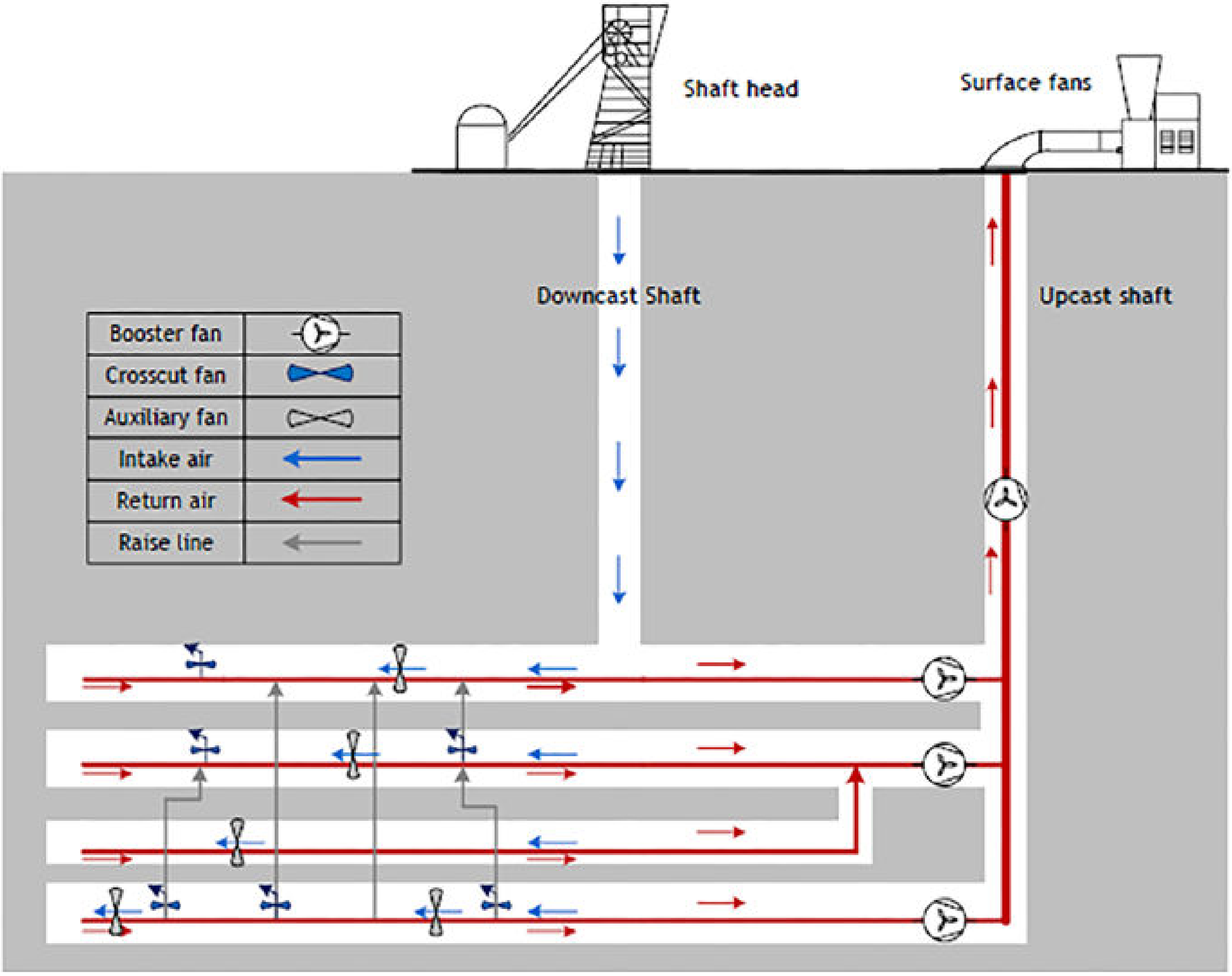
By the mid 1700s, collieries began using furnace ventilation – a simple but ingenious method. A fire was lit at the bottom of a return shaft; the rising hot gases created an upcast, drawing fresh air through the mine. This allowed deeper workings and more extensive networks of roadways, but it came with obvious risks. The furnace itself could ignite methane, and the system struggled to cope with the growing scale of industrial-era mines.

The Industrial Revolution brought the first real leap forward. Steam engines were adapted to drive large fans, replacing furnaces and giving mine managers far greater control over airflow. By the late 19th century, mechanical ventilation was becoming standard in major coalfields. Mines could now be sunk deeper, with multiple districts ventilated through regulated splits, doors, stoppings, and regulators.

The late 19th and early 20th centuries saw the emergence of purpose-built mine fans – Guibal, Waddle, Sirocco, and later axial-flow designs. Ventilation engineering became a science. Airflow could be measured, predicted, and balanced. Mines introduced ventilation plans, pressure monitoring, and systematic control of leakage. This era enabled the vast deep collieries of South Wales, Yorkshire, the Ruhr, and Appalachia.

From the mid 20th century onward, ventilation evolved from simply moving air to managing a complex atmospheric environment. Flame safety lamps gave way to electronic methane detectors, fixed monitoring systems, and automatic fan controls. Regulations tightened, requiring minimum





Typical configuration of an underground ventilation network

air quantities, continuous monitoring, and emergency ventilation protocols. As mechanisation increased dust levels, ventilation also became a tool for dust suppression and occupational health.

Today's underground coal mines operate with sophisticated ventilation-on-demand systems, computer modelling, and high-efficiency axial fans capable of moving hundreds of cubic metres per second. Airflow is dynamically adjusted to match production cycles, reducing energy consumption while maintaining safety. Refuge chambers, real-time gas telemetry, and emergency inertisation systems reflect a modern understanding of mine atmospheres as dynamic, controllable systems.

At every stage, ventilation dictated what was possible underground. Mines could only deepen when airflow improved. Mechanisation only became viable when dust and gas could be controlled. And the modern safety culture – from gas monitoring to explosion prevention – is built on the foundations laid by centuries of trial, error, and innovation in moving air.

Underground environments accumulate contaminants that surface operations naturally disperse. Diesel exhaust, blasting fumes, naturally occurring gases, dust, and heat all build up unless they are actively removed. Ventilation is the only mechanism capable of maintaining a safe atmosphere underground, and its performance directly shapes the health of personnel, the reliability of equipment, and the efficiency of the entire operation.

VENTILATION SYSTEMS IN TODAY'S MINES

Underground ventilation systems fall broadly into two categories: natural ventilation and mechanical ventilation. Natural ventilation relies on pressure and temperature differences between the surface and the workings, but as your document highlights, it is inherently unreliable because these pressure differences can be small and fluctuate throughout the day or season. Mechanical ventilation, by contrast, uses fans and ducting to generate a controlled pressure differential and deliver air where it is needed.

Fresh air typically enters through shafts or adits, and the objectives remain constant across all mine types: dilute and remove hazardous gases, control dust, manage heat, and supply oxygen for breathing and combustion. Diesel vehicles, human respiration, drilling, blasting, and natural emissions from the rock mass all contribute to the gas load that ventilation must handle.

BOUNDARY AND CENTRAL VENTILATION SYSTEMS

Ventilation networks are commonly classified as boundary (unidirectional), central (bidirectional), or combined

systems. The boundary system is widely regarded as the most efficient, with air flowing in a single direction from intake to return and achieving volumetric efficiencies of 70-80%. This configuration is especially common in metal mines working steep lodes, where intake and return shafts are positioned at opposite ends of the strike. Larger operations may use a central intake shaft with return shafts or winzes at either end, often supported by multiple exhaust fans.

The central or bidirectional system, more common in in seam coal mines, places intake and return shafts near the centre of the property. Air travels in opposite directions through parallel roadways separated by stoppings. While this arrangement allows earlier production and reduces development requirements, it suffers from higher leakage and lower volumetric efficiency – typically 40-50% – due to the number of stoppings and air crossings required.

AIRFLOW PATTERNS AND ENGINEERING CONSIDERATIONS

Several airflow patterns can be used within these systems. Ascensional ventilation introduces fresh air at the lower levels and allows it to rise along the working faces, sometimes generating natural ventilation pressure that assists fan performance. Descensional ventilation delivers air from the rise side downward, reducing heat accumulation and often producing cleaner, less dusty conditions. Antitropal ventilation describes situations where air and mineral flow in opposite directions, while homotropal ventilation refers to both moving in the same direction.

Ventilation engineering involves planning, implementation, and continuous monitoring. Engineers must calculate air requirements for current and future operations, design intake and return airways, select and install fans and control devices, and ensure that the system can deliver the required airflow. Regular monitoring of temperature, dust levels, airflow, and pressure is essential, and ventilation equipment must be inspected and maintained to ensure ongoing performance.

MECHANICAL VENTILATION AND FAN TECHNOLOGY

Mechanical ventilation relies on fans to generate airflow. Axial flow fans move air directly through the centre of a cylindrical housing using blades set at a defined pitch, while centrifugal fans draw air into a rotating impeller and discharge it radially. Large underground mines typically use high capacity axial or centrifugal fans as part of a primary exhaust based system, with the main fans located on the surface. Radial booster fans may be installed underground to overcome pressure losses in extensive workings.

Secondary ventilation systems distribute air to individual working areas using barriers, regulators, and ducting. Vent walls constructed from hessian screens coated with concrete provide a simple and cost effective method of sealing airways. Inflatable stoppings can be installed quickly to isolate areas, and doors may be incorporated into vent walls to maintain access while preserving airflow integrity.

VENTILATION CONTROL AND MONITORING INSTRUMENTS

Effective ventilation management requires a suite of monitoring instruments. The barometer is essential for detecting atmospheric pressure changes that may influence gas behaviour underground. Sudden drops in barometric pressure can cause gases trapped in abandoned workings

Centrifugal fans

Axial Air Flow fans

to expand and migrate into active areas, increasing the risk of explosive atmospheres.

The mine water gauge, a partially filled U tube, measures the pressure generated by the fan and reflects the total resistance of the mine and shaft system. Temperature and humidity are monitored using thermometers and hygrometers, while air velocity is measured with anemometers. These instruments provide the data needed to verify airflow quantity and distribution and to ensure that ventilation systems are performing as designed.

CONCLUSION

Ventilation remains one of the most critical engineering functions in underground mining. This article concludes that effective ventilation design and management are essential for maintaining safe working conditions, reducing losses, and ensuring that air reaches all parts of the mine in the required quantity and quality. By understanding the strengths and limitations of different ventilation systems, the behaviour of airflow, and the tools available for monitoring and control, mining professionals can ensure that their operations remain safe, efficient, and resilient.

Beyond the Belt: how modern conveyor technologies redefine Efficiency

Mechanical conveying systems are fundamental to the productivity and continuity of modern mining operations. They form the backbone of material-handling infrastructure, moving everything from run-of-mine ore to refined product with the consistency, safety, and efficiency that high-throughput sites demand. For engineers, designers, and operators across the mining sector, a clear understanding of how these systems have evolved – and how their design principles influence performance in abrasive, high-impact, and often unforgiving environments – is essential to improving reliability and reducing whole-of-life costs.

In this article, ***Gordon Barratt of Coal International and Mining & Quarry World*** examines the major conveyor technologies used across surface and underground operations, including belt, roller, chain, screw, and overhead systems. The discussion highlights the engineering considerations that matter most in mining: durability under heavy load, resistance to impact and wear, maintainability, energy efficiency, and integration with increasingly automated plant systems. It also explores the innovations reshaping conveyor performance, from advanced composite materials to smarter monitoring and control technologies.

By clarifying the role of conveyor systems in enhancing productivity, safety, and long-term operational resilience, this piece offers mining professionals practical insights that support better system selection, improved plant design, and stronger competitiveness in an industry where efficient material flow remains a decisive advantage.

HISTORICAL CONTEXT

The story of conveying in mining begins long before the appearance of anything recognisable as a modern belt system. Early civilisations relied on sledges, baskets, and simple mechanical aids to shift stone, ore, and earth, but these were intermittent and labour-intensive methods. The idea of continuous material movement – of a machine performing the work of many hands – did not truly take hold until the Industrial Revolution reshaped the technological landscape of Europe and North America. As factories adopted mechanised production in the late eighteenth century, engineers began experimenting with flat belts made from leather, canvas, or woven fabrics to move goods within workshops. These early conveyors were short, fragile, and limited in capacity, yet they introduced a principle that would eventually transform mining: the steady, uninterrupted flow of material.

Mining operations of the nineteenth century were expanding in scale and complexity, driven by deeper shafts, longer drifts, and rising global demand for coal and metals. Traditional haulage methods – hand tramming, horse-drawn tubs, and narrow-gauge rail – were increasingly inadequate. By the 1880's and 1890's, inventors and mine engineers began adapting factory belt conveyors for underground use, reinforcing frames, improving belt materials, and experimenting with tensioning systems to cope with abrasive ores and harsh conditions. These early mining conveyors were still relatively short and often used for loading, sorting, or stockpiling, but they demonstrated the potential for mechanised haulage to reduce labour, increase throughput, and improve safety.

A decisive shift occurred in the early twentieth century with the introduction of rubberised belts. Vulcanised rubber

Industrial narrow-gauge railways

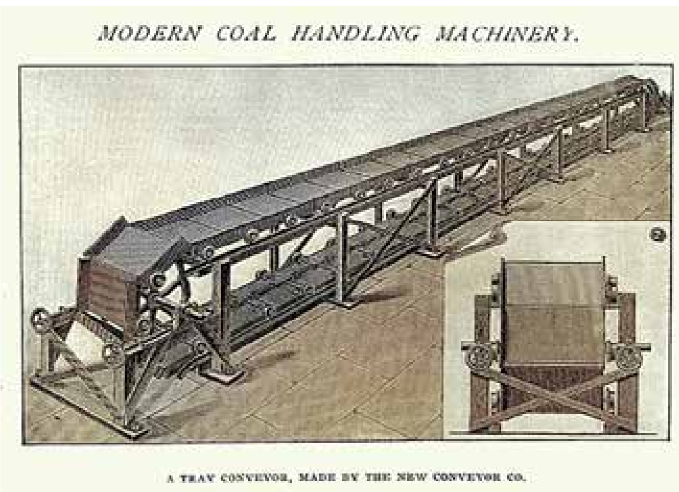
offered far greater durability, flexibility, and resistance to moisture and abrasion, enabling conveyors to extend over longer distances and operate reliably in damp, dusty, and confined underground environments. By the 1920's and 1930's, troughed belt designs had become standard, using angled idlers to cradle the belt and increase carrying capacity. This period also saw the emergence of standardised components – rollers, pulleys, bearings, and belt widths – which allowed mines to install, maintain, and expand conveyor systems more efficiently.

The mid-twentieth century marked the true industrialisation of conveying in mining. Electrification, improved motor technology, and advances in steel fabrication enabled conveyors to handle heavier loads and steeper gradients. Longwall coal mining, which demanded rapid and continuous removal of cut material, became a major driver of conveyor innovation. Armoured face conveyors (AFCs) were developed to operate directly at the coal face, feeding onto gate conveyors and then onto trunk belts that carried coal out of the mine. At the same time, surface operations embraced overland conveyors capable of spanning kilometres, crossing valleys, and replacing fleets of trucks. Steel-cord belts, introduced in the 1950's and 1960's, provided the tensile strength needed for these long-distance systems, while improved take-up mechanisms and braking systems allowed for controlled operation on steep terrain.

By the late twentieth century, conveying had become a backbone technology of global mining. Computerised control systems, variable-speed drives, and condition-monitoring sensors enhanced reliability and efficiency. Conveyor networks grew into integrated haulage systems linking extraction, processing, and stockpiling, often operating with minimal human intervention. In large open-pit mines, shiftable and semi-mobile conveyors began replacing truck haulage, reducing fuel consumption and operating costs. Underground, advances in fire-resistant belts, dust suppression, and automated tensioning improved safety and performance.

In the twenty-first century, the evolution of conveying continues to accelerate. High-tension steel-cord belts now span tens of kilometres, while pipe conveyors, sandwich belts, and curved overland systems allow material to be transported along complex routes with minimal environmental impact. Automation and digitalisation have transformed conveyors into intelligent systems capable of self-diagnosis, predictive maintenance, and real-time optimisation. As mining moves toward electrification, decarbonisation, and reduced surface disturbance, conveyors are increasingly positioned as the most efficient, sustainable, and scalable method of bulk material transport.

From crude ancient methods to today's high-capacity, sensor-rich haulage networks, the development of



conveying in mining reflects the broader trajectory of industrial progress: a shift from manual effort to mechanised continuity, from isolated machines to integrated systems, and from simple belts to sophisticated, long-distance arteries that sustain the modern mining industry.

Mechanical conveyor systems are indispensable across modern industry, but nowhere is their value more evident than in the mining sector – both surface and underground – where the continuous, reliable movement of bulk materials determines the pace, safety, and profitability of operations. In these environments, conveyors are not simply tools for transporting material; they are critical infrastructure that keeps extraction, processing, and distribution flowing. Whether hauling overburden across vast open-pit benches or carrying ore through confined underground drifts, conveyor systems reduce manual handling, minimise operational risk, and support the high-throughput demands that define contemporary mining.

Today's conveyor landscape reflects decades of engineering refinement, offering manufacturers a wide range of specialised systems tailored to the demanding conditions of mining. Belt conveyors dominate both surface and underground operations due to their ability to move large volumes over long distances and challenging terrain. Roller conveyors support heavy loads in processing plants and distribution hubs, while chain conveyors provide the durability required for harsh, abrasive mining environments. Screw conveyors remain vital for handling fine or granular materials in processing circuits, and overhead conveyors continue to serve niche applications where floor space is limited. Understanding the operational strengths and constraints of each system is essential for selecting the right solution, particularly in mining where reliability, maintainability, and safety are paramount.

ROLLER CONVEYORS

Conveyor rollers form the mechanical backbone of belt-based haulage systems in mining, and their behaviour has a direct influence on the efficiency, reliability, and long-term performance of every conveyor installation. Although often overshadowed by higher-visibility components such as drives, pulleys, and belting, rollers determine how smoothly material travels, how evenly loads are distributed, and how effectively the belt maintains its geometry under dynamic conditions. In modern mines – where conveyors may run continuously for thousands of hours per year – the engineering of the roller set is inseparable from the engineering of the conveyor itself.

The primary function of the carrying rollers is to support the loaded belt and maintain a stable material profile as it moves along the conveyor line. In most mining applications, this is achieved through a troughing configuration. A typical schematic representation would show three rollers mounted on a frame: a horizontal centre roller supporting the belt's mid-section, and two wing rollers angled upward to form a shallow trough. The angles of these wing rollers – commonly 20°, 35°, or 45° – determine the depth of the trough and therefore the volume of material the belt can safely carry. Engineers select these angles based on material characteristics, belt width, and required throughput. The geometry ensures that the load remains centred, reduces the risk of spillage, and distributes stress evenly across the belt carcass.

On the return side of the conveyor, return rollers support the empty belt as it travels back toward the loading point. Although the load is lighter, the engineering considerations remain significant. A schematic example would depict a single horizontal roller mounted beneath the structure, maintaining a straight, tension-controlled return path.

Conveyor systems – Quarry Mining

If the return belt is allowed to sag excessively, it can oscillate, flap, or drift laterally, introducing dynamic loads that accelerate wear on both the belt and the supporting structure. Properly spaced return rollers maintain belt tension, reduce vibration, and ensure that the belt re-enters the loading zone in a stable condition.

At loading points – where material is dropped onto the belt from chutes, hoppers, or transfer points – impact rollers are used to absorb the energy of falling material. These rollers often incorporate rubber rings or thickened shells that deform under impact, dissipating energy before it reaches the belt. A schematic description would show a closely spaced series of rollers positioned directly beneath the loading chute, with rubber-ringed surfaces arranged along the roller shell. The spacing between these rollers is typically reduced compared with standard carrying rollers, creating a reinforced impact zone that protects the belt from gouging, tearing, and premature fatigue.

To maintain proper belt tracking, guide rollers are installed along the conveyor structure to prevent lateral drift. These rollers do not carry vertical load; instead, they provide corrective force when the belt begins to wander. A schematic example would show small vertical rollers mounted on either side of the belt edge, engaging only when the belt deviates from its central path. In more advanced systems, guide rollers may be part of self-aligning frames that pivot slightly to steer the belt back into position. Effective tracking is essential for preventing spillage, reducing edge wear, and avoiding contact between the belt and the conveyor structure.

In environments where moisture, clay, or fine material creates adhesion problems, rubber-coated rollers are employed to improve traction and reduce slippage. These rollers feature a bonded rubber layer – sometimes patterned or grooved – to enhance grip and shed water. A schematic representation would show a standard steel roller shell overlaid with a rubber coating, designed to deform slightly under load and maintain consistent contact with the belt. This design reduces noise, dampens vibration, and improves belt stability in wet or contaminated conditions.

The advantages of high-quality rollers extend across the entire conveyor system. Precision-machined shells, sealed-for-life bearings, and corrosion-resistant housings allow rollers to withstand abrasive ores, high loads, and continuous operation without premature failure. Reduced friction lowers power consumption and minimises heat generation, contributing to longer belt life and improved energy efficiency. Over the lifespan of a conveyor

Designing transfer points for confined spaces installation, these factors translate into fewer stoppages, lower maintenance costs, and significantly improved system availability – key considerations for mining engineers tasked with designing or upgrading haulage infrastructure.

In contemporary mining operations, where conveyors may stretch for kilometres and operate around the clock, the roller set is no longer a simple mechanical accessory but a critical engineered subsystem. Its performance influences everything from belt tension and power draw to material stability and structural loading. By understanding the mechanical behaviour, design principles, and application-specific requirements of each roller type, engineers can ensure that their conveying systems achieve the reliability, efficiency, and longevity demanded by modern mining.

CHAIN CONVEYORS

Mining-grade high-strength circular chain is a critical transmission component used extensively across key pieces of underground and surface mining equipment, including scraper conveyors, transfer machines, and coal-cutting systems. The reliable operation of these machines depends on the performance of the circular link chain, which serves as the primary traction element. Within scraper conveyors in particular, the connecting ring functions as a high-strength mechanical link that directly influences the efficiency, stability, and safety of the entire conveying system. Any weakness in the chain or its connectors can compromise production continuity, making the quality and integrity of these components central to mining operations.

The mining circular link chain is typically constructed from open or flat connecting rings and is designed to serve as the traction chain for large coal-mining machinery. Because it forms the mechanical backbone of scraper conveyors and related systems, the chain must undergo rigorous inspection and testing to ensure that it meets the demanding requirements of mining environments. Its performance is not merely a matter of mechanical convenience; it is fundamental to the safe and continuous operation of the equipment it supports.

Circular chains are manufactured in a range of types depending on their intended function, including transmission chains, conveyor chains, traction chains, and specialised variants designed for unique applications. Their specifications vary accordingly. In mining, high-strength circular link chains are produced in widely used sizes such as 10 × 40, 14 × 50, 18 × 64, 22 × 86, 26 × 92, and 30 × 108, each selected to match the load, speed, and environmental conditions of the equipment. These dimensions reflect the evolution of chain design as mining machinery has grown in scale and complexity.

Technical standards for circular chains differ across regions and manufacturers. Many international producers follow the American ANSI standard, while several European manufacturers adhere to BS standards. Regardless of the standard adopted, two factors ultimately determine the quality of a mining circular chain: the processing technology and the material used. Historically, Chinese manufacturers relied on imported steels from the United States and Europe, but advances in domestic metallurgy have enabled the localisation of chain-grade materials without compromising performance.

Material grades for circular chains vary widely. Chains are classified into strength levels ranging from 30-grade to 120-grade, with higher grades used in the most demanding applications. The steels employed include Q235, 20MnSi, 20Mn2, 25MnV, and more advanced alloys such as 23MnNiMoCr54. Over time, Chinese chain materials have evolved from simple carbon-manganese steels to more sophisticated manganese-nickel-chromiu m-molybdenum alloys. As metallurgical technology has progressed, silicon and manganese contents have been reduced while chromium and molybdenum levels have increased, resulting in significantly improved toughness and fatigue resistance. With the growing performance demands placed on mining chains, manufacturers have begun developing new alloy systems tailored to specific operational challenges.

Chain making

Cobalt chains clarifier tank

The production process for mining circular chains follows a precise sequence: cutting, cold bending and weaving, jointing, welding, primary calibration, heat treatment, secondary calibration through pre-tensioning, and final inspection. Among these stages, welding and heat treatment are the most critical, as they directly influence the mechanical integrity and service life of the chain. Optimised welding parameters improve yield and reduce production costs, while an appropriate heat-treatment regime ensures that the material's inherent properties are fully realised. Modern mining chains are typically heat-treated using medium-frequency induction heating with continuous quenching and tempering. This method relies on electromagnetic induction to generate heat within the steel itself. As the chain passes through the inductor, alternating current induces a corresponding current within the metal, rapidly heating it to the required quenching temperature. This process allows precise control of heating rates and temperature uniformity, producing chains with excellent hardness, toughness, and fatigue resistance.

Understanding the compliance requirements and potential failure modes of mining circular chains is essential for engineers responsible for equipment reliability. Failures may arise from improper heat treatment, inadequate welding penetration, material defects, overloading, corrosion, or misalignment within the conveyor system. Thorough inspection, adherence to standards, and careful material selection are therefore indispensable in ensuring that circular chains meet the rigorous demands of modern mining operations.

In the complex ecosystem of modern mining, where productivity hinges on the seamless movement of vast quantities of material, heavy-duty conveyor chains continue to play a defining role. Although belt conveyors dominate long-distance haulage, chain-based systems remain indispensable in applications where extreme loads, abrasive materials, and demanding duty cycles exceed the capabilities of lighter equipment. Their mechanical resilience, metallurgical sophistication, and operational reliability make them essential components in both surface and underground mines. For engineers tasked with designing or maintaining material-handling systems, a deeper understanding of the engineering principles behind heavy-duty conveyor chains is critical to achieving long-term performance and system availability.

At the core of every heavy-duty conveyor chain lies a deceptively simple mechanical concept: a continuous loop of interlocking steel links driven by sprockets. Yet the engineering behind these links is anything but simple. Mining-grade chains are typically manufactured from high-strength alloy steels, often chromium-molybdenum blends, chosen for their ability to deliver both hardness and toughness. Heat treatment is central to their performance. Carburising and induction-hardening processes are used to create a hard, wear-resistant surface capable of resisting abrasion, while preserving a ductile core that can absorb the shock loads common in crusher-feed systems and apron feeders. Pins and bushings are usually through-hardened to withstand cyclic loading and impact forces. The metallurgical challenge lies in achieving the correct balance: too much hardness introduces brittleness, while insufficient hardness accelerates wear. Modern heat-treatment techniques allow manufacturers to achieve surface hardness levels in the region of 55 to 62 HRC while maintaining the internal resilience required for mining environments.

Mining exposes conveyor chains to a range of wear mechanisms that must be understood and managed. Abrasive wear is one of the most prevalent, driven by fine particles such as silica, coal dust, or crushed ore infiltrating the pin-bushing interface. This type of wear is particularly aggressive in hard-rock operations where sharp fines are ever-present. Impact wear is another major factor, especially in applications where large lumps of material strike the chain with significant force. Crusher-feed conveyors, apron feeders, and loading points all impose high-energy impacts that demand robust, through-hardened components. Corrosive wear is common in salt, potash, and certain underground coal environments, where moisture and chemical exposure degrade unprotected steel. Fatigue failure, driven by cyclic loading, misalignment, or inadequate lubrication, remains a critical concern for engineers, as it can lead to sudden and costly breakdowns. Understanding these mechanisms allows engineers to specify the correct chain design, material grade, and maintenance strategy for each application.

Lubrication is one of the most influential factors affecting chain life, yet it is often underestimated. Mining environments present unique challenges for lubrication systems, including dust ingress, moisture, and temperature extremes. Depending on the application, lubrication may be delivered through drip systems, forced-feed systems, or dry-film lubricants designed for dusty conditions where oil would attract abrasive particles. In corrosive

or fine-particle environments, sealed-joint chains offer significant advantages by preventing contaminants from entering the wear surfaces. Effective maintenance practices – such as monitoring chain elongation, inspecting pin and bushing wear, checking sprocket tooth profiles, and verifying alignment – extend service life and prevent catastrophic failures. Because chains can be rebuilt link by link, maintenance interventions are often more economical than full system replacements.

The operational advantages of heavy-duty conveyor chains are well established. Their ability to handle large lump sizes, high impact loads, steep inclines, and materials that are hot, sharp, or highly abrasive makes them indispensable in many mining applications. They are particularly effective in crusher-feed systems, apron feeders, underground trunk conveyors, and mill-feed systems where reliability and robustness are paramount. Their high load capacity and mechanical resilience allow them to operate at high speeds while moving substantial volumes of material, improving production flow and reducing reliance on mobile equipment. In underground operations, where ventilation constraints and traffic congestion limit the use of diesel haulage, chain conveyors often become the backbone of the entire material-handling system.

Safety is another significant advantage. By automating material movement, chain conveyors reduce the need for workers to interact directly with heavy or unstable loads. Modern systems incorporate emergency-stop circuits, obstruction sensors, and automated shutdown protocols that respond to abnormal conditions before they escalate. This controlled and predictable mode of operation enhances worker protection, particularly in confined or hazardous areas.

The economic benefits of chain conveyors extend beyond their operational performance. Although the initial capital cost may be higher than lighter systems, their long service life, low maintenance frequency, and modular repairability contribute to favourable whole-of-life economics. Chains resist stretching, tolerate impact loading, and can be repaired incrementally, reducing downtime and maintenance expenditure. Their energy efficiency, especially when compared with diesel-powered haulage, further reduces operating costs and supports the industry's growing emphasis on emissions reduction.

Across the mining sector, heavy-duty conveyor chains are used in a wide range of applications. Coal mines rely on them in feeder breakers and underground trunk conveyors. Hard-rock operations use them in crusher-feed systems, apron feeders, and mill-feed conveyors. Salt and potash mines benefit from corrosion-resistant chain designs tailored to their environments, while diamond mines depend on chains capable of withstanding extreme impact and abrasion. Their utility extends beyond mining into construction, agriculture, and heavy manufacturing, wherever dense, abrasive, or irregular materials must be moved reliably.

Comparative case studies illustrate the transformative impact of properly specified chain systems. In one hard-rock operation, replacing belt feeders with heavy-duty chain apron feeders reduced downtime by 40% due to improved resistance to impact and abrasive wear. An underground coal mine that transitioned from shuttle cars to chain-based trunk conveyors increased continuous miner utilisation by more than 20%, reducing congestion and improving safety. In a salt mine, the adoption of corrosion-resistant alloy chains extended service life from 18 months to more than four years, significantly reducing maintenance costs and improving system availability.

For mining engineers, the selection and specification of heavy-duty conveyor chains require careful consideration of load characteristics, environmental conditions, sprocket design, lubrication regimes, and maintenance strategies. When these factors are properly addressed, chain conveyors deliver a combination of durability, efficiency, and safety that few alternatives can match. They remain, in many respects, the quiet enablers of modern mining productivity – simple in concept, highly engineered in execution, and indispensable in practice.

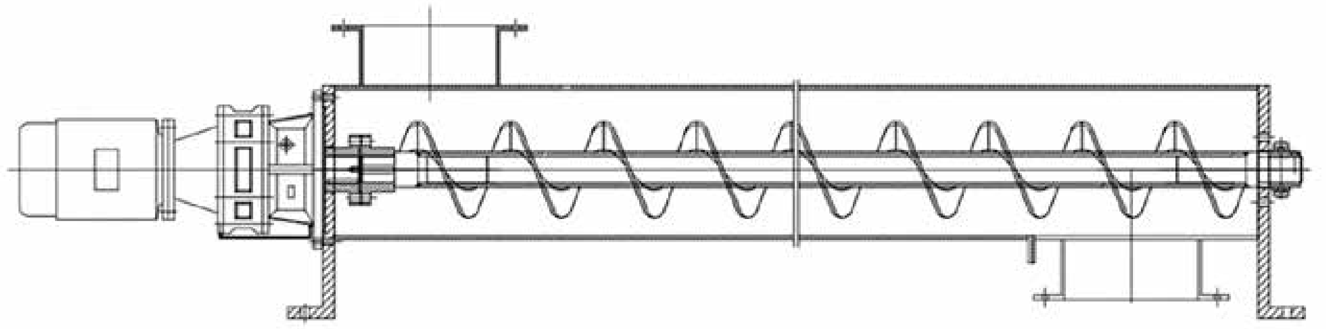
SCREW CONVEYORS

Among the many conveying technologies used in mining – from belt conveyors and apron feeders to bucket elevators and pneumatic systems – the screw conveyor occupies a distinctive niche. Its origins lie in the ancient Archimedean screw, but the modern industrial form emerged in the late nineteenth and early twentieth centuries as steel fabrication improved and continuous-processing industries demanded enclosed, controllable material movement. By the mid-1900's, screw conveyors had become standard equipment in coal preparation plants, mineral-processing circuits, and metallurgical operations.

A screw conveyor consists of a helical flight mounted on a central shaft and enclosed within a trough or tubular casing. As the screw rotates, material is advanced along the housing by a combination of rotational force, friction, and the geometry of the flights. Although mechanically simple, the design is highly adaptable, and several configurations are used in mining depending on the material and duty:

- Standard shafted screw conveyors, the most common type, used for general ore, concentrate, and reagent handling.
- Shaftless screw conveyors, ideal for sticky, viscous, or high-moisture materials such as filter cakes and dewatered tailings.
- Inclined and vertical screw conveyors, used where plant layouts require elevation changes without the footprint of a belt system.
- Live-bottom screw feeders, which regulate flow from bins and hoppers, ensuring consistent feed to downstream equipment.
- Wear-protected heavy-duty designs, incorporating abrasion-resistant flights, liners, and reinforced troughs for aggressive ores.

Installation is typically straightforward. Conveyors are mounted on structural frames or saddles, with the drive unit positioned at the discharge end to maintain tension and reduce back-driving. Troughs or tubes are sealed to control dust and prevent spillage – an important advantage



Diagramatic cut- away view of a Screw Conveyor

in both underground and surface plants. Modular sections allow assembly in confined spaces, while surface installations may incorporate multiple inlets, steep inclines, or variable-speed drives to integrate with process flows.

Within mining operations, screw conveyors are most commonly found in processing plants rather than in primary extraction. They are used to move crushed ore, feed mills, transfer flotation concentrates, handle reagents, and convey dewatered tailings or filter cakes. Their enclosed design makes them particularly valuable where dust suppression is essential, and their ability to meter material accurately supports stable downstream performance. In coal operations, they often serve as feeders for thermal dryers or as discharge conveyors beneath silos and hoppers; in metalliferous mining, they appear in smelters, refineries, and chemical-processing circuits where corrosive or high-temperature materials must be handled safely.

For mining operators, the advantages of screw conveyors are clear: compact footprints, excellent containment, predictable flow control, and the ability to handle difficult or abrasive materials with minimal spillage. While they do not replace belt conveyors for long-distance haulage, they remain indispensable for short-distance, enclosed, and controlled material movement – an enduring solution that has evolved alongside the industry's increasing demands for efficiency, automation, and environmental performance.

OVERHEAD CONVEYORS

Manual overhead conveyors continue to serve a practical role in mining and mineral-processing facilities, even as automation becomes more widespread. They are particularly useful in low- to medium-volume areas where flexibility, simplicity, and cost control are more important than high throughput. Workshops, fabrication bays, pump rebuild stations, and maintenance stores often rely on manual overhead systems to move components, tools, and assemblies between work zones. Because these conveyors operate through human effort rather than motors, they provide a reliable and low-maintenance means of transferring items without the complexity of automated drives. Their ability to handle loads approaching two tonnes makes them suitable for transporting heavy fabricated parts, pump casings, chute liners, and other equipment commonly serviced in mine maintenance operations.

These manual systems can be enhanced with switches, interlocks, and turntables, allowing operators to redirect loads through different work areas or navigate tight layouts typical of underground workshops or brownfield processing plants. This flexibility is particularly valuable when handling irregular or batch-based maintenance tasks, where the movement of components does not follow a fixed production rhythm.

Monorail overhead conveyors extend this capability into more structured, continuous movement across larger sections of a mining facility. Built around a single ceiling-mounted track, monorail systems are well suited to transporting components between maintenance shops, assembly bays, reagent-handling areas, and thermal-processing zones. In mineral-processing plants, they are often used to move wear parts, filter plates, furnace components, or chemical-handling vessels through drying, curing, or coating processes. Powered monorail systems use enclosed conductor lines to ensure reliable operation in dusty, corrosive, or high-temperature environments typical of concentrators, smelters, and hydrometallurgical plants. Their ability to incorporate elevation changes, drop sections, and controlled transfer points allows engineers to design efficient routes through congested plant layouts where floor space is at a premium.

Power-and-free overhead conveyors represent a more advanced solution for mining operations that require staged, sequenced, or highly controlled material flow. These systems use a powered chain in an upper track and free-moving trolleys in a lower track, enabling loads to accumulate, stop, or advance independently. In mining, this capability is valuable in component-preparation lines, rebuild workshops, metallurgical processing areas, and any environment where equipment must be queued for inspection, coating, assembly, or heat treatment. Power-and-free systems support dynamic accumulation and line balancing, making them suitable for operations that require variable takt times or staged workflows, such as preparing crusher components, assembling pump modules, or sequencing furnace parts for metallurgical processing. Their robust construction allows them to move heavy, awkward, or heat-treated components safely through multiple workstations.

Enclosed-track overhead conveyors provide an additional level of environmental protection and reliability, making them particularly well suited to the harsh conditions found in mining. Their fully enclosed steel or aluminium track shields chains and trolleys from dust, overspray, corrosive vapours, and abrasive particles – conditions commonly encountered in concentrators, smelters, and chemical-processing plants. This protective design reduces maintenance requirements,

Overhead mining conveyors

extends component life, and ensures consistent performance even in areas with high particulate loads or aggressive chemical exposure. The enclosed track also reduces noise and vibration, which is advantageous in inspection areas, control rooms, and metallurgical laboratories where noise exposure must be managed. These systems are often used in reagent-handling zones, coating lines, furnace-feed preparation areas, and any process where contamination control or environmental isolation is essential.

Across all variants – manual, monorail, power-and-free, and enclosed-track – overhead conveyors offer mining operations a means of moving materials and components through constrained, hazardous, or environmentally sensitive areas while preserving valuable floor space and maintaining predictable, controlled flow. Their adaptability and compatibility with both manual and automated workflows make them a strategic complement to the belt, chain, and screw conveyors that dominate bulk-material handling in the mining sector, filling a specialised but essential role in the broader material-movement ecosystem.

Recent advancements in engineering, materials science, and automation have further elevated the role of conveyors in mining. Intelligent systems equipped with sensors and real-time monitoring can detect belt misalignment, blockages, or mechanical wear before they escalate into costly downtime. High-strength, lightweight materials – such as advanced polymer belts and corrosion-resistant components – have improved durability in abrasive, moisture-laden, and high-impact environments typical of both underground and surface operations. The integration of robotics, automated sampling systems, and autonomous haulage technologies has created highly efficient, interconnected material-handling networks that support continuous mining and processing.

These innovations have had a profound impact on mining operations. Modern conveyors deliver higher throughput with greater accuracy, reducing reliance on truck haulage and lowering fuel consumption, emissions, and maintenance costs. Energy-efficient motors and smart control systems support sustainability goals, while the use of recyclable and environmentally responsible materials aligns with the mining industry's increasing focus on environmental stewardship. By reducing manual handling and exposure to hazardous conditions, advanced conveyor systems also enhance worker safety – an especially critical factor in underground mines where confined spaces and complex geology heighten operational risks.

Within the mining and bulk-materials industries, conveyor manufacturers play a central role in enabling efficient, high-volume material movement across some of the most demanding operational environments. In coal mining – both surface and underground – conveyor systems are indispensable for maintaining continuous production. Companies such as Komatsu, through its Joy product line, have become synonymous with underground coal haulage, supplying armoured face conveyors, stage loaders, and chain-based systems that form the backbone of longwall operations. Sandvik Mining and Rock Solutions similarly provides heavy-duty conveyor systems and chain-driven haulage equipment designed to withstand the abrasive, high-load conditions typical of deep coal seams. Complementing these system manufacturers are leading belting specialists such as Fenner Dunlop and Continental, whose flame-resistant, high-tension belts meet the stringent safety and performance requirements of underground coal environments. FLSmidth also contributes significantly to coal-handling infrastructure, supplying belt conveyors, feeders, and integrated systems for both underground mines and surface preparation plants.

In hard-rock mining, where operations must contend with sharp, abrasive ore and long transport distances, conveyor manufacturers focus on durability, capacity, and terrain adaptability. Metso is a major supplier of overland conveyors, belt feeders, and in-pit crushing and conveying (IPCC) systems used extensively in large copper, iron ore, and gold mines. Thyssenkrupp Industrial Solutions has established itself as a leader in curved overland conveyors and high-angle systems, technologies that reduce reliance on truck haulage in massive open-pit operations. Beumer Group also plays a prominent role in this sector, providing long-distance and pipe conveyor systems capable of transporting ore across rugged landscapes while minimising environmental impact. Supporting these system integrators are component manufacturers such as Rexnord, whose engineered chain, gear drives, and critical conveyor elements are widely used in heavy-duty hard-rock applications. FLSmidth again appears as a key supplier, offering robust material-handling solutions that integrate seamlessly with crushing and grinding circuits in large-scale mines.

Bulk-port handling represents another major domain where conveyor manufacturers exert significant influence. High-capacity export terminals for coal, iron ore, grain, and aggregates rely on continuous-duty conveyor systems capable of loading, unloading, stacking, and reclaiming vast quantities of material. Bruks-Siwertell is a global leader in this space, supplying ship unloaders, ship loaders, and port-side conveyor systems designed for high throughput and environmental efficiency. Beumer Group extends its expertise to port operations as well, providing belt conveyors, pipe conveyors, and stacker-reclaimers used in major terminals worldwide. Thyssenkrupp Industrial Solutions contributes large-scale ship loaders, bucket-wheel reclaimers, and long-distance port conveyors, particularly for iron ore and coal export facilities. FAM, known for its specialised port-side handling equipment, offers stackers, reclaimers, and ship loaders tailored to high-volume bulk operations. Metso also supports bulk-port infrastructure with conveyor systems and screening stations designed to integrate with large-scale loading and unloading processes.

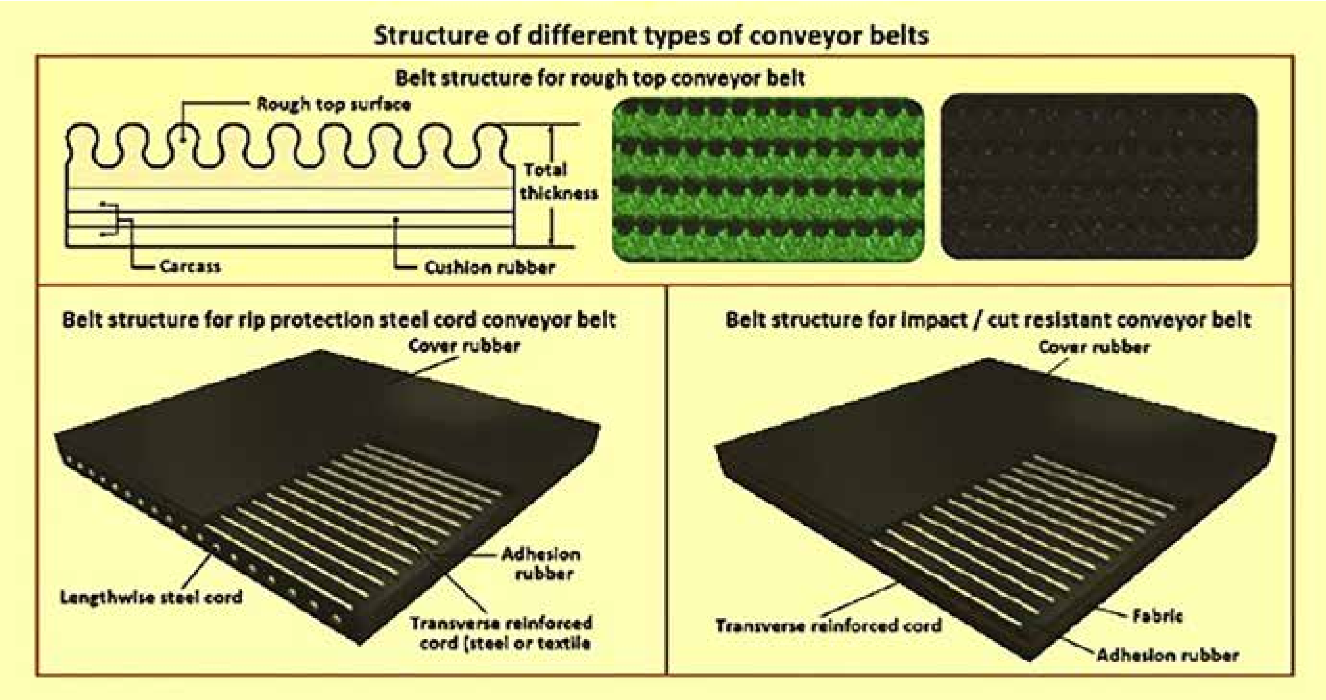
Across coal mining, hard-rock mining, and bulk-port handling, these manufacturers collectively shape the global material-handling landscape. Their technologies enable safer, more efficient, and more sustainable operations, ensuring that vast quantities of raw materials move reliably from extraction to processing to export.

Across mining and bulk-materials handling, the most advanced conveyor manufacturers are driving the industry forward through a combination of intelligent automation, high-performance materials, and large-scale engineering innovations. One of the most transformative developments is the rise of intelligent conveyor monitoring systems, now widely deployed by companies such as Sandvik, Komatsu, Metso, and Beumer. These systems use distributed sensors, condition-monitoring units, and real-time analytics to track belt alignment, chain tension, idler health, and drive performance. In underground coal operations, for example, Komatsu's longwall conveyors rely on continuous monitoring to detect chain wear or AFC loading anomalies before they escalate into production-stopping failures. Similarly, in hard-rock mines, Metso and Thyssenkrupp integrate advanced diagnostics into overland conveyors to manage the stresses of long-distance, high-tonnage transport.

Another major area of innovation lies in high-strength, specialised conveyor materials. Manufacturers such as Continental and Fenner Dunlop have developed steel-cord and aramid-reinforced belts capable of withstanding extreme tension, abrasion, and impact – conditions common in iron ore, copper, and coal operations. Fire-resistant and anti-static compounds are essential for underground coal mines, while heat-resistant and cut-resistant belts support hard-rock crushing circuits. These material advances have significantly extended belt life, reduced maintenance downtime, and improved safety across all mining sectors.

In conveyor belt construction, aramid refers to a class of high-strength synthetic fibres – most notably materials such as Kevlar – that are used to reinforce the belt carcass. Aramid fibres are aromatic polyamides engineered to deliver exceptional tensile strength while remaining remarkably lightweight. When incorporated into a conveyor belt, they provide a combination of strength, stability, and durability that rivals steel cords but without the associated weight or susceptibility to corrosion.

Fenner Dunlop aramid-reinforced conveyor bel



Conveyor belt construction

In practical terms, aramid reinforcement allows a conveyor belt to operate under high tension with minimal stretch, which is particularly valuable in long-distance or high-load applications. Because aramid fibres resist abrasion, impact, and heat, they perform well in demanding environments such as hard-rock mining, underground coal operations, and bulk-port handling. Their flame-resistant and non-conductive properties also make them suitable for underground coal mines, where safety requirements are stringent.

The use of aramid significantly reduces belt weight, which in turn lowers energy consumption and decreases the load on drive systems. This lighter construction enables longer conveyor routes, steeper inclines, and improved handling of sharp or abrasive materials. Aramid belts also require less maintenance, as they experience less elongation and maintain their structural integrity over extended service periods.

In essence, aramid in conveyor belt construction denotes a shift toward advanced, high-performance materials that enhance strength, safety, efficiency, and longevity across a wide range of mining and bulk-handling applications.

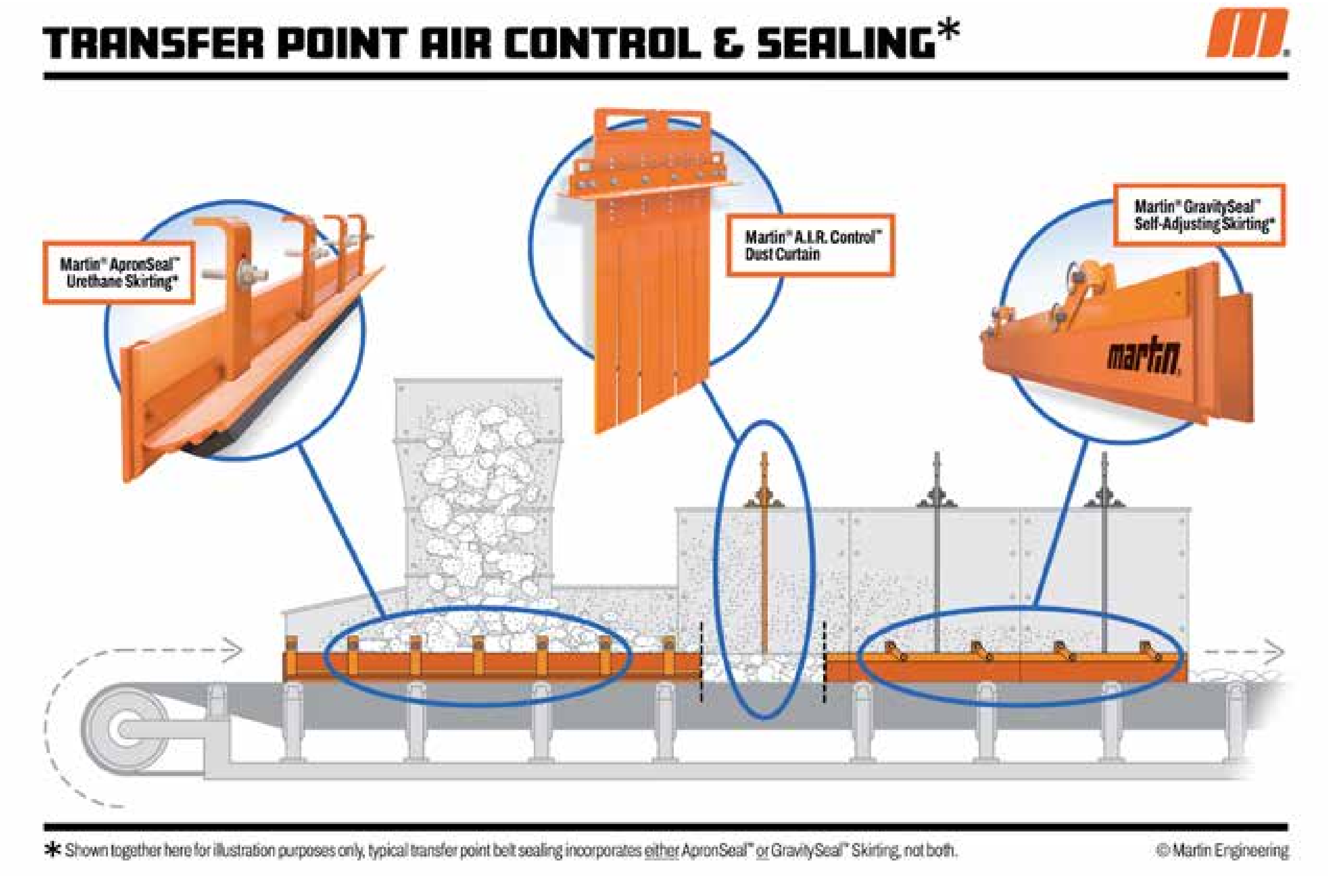
In large surface mines, the integration of in-pit crushing and conveying (IPCC) technology has become a defining trend. Companies like Metso and Thyssenkrupp are at the forefront of designing systems that replace or reduce truck haulage by linking mobile crushers directly to long-distance conveyors. This approach lowers fuel consumption, reduces emissions, and enables continuous material flow from the pit to the processing plant. Beumer's long-distance and pipe conveyors complement these systems by transporting ore across rugged terrain with minimal environmental disturbance, often replacing haul roads entirely.

Automation is also reshaping conveyor applications in both mining and port environments. Automated loading, stacking, and reclaiming systems, supplied by Beumer, FAM, and Thyssenkrupp, allow bulk-port terminals to handle enormous volumes of coal, iron ore, and grain with precision and minimal human intervention. These systems use programmable logic control, laser-guided positioning, and advanced drive technology to optimise stockpile formation and reclaiming efficiency. In ports where environmental regulations are strict, enclosed pipe conveyors and dust-suppression technologies help reduce particulate emissions during loading and unloading.

The integration of conveyors with robotics and autonomous equipment is another frontier. In hard-rock mines, conveyors increasingly interface with autonomous haul trucks, automated sampling stations, and robotic inspection tools. Underground coal operations use automated shearers and plough systems that synchronise with armored face conveyors, ensuring continuous, high-volume extraction. These technologies reduce human exposure to hazardous environments while improving consistency and throughput.

Finally, energy efficiency has become a central focus across all sectors. Manufacturers now employ variable-frequency drives (VFDs), regenerative braking systems, and low-rolling-resistance idlers to reduce power consumption. In long overland conveyors, regenerative drives can feed excess energy back into the grid, turning downhill haulage into a source of power rather than a cost. These innovations support both operational savings and broader sustainability goals.

Together, these technologies – intelligent monitoring, advanced materials, IPCC systems, automation, robotics integration, and energy-efficient drive solutions – represent the cutting edge of conveyor engineering. They enable mining and port operators to move greater volumes with higher reliability, lower environmental impact, and significantly improved safety, reinforcing the conveyor's role as a critical asset in modern material-handling infrastructure.



Martin Engineering introduces conveyor dust control innovations

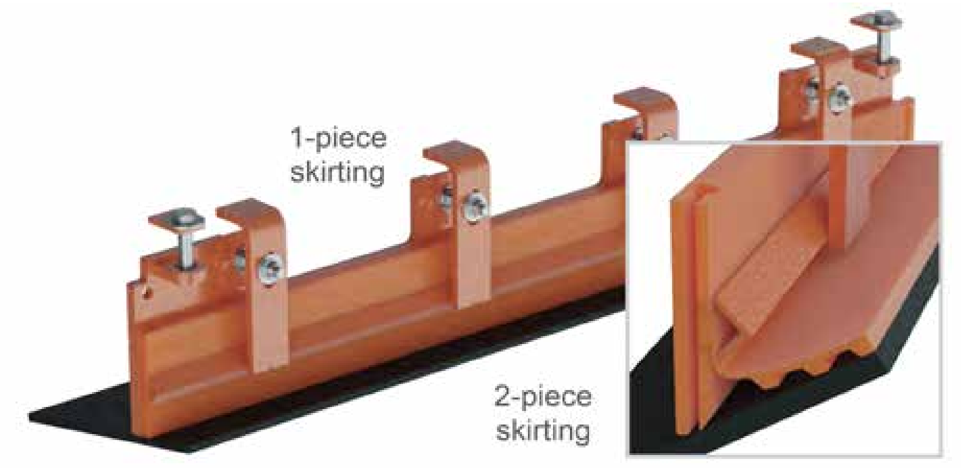
The global leader in belt conveyor technology, Martin Engineering, introduced the next generation of safe and effective transfer point dust control equipment. After rigorous testing across many applications, the Martin® ApronSeal™ Urethane Skirting, GravitySeal™ Self-Adjusting Urethane Skirting, and the A.I.R. Control™ Dust Curtain outperformed similar products in tackling fugitive dust and spillage. Retrofitted onto existing transfer points, the system uses no energy to control airborne dust. With safety features for fast external servicing, the designs deliver greater performance at a lower operating cost.

"When designing these, our focus was safety, performance, and longevity," said Bert Erdmann, Global Engineering Manager of Conveyor Products at Martin Engineering. "Compliance and ease of maintenance are top-of-mind for our customers. We've discovered that passive dust and spillage control at the point of emission with safe maintenance built in is the most effective and economical method of containment."

MARTIN® APRONSEAL™ URETHANE SKIRTING

Extending along the length of the skirtboard, this skirting's unique design provides multiple "pieces" of reliable containment for material fines. A primary strip is shaped to match the trough angle, creating a tight seal. The optional self-adjusting secondary outer flap covers slight variations in the belt's profile, trapping air and dust.

The ApronSeal™ Urethane Skirting requires only two inches (50 mm) of free belt area, and the self-adjusting secondary seal can be easily trimmed to match the available free belt area. Supplied in 60 in. (1524 mm) strips, it features convenient T-slot end connections for longer chutes. It is designed for external maintenance, improving safety and minimising service time.



The choice of one- or two-piece ApronSeal™ Urethane Skirting depends on the available space along the belt edge.

Made for belt speeds up to 900 fpm (4.5 m/s), the 90-durometer urethane is chemical-resistant and low-abrasion -- also available in a high-temperature option. With less friction than standard skirting, the ApronSeal™ offers a longer wear life.

GRAVITYSEAL™ SELF-ADJUSTING URETHANE SKIRTING

Using torsion arms that allow the low-friction urethane skirting to smoothly ride the vertical fluctuations in the belt, GravitySeal™ delivers a reliable skirtboard seal that prevents spillage and reduces dust emissions. The automatic corrections eliminate the need for downtime to adjust the skirting level due to wear.

Featuring a seal and clamp assembly, GravitySeal™ is designed for conveyor speeds up to 1300 fpm (6.5 m/s) with minimal free edge space, providing an effective seal with as little as 1.25 inches (32 mm) of free area on each side of the belt.

The unit's urethane sealing strip is available in continuous lengths up to 300 feet (91.4 m) and provides 2 inches (51 mm) of wear life. Replacement involves quickly and easily removing the linchpins and installing the new pre-punched strip.

A.I.R. CONTROL™ DUST CURTAIN

Engineered for enclosed conveyor transfer points, these dust-control solutions are modular urethane curtains with handles that allow a single worker to safely adjust or replace them from outside the enclosure. The safety features eliminate the need for confined-space entry and reduce service time to just minutes.

Each unit is a slide-in cartridge with individual urethane flaps that can be machine-cut to match the load's angle of surcharge. Positioning the curtains close to the material load allows the A.I.R. Control™ Dust Curtain to create controlled recirculation zones. This allows dust particles to agglomerate and settle out, enhancing overall transfer-point performance, significantly reducing respirable and nuisance dust emissions compared to conventional slit-rubber curtains.

DESIGNED FOR SAFETY AND COMPLIANCE

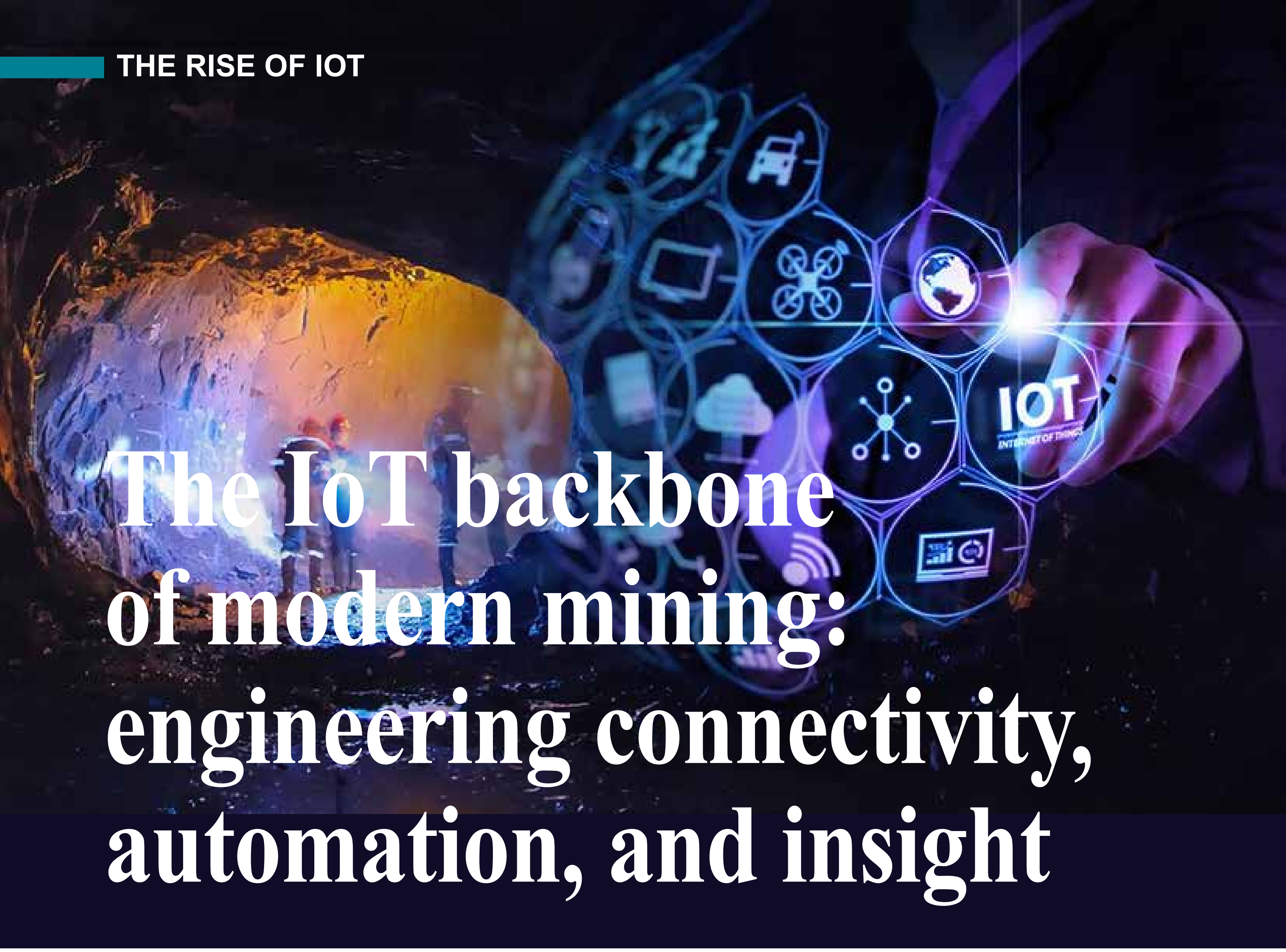
When installed on an existing transfer point, ApronSeal™ Urethane Skirting, GravitySeal™ Self-Adjusting Urethane Skirting, and A.I.R. Control™ Dust Curtains provide a highly effective passive dust control solution. They enhance compliance with air quality and workplace safety regulations without relying on expensive, high-maintenance, power-consuming dust capture systems like HVAC filtration or air cleaners.

GravitySeal™ Self-Adjusting Urethane Skirting moves up and down with the belt as material shifts, ensuring a sealed environment.

The A.I.R. Control™ Dust Curtain slows dust and turbulent air flow through the transfer point.

"We've found urethane to be a versatile and lasting material that can withstand the rigorous demands of the bulk handling industry," Erdmann concluded. "Martin has risen to the challenge of stringent dust standards by innovating more efficient and safer solutions."

Images: Copyright © 2026 Martin Engineering



The IoT backbone of modern mining: engineering connectivity, automation, and insight

As the mining industry accelerates its transition toward digitally enabled operations, the role of connected systems has become central to engineering safer, more efficient, and more resilient mines. In this feature, *Gordon Barratt of Coal International* examines how IoT technologies are reshaping the modern mining environment, from autonomous equipment and environmental sensing to advanced fleet coordination and secure industrial connectivity. This overview sets the stage for understanding the engineering principles and practical challenges that define the connected mine of today.

The rise of IoT across the mining sector is reshaping the way operations are run, bringing new levels of efficiency, safety, and sustainability to an industry that has long relied on rugged machinery and hard-earned experience. What once depended on manual checks, radio calls, and scheduled maintenance is now increasingly supported by networks of smart sensors and connected systems that give miners real-time visibility into the health of their equipment, the performance of their fleets, and the safety of their crews. This shift is not about replacing the skills of the workforce; it is about giving miners better tools to tackle the challenges that come with operating in some of the harshest environments on earth.

IoT technology is proving especially valuable in the fight against unplanned downtime. Sensors mounted on haul trucks, crushers, conveyors, and drilling rigs continuously track vibration, temperature, pressure, and wear patterns. Instead of waiting for a breakdown or relying solely on fixed maintenance intervals, maintenance teams can now see early signs of trouble and intervene before a failure occurs. Mines adopting predictive maintenance through IoT have seen unplanned downtime fall by as much as 25%, while equipment life is extended through more precise scheduling and smarter use of parts and labour. In an industry where every hour of lost production carries a heavy cost, this kind of foresight is becoming indispensable.

Beyond equipment health, IoT is transforming how mines manage their fleets and coordinate daily operations.

Real-time tracking and automated alerts help dispatchers keep machines moving, reduce bottlenecks, and respond quickly when conditions change. These connected systems support the growing use of automated and semi-autonomous equipment, from drilling rigs that adjust their own parameters to self-driving haul trucks that navigate safely through busy pit environments. As more mines adopt robotic machinery and AI-driven systems, IoT serves as the backbone that keeps these technologies communicating and performing reliably.

The push toward sustainability is also accelerating IoT adoption. IIoT networks give operators detailed insight into energy consumption, fuel burn, water use, and environmental impact. With this data, mines can fine-tune their processes, reduce waste, and meet increasingly strict environmental standards. IoT-powered monitoring extends from air quality and dust levels to ground stability and strata movement, helping protect both workers and the surrounding environment. These systems are becoming essential tools for mines striving to operate more responsibly while maintaining productivity.

Although mining has traditionally been cautious in adopting new technologies, the combination of IoT, automation, and AI is driving a new era of smart mining. Data analytics built on IoT sensor networks allow geologists and planners to analyse vast amounts of information from exploration sites, drilling campaigns, and production areas. By identifying patterns and highlighting areas with the highest potential, these tools help reduce exploration risk and direct resources where they will deliver the greatest return.

Across the mining lifecycle, IoT is no longer a futuristic concept – it is a practical, hard-working technology that supports safer, greener, and more profitable operations. From the pit to the plant, it is giving miners the information they need to make better decisions, keep equipment running, and protect the people who keep the industry moving.

As mining operations face mounting pressure to deliver higher efficiency, stronger safety performance, and measurable sustainability gains, the integration of IoT technologies is emerging as one of the most significant engineering shifts in the sector. IoT applications in mining are redefining how engineers design, monitor, and control the systems that keep operations running. Connected sensors, edge devices, and digital mining platforms are enabling a level of visibility and responsiveness that conventional instrumentation simply cannot match.

Across both surface and underground environments, IoT-enabled systems are transforming equipment monitoring and fleet management. Real-time data streams from haul trucks, drills, crushers, pumps, and conveyors allow engineers to track machine health with far greater precision. Instead of relying on periodic inspections or static maintenance intervals, predictive maintenance models built on IoT data can detect vibration anomalies, thermal deviations, lubrication issues, and early-stage component degradation. This shift from reactive to predictive maintenance is reducing unplanned downtime, improving asset availability, and extending equipment life – outcomes that directly influence production stability and cost control.

IoT is also accelerating the deployment of automated and robotic mining solutions. Modern mining robots, autonomous haulage systems, and digitally controlled drilling rigs depend on dense sensor networks to operate

safely and efficiently. These systems require continuous data exchange for navigation, collision avoidance, process optimisation, and environmental monitoring. IoT provides the communication backbone that allows autonomous equipment to function reliably within complex, high-risk mining environments.

Environmental compliance and sustainability targets are further driving IoT adoption. Distributed sensor networks now monitor air quality, dust levels, water discharge, tailings stability, and energy consumption in real time. This data gives engineers the ability to optimise process performance, reduce emissions, and ensure adherence to regulatory requirements. It also supports long-term planning by providing high-resolution datasets for modelling environmental impact and improving resource efficiency.

In essence, IoT is not simply an add-on to existing mining systems – it is becoming a core engineering tool that reshapes how mines are designed, operated, and maintained. By integrating IoT across the mining value chain, engineers gain the analytical power and operational insight needed to build safer, more resilient, and more sustainable operations capable of meeting the industry's evolving demands.

The rapid expansion of IoT technologies across the mining sector is reshaping how engineers design, operate, and maintain modern mining systems. What distinguishes IoT in mining is not simply the proliferation of sensors or connected devices, but the emergence of an integrated digital ecosystem capable of supporting autonomous equipment, real-time environmental monitoring, predictive maintenance, and advanced fleet coordination. These technologies are engineered to operate within the harsh, remote, and highly variable conditions that define mining environments, and they increasingly serve as the backbone of safe, efficient, and sustainable operations.

Among the most transformative developments are mining robots and autonomous drilling systems, which represent the highest level of IoT-enabled automation currently deployed in the field. These machines combine autonomous navigation, precision drilling, and remote operation to perform tasks that would otherwise expose personnel to significant risk. Their onboard systems integrate GPS guidance, geological sensing, and automated tool-handling mechanisms, enabling continuous drilling cycles and reducing operational variability. For engineers, these platforms demonstrate how IoT can merge mechanical precision with real-time data acquisition to improve both productivity and cost control.

Environmental monitoring has also evolved into a sophisticated IoT-driven discipline. Networks of environmental sensors now track air quality, temperature, humidity, and gas concentrations with a granularity that far exceeds traditional manual sampling. Smart lighting systems complement these networks by adjusting illumination dynamically based on occupancy and ambient conditions, reducing energy consumption while maintaining visibility standards. Together, these systems provide a continuous environmental profile of the mine, supporting regulatory compliance, ventilation planning, and worker safety initiatives.

Fleet management has undergone a similar transformation. IoT-enabled fleet systems collect and analyse data from haul trucks, service vehicles, and auxiliary equipment, providing engineers with real-time insights into location, engine performance, fuel consumption, and operator behaviour. When combined with external data such as weather patterns and haul-road conditions, these systems

support route optimisation, predictive maintenance scheduling, and load balancing. The result is a more efficient and environmentally responsible fleet operation that reduces idle time, fuel burn, and unplanned downtime.

Wearable safety devices extend IoT capabilities directly to the workforce. Smart helmets, proximity-detection systems, and biometric monitors provide continuous feedback on worker health, fatigue, and exposure to hazardous conditions. These devices integrate with centralised monitoring platforms to trigger alerts, initiate emergency responses, and support incident investigations. For engineers responsible for safety systems, wearables offer a new layer of situational awareness that complements traditional engineering controls.

Drones and automated haulage systems further illustrate the operational maturity of IoT in mining. Drones conduct high-resolution site surveys, inspect infrastructure, and monitor equipment conditions without requiring personnel to enter hazardous or inaccessible areas. Automated haulage systems, meanwhile, move material along predefined routes with consistent cycle times and reduced human exposure. Both technologies rely on secure embedded processors, industrial-grade wireless communications, and system-on-module architectures that ensure reliable operation under demanding conditions.

Despite these advances, IoT deployment in mining presents several engineering challenges. Remote sites often suffer from limited connectivity, creating latency issues that undermine real-time monitoring and control. Engineers must therefore design communication architectures that incorporate redundant links, edge-processing capabilities, and satellite or long-range wireless systems to maintain operational continuity. Scalability poses another challenge, as integrating IoT across large, heterogeneous operations requires standardised protocols, modular system architectures, and cloud-based platforms capable of handling vast data volumes. Data security remains a critical concern, with mining operations generating sensitive operational and geospatial data that must be protected through encryption, access controls, and rigorous cybersecurity practices.

Industrial grade connectivity solutions have become essential components of modern mining infrastructure. A comprehensive portfolio of ruggedised cellular routers now supports operations in remote, high vibration, and high temperature environments. These devices deliver stable connectivity for IoT systems, enable redundant communication paths, and incorporate advanced security features to safeguard operational data. When integrated with Remote Manager® platforms, they provide centralised oversight of distributed assets, allowing engineers to monitor device health, deploy configuration updates, and analyse historical performance data through a secure cloud interface. This capability strengthens predictive maintenance strategies and reduces the need for on site technical interventions.

Support for private network technologies, including CBRS and Anterix, further enhances the reliability and security of mining communications. Private LTE and similar architectures give operators greater control over bandwidth allocation, latency performance, and data governance. These networks are well suited to high bandwidth applications such as autonomous equipment control, real time video monitoring, and large scale sensor deployments, while maintaining the strict security protocols required for mission critical operations.

Together, these IoT technologies form a cohesive digital framework that enables mining engineers to design operations that are safer, more efficient, and more environmentally responsible. As the industry continues to advance automation, robotics, and data driven decision making, IoT will remain a foundational element of the modern mine, supporting both current operational needs and the long term evolution of mining systems.

Mine Surveying Since 1850

Note from the Author – Trevor Barratt

Mine surveying has played a foundational role in the development of modern mining. Since 1850 surveying professionals have shaped have the planning, safety, regulation and expansion of mining operations across generations. Mining is an industry defined by precision and accountability. The documentation of its history deserves the same standards. By recording the developments of mine surveying from early mechanical methods to modern digital systems- My work contributes to preserving industrial knowledge for future professionals, research and organisations.

FOREWORD- FROM THEODOLITES TO SATELLITES

If surveyors are like countries and the happier for being without histories, the mine surveyor must have led an enviable existence during the first 20 years or so of the period under review, for nothing startling either in instruments or in technique came to ruffle his inarticulate calm.

The beginnings of the mining history date back to ancient times, up to the second century B.C. One field closely related to mining activities is mine surveying. Mine surveying and mapping are disciplines that deal with the surveying and displaying of underground works and mining claims, in which their spatial relationships are determined against the surface.

This article reflects the early methods of surveying through to today's technology advances with a strong reference to the Uk and the worlds coal industry from 1850-Today

The decade previous to the founding of the Uk's Colliery Guardian (1858) had been more eventful; an act of 1850, dealing primarily with the inspection of mines in the UK, had made it compulsory to keep plans of collieries, and in 1855 an amending act gave the inspector power to insist upon them being drafted to a scale of not less than two chains to the inch.

These examples of parliamentary vigour had followed close on the heels of the invention by Gravatt of the dumpy level in 1848. and by John Headley, two years after of swinging sights carried on trunnions lying along the E.-W. line of the box of a miners dial. Both were important improvements that have stood the test of time. Incidentally, the latter is the only major alteration of design affecting the colliery surveys favourite instrument that comes directly from the coal mine side, accepting this, the Cornish surveyors and makers were responsible for the gradual development of the dial, until by 1860, vernier dials of high finish and considerable precision were turned out by Wilton of St Day and others.

At the time the most up to date treatise of mine surveying was W. Rickard's Miners Manual (1859); it deals competently with dumpy levelling and with fast needle dialling or 'racking'-for, as a legacy from early Theodolites, the dial of the period had a rack and pinion for the movement of the vernier over its circle.

Mr John Davis founder of Messrs. John Davis and Son was associated with the inventor in introducing the first Headley dials, so that, by 1860, the firm had nearly ten years' experience of their construction. The early Headley dials were provided with a rack and with a detachable, graduated vertical side arc, giving the angle of inclination and the percentage correction for lines measured on the slope. The vernier was inside the box.

In 1861. Casartelli, of Manchester, produced a dial with swinging sights and having a semi-circular graduated arc attached to the compass box by pivots a prolongation on the N.-S. diameter, thus enabling the arc to be raised in position for the measurement of vertical angles and swung down flat when such readings were not required.

The quiet score of years after 1860 were, we may thus gather, a time of assimilation: the dialler was learning to use and to depend more and more on fast needle traversing and on rather more elaborate dials, and he was replacing the old Y- level by the handier and more robust dumpy of the railway engineer. But even then, there were voices crying in the wilderness.

Arther Beanlands, a surveyor of great experience in the Northern coalfields of the UK, used the transit instrument for shaft connection before 1856, and continued to apply it with a degree of success which, for that method has never been surpassed. He was a consistent advocate of the theodolite for underground surveys and a disciple of Butler Williams- who first described three-stand traversing in 1842-in regard to the advantages of three tripods. The North of England Institute of Mining Engineers contains several papers on mine surveying. Beanlands writes of shaft connection and other matters. WF Howard urged upon an audience powerful to promote amendments, ‘that all plans of mine workings should be contoured, and adduced reasons that are even more cogent today than they were then; from J.A. Ramsay we glean the information that, in the enlightened Northern Coalfield-however it may have been in more benighted regions- underground levels were at the time connected fairly often with the ordinance datum; and R.S. Newell suggested using a magnetometer for precise work. H.D. Hoskold, mining engineer and able designer, constructed a mining theodolite before 1863- and an excellent instrument it was-and described it, and theodolite operations, in his book of that date. Though his practise was wholly abroad, his influence was considerable in the UK and his instruments held in high esteem.

More than 145 years ago – in 1881, to be exact – a young man named Bennett Hooper Brough, having just taken the Associateship of the Royal School of Mines set out to study mine surveying under the famous Borches at the Royal Prussian Mining Academy, Clausthal. A year later he returned to England as assistant to Sir Warrington Smythe, and in 1886, was appointed instructor in mine surveying at the Royal School of Mines in South Kensington. He moulded the subject into a systematic course, and its reputation and value were indicated by the fact that several associates returned to the school to take it. I cannot think of no better way of bringing out the changes in mine surveying that have taken place during the last half century than to compare the instruments and methods Broughs yellowing notes describe those of the present day.

The 1880s saw something of a renaissance in mine surveying. The need of accurate surveys and plans was being more fully realised. The subject was receiving

Early miners dial

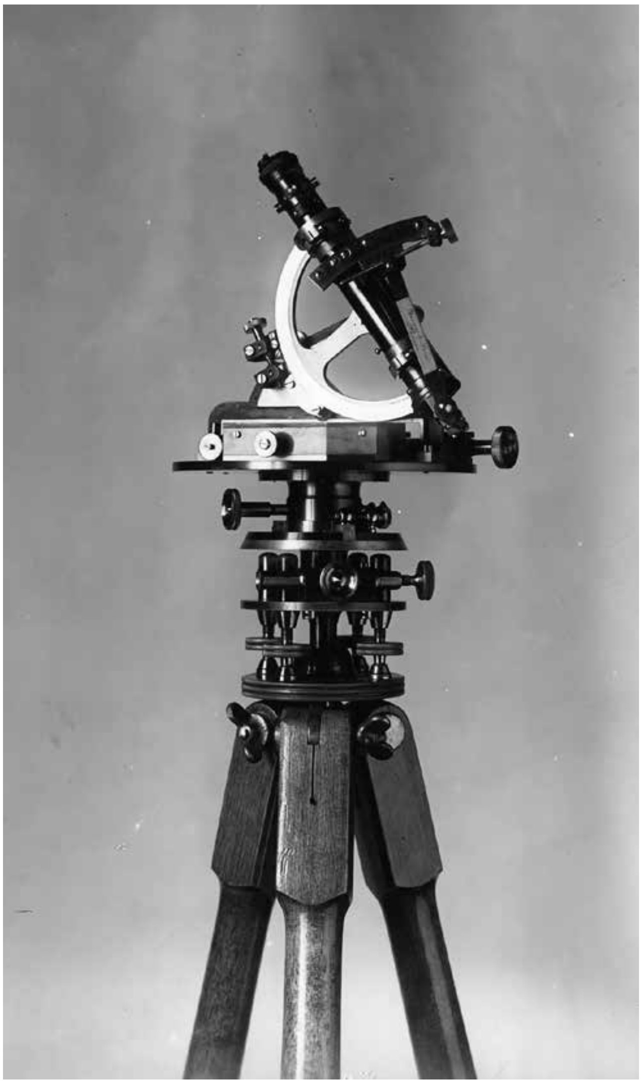
attention serious of those who were, in Howards happy phrase ‘ powerful to promote amendments ‘It was this demand that Brough set himself to meet; and by far the most significant event in the circumscribed world of mine surveying during the eighties was the building up, in London of a course that was soon to equal the best the Continent could provide. Both he and Lewis H. Cooke improved the quality of surveying in every mining field in the UK and abroad to which many students proceeded.

Cooke was appointed to the lectureship vacated by Brough in 1896 and held it to his death in 1929. A German scholar, like his predecessor he found much of his early inspirations in the writings of such authorities as Breithaupt, Weisbach, Borchers and Brathuhn; He critically analysed and tried out their methods; and it is, indeed owing to his advocacy that some of those methods- the shaft -connection processes of Weisbach and Weiss, for example- are now part in the stock-in-trade of the British mine surveyor. No history of the period would be anything but imperfect without an acknowledgement of the signal services of Lewis H. Cooke.

Broughs notes indicated how little the fundamental operations of surveying have changed-or for that matter, how little they can change. The properties of the triangle, for instance, stand for all time, and methods of reduction that share that rely on those properties must share in their immutability. In matters of practical detail, however, one is struck with the contrast between the seeming modernity of some of his descriptions and the naïve archaicness of others. Much attention was given to the calculation of

co-ordinates; yet there were several expressions of doubt as to the sustainable ability of the theodolite for underground work at all, the chief objection being its size and weight. There is a truth in the epigram that, in surveying there are three cardinal points- accuracy, speed, and clarity- and of these, the greatest is charity

The concluding decade of the 19th century witnessed a good many developments in mine surveying instruments. USA mining engineers, finding sighting down steep openings to be impossible with an ordinary theodolite, provided themselves, as long ago as 1855 or1856 with auxiliary telescopes attachable sometimes over the top and sometimes at the side of the instrument and, though less esteemed on this side of the Atlantic, the auxiliary telescope appeared regularly in the



Early Theodolite These instruments played a crucial role in the early mining industry, helping surveyors and engineers navigate and plan mining operations effectively.

catalogues of UK and German makers at the period reached. It was however, at the instance of another distinguished American engineer, Dunbar D. Scott that the auxiliary was brought int line with modern ideas.

Looking back in time at mine surveying and the equipment used as I hope I have done, gives a historical insight into what was then in comparison to What is Now. But it is a fact that more modern theodolites are still used in surveying today, although their role has shifted as more advanced instruments like total stations, GNSS receivers, and 3D scanners have become standard. They remain relevant because they provide precise angular measurement, are mechanically reliable, and are useful in environments where electronic instruments are impractical.

Even with modern digital tools, theodolites continue to serve important functions:

- High precision angle measurement – Theodolites are designed specifically for measuring horizontal and vertical angles with very high accuracy, sometimes down to seconds of arc.
- Reliability in harsh conditions – Optical theodolites do not rely on electronics or batteries, making them dependable in remote or extreme environments where power or sensitive electronics may fail.

DIGITAL INSTRUMENTS AND THE RISE OF TOTAL STATIONS

The most profound shift from the early 20th century onward was the replacement of purely optical instruments with electronic distance measurement (EDM) and, later, total stations. These instruments combined the functions of the theodolite with electronic distance measurement, enabling surveyors to capture angles, distances, and coordinates from a single setup.

This development fundamentally changed underground and surface surveying by:

- reducing the need for long, labour intensive tape measurements

- improving accuracy and repeatability
- enabling rapid traversing in confined or hazardous environments
- allowing data to be stored electronically rather than transcribed manually
- Total stations remain the backbone of many mine surveying operations today, especially in underground workings where GNSS signals cannot penetrate.
- Digital Instruments and the Rise of Total Stations

GNSS and Global Positioning in Surface Mining

The introduction of Global Navigation Satellite Systems (GNSS) – GPS, GLONASS, Galileo, BeiDou – brought a revolution in surface mine surveying. GNSS enabled:

- real time positioning of machinery
- rapid establishment of control networks
- automated guidance for drilling, blasting, and haulage
- continuous monitoring of pit walls and infrastructure

GNSS has become indispensable in open pit mines, where large, unobstructed skies allow for high precision satellite positioning.

LASER SCANNING AND 3D SPATIAL CAPTURE

The modern equivalent of the miners' dial and theodolite is the 3D laser scanner, capable of capturing millions of points per second. These instruments produce dense point clouds that accurately represent:

- underground roadways
- stopes and voids
- pit walls
- stockpiles
- conveyor systems and plant infrastructure

Laser scanning has transformed mine surveying by enabling:

- precise volume calculations
- deformation and subsidence monitoring

- safer mapping of inaccessible or unstable areas
- integration with digital mine models and BIM systems
- Cavity Monitoring Systems (CMS) extend this capability into areas too dangerous for personnel.

UAVS AND AERIAL PHOTOGRAMMETRY

The last decade has seen the widespread adoption of unmanned aerial vehicles (UAVs) for mine mapping. Drones equipped with cameras or LiDAR sensors provide:

- rapid, high resolution mapping of large areas
- accurate stockpile volumes
- change detection for safety and compliance
- reduced exposure of surveyors to hazardous terrain
- UAVs have become a standard tool in surface mining, complementing ground based instruments.

GEOPHYSICAL AND SUBSURFACE IMAGING

Where 19th century surveyors relied on geometry, plumb lines, and magnetic needles, modern surveyors can draw on advanced geophysical methods to understand the subsurface. These include:

- seismic reflection and refraction
- ground penetrating radar (GPR)
- electromagnetic and magnetic surveys
- gravity and microgravity techniques

These tools are used to detect voids, faults, abandoned workings, and ore bodies – tasks that were once impossible with mechanical instruments alone.

Digital Workflows and Integrated Mine Models

Perhaps the most significant change is not a single instrument but the digital ecosystem that now surrounds mine surveying. Modern workflows integrate:

- total station and GNSS data
- LiDAR and photogrammetry
- geological models
- mine planning software
- real time monitoring systems

This creates a digital twin of the mine – an evolving, three dimensional representation that supports planning, safety, and operational decision making.

Surveying has shifted from periodic measurement to continuous spatial intelligence.

CONCLUSION

The Continuity of Principles in a Changing Discipline

Looking back across the long arc of mine surveying – from the miners' dial and dumpy level, through the refinements of Brough and Cooke, to the precision theodolites of the late nineteenth century – it becomes clear that the discipline has been shaped less by sudden revolutions than by a steady, determined pursuit of accuracy, reliability, and clarity. Each generation of surveyors inherited the tools of the last, questioned their limitations, and sought improvements that would better serve the safety and efficiency of mining operations. The mechanical ingenuity of the Victorian period laid the foundations for the scientific rigour that followed, and the principles established then remain recognisable in the profession today.

Modern mine surveying, for all its digital sophistication, is still governed by the same imperatives that guided the early pioneers. The total station, GNSS receiver, laser scanner, and UAV are simply the latest expressions of a long tradition of measurement and verification. Where the nineteenth century surveyor relied on geometry, plumb lines, and magnetic needles, the twenty first century practitioner draws on satellites, lasers, and real time computation. Yet the underlying task – determining position, direction, and elevation with the greatest possible certainty – has not changed. Nor has the responsibility: to produce plans and data on which the safety of miners and the viability of operations depend.

It is striking that even as technology has advanced, the older instruments have not been rendered obsolete in spirit. The theodolite, whose weight and complexity once provoked debate among underground surveyors, survives today in digital form and remains indispensable where electronic systems falter. Its continued use is a reminder that the essential craft of observation endures beneath the layers of automation. The surveyor's judgement, patience, and understanding of error remain as vital now as they were in the days of Brough and Cooke.

What has changed most profoundly is the speed and scale at which information can be gathered and interpreted. Modern mines operate within digital ecosystems where surface and underground data flow continuously into integrated models. Laser scanning captures millions of points in seconds; drones map entire pits in a single flight; GNSS guides machinery with centimetre precision. Surveying has expanded from a periodic task to a real time service, supporting planning, monitoring, and decision making across the whole life of a mine. The surveyor is no longer merely a measurer of lines but a custodian of spatial intelligence.

And yet, for all this progress, the discipline remains rooted in the same values that shaped its early development: accuracy, safety, clarity, and accountability. These principles guided the work of the Victorian dialler, the early theodolite makers, the educators of the Royal School of Mines, and the generations that followed. They continue to guide the profession today, even as its tools evolve at a pace unimaginable to the surveyors of the nineteenth century.

In tracing the journey from the miners' dial to the digital twin, one sees not a series of disconnected innovations but a continuous thread of improvement. Mine surveying has always adapted to the needs of its time, and it will continue to do so as mines become deeper, more complex, and more automated. The story is far from finished, but its foundations – laid more than a century and a half ago – remain firm.

From Black Powder to Precision Blasting: 160 years of explosives in mining

About the Author – Trevor Barratt

Trevor Barratt has spent decades shaping mining communication through his wholly owned journals Coal International and Mining & Quarry World. His expertise spans technical editing, historical integration, and industry outreach. He is recognised for turning complex mining topics into accessible, engaging narratives that support training, marketing, and heritage preservation.

*This article is a **must read** reference for drill and blast professionals.*

Built on: Original 19th century archives from the Colliery Guardian (now Coal International)

Modern technical insights from today's blasting and explosives industry. Editorial authority from two globally recognised mining journals.

ABSTRACT

As I look back across more than a century and a half of explosive development, I'm reminded that progress in mining has never been accidental. It has always been driven by necessity – the need to protect miners, to improve productivity, and to understand the forces we work with beneath the earth. From the unstable nitroglycerine of the 1860s to today's digitally modelled blasts and precision electronic detonators, every generation has pushed the industry forward with ingenuity and determination.

Coal mining worldwide, in particular, has shaped this journey more than any other sector. The hazards of firedamp and coal dust forced early researchers, manufacturers, and regulators to confront the realities of underground work long before modern safety culture existed. The standards forged in the coalfields – permissible explosives, testing galleries,

shot firer training, and rigorous regulation – became the foundation upon which blasting practice in mines and quarries worldwide was built.

FOREWORD

Today's mining explosives market is experiencing significant advancements driven by the need for safer, more efficient, and more environmentally responsible blasting operations. I will highlight these modern developments later in this article. First, it is essential to understand the historical journey that brought us here – a journey in which the coal industry worldwide played a defining role.

To do that, we turn to the *Colliery Guardian (now Coal International)* Commemoration Number of 1935, published to mark the journal's 75th anniversary as the leading publication for the UK industry and later as Coal International (1995) becoming a leading worldwide journal.

The edition in 1935 provided an authoritative account of the evolution of explosives in British coal mines.

1860-1935: A PERIOD OF TRANSFORMATION

Between 1860 and 1935, coal mining underwent a profound transformation in how explosives were manufactured, regulated, and applied underground. This era spans the shift from unstable nitroglycerine-based products to scientifically engineered "permissible" explosives designed to reduce the risk of igniting firedamp and coal dust – hazards tragically illustrated by the major disasters of the period.

BETTER SAFE THAN SORRY

The disastrous explosions which occurred in the UK coal mines about the beginning of the period under review, because of their very nature, directed attention to the dangers associated with coal operations. Explosions had always promoted public interest in the hazards of the miners calling. During the 70years 1863-1932 the decennial average death rate per 1,000 persons employed underground in the UK decreased from 0.88 to 0.6. The lowest death rate from this cause.0.02 was recorded in 1917.

Excluding the year 1926, in which there was a long stoppage the direct result of a deep and escalating conflict between coal miners, mine owners, and the government, several intertwined factors pushed the industry into crisis, ultimately triggering the nine day General Strike and a much longer miners' lockout.

The reduction in the death rate can undoubtedly be attributed to the realisation that coal dust itself could have been the cause of the disastrous nature of colliery explosions worldwide.

With a view to eliminating the danger of explosions consequent upon the use of gun powder, many devices were invented and used to a small extent, but it was not until the so- called 'flameless' explosives were devised, and subsequently improved, that reasonable safety in shot firing operations was ensured. Before the adoption of coal dusting making, it innocuous, the application of water had been practiced.

Safer methods of firing explosives evolved over the years. The electrical initiation detonators and fuses in mining was first suggested by Abel in1883 and went on to provide the safest means of firing shots in safety lamp mines, also the use of sand-clay stemming showed to be very efficacious.

The first explosion at Cambrian Colliery UK in 1905 with the loss of 31 lives followed later by a second one shattered the peace of more than one Welsh valley, took away the breadwinner from a score of families, brought pain and sorrow to several local townships and mining communities, and added yet another disaster to the already list of such tragic events in the annuls of coal mining in the UK. Although the pit explosion is happily much less familiar to us all today than it was a century ago, this explosion brought a grim reminder to the country of at least one of the great potential perils of the miner's calling.

Explosions in coal mines were a worldwide problem and the Cambrian incident was followed within two or three weeks, by an explosion at Dhori Colliery in the state of Bihar, India with a loss of 375 lives; by one at Kyushi Colliery in Japan, with a loss of 237 lives; by another at Kakan Colliery in central Yugoslavia, with a loss of 125 lives and by still another smaller explosion at Rudabanya Colliery in Northern Hungary, with a loss of five lives: this was perhaps both unexpected and quite fortuitous.

It was universally accepted at the time that British mines were amongst the safest in the world, nevertheless these happenings in five different countries at once brought home very forcibly not only the fact that that the days of the disastrous explosions was not over, even in the best regulated countries.

Fast forward to today, recent explosions would have one believing through TV, radio and the press that explosions constitute the greatest cause of accidents and death, so often to grip the public imagination. It is unfortunate that this sort of publicity tends to distort the true focus of the accident problems in mines worldwide. Ask any miner what the greatest single source of accidents is and they will all say roof fall followed by haulage and transport. This does not distract from the fact that the explosion hazard as a potential source of a serious accident has received over many years the earnest attention of engineers, chemists, scientists and research workers to make the use of high explosives safer and more efficient.

HOW IT ALL BEGAN

In 1860, the only explosive available for use in coal mines was black powder. It remained a useful explosive for breaking up coal and rock deposits until the early 20th century, when it was gradually replaced by dynamite for most mining purposes.

The Arrival of High Explosives

It may never be known with certainty who invented the first explosive, black powder, which is a mixture of saltpetre (potassium nitrate), sulphur, and charcoal (carbon). The consensus is that it originated in China in the 10th century for its use in fireworks.

By 1935, black powder had disappeared entirely from gassy mines in the UK and other countries. In its place stood a new generation of high explosives – vastly more efficient, more controllable, and safer when handled with proper precautions.

The era of high explosives in coal mining began with three pivotal developments:

Nitroglycerine Explosives – Nitroglycerine was discovered by Sobrero in 1846, and the first ammonium nitrate explosives were patented by Ohlsson and Norrbin in 1867. but it was Alfred Bernhard Nobel a Swedish chemist, inventor, engineer, and businessman who became the most well-known for inventing dynamite and making it usable in mining operations.

He coined the name from the Greek *dynamis*, "power." The basis for the invention was his discovery that kieselguhr, a porous siliceous earth, would absorb large quantities of nitroglycerine, giving a product that was much safer to handle and easier to use than nitroglycerine alone. Dynamite No. 1, as Nobel called it, was 75% nitroglycerine and 25% guhr.

His invention of the use of nitroglycerine explosive with diatomite as a absorbent and then developing a gelatinous nitroglycerine explosive led to a new generation of mining explosives. Later, various powdery explosives with ammonium nitrate as the main component emerged one after another. He would later bequeath his fortune made in explosives development to establish the now famous Nobel Prizes. His life blended scientific brilliance, personal introspection, and a late life desire to leave a legacy of peace and progress.

He shaped modern industry in ways far deeper than "inventing dynamite." His influence runs through mining, construction, manufacturing, global trade, and even the culture of scientific innovation. What he created wasn't just a product – it was an entire industrial ecosystem.

Nobel's inventions forced the mining industry to adopt:

- Training standards
- Safety procedures
- Blast design principles
- Regulatory frameworks
- Specialist roles (shotfirers, explosive engineers)
- He didn't just change the tools – he changed the culture.

The life and times of Alfred Nobel are well documented on various websites the most respected being:

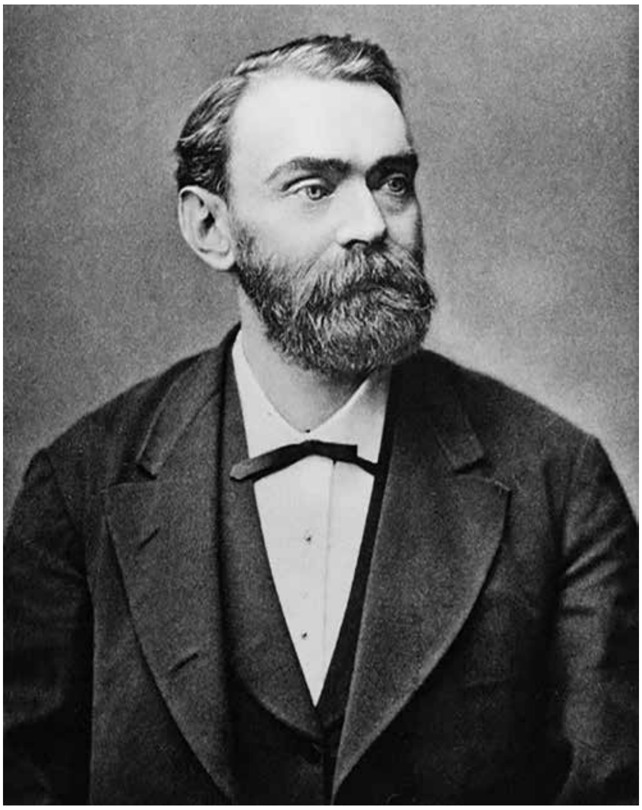
www.nobelprize.org/alfred-nobel

ANOTHER NOTEWORTHY STEP

THE MERCURY FULMINATE DETONATOR (NOBEL, 1867)

Mercury fulminate had been known since 1800, and metal detonator caps containing it appeared around 1814–1815. But Nobel's adoption of the detonator for industrial blasting was transformative. It provided the reliable initiation needed to detonate high explosives safely and consistently. Together, these innovations laid the foundation for modern blasting practice. Though mercury fulminate, like nitroglycerine and ammonium nitrate had been known for many years before their introduction into industry.

Early nitroglycerine was powerful but dangerously unstable, difficult to handle, and prone to freezing – which made it even more hazardous. Though a powerful explosive when used alone, the liquid nitroglycerine first used for blasting had many disadvantages It was inconvenient to use in any, but vertical and firm shot holes. It was dangerous to handle, and it readily froze becoming then less efficient on the one hand and still more dangerous on the other. Three distinct advances in nitroglycerine explosives enabled these drawbacks to be overcome, firstly the use of absorbent material such as Kieselguhr or wood meal.



Alfred Bernard Nobel

ABSORBENT MATERIALS (KIESELGUHR, WOOD MEAL)

Absorbing nitroglycerine into kieselguhr or wood meal created the first dynamites. Wood meal became particularly favoured because its partial oxidation utilised the excess oxygen in nitroglycerine, improving performance. The use of wood meal was also favoured since the slight excess oxygen of the nitroglycerine could be utilised by oxidation of the wood. More wood meal that could be thus oxidised was usually added, so that a further oxygen carrier, usually an inorganic nitrate, was added at the same time. In this way the composite modern explosives were made up of several constituents mixed together.

GELATINISATION WITH NITROCELLULOSE

The discovery that liquid nitroglycerine could be converted into a gelatinous solid by dissolving in it some 6 or 7% of collodion or nitrocotten was made by Nobel in 1875. Gelatinisation yielded a denser and more powerful explosive that became safer to handle. The modern blasting gelatine at the time consisted of nitroglycerine gelatinised with 8% upwards of nitrocotton, together with a small proportion of a stabiliser to retard decomposition in storage. This became too violent in its actions for many purposes; hence the gelignite's were developed to be made milder in their actions by the addition of potassium nitrate and wood meal. Adding a small proportion of nitrocellulose produced blasting gelatine – more stable, more powerful, and more water resistant than earlier dynamites.

LOW FREEZING EXPLOSIVES

One of the persistent challenges with early nitroglycerine explosives was their tendency to freeze at relatively mild temperatures. Frozen nitroglycerine not only lost efficiency but became markedly more sensitive to shock – a dangerous combination in the cold, damp conditions typical of many mining operations worldwide.

Nitroglycerine freezes at 13 degrees centigrade (55 degrees Fahrenheit). It crystallises very slowly but, during storage in cold weather, all explosives containing it freeze to a hard mass, which became unsuitable for use because of its hardness and insensitiveness. It is somewhat paradoxical that frozen nitroglycerine should be insensitive, for the danger in handling frozen nitroglycerine explosives suggests a much greater sensitivity.

The probable explanation at the time was that liquid nitroglycerine separates from explosives during freezing or, more likely, during partial thawing after freezing. Repeated accidents from this cause occurred over the years, so a lot of attention was made to the methods of rendering nitroglycerine less readily frozen.

The principal of lowering the freezing point of one substance by the addition of another became well known. Examples being spreading salt to make snow melt and the addition of glycerine to prevent freezing in car radiators.

Tetranitrodiglycerene was used in the first low freezing permitted explosives later being replaced by nitroglycol.

The explosive properties of nitroglycol were submitted to a thorough examination in the USA and was found to be more sensitive than nitroglycerine and safer to handle. Its explosive power was slightly superior. It had the disadvantage of being slightly more volatile and thus gave rise to headaches during the process of manufacturer.

Loading a drill hole underground

LOW DENSITY EXPLOSIVES

The properties of a blasting explosive may be varied within wide limits by alteration in its composition. The importance of density as a factor in deciding the action of an explosive had been known for a long time, and repeated efforts had been made to find means of reducing it, but it was not until 1927 that the first true low-density explosive was approved for coal mining. The new explosive being first introduced in the USA following the previous use of black powder as in many other countries. The first UK low density explosive was approved in January 1932. There were eleven on the permitted list at the time all proving of great value for coal purposes, over 20% of the weight of explosives used in 1933 being of this type.

The excellent results that ensured from the use of low freezing explosives had the effect that no fatal accidents were reported from mines and quarries in the UK for several years. These additives allowed explosives to remain pliable and reliable even in winter conditions or in deep, poorly ventilated workings where temperatures fluctuated dramatically.

Low freezing explosives represented a major step forward in operational reliability. They reduced misfires, improved consistency in shot performance, and – crucially – lowered the risk of accidental detonation during handling. By the early 20th century, low freezing dynamites had become standard in many mines worldwide particularly where cold conditions were a constant operational concern.

By proper methods of working, it was found the permissible explosives were just as effective as black powder in many workings whilst they provided less fumes and smoke and were easier to handle and less liable to be accidentally fired. The advantages then became offset by the introduction of pellet powder as the USA would refer to it that was similar to the black powder pellets in the UK. In 1931 nearly half the black powder used in the USA was in the form of pellet powder. It would be seen that even in 1931 there was a greater quantity of black powder used than of all high explosives, permissible and otherwise. The advantage of black powder being the absence of a shattering effect when it is used, so that it produced less fine coal and a greater size of lump. Many attempts were made to increase the yield of lump coal, the most important being known as 'cushion blasting,' the purpose of which is to spread the explosive effect over a greater surface of borehole.

Surface drilling rig

The difficulties of cushion blasting with the older type of explosive were overcome by the introduction of the low-density explosive, in which the cushioning is, in a sense incorporated in the cartridge. In other words, by decreasing the density by the same weight of explosive occupies a greater length of borehole so that its direct explosive effect acts on a greater length of material and thus, by being distributed over a greater area, has a smaller shattering effect on the coal.

Herein lies the main driving force for the developments of the low-density explosive in America, but other advantages also became apparent namely the use of different cartridges.

There were perhaps two main reasons for the introduction of low-density explosives in the UK, first was the higher price obtained in many districts for the larger grades of coal. The second was for finding a substitute for Bobbonite, an explosive which had for some time been kept on the permitted list, on sufferance only, because of its utility as a coal getter.

Four methods were tried in the period for the reduction of density of explosives, namely, loose packing, alteration in the granular state of the ammonium nitrate, impregnation of wood meal, and the use of substitutes for wood meal. Loose packing is not a practical method because it decreases the sensitivity of the explosive and the explosive materials pack more closely during transport. The other three methods had been used singly or together, but bulky substitutes for wood meal perhaps yielded the best results. The substances that were patented for this purpose in the USA included bagasse (pith and fibre of sugar cane), boiled bagasse, balsa wood, oat husks, maize stalks, ground popcorn and sphagnum (peat) moss. Wood disintegrated by saturation with high pressure steam, followed by rapid cooling, was also tried. The use of bulky plant material formed the basis of the first true low-density explosives in the USA which were introduced in 1927 by the Du Pont Co.

EXPLOSIVES OF LOW BALLISTIC STRENGTH

The spreading action of a low-density explosive was attained by distributing the explosive constituents over a greater volume of cartridge. The same effect was obtained by mixing with the explosive a greater quantity of its non-explosive constituents such as sodium chloride. The objection to this was the inevitable loss of sensitivity of the explosive, which was overcome by the then manufactures. As a result, the initial blow of the explosive and, consequently, the shattering effect was considerably reduced.

AMMONIUM NITRATE EXPLOSIVES (FAVIER, C. 1884)

Although ammonium nitrate explosives were first patented by Ohlsson and Norrbin in 1867, it was Frenchman P.A. Favier's work in the 1880s that made them practical. These mixtures would later become the foundation of safer, cooler burning explosives for gassy mines. They were easier and cheaper to manufacture and safer to handle. They required a hydrocarbon sensitiser to ensure detonation, trinitrotoluene being used for this purpose in the UK, while a small proportion (at least 4%) of nitroglycerine became compulsory in Germany. They have a lower sensitivity than nitroglycerine explosives and absorb moisture rather easily, but the latter disadvantage was overcome by waxing the paper wrapper of the cartridges used or by cartridging in metal containers. In 1933, 12,087,032 lb. of nitroglycerine explosives were used in UK coal mines and 4,460,186 lb. of ammonium nitrate explosives containing no nitroglycerine, but it must be remembered that, with a few exceptions, all nitroglycerine explosives contained ammonium nitrate. The use of ammonium nitrate also had certain advantages in reducing the flame temperature of an explosive and had an important influence in the development of permitted coal mining explosives.

In the 1950s, ammonium nitrate fuel oil mixture (ANFO) and slurry explosive were invented successively. In the 1970s, emulsion explosive was developed. Liquid oxygen has also been used as an explosive in some mines

CARDOX

The introduction of Cardox in the UK became one of the outstanding advances over the period, because of the complete departure from ordinary explosive techniques. The Cardox blasting device consisted of a strong steel shell that contained a charge of liquid carbon dioxide and a heating device. By means of this heating device, the liquid carbon dioxide is converted almost immediately into gas at high pressure. The pressure produced was sufficient to shear a disc at one end of the cartridge, when the gas escapes and exerts a disruptive effect on the surrounding strata.

The advantages claimed for the Cardox device were:

1. The increased safety in the presence of firedamp and in handling.
2. Increased yield of lump coal and easy recovery of misfires.
3. little disturbing effect on roof and supports near the shot hole and absence of fumes.

THE RISE OF PERMISSIBLE EXPLOSIVES

As understanding of firedamp and coal dust hazards deepened, it became increasingly clear that even improved nitroglycerine explosives posed unacceptable risks in gassy mines. The flame temperature and violent detonation characteristics of early high explosives could ignite methane or raise coal dust into an explosive suspension.

This led to the development of "permissible explosives" – formulations engineered specifically to minimise flame, reduce detonation temperature, and limit the risk of igniting flammable atmospheres.

KEY CHARACTERISTICS

- Lower flame temperature
- Reduced after flame duration
- Cooler detonation products
- Inclusion of flame suppressing salts
- Controlled energy release tailored to coal cutting needs
- These explosives were not simply "safer dynamites"; they were purpose designed for the unique hazards of mining. Their introduction marked the beginning of a scientific approach to blasting safety.
- **Testing Stations and Scientific Evaluation**
- The late 19th and early 20th centuries saw the establishment of formal testing stations, where explosives were evaluated under controlled conditions. These facilities – including the famous testing galleries – allowed researchers to measure:
- Flame length
- Ignition probability in methane air mixtures

- Detonation pressure
- Fume characteristics
- Cartridge behaviour under confinement
- Explosives were graded and approved based on their performance, and only those meeting strict criteria were permitted for use in gassy mines. This was a revolutionary shift: for the first time, explosives were not judged solely on power, but on safety performance under realistic mining conditions.
- The testing stations also drove innovation. Manufacturers competed to produce explosives that met or exceeded permissible standards, leading to rapid improvements in formulation, consistency, and reliability.
- **Regulation and Standardisation (1900–1935)**
- By the early 20th century, the UK had developed one of the most advanced regulatory frameworks for explosives in mining.
- Key developments included:
- **Approved Lists of Explosives**
- Only explosives that passed official testing could be used in designated mines. This created a clear distinction between:
- **Permissible explosives** (approved for gassy mines)
- **Non permissible explosives** (restricted to non gassy conditions)
- **Shot Firer Certification**
- Blasting operations could only be carried out by trained, certified shot firers. This professionalisation reduced accidents caused by poor handling or incorrect charging.
- **Rules for Storage and Transport**

Explosives had to be:

- Stored in approved magazines
- Transported in locked, spark proof containers
- Issued in controlled quantities
- Accounted for after each shift
- **Charging and Firing Regulations**
- Restrictions on cartridge size and number
- Mandatory stemming requirements
- Prohibition of certain explosives in specific seams
- Introduction of electrical firing systems to replace fuse based ignition
- By 1935, the combination of improved explosive formulations, scientific testing, and strict regulation had dramatically reduced the risk of ignition during blasting. While coal mining remained inherently hazardous, the industry had taken major strides toward controlling one of its most unpredictable dangers.

TRANSITION TOWARD MODERN EXPLOSIVES

By the mid 1930s, the direction of travel was clear:

- Nitroglycerine based dynamites were declining in coal mines.
- Ammonium nitrate mixtures were becoming dominant due to their cooler flame and lower sensitivity.
- Research into water based gels and slurry precursors was underway.
- The concept of tailoring explosives to specific geological conditions was firmly established.
- The groundwork had been laid for the post war evolution of emulsions, ANFO, and the highly engineered blasting agents used today.

FROM 1935 TO THE PRESENT: THE EVOLUTION TOWARD MODERN BLASTING

By 1935, the foundations of modern blasting practice were firmly in place. The industry had moved from black powder to nitroglycerine based dynamites, then to ammonium nitrate mixtures and scientifically tested permissible explosives. The decades that followed would build on this legacy, transforming explosives from simple chemical mixtures into highly engineered blasting agents designed for precision, safety, and environmental responsibility.

THE POST WAR SHIFT: ANFO AND BULK EXPLOSIVES

The most significant development after the 1930s was the introduction of **ANFO (Ammonium Nitrate-Fuel Oil)** in the 1950s. Simple, inexpensive, and remarkably effective.

The post war period introduced systems-level thinking in blasting. Advances in drilling technology produced deeper and more uniform blast holes requiring explosives with predictable detonation velocities. Electric detonators and millisecond delays allowed engineers to shape blast outcomes. This era marked the beginning of fragmentation engineering where blast results were measured, analysed and optimised.

ANFO rapidly became the dominant blasting agent in mining and quarrying. Its advantages were clear:

– Low cost and easy manufacture
– High stability and low sensitivity
– Suitability for bulk loading
– Predictable performance in dry conditions

Although ANFO was less suited to wet or water logged environments, it marked the beginning of a new era: bulk explosives delivered directly into the borehole, reducing handling risks and improving productivity.

WATER BASED EXPLOSIVES: SLURRIES AND EMULSIONS 1960S

From the 1960s onward, research focused on overcoming ANFO's limitations. This led to the development of slurry explosives and later emulsion explosives, both of which offered:

- Excellent water resistance
- High energy density
- Greater control over detonation velocity
- Improved safety in storage and transport

Emulsions, in particular, became the backbone of modern underground blasting. Their ability to be sensitised on site – often moments before loading – dramatically reduced the risk of accidental initiation during transport or handling.

1970S-1980S: NON-ELECTRIC INITIATION AND RELIABILITY

The development of non-electric initiation systems (such as shock tube technology) greatly improved safety and reliability. From a technological standpoint this reduced systematic risk and allowed blasting operations to integrate more with modern, electrified mine sites.

1990S- COMPUTATIONAL MODELLING AND BLAST SIMULATION

With the rise of computing, blasting entered the digital planning era.

– Engineers began using software to model:
– Rock mass properties
– Detonation timing features
– Stress wave propagation
– Fragment size distribution

This transformed blasting from a rule of thumb practise into a data driven engineering discipline. Explosives were increasingly selected and deployed based on modelled outcomes rather than experience alone.

2000S-2010S

ELECTRONIC DETONATORS AND PRECISION BLASTING

Electronic detonators represented a major technical leap providing millisecond to microsecond accuracy. This precision enabled

- Improved ore recovery
- Lower energy losses
- Better crushing efficiency
- Reduced vibration and flyrock
- Improved fragmentation and wall control

This precision allowed mines to design blasts that were not only safer but also optimised for downstream processes such as loading, hauling, and crushing. Blasting became integrated into the entire mining value chain from drilling to milling.

TODAY

DIGITAL INTEGRATION AND AUTOMATION

Today, explosives are part of a fully integrated digital ecosystem. Modern blasting incorporates:

- GPS-linked blast design
- 3D geological modelling
- Drone based survey data
- Wireless detonator programming
- Cloud-based analytics
- Borehole deviation measurement
- Real time blast simulation
- Autonomous charging and initiating systems
- Automated loading

The result is a level of control unimaginable to the miners of the 1860s – or even the 1930s. Blasts can be designed to minimise vibration, reduce overbreak, control dust, and improve fragmentation, all while maximising safety.

ENVIRONMENTAL AND SAFETY PRIORITIES

Contemporary explosives development is shaped by global expectations around sustainability and worker protection.

Key trends include:

- Reduced NOx emissions
- Lower toxicity formulations
- Recyclable packaging
- Reduced explosive fumes in confined spaces
- Automated or remote loading to remove personnel from hazardous zones

These innovations reflect the same driving force that shaped the industry in the late 19th and early 20th centuries: the need to protect miners while improving productivity.

A CENTURY AND A HALF OF PROGRESS

From the unstable nitroglycerine of the 1860s to today’s digitally controlled, water resistant emulsions and precision detonators, the evolution of mining explosives has been one of the most remarkable technological journeys in industrial history.

The story of explosives is ultimately a story of people – miners, blasting engineers, chemists, manufactures and innovators – all striving to make the industry safer and more efficient. Their work continues, and so does ours: to record, to inform, and to ensure that the lessons of the past guide the progress of the future. For companies working in the explosives industry, **this history** matters. It explains why your products exist, how the industry got here, and where innovation is heading next.

WHY IT MATTERS

As mines go deeper and sustainability pressures intensify, the industry faces a familiar challenge: How do we deliver more energy, more precisely, with less environmental impact?

The answer lies in the same principles that have guided 160 years of innovation:

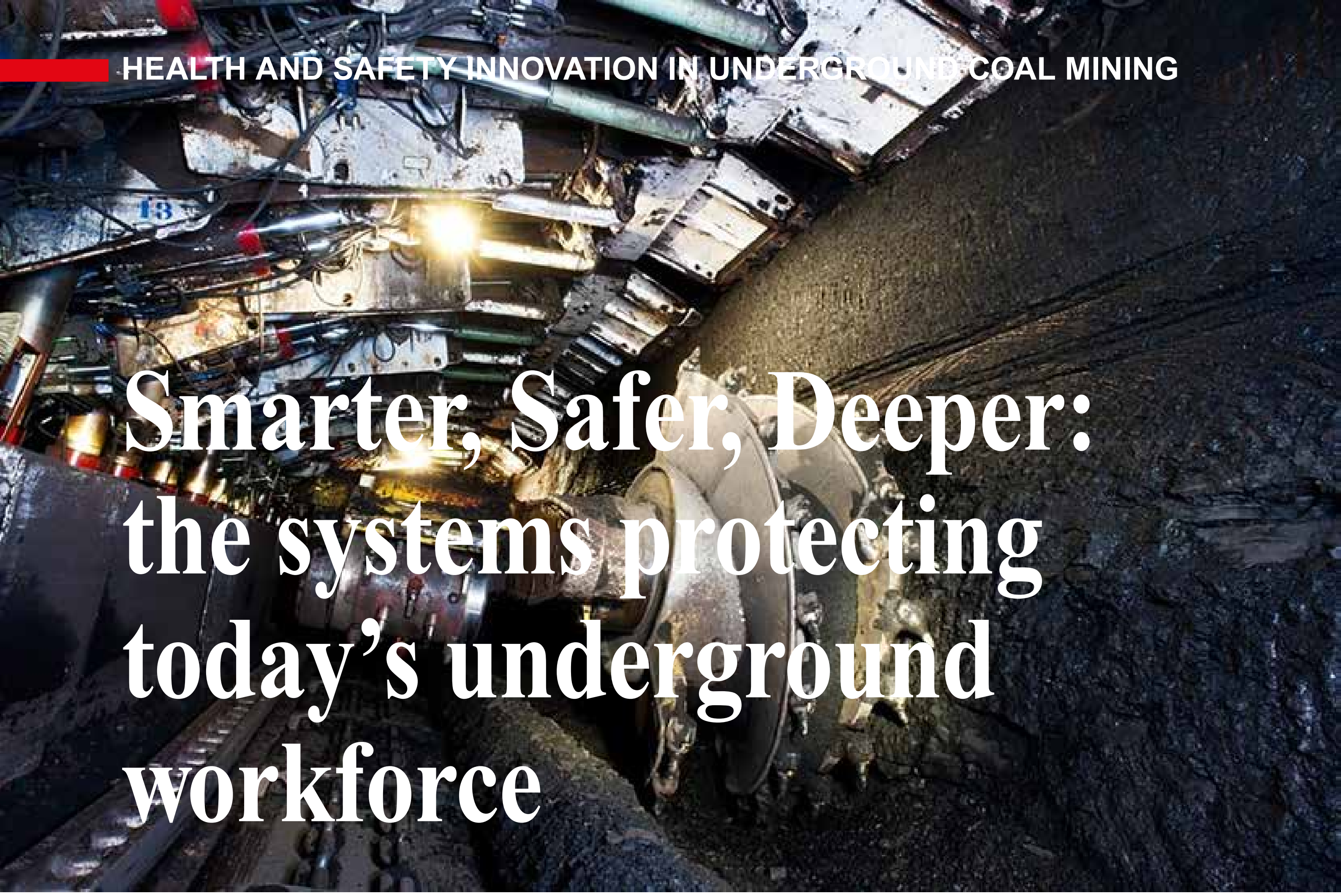
- Engineered formulations
- Reliable initiation
- Scientific testing
- Data driven design
- Continuous improvement

The past isn’t just history. It’s a roadmap.

MOVERS AND SHAKERS

There are several mining explosives manufactures worldwide who have a long history in mining explosives within the period covered by this report however we focus on Austin Powder Co. a true pioneer in the industry who have shaped the evolution of blasting for nearly two centuries.

– Company profile
– Relevant case study
– Relevant photographs
– Company Logo
– Questions and answers if relevant.



Smarter, Safer, Deeper: the systems protecting today's underground workforce

Underground coal mining is entering a new phase in which health and safety innovation is no longer an adjunct to production but the defining driver of engineering progress. The modern mine is being reshaped by technologies that directly target the most persistent hazards of the underground environment: airborne dust, ground instability, restricted visibility, and the need to place people close to machinery. Robotics, advanced dust suppression systems, intelligent support structures, and real time sensing networks are converging to create a working environment that is fundamentally safer, more predictable, and more controllable than at any point in the industry's history.

Together, these innovations signal a decisive shift toward an underground environment where hazards are identified earlier, controlled more effectively, and increasingly managed by machines rather than people. As robotics, dust control engineering, structural support design, and sensor driven monitoring continue to mature, underground coal mining is moving toward a model in which safety is embedded not only in procedures but in the very architecture of the mine itself. ***Gordon Barratt of Coal International takes a detailed look at some of these innovative approaches currently being used***.

STRUCTURAL SAFETY

Structural safety in underground coal mining has undergone a profound transformation over the past several decades, evolving from a largely reactive practice into a sophisticated engineering discipline built around prediction, monitoring, and intelligent response. Where early support systems were designed simply to resist the immediate loads imposed by the roof and ribs, modern supports are engineered to understand, interpret, and adapt to the behaviour of the rock mass. This shift has been driven by advances in materials science, automation, sensing technologies, and the integration of digital systems that allow engineers to manage ground conditions with unprecedented precision.

The earliest forms of roof support relied heavily on timber props and simple steel arches, systems that provided basic resistance but offered little insight into the stresses acting on the strata. Failures were often sudden, and the warning signs subtle or invisible. As mining advanced into deeper and more geologically complex seams, the limitations of these traditional supports became increasingly apparent. The introduction of steel rock bolts and cable bolts marked a major step forward, anchoring the roof to more competent strata and creating a reinforced rock beam capable of carrying greater loads. Yet even these systems, while stronger and more reliable, were still fundamentally passive. They held the ground in place but could not communicate how close they were to failure or how conditions were changing over time.

The emergence of powered roof supports in longwall mining represented a turning point. These hydraulic systems not only provided high-capacity support but also introduced the concept of controlled yielding, allowing the roof to deform in a managed way while maintaining stability at the face. Their ability to advance automatically with the shearer reduced the need for miners to work in unsupported

areas, significantly improving safety. Over time, powered supports became more sophisticated, incorporating load cells, pressure sensors, and automated control systems that allowed operators to monitor support performance and detect abnormal loading patterns. This marked the beginning of a more intelligent approach to structural safety – one in which supports were no longer static structures but active participants in ground control.

Today, structural safety is being reshaped by the integration of smart technologies that turn support systems into continuous sources of engineering data. Modern supports are equipped with sensors that measure load, displacement, vibration, and hydraulic pressure, transmitting real time information to surface control rooms. These data streams allow engineers to identify zones of increasing stress, track the progression of roof deformation, and intervene before conditions deteriorate. In some operations, sensor networks extend beyond the supports themselves, with distributed monitoring systems embedded in the roof and ribs to detect micro seismic activity, strata movement, and early signs of instability. This level of insight was unimaginable in earlier eras of mining.

The intelligence of support systems is further enhanced by robotics and automation. Robotic installation units reduce the need for manual handling of heavy components, lowering the risk of injury while improving installation accuracy. Automated longwall systems adjust support pressures and advance sequences based on real time geological feedback, ensuring that the supports respond dynamically to changing conditions at the face. These capabilities not only improve safety but also contribute to more consistent production, as stable ground conditions reduce downtime and equipment damage.

Materials science has also played a crucial role in the evolution of structural safety. High strength steels, corrosion resistant alloys, and composite materials have extended the lifespan and reliability of supports, particularly in wet or chemically aggressive environments. Yielding bolts, resin anchored systems, and innovative reinforcement designs have improved the ability of supports to accommodate ground movement without catastrophic failure. These advances allow engineers to tailor support strategies to specific geological conditions, creating systems that are both stronger and more adaptable.

The result of these developments is a fundamentally smarter support system – one that combines mechanical strength with digital intelligence, predictive capability, and automated response. Structural safety is no longer defined solely by the capacity of the support but by the quality of the information it provides and the speed with which engineers can act on

that information. In this new paradigm, the underground environment becomes more transparent, hazards are identified earlier, and interventions are more targeted and effective.

As underground coal mining continues to evolve, the integration of smart supports with robotics, ventilation controls, and mine wide sensor networks will further strengthen the safety envelope around the workforce. The future mine will be one in which structural stability is continuously monitored, dynamically managed, and increasingly automated – an environment where engineering insight and technological innovation work together to protect miners and sustain production. This transformation marks one of the most significant advances in the history of underground coal mining, redefining what is possible in ground control and setting new standards for safety and operational excellence.

ROBOTIC PLATFORMS

Robotic platforms are becoming one of the most transformative forces in underground coal mining, reshaping both the productivity profile of operations and the safety envelope surrounding the workforce. What began as isolated trials of remote controlled machinery has evolved into a sophisticated ecosystem of autonomous and semi autonomous systems capable of performing tasks once considered too hazardous, too repetitive, or too physically demanding for human miners. Their impact is now measurable across the full mining cycle, from development and extraction to haulage, inspection, and environmental control.

The most immediate contribution of robotics to underground coal mining lies in the removal of personnel from high risk zones. Traditional mining methods require workers to operate close to the face, within confined headings, or alongside heavy equipment where exposure to dust, noise, gas accumulations, and ground instability is unavoidable. Robotic platforms – whether continuous mining machines with autonomous guidance, inspection robots navigating unsupported areas, or robotic arms performing cutting and drilling – allow these tasks to be carried out without placing people in harm's way. By shifting human oversight to remote control rooms or supervisory stations, mines reduce exposure to the hazards that have historically contributed to injuries and occupational disease.

Productivity gains arise from the same capabilities that enhance safety. Robots do not fatigue, require breaks, or experience the physical limitations that constrain human performance in hot, dusty, or low visibility environments. Autonomous haulage units can operate continuously, maintaining steady production flow even during shift changes. Robotic cutting systems maintain consistent advance rates, reducing the variability associated with manual operation. In longwall operations, automated shield movement and shearer guidance systems ensure optimal cutting height and face alignment, reducing downtime caused by misalignment, equipment damage, or uneven strata conditions. These improvements translate directly into higher output, more predictable production schedules, and better utilisation of capital equipment.

Robotic platforms also bring a level of precision that enhances both efficiency and resource recovery. Advanced sensing technologies – lidar, radar, inertial navigation, and machine vision systems – allow robots to map underground environments, detect geological anomalies, and adjust their operations in real time. This precision reduces over cutting, minimises dilution, and improves the quality of the extracted coal. In development headings, robotic drilling units can position holes with exact spacing and orientation, improving blast outcomes and reducing the need for rework. In longwall operations, automated horizon control systems maintain the shearer within the optimal coal band, reducing contamination and improving yield.

Safety benefits extend beyond physical separation from hazards. Robotic platforms are increasingly integrated with mine wide monitoring systems that provide continuous data on gas concentrations, airflow, roof movement, and equipment health. Inspection robots equipped with gas sensors, thermal imaging, and structural health monitoring tools can enter areas that are inaccessible or unsafe for humans, providing early warning of deteriorating conditions. These capabilities support proactive risk management, allowing engineers to intervene before minor issues escalate into major incidents. In some operations, robots are used to assess roof conditions after blasting or collapse, enabling safe re entry and reducing downtime.

The introduction of robotics has also improved emergency response capabilities. Robots can be deployed into areas affected by fire, explosion, or roof fall to assess conditions, locate trapped personnel, or deliver supplies. Their ability to operate in toxic atmospheres or unstable ground conditions provides critical information that would otherwise be unavailable, improving the effectiveness and safety of rescue operations.

From an operational standpoint, robotics reduces the physical strain on workers, lowering the incidence of musculoskeletal injuries associated with manual handling, repetitive tasks, and awkward postures. Remote operation consoles allow operators to work in climate controlled environments, improving comfort and reducing fatigue. This shift not only enhances safety but also broadens the potential workforce by reducing the physical demands traditionally associated with underground mining.

The integration of robotics into underground coal mining is also helping to address workforce challenges. As experienced miners retire and recruitment becomes more difficult, robotic systems provide a means of maintaining production levels without increasing labour intensity. They also create new roles focused on supervision, maintenance, programming, and data analysis – positions that attract a broader range of skills and support the long term sustainability of the industry.

Looking ahead, the convergence of robotics with artificial intelligence, machine learning, and digital mine platforms will further amplify these benefits. Autonomous systems will become more adaptive, capable of learning from geological conditions, optimising their own performance, and coordinating with other machines. Multi robot systems will collaborate to manage entire sections of the mine, from cutting and loading to haulage and environmental control. As these technologies mature, underground coal mining will move toward a model in which human workers oversee operations from safe, remote locations while robotic platforms perform the most hazardous and physically demanding tasks.

In this evolving landscape, robotics is not simply an add on to existing mining methods but a catalyst for a fundamentally safer and more productive underground environment. By reducing exposure to hazards, improving operational precision, and enabling continuous, high efficiency production, robotic platforms are redefining what is possible in underground coal mining. Their success marks a decisive step toward a future in which safety and productivity are not competing priorities but mutually reinforcing outcomes of intelligent, technology driven mining systems.

SENSORS

Sensor technology has become one of the most influential drivers of health and safety improvements in underground coal mining, fundamentally changing how hazards are detected, interpreted, and controlled. What was once a reactive discipline – responding to incidents after they occurred – has evolved into a proactive, data driven system in which real time monitoring, predictive analytics, and automated responses work together to protect miners and stabilise the underground environment. Sensors now permeate every aspect of the mine, from ventilation and gas control to ground support monitoring, equipment health, and worker tracking, creating a level of situational awareness that previous generations of engineers could only imagine.

The most transformative impact of sensor technology lies in atmospheric monitoring. Underground coal mines have always faced the risk of methane accumulation, oxygen depletion, and the presence of toxic gases such as carbon monoxide. Historically, these hazards were managed through periodic manual sampling and fixed monitoring stations that provided only limited coverage. Modern sensor networks, by contrast, offer continuous, distributed measurement of gas concentrations throughout the workings. Wireless gas sensors, fibre optic systems, and multi parameter detection units transmit real time data to surface control rooms, enabling engineers to identify trends, detect anomalies, and respond to dangerous conditions before they escalate. Automated alarms, ventilation adjustments, and equipment shutdowns can be triggered instantly, reducing the likelihood of explosions, fires, or asphyxiation events.

Dust control has also been transformed by sensor driven monitoring. Coal dust remains one of the most persistent health hazards in underground mining, contributing to respiratory diseases and increasing the risk of explosions. Modern particulate sensors measure dust concentrations with high precision, allowing ventilation systems, water sprays, and dust suppression equipment to be adjusted dynamically. These sensors can be integrated directly into cutting machines, conveyors, and longwall shearers, providing immediate feedback on dust levels at the source. The result is a more stable and predictable working environment in which exposure is minimised and compliance with regulatory limits is easier to maintain.

Ground control is another area where sensor technology has reshaped safety practices. Roof falls have long been one of the leading causes of injuries and fatalities in underground coal mines. Today, load sensing bolts, instrumented supports, and distributed micro seismic monitoring systems provide continuous insight into the behaviour of the rock mass. These sensors detect subtle changes in stress, deformation, and vibration that may indicate impending instability. Engineers can use this data

to identify hazardous zones, adjust support strategies, and evacuate personnel if necessary. In longwall operations, shield pressure sensors help operators understand how the roof is responding to extraction, allowing for more precise control of support systems and reducing the risk of sudden collapses.

Equipment health monitoring has also benefited from the integration of sensors. Modern mining machinery is equipped with vibration sensors, temperature probes, hydraulic pressure monitors, and electrical load detectors that track the condition of critical components. Predictive maintenance algorithms analyse this data to identify early signs of wear or failure, allowing repairs to be scheduled before breakdowns occur. This not only improves safety – by reducing the risk of mechanical failures that could endanger workers – but also enhances productivity by minimising unplanned downtime.

Worker safety is further strengthened by personnel tracking systems that use RFID tags, Bluetooth beacons, or ultra wideband positioning to monitor the location of miners in real time. These systems improve emergency response by providing accurate information on who is underground and where they are located. They also support proximity detection systems that prevent collisions between workers and mobile equipment, one of the most common causes of underground injuries. When integrated with ventilation and gas monitoring networks, personnel tracking data can be used to ensure that workers are not entering hazardous zones or areas with poor atmospheric conditions.

The convergence of sensor technology with robotics and automation is amplifying these benefits. Robotic inspection units equipped with gas sensors, thermal cameras, and structural health monitoring tools can enter areas that are unsafe for humans, providing detailed assessments of conditions after blasting, roof falls, or fires. Autonomous vehicles use lidar, radar, and machine vision sensors to navigate complex underground environments, reducing the need for human operators in hazardous areas. These systems not only enhance safety but also generate high resolution data that improves the accuracy of mine planning models and hazard prediction tools.

Looking ahead, the integration of sensor networks with artificial intelligence and digital twin platforms will further transform health and safety management. Mines will be able to simulate atmospheric behaviour, predict ground control issues, and optimise ventilation in real time based on sensor inputs. Machine learning algorithms will identify patterns that human operators might miss, providing early warnings of emerging risks. As sensor technology becomes more robust, energy efficient, and interconnected, underground coal mines will move toward a fully intelligent safety ecosystem in which hazards are continuously monitored, automatically mitigated, and increasingly prevented altogether.

In this evolving landscape, sensor technology is not merely an enhancement to traditional safety practices – it is redefining the entire philosophy of underground risk management. By providing continuous visibility into the conditions that shape the underground environment, sensors enable a level of control, prediction, and responsiveness that fundamentally improves both safety and productivity. The modern coal mine is becoming a data rich, sensor driven operation in which engineering decisions are informed by real time insight and where the protection of workers is embedded directly into the technological fabric of the mine.

ADVANCED VENTILATION AND AIRFLOW ENGINEERING

Modern ventilation systems have become one of the most advanced and strategically important components of underground coal mining, evolving far beyond the traditional model of fixed fans and static airways. Today's systems operate as intelligent, dynamically controlled networks capable of responding instantly to the changing conditions of the underground environment. This transformation has been driven by the need to manage increasingly complex mining layouts, deeper workings, and stricter health and safety expectations. As a result, ventilation engineering has shifted from a largely mechanical discipline to a sophisticated blend of automation, sensing, modelling, and real time control.

At the heart of this evolution is the widespread adoption of variable speed fans. Unlike conventional fixed speed units, variable speed fans adjust their output automatically based on atmospheric conditions, equipment activity, or operational demand. When methane levels rise, dust concentrations increase, or additional equipment is brought online, the system can increase airflow instantly to maintain safe conditions. Conversely, during periods of reduced activity, airflow can be lowered to conserve energy without compromising safety. This dynamic control not only improves atmospheric stability but also reduces power consumption, which is one of the largest operating costs associated with underground ventilation.

Automated regulators and ventilation doors further enhance this responsiveness. These devices adjust airflow distribution throughout the mine, opening or closing in real time to direct fresh air to active headings and dilute contaminants at their source. In longwall operations, for example, automated regulators can maintain consistent airflow across the face even as the panel advances and the geometry of the workings changes. This level of precision was impossible with manual systems, which relied on periodic adjustments and often lagged behind actual conditions underground.

Real time airflow modelling has become another cornerstone of modern ventilation management. Using data from distributed sensors, control systems continuously calculate airflow patterns, pressure differentials, and gas dispersion throughout the mine. This allows engineers to visualise the underground atmosphere as a living system – one that can be monitored, predicted, and controlled with far greater accuracy than ever before. When integrated with gas sensors, dust monitors, and equipment tracking systems, these models provide a comprehensive picture of how mining activities influence air quality and how the ventilation network must adapt to maintain safe conditions

Computational fluid dynamics (CFD) modelling has also become a powerful tool during the planning and design stages. CFD allows engineers to simulate airflow behaviour in complex geometries, identify potential dead zones, and optimise the placement of fans, regulators, and stoppings before development begins. By modelling methane layering, dust dispersion, and heat flow, CFD helps ensure that ventilation circuits are both efficient and resilient. This predictive capability reduces the risk of unforeseen hazards and supports more effective long term planning, particularly in deep or geologically challenging operations.

The integration of ventilation systems with sensor networks has further strengthened safety outcomes. Continuous monitoring of methane, carbon monoxide, oxygen levels, and dust concentrations provides the data needed for automated responses. When thresholds are approached, alarms activate, fans ramp up, and equipment may be shut down automatically. This rapid response capability is critical in preventing gas build ups, oxygen deficient zones, or explosive atmospheres – conditions that historically contributed to some of the most serious incidents in underground coal mining.

In addition to atmospheric control, modern ventilation systems support improved thermal management. As mines extend deeper and equipment becomes more powerful, heat load increases. Intelligent ventilation systems can adjust airflow to manage temperature more effectively, improving working conditions and reducing heat stress for personnel. This is particularly important in mechanised operations where equipment generates significant heat in confined spaces.

The shift toward intelligent ventilation has also improved emergency preparedness. In the event of a fire, explosion, or roof fall, ventilation systems can be reconfigured remotely to isolate affected areas, redirect smoke, or support rescue operations. Real time modelling helps predict how contaminants will spread, allowing emergency teams to make informed decisions quickly. This capability represents a major advance over older systems, which often lacked the flexibility or data needed to respond effectively during critical incidents.

Ultimately, the development of intelligent, dynamically controlled ventilation networks marks a fundamental shift in how underground coal mines manage health and safety. Ventilation is no longer a static background system but an active, adaptive component of the mine's safety infrastructure. By combining variable speed fans, automated regulators, real time modelling, and advanced simulation tools such as CFD, modern mines can maintain optimal atmospheric conditions with a level of precision that was previously unattainable. This evolution not only reduces the risk of gas explosions, dust exposure, and oxygen deficient zones but also supports more efficient, productive, and sustainable mining operations.

EMERGENCY RESPONSE AND REFUGE TECHNOLOGY

Refuge and emergency response technologies have undergone a profound transformation in underground coal mining, driven by the industry's determination to reduce fatalities, improve survivability, and protect rescue teams during the most critical moments of an incident. Modern refuge chambers and emergency response robots now form a complementary safety architecture that provides miners with secure, life sustaining environments while enabling rapid, risk free assessment of hazardous zones. Together, these innovations represent one of the most significant advances in underground emergency preparedness in decades.

Refuge chambers have evolved from basic sealed shelters into highly engineered life support systems capable of

sustaining trapped miners for extended periods. Early chambers offered only minimal protection, relying on passive air supplies and limited communication. Today's units are designed to withstand explosions, fires, and roof falls, maintaining structural integrity even under extreme conditions. Their life support capability has expanded dramatically, with integrated oxygen generation systems, carbon dioxide scrubbers, and air cooling units that maintain breathable, temperature controlled environments for days at a time. These systems operate autonomously, ensuring that miners have access to clean air, potable water, and essential supplies even if external infrastructure is compromised.

Communication has become a defining feature of modern refuge chambers. Advanced systems now include hard wired or wireless communication links that allow trapped personnel to maintain contact with surface control rooms. This connectivity provides reassurance to miners, supports coordinated rescue planning, and enables real time updates on atmospheric conditions inside and outside the chamber. Integrated monitoring systems track internal gas levels, temperature, humidity, and pressure, transmitting this data to emergency teams so they can assess the wellbeing of occupants and adjust rescue strategies accordingly. In many operations, refuge chambers are now fully integrated into the mine's digital communication network, ensuring continuous visibility even during large scale incidents.

The introduction of emergency response robots has further strengthened underground survivability by reducing the need for human rescuers to enter hazardous zones. These robots are designed to operate in environments that are too dangerous for personnel – areas with toxic gases, unstable ground, fire, or the aftermath of explosions. Equipped with gas sensors, thermal imaging cameras, lidar mapping systems, and high definition video, they provide detailed situational awareness that would otherwise be impossible to obtain without exposing rescue teams to significant risk. Their ability to navigate debris, confined spaces, and low visibility conditions makes them invaluable during the early stages of an emergency, when rapid assessment is critical.

One of the most important capabilities of emergency response robots is their role in locating trapped personnel. Using onboard sensors and communication relays, they can detect signs of life, identify safe pathways, and relay information back to rescue coordinators. Some units are designed to deliver essential supplies – oxygen canisters, medical kits, communication devices, or water – to miners who may be stranded outside refuge chambers. This capability can extend survivability significantly, especially in complex or multi entry mines where access routes may be blocked or compromised.

Robotic systems also support structural assessment after incidents. By mapping roof conditions, detecting hotspots, and identifying gas accumulations, they allow engineers to evaluate the stability of the affected area before sending in rescue teams. This reduces the likelihood of secondary incidents, which historically have posed some of the greatest risks to emergency responders. In many cases, robots can perform tasks that would otherwise require multiple personnel, such as inspecting conveyor belts, checking ventilation controls, or verifying the integrity of stoppings and seals.

The combined impact of advanced refuge chambers and emergency response robotics is a step change in underground emergency management. Refuge chambers provide miners with a safe, controlled environment where they can survive until rescue teams arrive, while robots extend the reach and capability of those teams without exposing them to immediate danger. Together, they create a layered safety system that improves the chances of survival, accelerates rescue operations, and reduces the physical and psychological burden on both miners and responders.

As underground coal mining continues to evolve, these technologies will become even more integrated. Future systems may include autonomous robots capable of guiding miners to refuge chambers, chambers that automatically interface with ventilation and gas monitoring networks, and AI driven emergency response platforms that coordinate rescue efforts based on real time data. What is already clear is that refuge chambers and emergency response robotics have redefined what is possible in underground safety, shifting the industry toward a future in which survivability is maximised and risk to rescue teams is minimised.

CONCLUSION

Collectively, these technologies are redefining the very concept of health and safety in underground coal mining. The industry is moving toward an operational model in which risk is engineered out of the environment wherever possible, and where human expertise is applied from positions of oversight rather than exposure. The result is a mine that is not only safer but also more productive, more efficient, and better equipped to meet the demands of modern energy markets. As these innovations continue to mature and integrate, they will shape a future in which underground coal mining is defined not by its hazards, but by the sophistication of the systems designed to control them.