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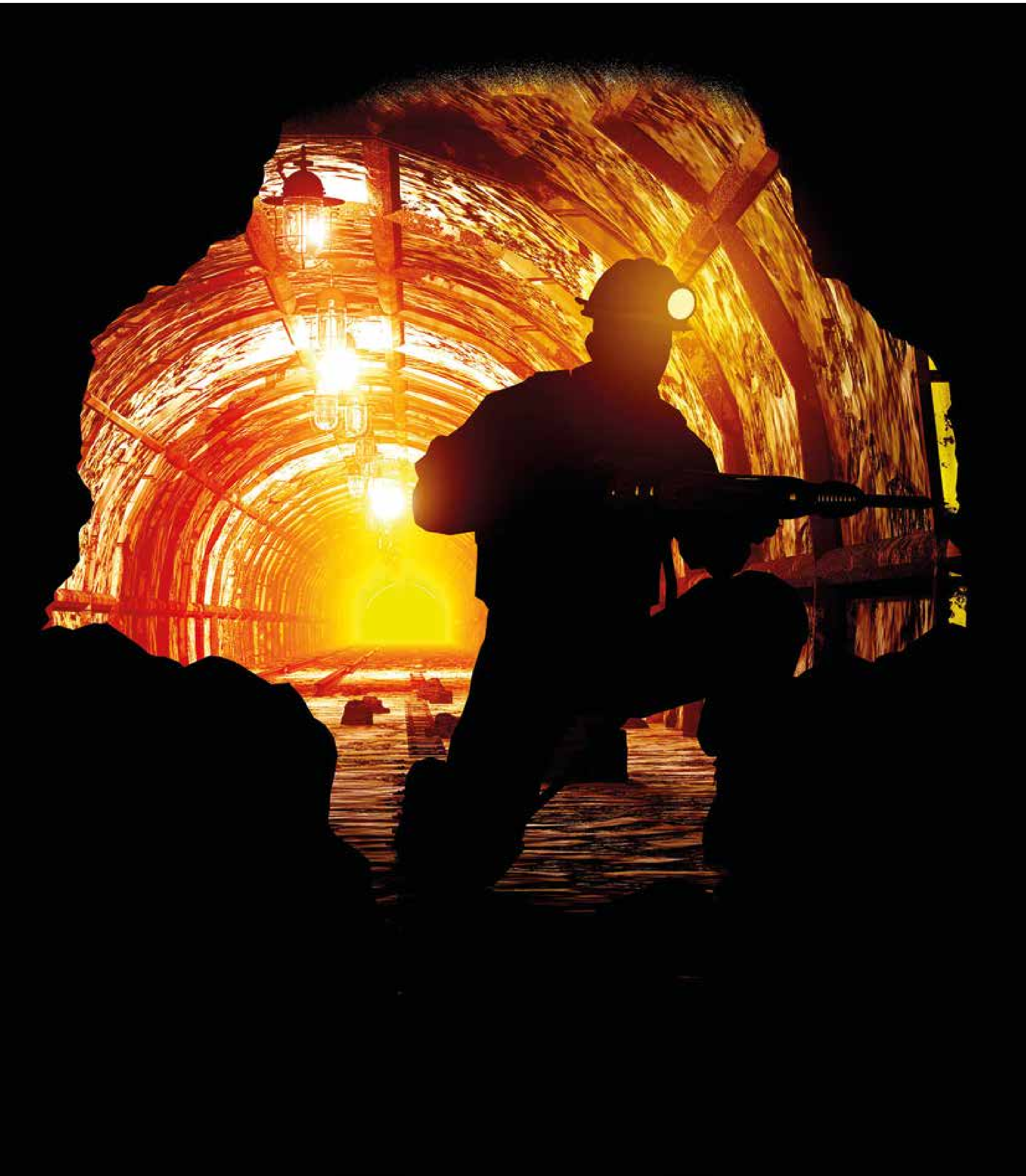
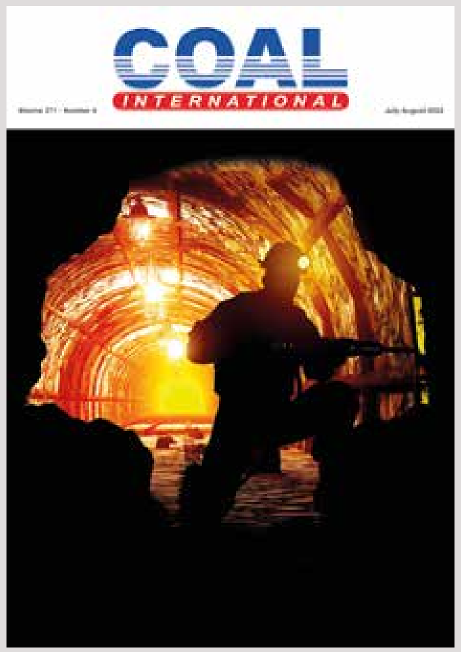


Volume 271 • Number 4 • July-August 2023

CONTENTS



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Glencore submits alternative proposal to Teck

Major miner Glencore has confirmed that it has submitted an alternative proposal to Teck Resources' board of directors to acquire its steelmaking coal business for cash.

Teck Resources is one of Canada's leading mining companies which specialise in mining commodities such as steelmaking coal, copper, and zinc.

In early April, Teck turned down Glencore's $US23 billion offer, which lead to Glencore adding $US8.2 billion in cash to the takeover offer.

Not long after this, Teck withdrew its proposal to split the company, which industry experts said may cause the coal major to attempt another takeover offer.

Now, it has submitted an alternative proposal.

"While Glencore remains willing to pursue its proposed merger demerger, Glencore has made this alternative proposal to acquire (Teck's steelmaking coal business) as it is expected to allow for a value accretive demerger of the combined coal and carbon steel materials business to its shareholders," Glencore said in its statement.

The major miner noted its strong support of the transaction from its shareholders and it said if a transaction were to materialise, it would demerge CoalCo once it has sufficiently delivered approximately 12-24 months from close.

"Glencore would manage its post-demerger balance sheet, post servicing its formulaic base distribution, to a revised c.US$5 billion net debt cap, down from the current level of c.US$10 billion, alongside our continued commitment to minimum strong BBB/Baa ratings," the company said.

Glencore stated its full committed to ensuring the proposed acquisition would benefit Canada and maintained it is open to working with Teck.

"(We are) open to working with Teck to identify a comprehensive suite of commitments for the benefit of all relevant stakeholders which would enhance Teck's steelmaking coal business existing presence and capital investments in Canada, as well as its community, social, labour and environmental programmes," Glencore said.

Polish government won't close Turów mine despite court ruling

Polish Prime Minister Mateusz Morawiecki vowed to resist attempts to close the Turow lignite mine, a subject of conflict between Poland and Czechia, despite a court order ruling the suspension of work.

In its ruling delivered recently, the Warsaw court suspended a decision to allow the coal mining concession at Turów to be extended because it could cause significant damage to the environment, as announced by the Frank Bold Foundation, Greenpeace and the EKO-UNIA Ecological Association in a joint statement.

But Prime Minister Mateusz Morawiecki remained defiant even in the face of the ruling, stating, "we will not let this mine close. We will do everything to make it function normally until 2040."

"No courts, whether from Brussels or Warsaw, will dictate to us what is meant by Poland's energy security, the security of families," he said in Bogatynia, where the mine is located.

In September 2021, the EU Court of Justice imposed a daily fine of €500,000 on Poland for failing to implement its ruling concerning closing operations at the colliery.

Though it later withdrew its legal complaint, the Czech Republic, whose border is near the mine, filed its own suit, citing the harmful impact on the environment, particularly air and groundwaters in the Liberec Region.

In February 2022, an agreement was reached between Morawiecki and his Czech counterpart Petr Fiala, under which Poland paid the Czech Republic €45 million in compensation for the damage. Consequently, Czechia withdrew the lawsuit from the EU court.

In September 2022, the General Environmental Protection Authority (GDOS) extended the environmental permit for Turów, which faced criticism from environmental NGOs. Two months later, they filed a complaint against the Polish-Czech deal and the GDOS decision before the Regional Administrative Court in Warsaw.

The organisations, including the three that issued the joint statement on the court's ruling, said the environment around the Turów lignite mine is still being affected.

China June output rebounds from six-month low as heatwave boosts demand

China's average daily coal production rebounded in June from a six-month low the prior month, official data showed, as miners ramped up output to meet increasing demand from power generators amid a heatwave.

China churned out 390.1 million metric tons of coal last month, up 2.5% from a year earlier and 1.2% from May, data from the National Bureau of Statistics (NBS) showed.

Daily production in June was equivalent to 13 million metric tons, up from May's 12.43 million metric tons, which was the lowest level since October 2022.

Coal output during the first half of 2023 reached 2.3 billion metric tons, 4.4% higher than the same period last year.

Miners have been urged by the government since June to step up output to fill their supply contracts with utilities as rounds of blistering heatwaves have swept across large swathes of China since late June.

Daily coal consumption in eight coastal provinces in June surpassed the levels seen over the same period of the past four years, data compiled by the China Coal Transportation and Distribution (CCTD) showed.

Record temperatures continue to boost air conditioning demand, driving daily coal use at utilities last week to 2.4 million metric tons, highest by far this year, according to data provider Wind and the CCTD.

China's peak summer power demand typically starts in late June and lasts for two months.

China's National Climate Centre forecast that most of the country could see temperatures 1 to 2 degrees Celsius (1.8 to 3.6 Fahrenheit) higher than normal this month and next, while precipitation could be 10% to 20% lower than average.

That suggests stronger power demand but possibly lower output from hydropower stations.

Hampering efforts to lift coal production, however, China's mining safety watchdog tightened inspections in late June, after deadly accidents were disclosed at an iron ore mine in Shanxi and at a coal mine in Liaoning provinces.

Chinese mines are known to be among the deadliest in the world and the country has carried out several rounds of mining safety checks since late February following an accident in Inner Mongolia that killed dozens of people.

The average operations rate at major coal mines in the hubs of Shanxi, Shaanxi and Inner Mongolia fell to 82% in June from 84% in May, data compiled by the CCTD showed.

But coal output is expected to increase further as some miners in Inner Mongolia could be allowed to restart this month after being shut down since March to improve mining safety.

Presidency outlines criteria to be used before revising decommissioning schedule

The Presidency has moved to outline the criteria that will be used before any decision is made to delay the decommissioning of certain coal-fired power stations, to take account of the prevailing supply deficit, and has also dismissed suggestions that there is any plan to extend the life of the stations.

Addressing the Presidential Planning Commission (PCC) recently, project management office head Rudi Dicks acknowledged that the decision to potentially revise the schedule had raised questions both domestically and with the International Partners Group that had agreed to provide $8.5-billion-worth of concessional funding to support South Africa's Just Energy Transition Investment Plan (JET-IP).

"In the context of our energy crisis, there is a conversation we are having about whether we can delay decommissioning, but that's very different from extending the life of power plants," Dicks said.

Cabinet, he added, had reaffirmed the country's commitment to the decarbonisation targets outlined in its Nationally Determined Contribution, as well as to the goal of transitioning towards net-zero.

"However, care will be taken to ensure that the manner in which these commitments are achieved does not compromise energy security or the immediate priority of reducing loadshedding."

He told PCC commissioners that any revision to the decommissioning would be informed by a comparison of the costs of refurbishing older coal-fired power stations with the cost of investing in replacement capacity, including renewables, batteries and gas.

In addition, Dicks said the following three assessments would be undertaken ahead of any revision, including:

- A technical assessment by a consortium of international experts appointed by the National Treasury into the feasibility and cost of refurbishing and/or repowering each power station;
- A modelling exercise to be undertaken by the National Energy Crisis Committee (Necom) of estimated future capacity from various other sources compared with existing capacity and projected demand growth; and
- A modelling exercise to be undertaken by the JET-IP Project Management Unit and/or the PCC of the impact of any delay on the country's decarbonisation trajectory.

He reported that these assessments should be completed by July and the outcome would be presented to Cabinet for approval. In addition, no decommissioning would take place until the technical assessments were completed.

Dicks said any possible revision could affect Camden, Grootvlei and Kriel, which were reportedly performing better than some of the younger stations in the Eskom fleet.

Particular reference was made to Camden, which is meant to be fully decommissioned over the coming two years, but which is operating at a 60% energy availability factor (EAF) – a level that the full fleet reached for the first time since September 2022 only on June 2 this year, despite a target having been set for such an EAF to be achieved by the end of March.

He promised that any revision would not be based on a "thumb suck" but by the evidence emerging form the assessment under way.

Dicks also reported that the JET-IP implementation plan framework would be published in July, following which focus groups would be assembled in July and August on electricity infrastructure, the just transition in the electricity sector and in Mpumalanga in particular, as well as on new energy vehicles, green hydrogen, skills and on municipalities.

"The JET-IP Implementation Plan will be finalised thereafter and recommended for approval by the JET-IP Inter-Ministerial Committee in October 2023," Dicks reported.

Mpumalanga Premier Refilwe Mtshweni-Tsipane said that, given the prospect of economic losses for coal-dependent communities, strategies were needed to ensure growth in other sectors such as agriculture, tourism, manufacturing and renewables.

"The constant refrain as I travel across the province, especially in the coal belt, is that the transition cannot be 'just' if they are left behind.

"[Many] in the province are concerned about the pace of the planned decommissioning and repurposing of our coal fired power plants," she said, highlighting that the province, which was home to 4.68-million people, already faced serious "developmental deficits" and an unemployment rate of 38.5%.

"Let us move on this in an informed and consultative manner, bringing along our communities and stakeholders," Mtshweni-Tsipane appealed.

South Africa's Power Crisis Will Continue Until 2025 – and Blackouts Will Take 5 Years to Phase Out

South Africa is in the middle of a severe electricity crisis, with enforced power cuts that have worsened every year. Electricity is sometimes unavailable for 10 hours a day. The shortfall is the consequence of frequent breakdowns at its ageing coal power plants, which constitute 74% of the country's generating capacity.

In theory, improving the performance and reliability of the existing coal plants would resolve the power crisis. This remedy is promoted in some quarters. But it's easier said than done. To function satisfactorily, many of the plants would require a complete overhaul, which would be both time consuming and prohibitively costly.

Estimates suggest that South Africa needs around 6,000MW of extra capacity to overcome the current deficit. The following sections explain why I predict it is likely to require as long as five years to eradicate this shortfall, though partial improvement should already be felt by the end of 2024.

Building new coal, nuclear or gas plants is still being considered to improve future power supply, but these typically require construction times of 10 years. They would therefore not play a role in the short- to medium-term period under consideration, and I don't discuss them further here.

Time lines for fixing existing power stations

The 4,800MW Kusile and its twin Medupi are the two largest power stations in South Africa, and among the biggest coal plants in the world. Their construction was commissioned in 2007. At the time they were expected to guarantee South Africa ample electricity supply and allow the decommissioning of older plants.

But the construction of the plants proceeded disastrously. Costs escalated to more than double the initial projections and construction was much slower than anticipated. One of Kusile's six units has still not been finished.

Calamity also struck twice in the first few years of operation. The damage caused by an explosion at Medupi's Unit 4 in 2021 resulted in so much damage that the unit not yet been brought back on line. Then in October last year a chimney at Kusile collapsed. This forced the closure of three Kusile units.

The 1,800MW Koeberg nuclear power plant has in recent decades contributed about 5% of South Africa's electricity. It will reach the end of its initially projected 40-year lifespan in 2024. To extend its operating licence for a further 20 years, the National Nuclear Regulator requires specific part replacements and upgrades, the most significant being the installation of new steam generators.

These operations were initially projected to require 10 months (five months for each of Koeberg's two units) to be completed. The attempted upgrade of the first unit early last year was aborted after it became clear that preparations for the project were incomplete.

The second attempt began in January this year. But it has already been acknowledged that this stage, initially projected to end in June, will not be completed until at least August. After that a similar process will commence for the other unit, and this will be followed by a 200 day planned outage.

Koeberg is therefore effectively only running at half-power, and this state of affairs will likely continue into 2025.

Gas power ships

Amid clear signs of a deepening power crisis, the minister of mineral resources and energy in 2021 announced successful bids to supply 2,000MW of emergency power. The bulk of this award, 1,200MW, was allocated to Turkey's Karpowership, a company with a fleet of floating gas plants to be shipped in and moored in three of South Africa's ports – Richards Bay, Nqurha and Saldanha.

The award attracted controversy, with accusations that the terms of reference of this bidding round amounted to an unfair advantage to Karpowership. Court challenges queried the legality of the environmental impact approvals too.

The key objection to the Karpowership deal is that it would cement what is painted as an arrangement for temporary emergency power for a 20-year period.

This opposition and delays in some other projects reaching financial close mean that the emergency programme is at least a year behind schedule. Some might come on line at the end of 2023, but the added capacity would decrease South Africa's electricity shortfall by only a moderate amount.

Renewables

The Renewable Energy Independent Power Producer Procurement Programme was designed to enable the production of mostly solar and wind energy by private developers, who would then sell it to the power utility, Eskom.

Given the intermittency of sunshine and wind, solar and wind farms in South Africa on average typically only produce about 25% (solar) and 35% (wind) of what they can generate under ideal conditions. Meeting a national shortfall of 6,000MW with one of these technologies alone would therefore require solar farms with a total capacity of 24,000MW, or wind farms with a total capacity of 18,000MW.

Two rounds of

establishing new plants under the renewables programme are under way. The first of these should see 1,000MW of solar power and 1,600MW of wind power come on stream by early 2025, while the second round will see a further 1,000MW of solar projects completed about a year later.

A mega-initiative to install 15,000MW of solar and wind power has recently been touted by the new electricity minister. While this would massively ameliorate the power scarcity, it would be very challenging to construct such a large number of solar plants simultaneously, due to potential import bottlenecks and a shortage of skilled installers. So while some of these plants might be ready by late 2025, the entire programme is likely to require five years.

Domestic and private solar installations

The greatest progress in accelerating electricity production has been achieved by small-scale solar power installation initiatives, ranging from municipal or private enterprise solar farms to solar panels on household roofs. Although this component is still comparatively small, late last year the president announced that projects amounting to a total of 9,000MW were under development.

Despite the major growth in this sphere, the rollout of private solar installations is hampered by the same constraints faced by the renewables programmes: import bottlenecks and skills shortages. While municipalities and smaller entities able to get such programmes working will experience considerable relief from power cuts, these initiatives will only moderately cut the national shortfall.

The timeframe for a possible recovery

Any remedies to the South African power crisis initiated now or already under development are not going to have a significant impact this year. The projections also assume that no major setback like last year's Kusile accident is imminent.

1,000-2,000MW might be added to the generating capacity towards the end of the year, but a substantial decrease in the power shortage will only be possible towards the end of 2024, if Kusile repairs are then completed as expected, and when several renewable energy initiatives should come on line.

Ending power cuts completely will probably take another five years if the infusion of more solar and wind capacity proceeds as currently planned.

Epiroc and SSAB explore fossil-free steel

Epiroc and SSAB has expanded its previously established collaboration by exploring possibilities to use fossil-free steel when manufacturing spare parts and components with additive technology.

In late April, Epiroc extended its partnership with SSAB through a delivery agreement, which focuses on SSAB Zero, SSAB's fossil carbon emission-free recycled steel produced using sustainable energy sources, being utilised in Epiroc's battery-electric range of underground mine trucks and loaders.

Now, both companies will partner to explore ways in which fossil-free steel can be used when manufacturing spare parts and components with additive technology.

The initial step in this process has been to create a prototype of a hydraulic block for a mining rock drill using additive technology with conventional steel powder. The traditional manufacturing with milling and drilling requires this type of part to be plugged and sealed after production.

When using additive manufacturing, six potential points of leakage can be eliminated. Another benefit is the possibility to improve the flow of the hydraulic oil since sharp edges can be avoided when the channels are printed in the part.

While traditional manufacturing uses a block of steel weighing approximately 50 kilograms (kg), the optimised design for additive manufacturing uses 7.5kg of steel for producing this part.

"This reduces the amount of material needed for production with 85% in this case, which leads to more efficient use of raw materials".

Epiroc said with the prototype successfully produced with additive manufacturing the next step in the process is to experiment with fossil-free steel powder.

Epiroc engineering manager Anders Flodman said that this opportunity creates a lot of potential.

"Production and shipping of spare parts are interesting areas for us to explore going forward. There is a lot of potential in many ways, we can decrease lead times, increase availability, cut-cost on transportation and most important of all, reduce our environmental footprint", Flodman said.

The prototype has been produced in SSAB's newly opened facility for steel powder at the production plant in Oxelösund, Sweden.

Pennsylvania's largest plant is shutting down

The 1,888-megawatt (MW) plant, located around 50 miles east of Pittsburgh, was built near coal reserves and included what was then a high-capacity (345-kilovolt) transmission line to service areas in western New York and Eastern Pennsylvania.

It began to generate electricity in 1969 when Units 1 and 2 entered service. Unit 3 was added in 1977. For 30 years, the plant operated almost continuously, achieving a utilization rate, called a capacity factor, near 90%, according to the US Energy Information Administration (EIA).

The Homer City coal plant sold for $1.8 billion in 1991 when Pennsylvania was deregulating its electricity market. At the time, coal-fired generation accounted for about 53% of the US's power supply, and natural gas only accounted for around 12%. But now, natural gas is now the source of 40% of the electricity in the US, and coal has dropped to 20%.

As Homer City became less competitive economically and was dispatched for load following – that is, it adjusted its power output as demand for electricity fluctuated – rather than for baseload power, the plant generated less electricity, and its capacity factor dropped. (Baseload power plants can generate dependable power to consistently meet demand.)

The Homer City plant operated at an annual capacity factor of 82% in 2005. By 2022, the capacity factor had dropped to 20%, contributing to the decision to retire the plant, along with "the low price of natural gas, a dramatic spike in the cost of its ongoing coal supply, unseasonably warm winters, and increasingly stringent environmental regulations," according to William Wexler, CEO of Homer City Generation, in a written statement.All five of Pennsylvania's remaining coal plants are scheduled to either shut down or be converted to natural gas by 2028. The state is the US's second-largest natural gas producer after Texas.

Pennsylvania ranks near the bottom – 45th – among US states when it comes to generating renewable energy, and it's currently ranked 24th in the country for installed solar, according to the SEIA. Only 3% of total energy comes from wind, solar, and hydro in the Keystone State.

Government backlash

"Once they tried to conquer Poland, and today see that it is enough to control the elites, knowing that the elites somewhere in Warsaw serve foreign interests," Morawiecki said, referring to the international character of the organisations that filed the complaint and comparing their actions to the partition of Poland by Prussia, Austria and Russia in the late 18th century.

The ruling Law and Justice (PiS) party often cites alleged foreign interference as threatening Poland's independence. It refers to the opposition as the self-proclaimed elites that PiS deprived of influence when it came to power in 2015.

The government "will not agree to an illegal decision" by the court concerning suspending the mine's operation, the prime minister wrote on Facebook.

"We cannot implement it, and we will do everything for it to be repealed," he added.

According to Morawiecki, the adjacent Turów power plant produces 8% of Poland's energy, while the court's verdict means suspending the permit that allows Turów to mine lignite after 2026.

The ruling is unenforceable because it cannot be implemented without jeopardising Poland's energy security, Polish EU Minister Szymon Szynkowski vel Sęk told state broadcaster TVP Info, adding that implementing the judgement would "cause extraordinary social and economic harm."

The Turów complex helps ensure energy security for Poland and the region for the coming years, tweeted Climate Minister Anna Moskwa. The Polish government will not allow mining to be stopped and thousands of jobs to be lost for the region's people, she insisted.

Prague welcomes the ruling

"The decision of the Polish court shows that the lawsuits against mining in Turów have a justified basis and do not stand on water," commented Petra Kalenská, the lawyer at Frank Bold, who is dealing with the Turów case.

According to her, the report submitted by the Polish miner, PGE, suffers from serious flaws. Among other things, it does not consider the impact on Czech groundwater or the landslides in Zittau.

"It is essential that the mining impact report describes the true extent of the damage caused by mining and includes measures to prevent such damage. Without this, mining cannot continue," Kalenská said.

MEP Mikuláš Peksa from the Czech Pirate Party, which belongs to the ruling coalition in Czechia, believes the verdict is even more worth noting, given the doubts over the judicial independence in Poland.

"I was delighted that despite the tragic state of the PiS-glossed Polish judiciary, the Warsaw judge dared to say something so contrary to the interests of the state-owned PGE and, on the contrary, effectively confirming the complaints of the Czech citizens who live in the Turów area," he tweeted.

"It is only a pity that the government too often gives in to PiS' demands without resistance."

Polish government outlines offer to buy coal assets from state energy firms

Poland's government has outlined details of the billions of zloty it is proposing to pay state energy firms to buy their coal assets. The move is part of a process to create a new separate entity to gradually wind down the use of coal and allow other energy firms to focus on developing lower-emission sources.

The four firms – PGE, Tauron, Energa and Enea – received a proposal from the state assets ministry on behalf of the state treasury. It outlined purchase prices and debt settlement mechanisms that will now be negotiated further.

Enea would receive almost 2.5 billion zloty (€560 million) for its shares in Enea Wytwarzanie – Poland's largest producer of electricity from hard coal – and 632 million zloty for Enea Elektrownia Połaniec, a coal power plant. The state treasury will also provide guarantees covering up to 70% of 2.4 billion zloty in debts owed to Enea by the subsidiaries.

A similar purchase amounting to 849 million has been proposed to PGE, 153 million to Energa and a symbolic 1 zloty to Tauron. PGE and Tauron have also been offered deals relating to debt owed by their subsidiaries.

The state assets ministry notes that the offer made is part of the "final phase" in setting up an entity called the National Energy Security Agency (NABE), which was approved by the government last year.

NABE is being created to take control of state energy firms' coal assets, which in turn is supposed to help those firms more easily obtain financing for investment in cleaner forms of energy.

Poland still produces around 70% of its electricity from coal, by far the highest proportion in the European Union. While the government still sees coal remaining the main source of energy for some time, it has taken steps to transition towards renewables and nuclear, which together will generate three quarters of power by 2040.

"NABE will guarantee energy security in the transformation process," wrote the ministry on Saturday. It noted that, as a result of EU climate policies, "financial institutions have been limiting their involvement in financing entities with coal assets".

Wojciech Dąbrowski, the CEO of PGE, said that he welcomed the ministry's proposal, which would help his firm with "obtaining financing for investments in line with the strategic direction that we – as a leader of the energy transformation in Poland – have set for ourselves".

Shares in the four state energy firms subject to the proposal rose this morning – 30% for Enea, 24.7% for Tauron, 20% for PGE and 4% for Energa – notes financial news service Bankier.pl

Under plans being developed by the government and state energy firms, Poland's first nuclear power plant is due to open by 2033, with two more to subsequently follow.

A number of state and private firms are also developing plans to launch so-called small modular reactors (SMRs) to produce nuclear energy.

Recent years have seen a rapid expansion in renewables, especially solar, in Poland. The government and state energy firms are also planning to develop both offshore and onshore wind in the coming years.

Mahanadi Coalfields to provide VR-based safety & operational training to 17,000 workforce

State-owned Mahanadi Coalfields Ltd (MCL) has introduced a virtual reality-based programme to provide safety and operational training to its 17,000-strong workforce, an official statement said recently. The company has earmarked a budget of Rs 6.5 crore for skill enhancement among coal miners, the Coal Ministry said in a statement. "Mahanadi Coalfields Limited (MCL) has introduced a Virtual Reality (VR)-based skill development programme for providing safety and operational training to its 17,000 workforce by 2026. It has earmarked a budget of Rs 6.5 crore for skill enhancement among coal miners," it said

Introduction of VR-based training for around 17,000 departmental as well as contract employees will serve as a major initiative for 18 training modules leveraging this modern technology. Om Prakash Singh, Chairman-cum-Managing Director of MCL stated that regular training and upgradation of skills is required by leveraging cutting-edge technologies to match the advancements and introduction of new technology in the mining sector.

Coal's Dying Light

Coal communities across the country are struggling to adapt as the nation transitions away from the dirtiest fossil fuel. Now, a historic amount of federal funding is available to help diversify their economies and aid in the transition to a low carbon future as long as the money can get in local hands.

Like many towns across Appalachia, coal left Jenkins behind a long time ago.

Mayor Todd DePriest calls it "the city built on coal." Mines literally ran underneath and all around it, but the last coal company to mine nearby closed in 1988.

"Coal's still on everybody's mind," he said. "I guess people let go a little different than others."

The coal taxes that once helped fund city services have dwindled. The population is a fraction of what it was. Then, last July, historic flooding destroyed about 100 homes in the community and killed dozens of people across the region. A year later, DePriest is still working to get residents back in their homes.

"I have to brag on the people of Jenkins. They've had real patience," he said. "I know that is going to run out, and I'm hoping they see some real progress with what we've been working on."

Nearly 15 million Americans live in communities impacted by coal mine and power plant closures, according to an LPM News analysis. Nearly three-quarters of them make less than the national median household income.

The largest concentration of closures runs through the Appalachian Mountains spanning from Alabama to Pennsylvania. Central Appalachia, including parts of West Virginia, Kentucky, Virginia and Ohio, is among the hardest hit.

Coal production peaked in the U.S. in 2008, but many of the Appalachian communities that are dependent on the coal industry have been in decline for decades, and are in search of a new economic future.

"This problem is really big," said Rachael Young, who works for the Just Transition Fund, a non-profit promoting equitable, low-carbon solutions for coal communities. "Most of these are rural communities that have existing economic distress that the closure of these coal plants exacerbates and contributes to."

These energy communities across the U.S. are on the losing end of a decades-long transition away from coal, but a historic amount of federal funding is now available to help revitalize them. Federal legislation passed during the Biden Administration includes more than $900 billion to help U.S. energy communities like Jenkins.

"The level of federal investment is just, truly historic, and the window will close," Young said. "And it's really important to take full advantage of the opportunity to make sure that it gets to the people and places that really need it the most."

The money is there. How do communities like Jenkins get a piece of it?

Connecting the federal to the local

Between the Bipartisan Infrastructure Law and the Inflation Reduction Act, federal agencies set aside more than $900 billion to transform energy communities like those in Appalachia, according to the Interagency Working Group on Coal and Power Plant Communities and Economic Revitalization.

"If we have a mine or any coal infrastructure or a power plant that has closed its doors, there's billions of dollars there for investments in those facilities, again creating jobs where they have historically been," said Working Group Executive Director Brian Anderson.

The infrastructure deal includes funding to help rebuild the country's roads and bridges, improve air and seaports, expand access to high speed internet and clean drinking water. The Inflation Reduction Act represents the largest congressional action ever taken to address the climate crisis. It includes funding to expand renewable energy and clean up sites once used for fossil fuel extraction.

There are hundreds of competitive grants and loans, clean energy and manufacturing tax credits, and state and tribal funding opportunities. There's more than $35 million to help farmers and small businesses buy solar systems and make energy efficiency improvements; Tens of millions of dollars in ongoing funding to clean up abandoned mine lands; a direct loan program to assist people in poverty purchase housing in rural areas; and funding for small towns to improve their drinking water and sewage systems.

Anderson, who was born and raised in West Virginia, said his own grandfather was displaced by changing economic conditions when the coal mines shifted toward mechanization decades ago.

"We want to make sure that the communities where jobs might be displaced have the opportunity to see those investments and participate actively in the manufacturing sector that will underpin the coming energy transition," he said. "It comes down to not leaving these communities behind."

Anderson and other federal experts say the key to success for these communities depends on economic diversification. There's no silver bullet, but by providing a number of pathways for communities to make their own decisions, the economies in these regions can transform, he said.

Mayor Todd DePriest sits for a portrait in his office at Jenkins City Hall on June 30, 2023 in Jenkins, Kentucky.

For eastern Kentucky, Anderson thinks that will involve the expansion of rural broadband, spurring investment in the region's industrial parks, participating in the supply chains of the large manufacturers headed to the region, redeveloping retired power plants, developing renewable energy like wind and solar, promoting tourism and cleaning up the environmental pollution left behind at abandoned mines, and oil and gas sites across the region.

"It's about time that we start investing in those communities that have really driven our economy for the last century," Anderson said.

Getting the first grant

The federal funding itself is the first half of an uphill battle that now relies on coal communities learning about and accessing the funding needed for improvements. Hiring a grant writer costs money that many city governments don't have, and some of the application processes can be involved.

The Appalachian Regional Commission is among the nonprofits stepping in to act as liaisons between the federal government and local communities. The commission offers its own grants, as well as training and technical assistance to local governments, nonprofits and development districts.

"In most cases it's getting that first grant," said Gayle Manchin, federal co-chair for the Appalachian Regional Commission who's married to Sen. Joe Manchin of West Virginia. "Once you get the first grant then you kind of feel like you know what you are doing."

In May, federal officials held a community forum designed to help rural communities find the resources they need to create jobs, build infrastructure and support long-term economic prosperity in the region using available federal funding.

It was kind of like speed dating for government funding. People took their ideas to representatives from all these different agencies looking for a good match. Rather than drink from the firehouse of grants.gov, they offered personalized advice to people on how to best match ideas and funding.

The Rural Partners Network, the U.S. Department of Agriculture, the Department of Energy, Veterans Affairs, the Environmental Protection Agency, Federal Emergency Management Agency, Economic Development Administration and the Energy Communities Interagency Working Group were among the organizations present.

Local community leaders talked about their successes revitalizing their communities using low-interest loans and grants. Redevelopment agencies pitched their ideas to federal liaisons and a bipartisan group of state leaders – including Democratic Gov. Andy Beshear's senior advisor Rocky Adkins – came to show their support.

"I'm here as somebody that was impacted by the downturn of the coal economy," Adkins said. "We're not asking for a handout. We're asking for what we've earned and deserved. Eastern Kentucky helped rebuild America, it's America's time to help rebuild eastern Kentucky."

The road to Pine Mountain State Resort Park in May 2023.

Republican state Sen. Johnnie Turner of Harlan also attended the session in May. He told LPM News he blames the Biden Administration's environmental policies for the decline of coal in the region. Nonetheless, Turner said he was glad to see federal liaisons meeting with community leaders and funding revitalization efforts.

"I mean, it's blessed to happen here and to put everybody on the same page to start working towards helping," Turner said.

Funding for Jenkins

When the city of Jenkins flooded last year, so did City Hall. They mucked and gutted it in two days and walked around on dusty, concrete floors for a while.

"I wasn't in no hurry to put it back, because most people were still in their homes trying to deal with it. I figured it wasn't going to hurt us," he said.

There's a giant foam core check made out to the city on behalf of the state government leaning against a pile of boxes in the corner. His desk is tidy, but piled high with paperwork.

"We're fortunate, in a way, that all of our buildings downtown have businesses in them," he said. "But that's also not good because when someone wants to open up something new we don't really got no place for them."

DePriest said he's glad to see the federal government stepping in to help coal communities like his. Dealing with the government, trying to figure out the different pots of money, that's an art he works at every day.

In fact, he'd planned on going to the Pineville summit, but realized afterwards he was already booked with another grant opportunity; one from the U.S. Environmental Protection Agency to help downtowns improve recreational opportunities in rural areas.

DePriest doesn't believe there is one easy solution to help communities like his, but he said that the state and federal government has been a big help to his community in the wake of the floods, and the long standing economic downturn.

"I've got people that were engineers for the mines that I thought would be dead against solar, but you know, they're willing to talk about it now," DePriest said.

DePriest said conversations about climate change are above his pay grade. He is, however, preparing for more intense rainfall and keeping his ears open as to how government funding can help.

"There's not going to be one thing that saves us," DePriest said. "It's going to take us to save us. Nobody's going to come down and do it for us."

Strategies to reduce emissions from fossil fuel operations

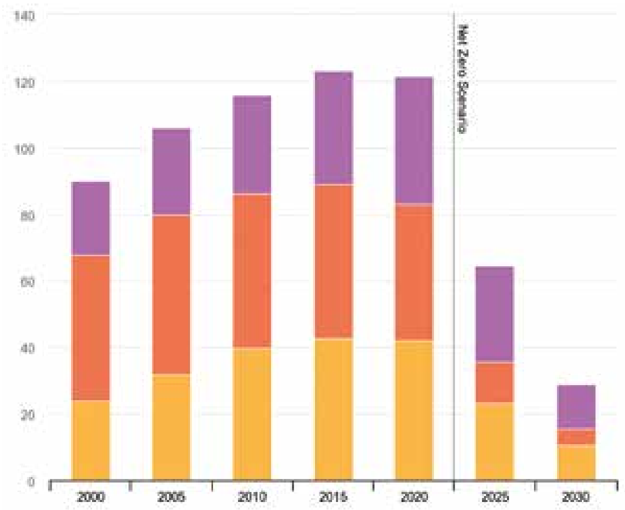
Methane emissions from fossil fuel operations are a significant contributor to human-caused methane emissions, and addressing these emissions presents a valuable opportunity for near-term climate action. Methane is a potent greenhouse gas, with a much higher warming potential than carbon dioxide over a shorter time frame.

Fossil fuel operations account for more than one-third of human-caused methane emissions. These emissions represent one of the best near-term opportunities for climate action because the pathways for reducing them are known and understood. Achieving a 75% reduction in emissions from fossil fuel operations, as set out in the IEA's Net Zero Emissions by 2050 Scenario would take the world most of the way towards fulfilling the Global Methane Pledge.

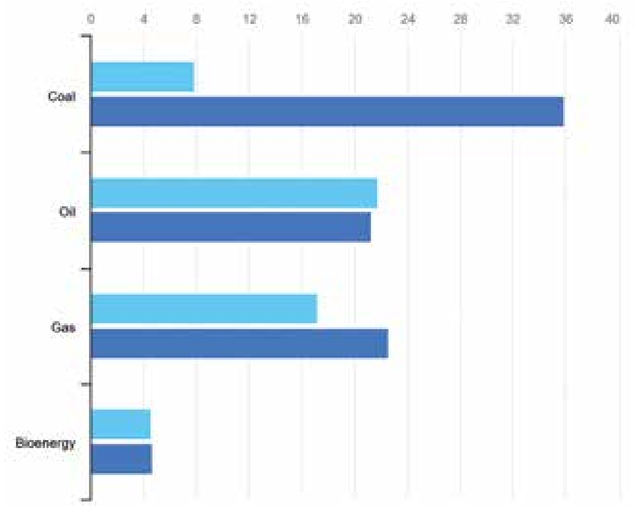
A BROAD COALITION IS NEEDED TO PUT METHANE EMISSIONS FROM FOSSIL FUEL OPERATIONS ON A PATH TOWARDS NET-ZERO

Countries that have joined the Global Methane Pledge currently account for over 45% of total human-caused methane and for about one third of methane from fossil fuel operations. Even if these countries take every available step to reduce emissions within their borders, it would still not deliver a 30% reduction in global emissions by 2030. Forward-leaning countries need to capitalise on the momentum created by the Global Methane Pledge to bring new members to the coalition.

Methane emissions from fossil fuels, historical and in the Net Zero Scenario, 2020-2030.



Methane emissions from energy from Global Methane Pledge participants and non-participants, 2021.

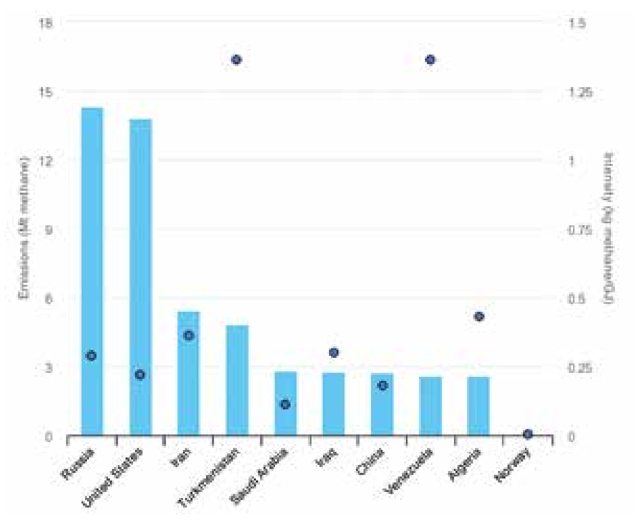


EMISSIONS CAN BE GREATLY REDUCED USING PROVEN TECHNOLOGIES AND POLICIES

The methane emissions intensity of oil and gas operations varies greatly across countries, with the best performing countries having an emission intensity over 100 times lower than the worst performers. High emission intensities from oil and gas operations are not inevitable; they are an "above-ground issue" that can be addressed cost-effectively through a well-established combination of high operational standards, firm policy action and technology deployment.

OVER 40% OF OIL AND GAS EMISSIONS COULD BE REDUCED AT NO NET COST USING WELL-KNOWN EXISTING TECHNOLOGIES

The technologies and measures to prevent methane emissions from oil and gas operations include leak detection and repair campaigns, installing emissions control devices, and replacing components and devices that emit methane in their normal operations.

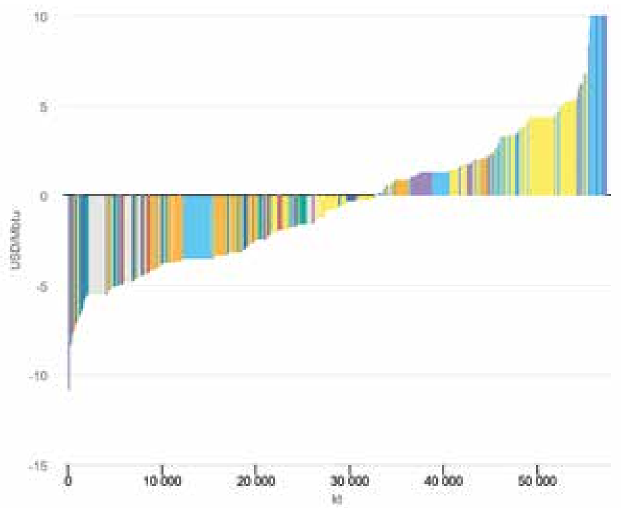


The cost effectiveness of abatement measures vary by country, depending on the prevailing emissions sources, capital and labour costs, and natural gas prices. We estimate that it is technically possible to avoid over 70% of today's methane emissions from global oil and gas operations. Based on average natural gas prices over the past five years, over 40% of methane emissions from oil and gas operations could be avoided at no net cost as the outlays for the abatement measures are less than the market value of the additional gas that is captured. Based on the elevated natural gas prices seen in 2021, almost all of the options to reduce emissions from oil and gas operations worldwide could be implemented at no net cost.

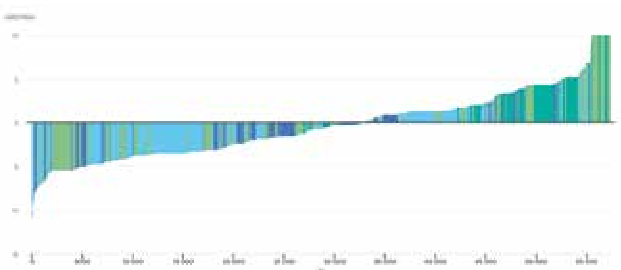
UNIVERSALLY ADOPTING TRIED-AND-TESTED POLICIES WOULD CUT WORLDWIDE EMISSIONS FROM OIL AND GAS OPERATIONS IN HALF

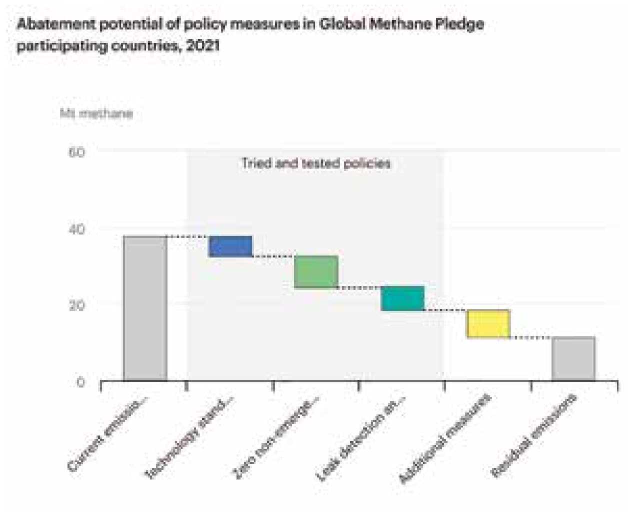
As outlined in Curtailing Methane Emissions from Fossil Fuel Operations, a range of well-established policy and regulatory tools exist to help countries create the right incentives. These "tried and tested" policies include leak detection and repair requirements, equipment mandates and measures designed to limit non-emergency flaring

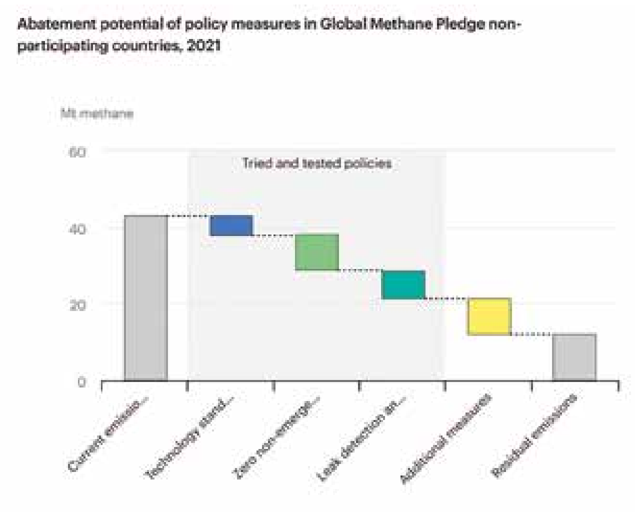
Marginal abatement cost curve for oil and gas-related methane emissions by mitigation measure, 2021.



Marginal abatement cost curve for oil and gas-related methane emissions by policy option, 2021.







and venting. Adopting these policies globally would reduce emissions from oil and gas emissions by half.

There are additional available policies available that would result in the full adoption of all technically feasible abatement options and lead to a 70% reduction in methane emissions from oil and gas operations. These include emissions pricing, financing instruments, and performance standards that would need to be supported by robust measurement-based monitoring regimes.

Several countries have adopted elements of these tried and tested policies, but no country has adopted all of them. Even early movers on methane regulation need to redouble their efforts to reach their full abatement potential. In parallel, these countries can support others by providing technical assistance and support, especially for countries that may be considering methane emissions for the first time.

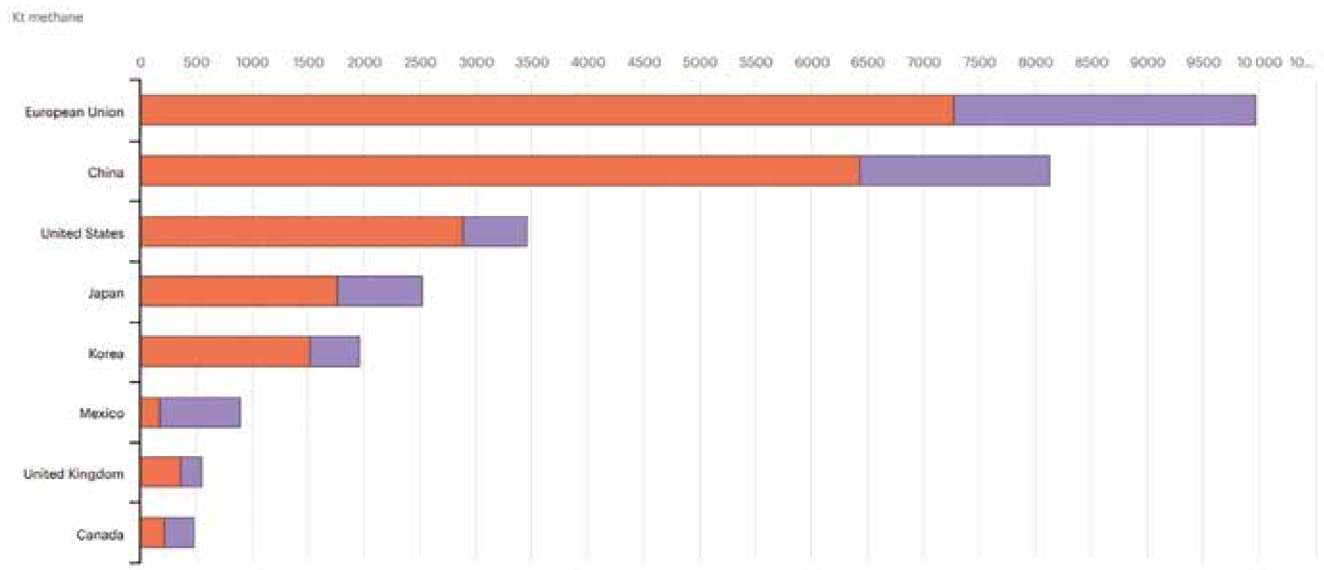
The IEA's Policies Database brings together more than 350 examples of policies that can directly or indirectly support methane abatement. Building on these examples, the IEA has prepared a detailed "how-to" guide for policy makers looking to develop new methane policies and regulations. This Regulatory Roadmap and Toolkit collects the experience of regulators around the world and can serve as a blueprint to support further technical assistance and capacity building efforts.

INCENTIVES, DIPLOMATIC ENCOURAGEMENT AND INSTITUTIONAL SUPPORT COULD LEAD TO MAJOR REDUCTIONS FROM INTERNATIONALLY TRADED OIL AND GAS

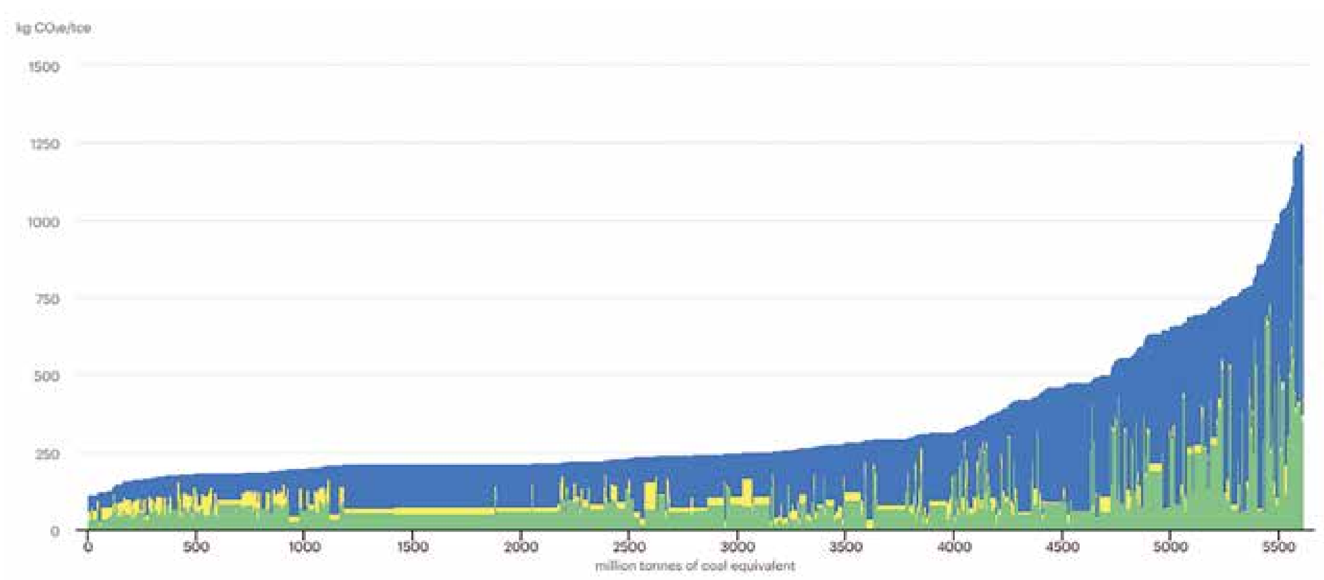
Much fossil fuel production takes place in countries that have not joined the Global Methane Pledge, yet around 40% of their oil and gas production is exported to countries that joined the Pledge.

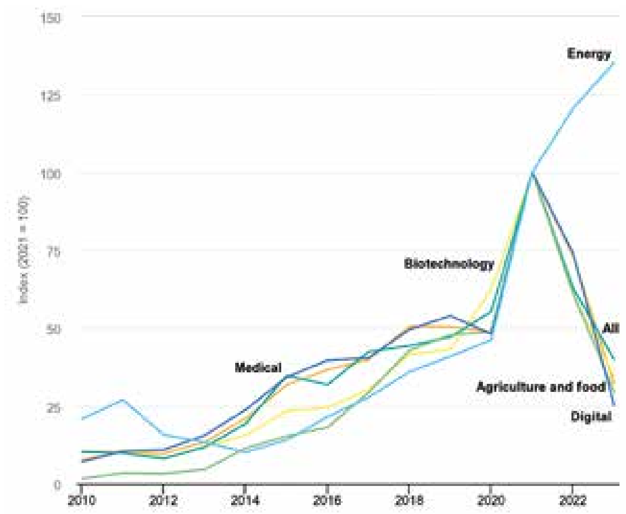
These importers can encourage reductions from their trading partners through a mix of actions, including diplomatic pressure, incentives, technical and institutional support, and trade measures. Examples include financing instruments, emissions certificates, price premiums for lower intensity gas, minimum intensity standards and border adjustment mechanisms. Efforts are more likely to be effective if paired with technical and institutional support to enhance regulatory capacity and mitigate distributional impacts. If countries with strong methane commitments enrol their trading partners, this could reduce global emissions from oil and gas operations by more than 10 Mt, boosting the reductions that could be achieved through domestic action alone by around 50%.

Methane emissions of imported oil and gas in selected countries and regions, 2020.



Indirect CO2 and methane emissions from global coal supply, 2021.



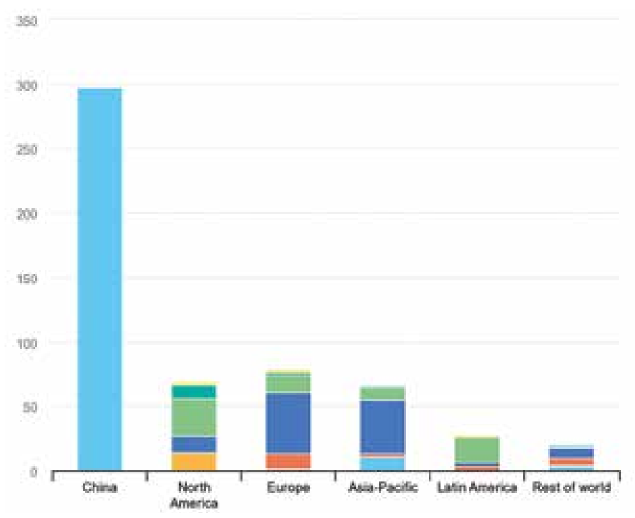


EARLY WARNING SYSTEMS TO PINPOINT LEAKS COULD FACILITATE TIMELY ACTION AND LARGE REDUCTIONS IN EMISSIONS

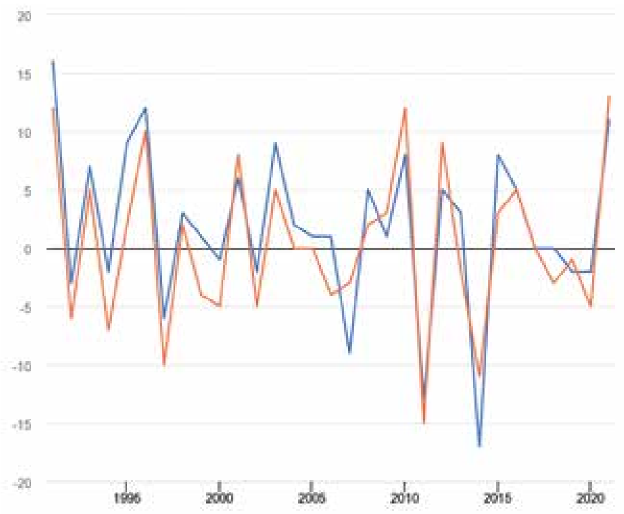
Efforts to improve transparency in emissions data could be particularly effective at bringing in new partners while simultaneously improving our understanding of emissions. The European Union has committed to several efforts to improve the transparency of emissions data, including funding the International Methane Emissions Observatory, actively supporting the Oil and Gas Methane Partnership 2.0, and proposing to collect and make public information collected from operators and importers under its recently proposed methane regulations. These measures may encourage the uptake of measurement and reporting standards and help companies and countries identify abatement opportunities.

Satellite technology in particular has the potential to drive significant reductions. Existing satellites and processing technologies can already detect and quantify large leaks over a wide geographic area. Governments and companies should explore establishing transparent systems to efficiently alert regulators, operators and other stakeholders to large leaks as soon as they are detected. This would require creating a network of contacts to allow rapid communication of leaks to those on the ground best able to address them. Based on current instruments and capabilities, we estimate that such a system could already avoid close to 3 Mt of methane emissions associated with large emissions events each year. Private companies and industry groups may also look to establish similar dedicated networks of monitoring devices covering their facilities to rapidly accelerate their responses to leaks.

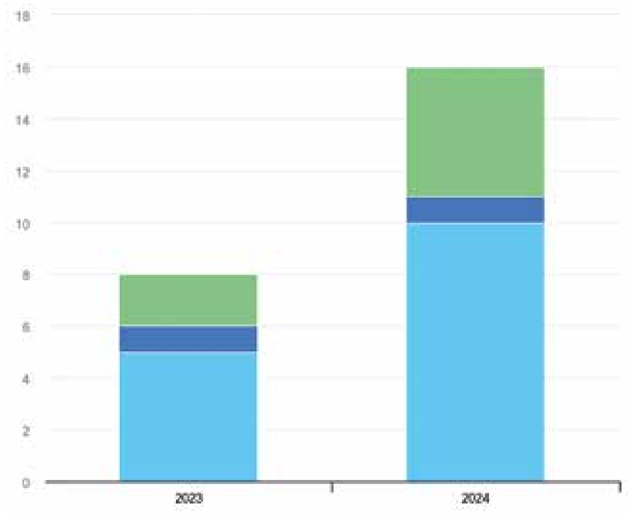
Solar PV and wind forecast by primary procurement type, 2023-2024

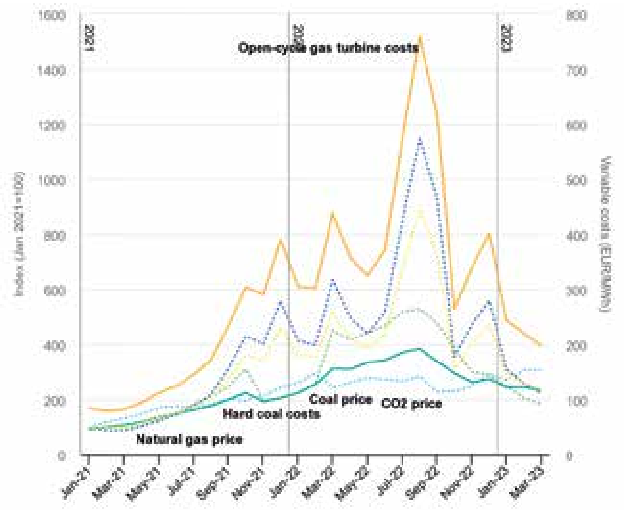


Correlations between annual heating degree days and final direct consumption of natural gas in buildings in the European Union, 1991-2020.



Natural gas consumption displaced by projected additional renewable energy supply in the European Union in 2023 and cumulative in 2024.





VOLUNTARY INITIATIVES CAN PLAY A KEY ROLE IN ENSURING TIMELY REDUCTIONS

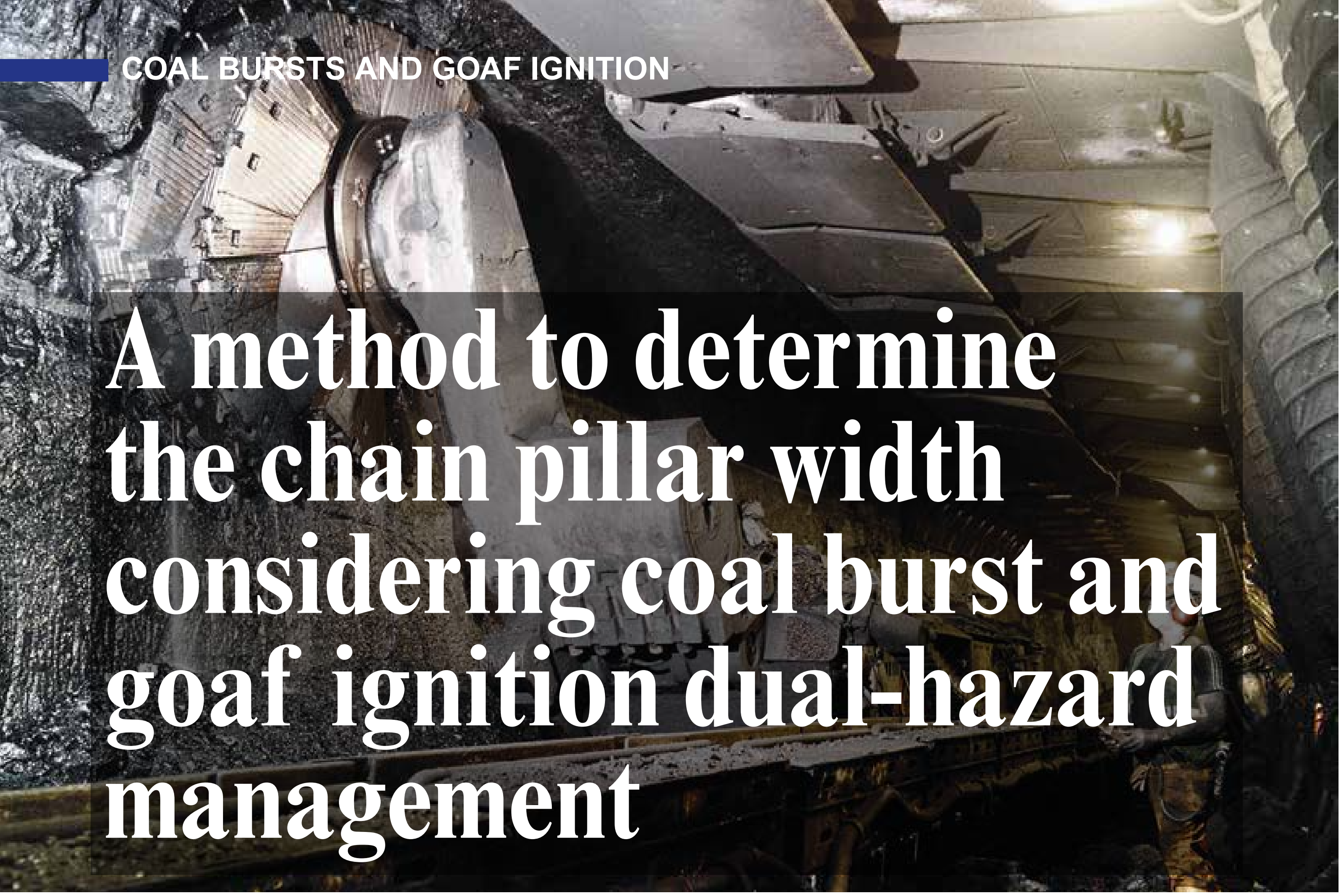
Along with actions by governments, the industry and investment community have important roles to play in driving rapid cuts and furthering abatement efforts. Companies can often move more quickly than governments, particularly where regulatory capacity is limited; companies are also closer to the problem at hand and have the required technical capabilities to manage methane emissions. Investors and financiers can play an important role by sending clear signals that good performers will be rewarded, as well as working with companies to set targets and hold them to account.

A number of oil and gas companies have already set targets to limit emissions, or reduce their emissions intensity. There are many voluntary, industry-led initiatives including the Methane Guiding Principles, the Oil and Gas Climate Initiative, the Oil and Gas Methane Partnership 2.0 and the China Oil and Gas Methane Alliance. Through these initiatives, companies have committed to reduce their emissions intensity over time, advocate for sound methane policy and regulation and to be more transparent about their emissions. While these initiatives are a promising step, they have so far not delivered demonstrable reductions on a wide scale. In order to drive the level of reductions needed, companies should adopt a zero tolerance approach to methane leaks from their facilities.

AVOIDING METHANE EMISSIONS FROM COAL IS CHALLENGING BUT MITIGATION OPTIONS EXIST

Tackling methane from coal operations is more challenging than for oil and gas operations. Reductions in consumption can play a major role in bringing down methane emissions but there are also significant opportunities to reduce emissions in the near term based on existing technologies. In the IEA's Net Zero Emissions by 2050 Scenario, coal use drops by 55% from 2020 to 2030, and by almost 90% by 2050. This decline would significantly cut methane emissions from coal mines as well as emissions of CO2 and other air pollutants; emissions reductions would be even larger if concentrated on the worst-performing coal assets. For example, removing the worst-performing quartile of production would remove around 25 Mt of methane while removing the best performing quartile would only remove about 4 Mt.

While reducing coal use would go a long way towards reducing emissions, policies and measures are still needed in the meantime to address methane leaks from coal operations. These include requirements for operators to capture methane using degasification wells and drainage boreholes prior to the start of production. For mines already in operation, ventilation air methane is often already captured. This can be used as an energy source, for example to heat mine facilities or for coal drying. These technologies have already been implemented in numerous sites, but are still far from being standard industry practice. Policies and regulatory regimes are needed to broaden their use, either by creating proper incentives or by directly mandating that mine operators adopt these technologies.



A method to determine the chain pillar width considering coal burst and goaf ignition dual-hazard management

High rock stress and ground temperature pose great threats to the routine production of longwall top coal caving (LTCC) panels. In this risky condition, the width of the chain pillar is considered a factor adjustable for controlling coal burst and goaf ignition hazards. However, a contradiction, as suggested by longwall experience, is that narrowing the pillar helps coal burst prevention but negatively leads to higher self-ignition potentials, while widening the pillar restrains goaf ignition but increases the likelihood of coal burst. This paper conducted a case study on a longwall panel from Tangkou Mine, China. The paper first analysed stress, elastic strain energy, and goaf temperature variation with varying pillar widths, by which the coal burst risk index δr and goaf ignition risk index Qs were defined and correlated to pillar width D. Further, a pillar width determination method considering coal burst and goaf ignition dual-hazard management was developed by means of the operating point principle.

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Coal burst and goaf ignition are two frequent risks in underground coal mining, potentially threatening mine safety and routine production[1-4]. The potentials can be very high as the mine depth exceeds 1000m due to great rock stress and high ground temperature[5]. In this environment, compared to a fully mechanised mining method, the longwall top coal caving (LTCC) method has greater coal burst and goaf ignition potentials, as LTCC leads to significant ground pressurisation due to the large mining height and leaves residual coals of about 15% of the total reserve in goaf voids. As indicated by LTCC experience, adjusting the chain pillar width can help control the coal burst and goaf ignition considering its effect on ground stress and goaf-to-goaf ventilation. However, determining the optimal width is rather challenging because of a contradiction that wide pillars accumulate more elastic strain energy and simultaneously result in coal recovery ratio decline[6-8], whereas narrow pillars are less capable of hindering air leakage via fractures into adjacent goafs and causing goaf ignition in the high ground temperature environment, as shown in **Figure 1**. Therefore, developing a method to determine the chain pillar width is of great significance for mine safety and production.

A mass of studies has been conducted to understand coal burst mechanisms and safety control[9-12]. For the contributing factors, Bukowska[13] and Dyke *et al.*[14] identified that the depth of cover, geological structures, coal measure rock mechanics, coal seam thickness, and basement thickness have varying influences on the coal burst behaviour. Mazaira and Konicek[15] and Pu *et al.*[16] proposed that, in addition to coal measure geology, coal burst is also correlated to panel configuration pattern, panel geometry, and mining methods. Kaiser and Cai[17] suggested the correlation between coal burst and ground support parameters, further developing an interactive ground support design tool taking account of coal burst management. Dou *et al.*[18] identified the impact of overburden structure variation on coal burst and discussed the mechanism from an energy variation perspective. Saharan and Mitri[19] found that destressing blasting can be an effective technology to decrease the coal burst potential, to which destressing drilling, hydraulic softening, backfilling, ground support reinforcement, and nonpillar mining have similar functionality. Huang *et al.*[20] tested the effectiveness of hydraulic fracturing in restraining coal burst hazards, of which the fundamentals involved coal and rock mass strength reduction. Konicek *et al.*[21] proposed that drillhole blasting can be applied to control coal burst hazards in deep mines. Besides geological factors, chain pillar failure is likely to induce coal burst[22]. From the energy accumulation and dissipation perspective, Vardar *et al.*[23] and Xue *et al.*[24] analysed pillar energy transfer due to structural failure, unraveling the mechanism of pillar failure inducing coal burst[23,24]. Wang et al. verified that an inappropriate pillar width can lead to severe mine seismicity and coal burst, based on which a pillar width design method was developed via numerical simulations[25]. These studies focused on the pillar width design considering coal burst management, ignoring the pillar width impact on goaf ignition.

Goaf ignition is another safety threat and has attracted extensive studies especially about the ignition inducements and control techniques[26-29]. Yuan and Smith[30] investigated the impact of the surface area of coals and reaction heat. Taraba *et al.*[31] analysed the impact of coal particle diameter on the oxidation heating zone and gas. Mu[32] identified the longwall retreat rate as a key factor contributing to residual coal ignition in previous panel goafs. Liu *et al.*[33] and Liu and Qin[34] proposed that increasing the retreat rate and decreasing residual coals and ventilation rate can help restrain the goaf ignition risk, further determining the minimum retreat rate for goaf ignition control according to the critical temperature of coal self-ignition. Currently, available technologies and materials for coal self-ignition control include grouting, fire retardant, gel materials, and inert gases[35,36]. Colaizzi[37] developed a porous foam cement material to prevent coal ignition. Qin *et al.*[38] developed a FA-based three-phase foam material to prevent and eliminate goaf ignition potentials. These technologies have proved effective in goaf ignition control but inevitably increase economic inputs and decrease production effciency. Therefore, determining the chain pillar width of LTCC panels with high coal burst and goaf ignition potentials should consider the width impact on pillar behaviour and residual coal ignition in adjacent goaf voids. This research can help control mine hazards without additional economic input. In this context, this paper selected an LTCC panel LW6304 from Tangkou Mine in Shandong Province, China, as a case, of which the negative factors include the great depth of cover and high tendency in coal burst and goaf ignition. The paper studied pillar pressurisation, pillar energy variation, and oxidation heating zone variation under different pillar width conditions. On this basis, a method to determine the optimal pillar width with considerations of coal burst and goaf ignition control was developed and further proved effective by a field trial in the mine.

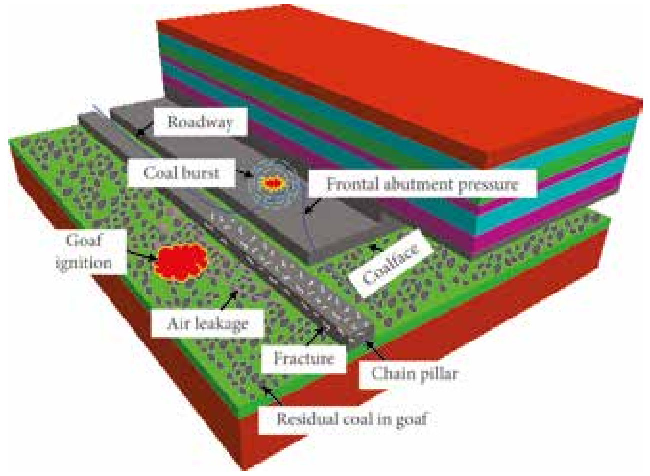

Figure 1: Coal burst and goaf ignition in LTCC system.

STUDY SITE

LW6304 is 960 to 985m deep, 980m on average, working a mining height of 10m and dip angle of 3°. In situ observation indicated that the coal has a high ignition tendency, with a self-ignition period of 21 days as the shortest. The average gas content of the coal seam is $2.54m^3/t$. The geological structure is simple, characterising a minor impact on longwall activities. **Table 1** lists the coal measure lithology and parameters. LW6304 adopted the LTCC mining method, 4m cutting height, and 85% recovery ratio. The panel was divided into two sections, incorporating a 610m long and 182m wide section in the inner position and a 1065m long and 60m wide section in the outer position. LW6304 adjoined LW6305 goaf within the 345 to 610m range from the LW6304 set-up position; the panel width of LW6305 was 55m. **Figure 2** exhibits the panel configuration.

The great depth of cover and large mining height resulted in significant frontal abutment pressurisation, coupled with significant dynamic loading due to the large space for rock block rotation. To prevent coal burst, the panel adopted goaf-side entry tunnelling to leave a 5m wide pillar. In this

COAL BURSTS AND GOAF IGNITION

Table 1: Coal measure lithology and parameters.

Lithology	Thickness (m)	Density (kg/m3)	Bulk modulus (GPa)	Shear modulus (GPa)	Angle of friction (°)	Cohesion (MPa)	Tensile strength (MPa)
Fine sandstone	4.0	2545	2.45	1.56	35	1.8	1.54
Medium sandstone	4.0	2840	3.02	1.84	34	2.5	2.34
Siltstone	4.0	2635	2.16	1.23	39	3.3	1.80
Mudstone	2.5	2450	1.25	1.66	37	2.1	1.60
Medium sandstone	5.0	2645	4.24	2.33	35	3.4	2.91
Mudstone	4.5	2643	0.96	0.3	30	1.5	0.87
Coal	10.0	1401	0.68	0.50	26	0.9	0.41
Siltstone	3.0	2650	2.38	1.42	40	2.4	2.02
Fine sandstone	10.0	2665	3.51	1.50	35	2.6	2.78

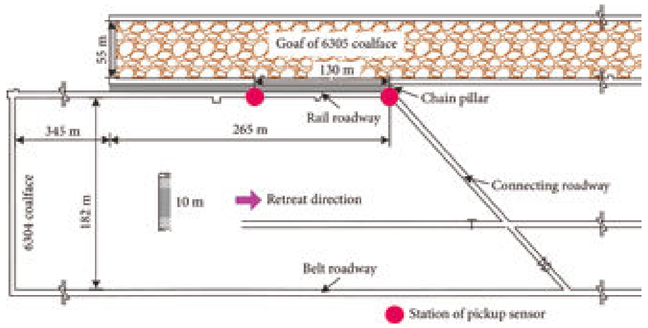

Figure 2: Panel layout.

narrow pillar condition, the panel experienced localised pillar failure, and the residual coals in LW6305 goaf tended to ignite, as indicated by (i) significant CO concentration increases, greater than 50ppm many times and sometimes up to 75ppm (parts per million), and (ii) frequent out-of-limit alarms of coal bed methane. Because of the problems, LW6304 production was sometimes suspended, during which coal ash solutions and nitrogen were injected into LW6305 goaf to prevent residual coal ignition. The risk itself and corresponding measures delayed the routine production, simultaneously increasing additional inputs.

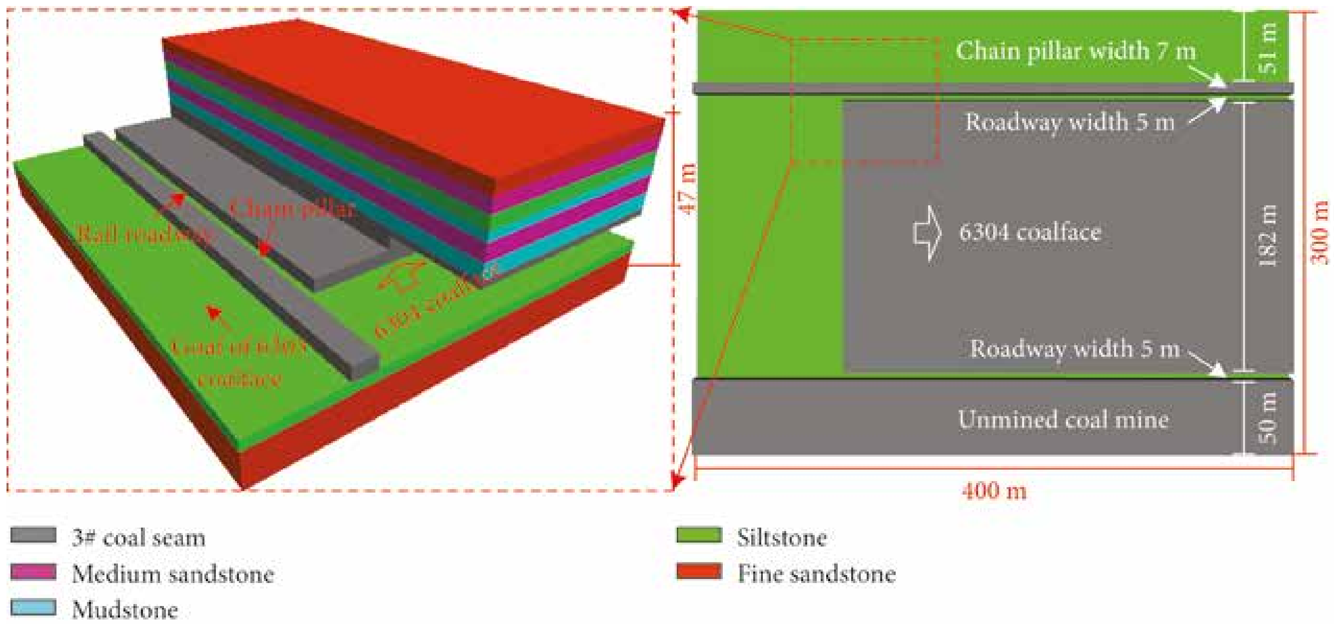

Figure 3: Model configuration.

CHAIN PILLAR IMPACT ON COAL BURST

Numerical simulation is frequently used to study geotechnical problems in underground mining, tunnelling, and slope stability[39]. FLAC3D (Fast Lagrangian Analysis of Continua in 3 Dimensions) software is a numerical modeling software for geotechnical analyses, which is widely used in the design and analysis of engineering in civil, mining, and geotechnical excavations, etc. In this paper, a continuum-based model using FLAC3D was established to simulate the maximum principal stress regime and elastic strain energy variation with varying pillar widths, thus assessing the impact of chain pillar width on coal burst behaviour.

Model Configuration.

The model adopted the parameters summarised in **Table 1** and 7m wide chain pillar, totally 400m long, 300m wide, and 47m high, as shown in **Figure 3**. LW6304 panel length was 182m, and the roadway width was 5m. The model adopted a fixed-displacement boundary for the bottom and roller boundary for the four lateral edges, applying 23.25 MPa stress vertically on the top to simulate the loading of unmodeled overlying strata. The rock behaviour obeyed the Mohr-Coulomb criterion and was calibrated using measured results (see[40-42] for model calibration procedures).

Pillar Stress and Energy Variation.

The coal body around LW6304 experienced stress redistribution and significant concentration in localised areas. The ground pressurisation led to elastic strain energy accumulation in the chain pillar and thus high potentials of coal burst, implying that the stress profile and energy variation can be critical indexes to quantify the coal burst tendency under different pillar width conditions. Therefore, in the model, the initial pillar width of 7m was changed to 3, 5, 9, and 11m to obtain the corresponding stress and energy responses.

Stress Profile.

Along the longwall retreat direction, vertical sections were extracted via the peak maximum principal stress point, as shown in **Figure 4**.

As can be seen from **Figure 4**, the maximum principal stress regime varies a lot from the 3m to 11m wide pillar conditions, featuring an increase trend with the pillar width. In narrow pillar (3 and 5m width) configurations, the peak maximum principal stress is smaller in the pillar than in the panel abutment (solid coal body) where stress concentrates. The chain pillar shows significant squeezing deformation. As the pillar width is greater than 7m, the stress concentrates towards the pillar, varying from 44.3 MPa in the 5m width condition to 76.1 MPa in the 11m width condition, as shown in **Figure 5**. Fitting the data obtained the correlation of pillar stress with width, $y = 100{:}54 - 112{:}02e^{-0{:}14x}$ ($R^2 = 0{:}98$), a negative exponential relation.

Elastic Strain Energy Variation.

The simulation obtained the elastic strain energy variation with varying pillar widths, as exhibited in **Figure 6**.

Figure 6 shows that the pillar strain energy has a rapid increase and decrease, ultimately levelling off with minor fluctuations, characterising an evident energy accumulation and release. The energy increase rate is related to the pillar width: the wider the pillar, the greater the increase rate and peak value. Taking the 3m width as a reference, the maximum elastic strain energy becomes 1.12, 1.17, 1.31, 1.42 times in 5, 7, 9, and 11m width conditions. Another phenomenon is that the times of pillar energy release increase with pillar width. In 9 and 11m width conditions, the maximum energy release is $1{:}31 \times 10^5$ J and $1{:}91 \times 10^5$ J, respectively. Narrowing the pillar width to 7m can reduce the energy release to be lower than 1×10^5 J.

Coal Burst Risk Assessment.

Based on the maximum principal stress profiles and elastic strain energy variation in varying pillar widths, the paper further assessed coal burst potentials and obtained a reasonable pillar width range considering coal burst management.

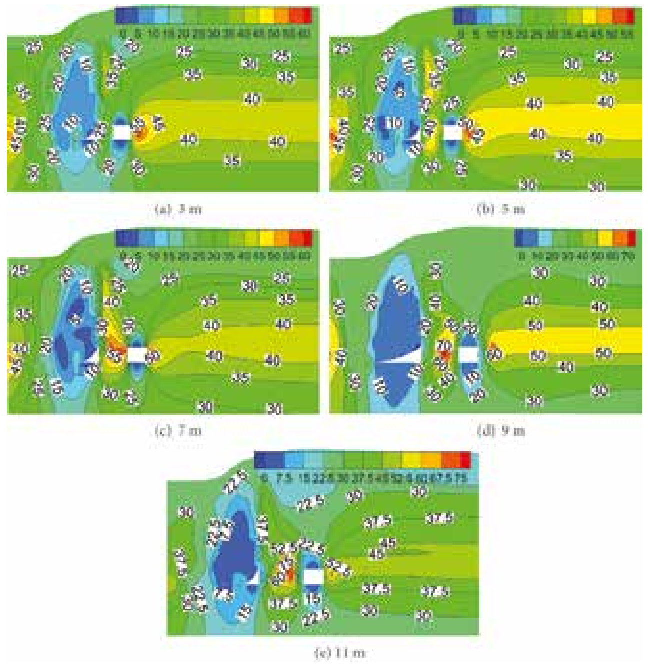

Figure 4: Maximum principal stress profiles with different pillar widths.

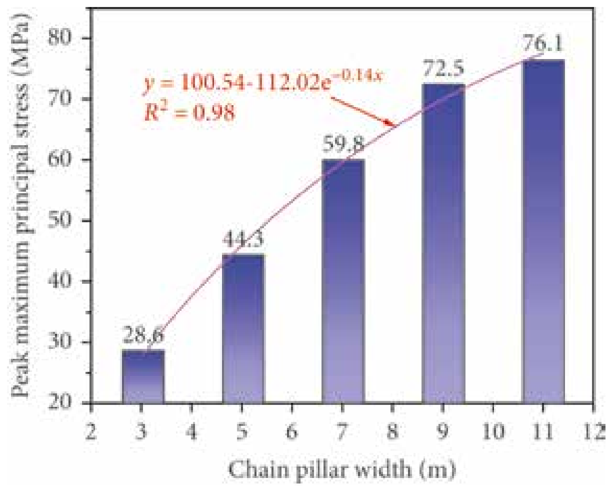

Figure 5: Peak maximum principal stress under different pillar width conditions.

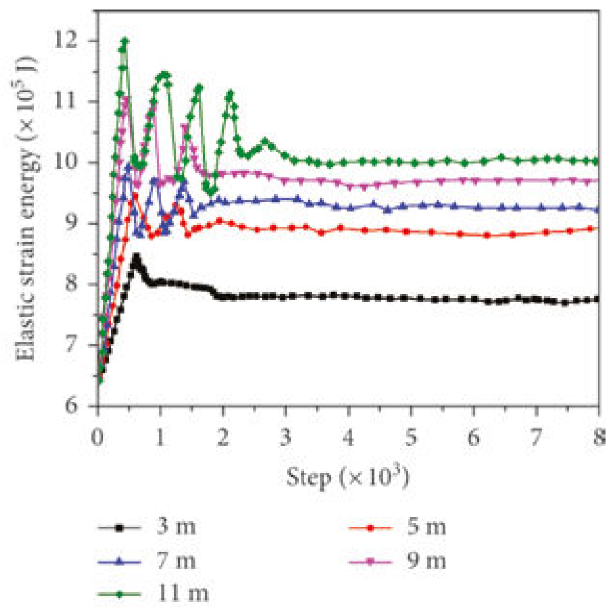

Figure 6: Elastic strain energy of the chain pillar

Table 2: LW6304 coal burst gradings.

Coal burst intensity	No risk	Weak	Medium	Strong
Threshold	δ_r < 0:53	0:53 < δ_r < 2:86	2:86 < δ_r < 3:67	δ_r > 3:67

Table 3: Coal burst risks of different panel widths.

Chain pillar width (m)	Peak maximum principal stress (MPa)	δ_r	Coal burst intensity
3	28.6	1.17	Weak
5	44.3	1.81	Weak
7	59.8	2.44	Weak
9	72.5	2.96	Medium
11	76.1	3.11	Medium

Coal burst is a frequent mine hazard and has attracted a mass of studies[43-45]. Dou *et al*. proposed a representative method to quantify the coal burst tendency by defining an index referred to as the stress concentration coefficient, δ_i. The index measures the product of all components determined as the ratio of the maximum principal stress to the self-weight stress in localised areas. The coal burst potential can be obtained by comparing δi and the stress threshold of coal burst. This method also includes coal burst potential classification[43].

The factors contributing to coal burst problems in underground coal mining include geological structures, abutment pressurisation, overburden strata movement, and coal measure lithology. For mine stress, the paper considered frontal abutment pressurisation and side abutment pressurisation induced by LW6305 mining operation, defining the ratio of the maximum principal stress to the self-weight stress as a coal burst risk index, δ_r. For LW6304, the selfweight stress (σ_0) is 24.5 MPa, and the uniaxial compressive strength (R_C) of coals was tested to be 13 MPa, cooperatively yielding the coal burst intensity gradings as listed in **Table 2**[43]. Further, according to the maximum principal stress obtained in the numerical simulation, LW6304 coal burst potentials in varying pillar width conditions were calculated and summarised in **Table 3**.

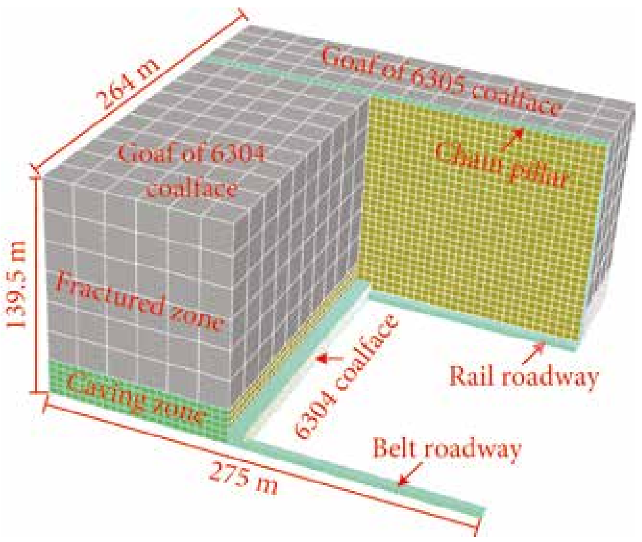

Figure 7: Goaf ignition model established in Ansys Fluent.

Table 3 shows that narrow pillars (3, 5, and 7m wide) have an index lower than 2.86, subject to a weak coal burst intensity according to **Table 2**. Widening the pillar to 9m increases the intensity to a medium level. By comparison, the LW6304 chain pillar width should be smaller than 9m, by which the coal burst potentials can be controlled to some extent.

CHAIN PILLAR IMPACT ON GOAF IGNITION

The impact of chain pillar width on goaf ignition was studied using an Ansys Fluent numerical model. Ansys Fluent software is a computational fluid dynamics software to solve the sophisticated models for multiphase flows, chemical reaction, and combustion, which is widely used in the study of goaf ignition (https://www.ansys.com/products/fluids/ansys-fluent). In the model, the pillar width had the same configuration as the previous model, by which the oxidation heating zone variation was obtained and analysed.

Model Design and Configuration.

The model was established in Ansys Fluent software, geometrically 275m long, 264m wide, and 139.5m high, as shown in **Figure 7**. Combined with on-site drilling observation and FLAC3D numerical simulation, the height of the caving zone was 23m, and the fractured zone was 116.5m.

Goaf ignition potentials depend on pillar porosity. Considering that the chain pillar is subject to compressive stress during the longwall retreat process, the pillar porosity can be determined via **Equation 1**[46]:

Equation 1

$$\eta = \frac{\eta_0 - \varepsilon_v + \sigma_0/K}{1 - \varepsilon_v}$$

where η is the pillar porosity, η0 is the initial porosity, ε_v is volumetric strain, σ_0 is the virgin in situ stress, calculated by $\sigma_0 = (\sigma_1 + \sigma_2 + \sigma_3)/3$, and K is the bulk modulus. Incorporating the laboratory test and numerical simulation results obtained the pillar porosity, respectively, 0.21, 0.19, 0.15, 0.11, and 0.09 with pillar width increased from 3, 5, 7, and 9 to 11m. The goaf porosity was assumed to be 0.3 (LW6304) and 0.25 (LW6305) according to the compaction degree of collapsed rock. The belt roadway worked for air-in ventilation, providing fresh air with O_2 of 12% and N_2 of 77%. Other gas components of air have little influence on the results due to their small content, which is not considered in the simulation. According to the geological conditions of LW6304, the gas content of the coal seam had little influence on the goaf ignition. Therefore, the influence of coal seam gas content on goaf ignition was not considered here. The model adopted the standard *K-ε* turbulent model for iterative calculation. The permeability governing equation used in the Ansys Fluent model is derived from the Carman formula of porous media[47]. The expression is

Equation 2

$$\overline{K} = \frac{\overline{D}_m^2 \cdot \left(\overline{K}_p^2 - 1\right)^2}{180},$$

Table 4: $\overline{D}_m$ and $\overline{K}_p$ at different areas of goal in the LTCC panel.

Distance from the coalface (m)	$\overline{D}_m$ (m)	$\overline{K}_p$
0-20	0.35	1.32
20-80	0.30	1.23
>80	0.20	1.12

where $\overline{K}$ is the permeability in goaf, $\overline{D}_m$ is the average particle size of fractured rock mass in goaf, and $\overline{K}_p$ is the average coefficient of bulk increase of fractured rock mass in goaf. $\overline{D}_m$ and $\overline{K}_p$ at different areas of goal in the longwall top coal caving coalface are different. Their relationship is shown in **Table 4**[47].

Simulation Results.

The oxidation heating zone profiles were obtained via the goaf ignition model. By assuming 10% O_2 concentration as the threshold of the oxidation heating zone against the asphyxiation zone[48], the oxidation heating zone of LW6305 goaf was determined, coupled with the zone edge distance away from LW6304 (**Figure 8**).

As indicated by **Figure 8**, the maximum distance of the LW6305 heating zone edge to the LW6304 face has a negative correlation to pillar width. In detail, the maximum distance decreases from 128.1 to 50.4m as the pillar width increases from 3 to 11m. Taking the 11m width condition as a reference, the maximum distance is 2.54 times in the 3m pillar width condition, gradually declining to 2.25 times (5m width), 1.90 times (7m width), and 1.48 times (9m width). In addition, the air-in ventilation roadway has a generally greater oxygen concentration than the air-out ventilation roadway.

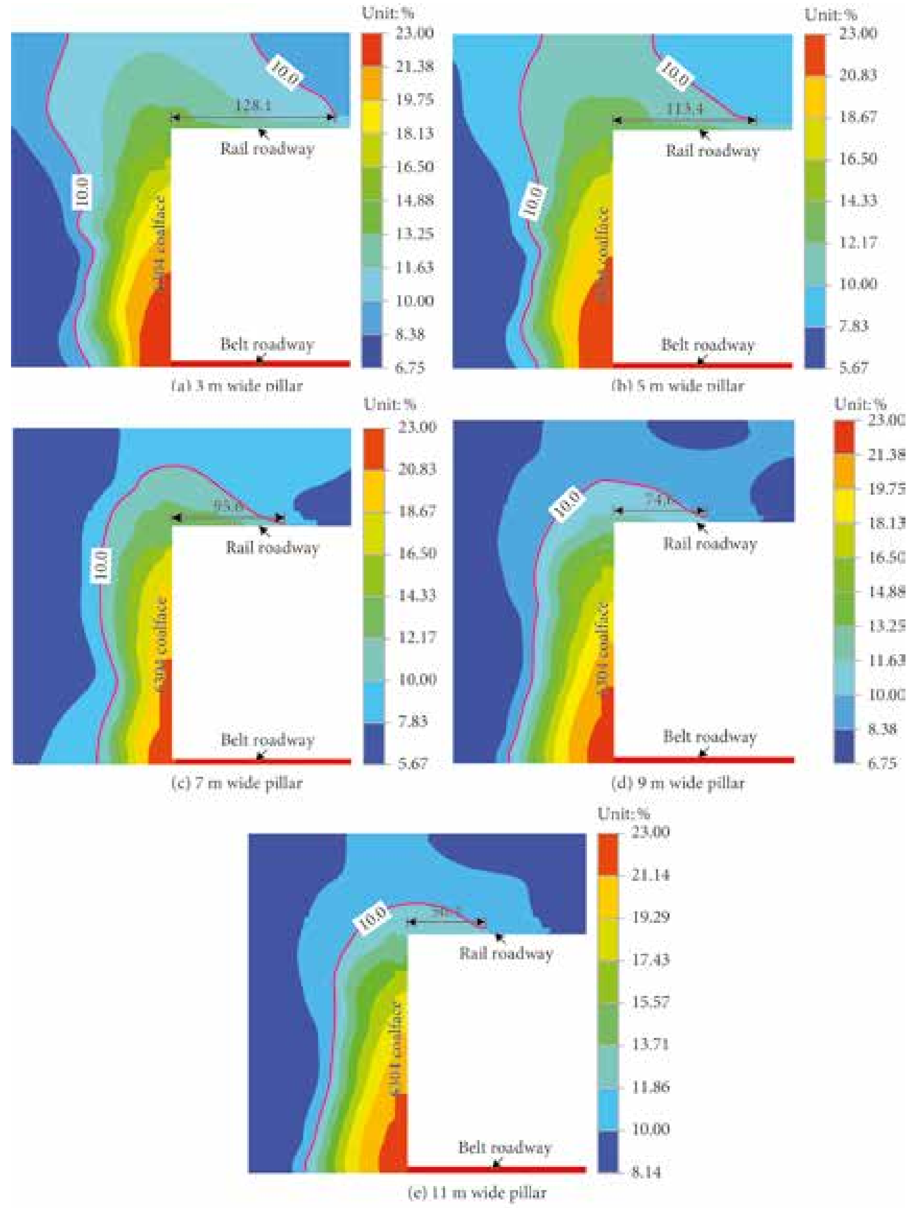

Figure 8: Oxidation heating zone profiles in different pillar width conditions.

Table 5: Goaf ignition risks in different pillar width conditions.

Chain pillar width (m)	S_{max} (m)	L_0 (m)	Q_s	Goaf ignition tendency
3	128.1	105	1.22	High
5	113.4		1.08	High
7	95.6		0.91	Low
9	74.6		0.71	No risk
11	50.4		0.48	No risk

Goaf Ignition Risk Assessment.

Goaf ignition is likely to occur in the oxidation heating zone. In mining practice, the goaf ignition risk is frequently assessed by comparing the longwall retreat distance in a certain period (L_0) with the maximum distance of the heating zone to the current coalface position (S_{max}). In cases of $S_{max} \geq L_0$, the previous panel goaf tends to ignite spontaneously; in $S_{max} < L_0$ cases, the goaf ignition potential is considered lower, meaning a safe environment for longwall mining.

The mine data indicates that the shortest self-ignition period of LW6304 and LW6305 coals should be 21 days, and the retreat rate is 5 m/d. Therefore, LW6304 coalface marches a distance (L_0) of about 105m in the potential goaf ignition period. Further define a goaf ignition risk index Q_s as the ratio of S_{max} to L_0. The potential of LW6305 goaf ignition in response to different pillar widths was quantified as summarised in **Table 5**.

Table 5 indicates that, as the chain pillar width is not greater than 5m, residual coals in the adjacent goaf tend to ignite, with the goaf ignition risk index (Q_s) higher than 1. Widening the pillar to 7m or larger can decrease Q_s to be smaller than 1, a low ignition tendency. Therefore, LW6304 chain pillar width should be more than 5m considering goaf ignition control.

CHAIN PILLAR WIDTH DETERMINATION AND FIELD TRIAL

The Optimal Width Determination.

The above analyses revealed that widening the chain pillar helps decline the coal burst potentials but negatively increases the possibility of goaf ignition, a contradictive requirement of controlling both mine hazards on the pillar width. However, there may exist an optimal pillar width that allows both hazards to be balanced, for which the optimal value can be determined according to the operating point principle. The operating point selection has been widely applied to obtain the optimal working condition of ventilation and water pump facilities[49,50]. This paper also used the operating point selection for determining the chain pillar width, which includes the following steps:

(i) Establish the correlation $\delta_r = f(D)$ between the coal burst risk index δ_r and pillar width D and correlation $Q_s = g(D)$ between the goaf ignition risk index Q_s and D

(ii) Plot the two correlation curves $\delta_r = f(D)$ and $Q_s = g(D)$ on a chart

(iii) Demarcate the threshold regarding δr ≤ 2:86 (no risk or low coal burst intensity) and Qs ≤ 1 (no risk or low goaf ignition tendency) and thus obtain a range of pillar width

(iv) Take the intersection of two curves as the optimal pillar width, as shown in **Figure 9**

Figure 9 indicates that both hazards have exponential correlations to pillar width, in detail a negative correlation for coal burst and a positive correlation for goaf ignition. Configuring the threshold suggests a reasonable pillar width from 5.9 to 9.2m; if smaller than 5.9m, the pillar has a minor effect on goaf ignition control, while if greater than 9.2m, the pillar tends to undergo a coal burst problem. The two correlation curves intersect at the point of 6.7m width, implying that the optimal pillar width should be 6.7m, rounded to be 7m for mine operation convenience.

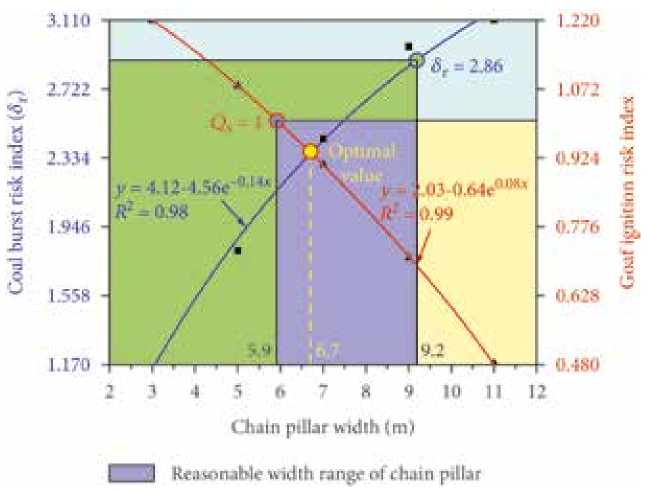

Figure 9: The optimal chain pillar width determination.

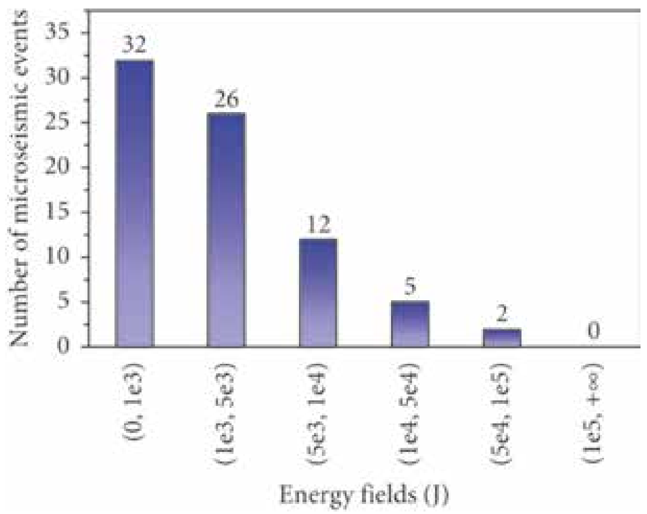

Figure 10: Mine seismicity statistics.

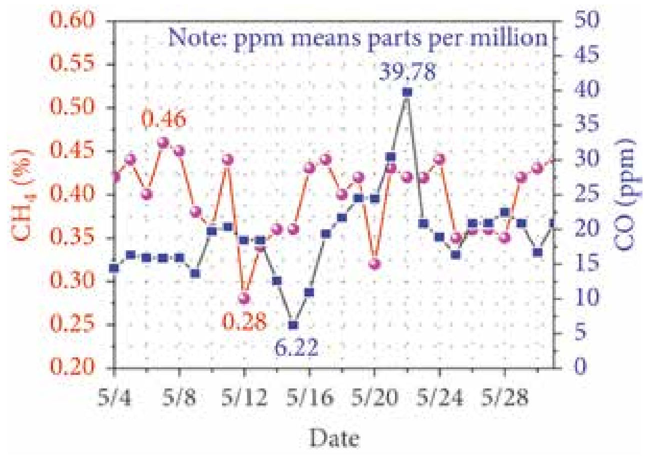

Figure 11: CH4 and CO concentration variation.

Field Trial.

The LW6304 chain pillar was constructed 7m wide in practice. When LW6304 coalface approached LW6305 goaf, mine seismicity and gas (CH_4 and CO) concentration were monitored along the roadway, as shown in **Figure 2**. The monitoring lasted for 28 days and collected continuous seismicity and gas concentration variations as shown in **Figures 10** and **11**, respectively.

The measurement results show that each seismic event had an energy release lower than 1 X 10^5 J, practically small energy release events. The events with 0 to 5 X 10^3 J energy release dominated, taking 75% of the total amount. No coal burst phenomenon was observed. In the 7m width condition, the CH_4 concentration ranged from 0.28 to 0.46%, not triggering out-of-limit alarming. The CO concentration ranged from 6.22 to 39.78 ppm, with the maximum of 39.78 ppm, far lower than the alarm value of goaf ignition. These results indicate that the 7m wide pillar can help control the coal burst and goaf ignition risks, verifying the effectiveness of the pillar width determination method.

DISCUSSION AND CONCLUSION

LTCC panels have coal burst and goaf ignition potentials. Adjusting the chain pillar width can help control both mine hazards, however characterising an opposite influencing mechanism: a narrow pillar prevents excessive energy accumulation and rapid energy release but possibly causes air leakage into goaf voids and hence goaf ignition. Therefore, the pillar width determination should consider the pillar impact on coal burst and goaf ignition.

The pillar strain energy experiences a rapid increase and decrease and ultimately levels off with longwall retreat, behaving significant energy accumulation and release. The pillar width has a positive correlation with the energy accumulation rate, peak energy, and times and amount of energy release. Setting the pillar smaller than 9.2m can decrease the coal burst risk index lower than the weak coal burst. From the coal burst control, the LW6304 chain pillar should be smaller than 9.2m. The distance from the LW6305 oxidation heating zone to the LW6304 coalface has a negative correlation with the pillar width. As the pillar width is greater than 5.9m, the goaf ignition risk index is smaller than the no risk tendency. From the goaf ignition control, the LW6304 chain pillar should be wider than 5.9m.

The paper develops a pillar width determination method by virtue of operating point selection. The method plots the coal burst risk index (δ_r) and goaf ignition risk index (Q_s) curves against the pillar width on a chart and thus determines a reasonable width range by demarcating $\delta_r \leq$ 2:86 and $Q_s \leq 1$. The optimal width can be located as the intersection point of both curves $\delta_r = f(D)$ and $Q_s = g(D)$. Combined with the on-site construction, the optimal chain pillar width of LW6304 coalface is 7m. This method has been verified effective in determining the chain pillar width by a field trial.

REFERENCES

1. J. Kabiesz and J. Makówka, “Selected elements of rock burst state assessment in case studies from the Silesian hard coal mines,” Mining Science and Technology, vol. 19, no. 5, pp. 660-667, 2009.
2. E. Kabwe and Y. Wang, “Review on rockburst theory and types of rock support in rockburst prone mines,” Science and Technology, vol. 5, no. 4, pp. 104-121, 2015.
3. M. Qiao, T. Ren, J. Roberts, X. Yang, Z. Li, and J. Wu, “New insight into proactive goaf inertisation for spontaneous combustion management and control,” Process Safety and Environmental Protection, vol. 161, pp. 739-757, 2022.
4. C. Zhang, I. Canbulat, B. Hebblewhite, and C. R. Ward, “Assessing coal burst phenomena in mining and insights into directions for future research,” International Journal of Coal Geology, vol. 179, pp. 28-44, 2017.
5. S. Zhang, G. Fan, S. Jiang, Z. Fan, S. Li, and H. Ni, “Dualhazard control mechanism of burst-prone and spontaneous combustion coalface considering effect of retreat speed,” Energy Reports, vol. 7, pp. 278-288, 2021.
6. N. Li, M. Zare, C. Yi, and R. Jimenez, “Stability risk assessment of underground rock pillars using logistic model trees,” International Journal of Environmental Research and Public Health, vol. 19, no. 4, 2022.
7. C. Mark and M. Gauna, “Pillar design and coal burst experience in Utah Book Cliffs longwall operations,” Mining Science and Technology, vol. 31, no. 1, pp. 33-41, 2021.
8. P. Wang and H. Luan, “Size effect analysis of remaining coal pillar on rock burst caused by fault,” Bulletin of Engineering Geology and the Environment, vol. 81, no. 3, pp. 1-15, 2022.
9. R. S. Faradonbeh and A. Taheri, “Long-term prediction of rockburst hazard in deep underground openings using three robust data mining techniques,” Engineering with Computers, vol. 35, no. 2, pp. 659-675, 2019.
10. C. Mark, “Coal bursts in the deep longwall mines of the United States,” Coal Science and Technology, vol. 3, no. 1, pp. 1-9, 2016.
11. J. Ptáček, “Rockburst in Ostrava-Karvina Coalfield,” Procedia Engineering, vol. 191, pp. 1144-1151, 2017.
12. C. Wang, G. Si, C. Zhang, A. Cao, and I. Canbulat, “Ground motion characteristics and their cumulative impacts to burst risks in underground coal mines,” Geomechanics and Geophysics for Geo-Energy and Geo-Resources, vol. 8, no. 1, pp. 1-18, 2022.
13. M. Bukowska, “The probability of rockburst occurrence in the Upper Silesian Coal Basin area dependent on natural mining conditions,” Journal of Mining Science, vol. 42, no. 6, pp. 570-577, 2006.
14. M. A. DykeVan, W. H. Su, and J. Wickline, “Evaluation of seismic potential in a longwall mine with massive sandstone roof under deep overburden,” Mining Science and Technology, vol. 28, no. 1, pp. 115-119, 2018.
15. A. Mazaira and P. Konicek, “Intense rockburst impacts in deep underground construction and their prevention,” Canadian Geotechnical Journal, vol. 52, no. 10, pp. 1426-1439, 2015.

16. Y. Pu, D. B. Apel, V. Liu, and H. Mitri, "Machine learning methods for rockburst prediction-state-of-the-art review," Mining Science and Technology, vol. 29, no. 4, pp. 565-570, 2019.
17. P. K. Kaiser and M. Cai, "Design of rock support system under rockburst condition," Engineering, vol. 4, no. 3, pp. 215-227, 2012.
18. L. M. Dou, X. Q. He, H. He, J. He, and J. Fan, "Spatial structure evolution of overlying strata and inducing mechanism of rockburst in coal mine," Transactions of Nonferrous Metals Society of China, vol. 24, no. 4, pp. 1255-1261, 2014.
19. M. R. Saharan and H. Mitri, "Destress blasting as a mines safety tool: some fundamental challenges for successful applications," Procedia Engineering, vol. 26, pp. 37-47, 2011.
20. B. Huang, C. Liu, J. Fu, and H. Guan, "Hydraulic fracturing after water pressure control blasting for increased fracturing," International Journal of Rock Mechanics and Mining Sciences, vol. 48, no. 6, pp. 976-983, 2011.
21. P. Konicek, K. Soucek, L. Stas, and R. Singh, "Long-hole destress blasting for rockburst control during deep underground coal mining," International Journal of Rock Mechanics and Mining Sciences, vol. 61, pp. 141-153, 2013.
22. M. Zhang, J. Zhang, F. Jiang, and Z. Jiao, "Design of rib pillars in deep longwall mines based on rockburst and waterseepage prevention," Energy Science and Engineering, vol. 9, no. 2, pp. 256-266, 2021.
23. O. Vardar, F. Tahmasebinia, C. Zhang, I. Canbulat, and S. Saydam, "A review of uncontrolled pillar failures," Procedia Engineering, vol. 191, pp. 631-637, 2017.
24. Y. Xue, Z. Cao, and W. Shen, "Destabilization and energy characteristics of coal pillar in roadway driving along gob based on rockburst risk assessment," Science, vol. 6, no. 7, 2019.
25. B. Wang, S. Zhu, F. Jiang, J. Liu, X. Shang, and X. Zhang, "Investigating the width of isolated coal pillars in deep hardstrata mines for prevention of mine seismicity and rockburst," Energies, vol. 13, no. 17, p. 4293, 2020.
26. C. Sensogut, M. Kaufmann, and E. Petit, "An approach to the modelling of spontaneous combustion in the goaf," Journal South African Institute of Mining and Metallurgy, vol. 102, pp. 311-313, 2002.
27. Z. Song and C. Kuenzer, "Coal fires in China over the last decade: a comprehensive review," International Journal of Coal Geology, vol. 133, pp. 72-99, 2014.
28. D. D. Tripathi, "New approaches for increasing the incubation period of spontaneous combustion of coal in an underground mine panel," Fire Technology, vol. 44, no. 2, pp. 185-198, 2008.
29. S. Wessling, W. Kessels, M. Schmidt, and U. Krause, "Investigating dynamic underground coal fires by means of numerical simulation," Geophysical Journal of the Royal Astronomical, vol. 172, no. 1, pp. 439-454, 2008.
30. L. Yuan and A. C. Smith, "Numerical study on effects of coal properties on spontaneous heating in longwall gob areas," Fuel, vol. 87, no. 15-16, pp. 3409-3419, 2008.
31. B. Taraba, V. Slovak, Z. Michalec, J. Chura, and A. Taufer, "Development of oxidation heat of the coal left in the minedout area of a longwall face: modelling using the fluent software," Journal of Mining and Metallurgy Section B Metallurgy, vol. 44, no. 1, pp. 73-81, 2008.
32. Y. Mu, "Spontaneous combustion characteristics and air leakage control technology of half isolated island fully mechanized caving face," Advanced Materials Research, vol. 718-720, pp. 1639-1644, 2013.
33. W. Liu, Y. Qin, Y. Hao, T. Gui, and J. Jia, "Minimum secure speed of fully mechanized coal face based on critical temperature of coal spontaneous combustion," Journal of Coal Science and Engineering (China), vol. 19, no. 2, pp. 147-152, 2013.
34. W. Liu and Y. Qin, "Multi-physics coupling model of coal spontaneous combustion in longwall gob area based on moving coordinates," Fuel, vol. 188, pp. 553-566, 2017.
35. S. R. Michalski, "The Jharia mine fire control technical assistance project: an analysis," International Journal of Coal Geology, vol. 59, no. 1-2, pp. 83-90, 2004.
36. F. Zhou, D. Wang, Y. Zhang, Y. Zhang, and X. Li, "Practice of fighting fire and suppressing explosion for a super-large and highly gassy mine," Journal of China University of Mining & Technology, vol. 17, no. 4, pp. 459-463, 2007.
37. G. J. Colaizzi, "Prevention, control and/or extinguishment of coal seam fires using cellular grout," International Journal of Coal Geology, vol. 59, no. 1-2, pp. 75-81, 2004.
38. B. Qin, Y. Lu, Y. Li, and D. Wang, "Aqueous three-phase foam supported by fly ash for coal spontaneous combustion prevention and control," Advanced Powder Technology, vol. 25, no. 5, pp. 1527-1533, 2014.
39. S. Zhang, G. Fan, D. Zhang, S. Li, Y. Fan, and T. Luo, "Impacts of longwall mining speeds on permeability of weakly cemented strata and subsurface watertable: a case study," Natural Hazards and Risk, vol. 12, no. 1, pp. 3063-3088, 2021.
40. T. Kazerani and J. Zhao, "Micromechanical parameters in bonded particle method for modelling of brittle material failure," International Journal for Numerical and Analytical Methods in Geomechanics, vol. 34, no. 18, pp. 1877-1895, 2010.
41. S. Zhang, X. Wang, G. Fan, D. Zhang, and J. Cui, "Pillar size optimization design of isolated island panel gob-side entry driving in deep inclined coal seam case study of Pingmei No. 6 coal seam," Journal of Geophysics and Engineering, vol. 15, no. 3, pp. 816-828, 2018.
42. D. Zhu, Y. Wu, Z. Liu, X. Dong, and J. Yu, "Failure mechanism and safety control strategy for laminated roof of wide-span roadway," Engineering Failure Analysis, vol. 111, article 104489, 2020.
43. L. Dou, H. He, J. He, and Z. Wang, "New method of rockburst risk assessment using relative stress concentration factor superposition," Journal of China Coal Society, vol. 43, pp. 327-332, 2018.
44. S. K. Sharan, "A finite element perturbation method for the prediction of rockburst," Computers and Structures, vol. 85, no. 17-18, pp. 1304-1309, 2007.
45. J. Zhou, X. Li, and X. Shi, "Long-term prediction model of rockburst in underground openings using heuristic algorithms and support vector machines," Safety Science, vol. 50, no. 4, pp. 629-644, 2012.
46. Y. Qin, L. Wang, B. Li, and L. Cui, "Change law study on porosity of the coal and rock in compression test," Mineral Engineering Research, vol. 25, pp. 1-3, 2010.
47. S. Li, M. Qian, and P. Shi, "Study on bed-separated fissures of overlying stratum and interstice permeability in fullymechanized top coal caving," Chinese Journal of Rock Mechanics and Engineering, vol. 19, pp. 604-607, 2000.
48. J. Xie and S. Xue, "Study on division index and method of three spontaneous combustion zones in goaf of fully mechanized top coal caving mining face," Coal Science and Technology, vol. 39, pp. 65-68, 2011.
49. M. F. Kocher and J. Subbiah, "Analytical solution for speed to achieve a desired operating point for a given fan or pump," Applied Engineering in Agriculture, vol. 32, no. 6, pp. 751-757, 2016.
50. R. Simpson and A. Marchi, "Evaluating the approximation of the affinity laws and improving the efficiency estimate for variable speed pumps," Journal of Hydraulic Engineering, vol. 139, no. 12, pp. 1314-1317, 2013.

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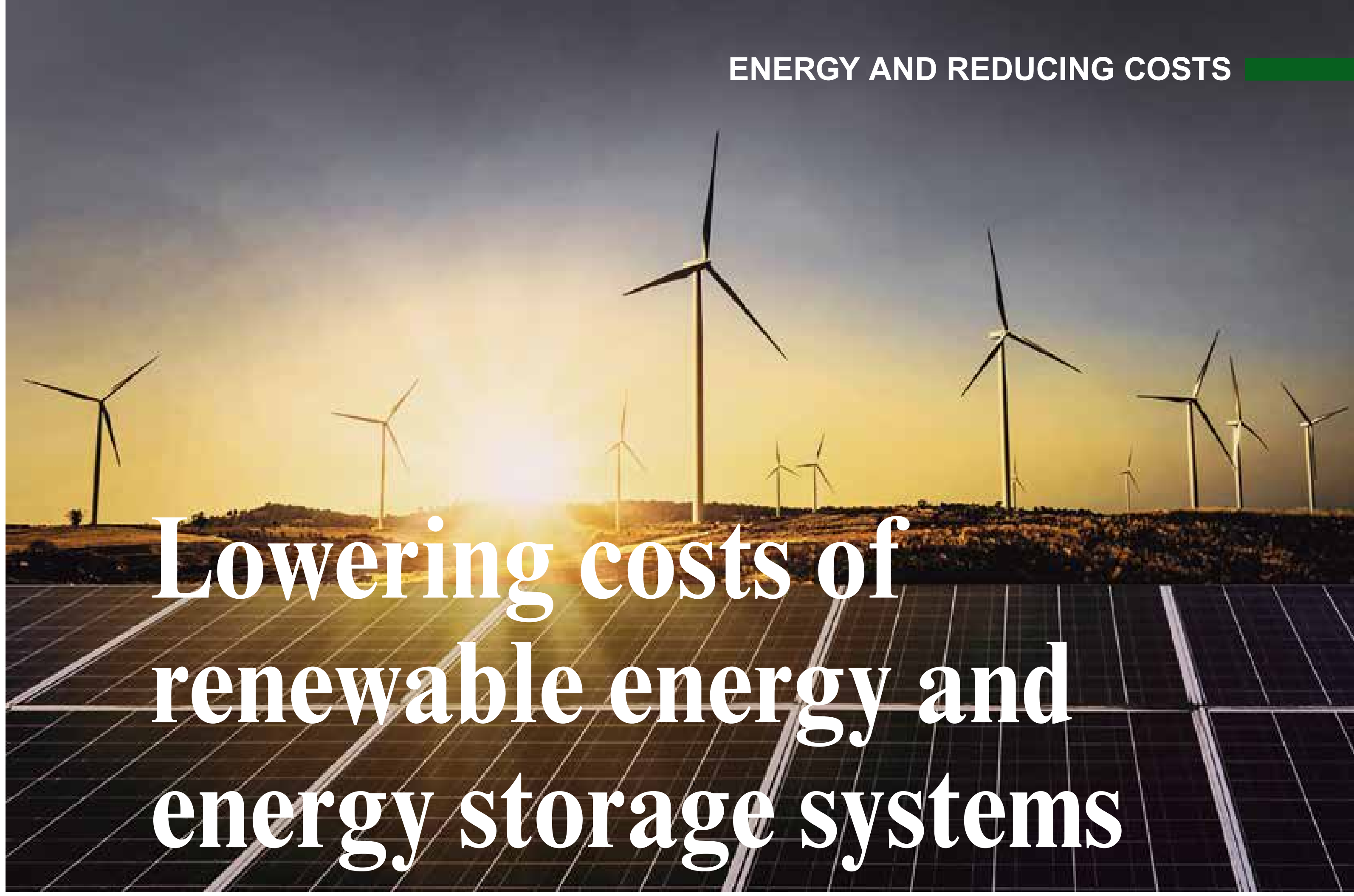

Lowering costs of renewable energy and energy storage systems

The mining industry has traditionally relied heavily on fossil fuels to meet its energy demands. However, the increasing availability and decreasing costs of renewable energy sources, coupled with advancements in energy storage systems, are driving a greater adoption of clean energy within the industry. Coal International takes a brief look at how lowering costs of renewable energy and energy storage systems are contributing to the increased use of clean energy in mining:

Cost competitiveness: Over the past decade, the cost of renewable energy technologies such as solar and wind power has dropped significantly. These renewable sources have become increasingly cost-competitive with traditional fossil fuel-based power generation methods. As a result, mining companies are finding it economically viable to invest in renewable energy installations.

Favourable economics: The mining industry often operates in remote areas where grid access is limited or non-existent. In such locations, relying on diesel generators for power generation can be expensive due to transportation and logistics costs. Renewable energy systems, on the other hand, can be deployed off-grid, providing a reliable and cost-effective energy solution for mining operations.

Energy efficiency: The mining industry is energy-intensive, and reducing energy consumption is a key focus for improving operational efficiency. Integrating renewable energy sources and energy storage systems allows mining companies to optimize their energy usage. For instance, excess energy generated during low-demand periods can be stored in batteries and used during peak hours, reducing the overall reliance on fossil fuels.

Environmental regulations and social responsibility: Mining companies are increasingly under pressure to reduce their carbon footprint and mitigate the environmental impact of their operations. Adopting renewable energy sources helps companies comply with stringent environmental regulations and demonstrate their commitment to sustainable practices, which can enhance their reputation and social license to operate.

Long-term cost stability: Renewable energy sources such as solar and wind offer stable long-term pricing as they are not subject to the volatility of fossil fuel markets. By investing in renewable energy infrastructure, mining companies can secure a more predictable and stable energy supply, protecting themselves from future energy price fluctuations.

Technological advancements: Advances in energy storage technologies, such as the development of more efficient batteries and other storage systems, have made it easier to store excess renewable energy for use when needed. These advancements have addressed the intermittency issues associated with renewable sources, making them more reliable and attractive for mining operations.

Overall, the lower costs of renewable energy and energy storage systems have made clean energy solutions increasingly attractive for the mining industry. By adopting renewable energy, mining companies can reduce operational costs, enhance environmental performance, and contribute to a more sustainable energy future.

SMM: a global energy and mining conference discussed a number of issues that might have been discussed a few years ago. For example, a team of mining developer executives raised the topic of which milestone might be achieved first: electrified mines, carbon-free fleets or 100% renewable energy-driven businesses.

Topics like this are being discussed, reflecting the application and development of renewable energy in the mining industry in recent years. While mining companies that mine minerals such as gold, copper, lithium and cobalt are increasingly emphasizing the importance of reducing carbon emissions, economic viability is the real driver of their active deployment of solar power, wind power and energy storage systems.

According to statistics, energy costs account for 15% to 40% of mine operating costs. Traditionally, the electricity of mining equipment is satisfied by power grids or fuel generators. Mining around the world requires a lot of energy. According to a survey released by the Colombian Centre for Sustainable Investment, the energy demand of the mining industry accounts for 1.25% to 11% of the total global energy demand, which is broad because it includes downstream industries.

Because many mines are located in remote areas, costly fuel must be transported over long distances, and it is often difficult to obtain electricity from the grid. With the continuous decline in the cost of wind power, solar power generation and energy storage systems, clean energy has become an economically attractive option. By 2022, the cost of energy storage systems will be 61% lower than in 2013, and the cost of solar power generation will be 40% lower than in 2013, according to research firm Wood Mackenzie.

These factors have prompted mineral developers around the world to actively adopt clean energy. The Rocky Mountain Research Institute released a survey on the Application of Renewable Resources in Mines, which shows that the installed capacity of renewable energy deployed in 88 mines in 26 countries is nearly 1.8 GW, in addition to the planned deployment of 3GW renewable energy projects.

DEPLOYMENT OF SOLAR + ENERGY STORAGE PROJECT IN MALI

In early December 2019, Canadian gold miner B2Gold announced that it had signed a contract with the Wasiland Group to purchase one of its 17MW/15MWh energy storage systems to optimize the energy system of its Fekola mine in southwestern Mali. The mine is powered by a 64MW fuel generator, but earlier this year the company announced it would deploy solar power facilities with 30MW installed capacity.

Risto Paldanius, Director of Energy Optimization and Storage Business Development, Wasiland Group, said: "the mining period of the mine has been extended and is therefore studying how to provide additional electricity and how to produce in a more sustainable manner. They decided to use a hybrid of fuel generators and solar power plants, so the next question was how to manage

Rocky mountain Institutes new Headquarters.

intermittent solar power facilities and how fuel generators would respond. To that end, they concluded that there was a need to deploy energy storage systems to help integrate assets to maximise the use of renewable energy, to achieve the lowest energy costs and to reduce carbon emissions.

Paldanius says adding solar power means B2Gold can reduce the cost of buying and transporting substantial amounts of fuel each year. In addition, Wasiland's GEMS technology optimises the combination of solar power generation facilities and energy storage systems and fuel power generation facilities, which is expected to reduce the mine's electricity costs by 7% and carbon emissions by about 390 tons per year. "Investment in solar power generation facilities and energy storage systems can be rewarded within a few years," Paldanius said.

LONG-TERM OPERATION, LONG-TERM SAVINGS

While improvements in the overall economy and sustainability are important drivers of the deployment of renewable energy power generation facilities and energy storage systems in the mining industry, the deployment of energy solutions varies from place to place. For new mines, the deployment of renewable energy power generation facilities and energy storage systems is more economical and feasible, making the deployment of hybrid energy or the full adoption of renewable energy systems an obvious option.

For mines that are already connected to the grid or receive electricity from oil-fired generators, investment in the deployment of renewable energy power generation facilities and energy storage systems depends on the life expectancy of the mine. "have lower energy costs and reduced carbon emissions stimulated investment in renewable energy power generation facilities?" Paldanius said. This is the biggest problem. They will make financial calculations about the operation of the mine, depending on the price at which they mine the mine."

In mines where electricity is mainly provided by oil-fired generators, the energy storage system becomes an important part of the deployment of renewable energy power generation facilities, because dispatchable power generation resources are needed to balance the intermittence of wind or solar power generation.

"Mines may need more power from oil-fired generators, which means they operate less efficiently and consume more fuel, but in order to keep the generators running, they may eventually have to reduce the deployment of solar or wind power facilities," Paldanius said."

He said Wasiland had made full use of its experience in building microgrids on the Caribbean island of Bonaire in the design of mining energy systems. Paldanius said, "there is no significant difference in implementation, and it may even be easier for mines to use renewable energy power generation facilities, as they usually operate round the clock and the load may be more stable than the load on the island. In terms of making full use of the economic benefits of renewable energy power generation facilities and energy storage systems in mines, the application of the mining industry is only the beginning. There are many ways to do this, and I think as mines like Fekola start to make money, more and more renewable energy power generation facilities will be deployed."

Coal preparation technology: status and development

Coal International MD Trevor Barratt takes a sneak preview at three of the worlds top producers and how they are facing up to the many challenges to improve

CHINA

China is the largest coal producer and consumer in the world, accounting for about half of the global coal output and demand. Coal is the main source of energy and raw material for China's economic development. However, China also faces many challenges in coal utilization, such as low quality, high pollution, low efficiency, and resource depletion.

To address these challenges, China has been developing and applying various coal preparation technologies to improve the quality and value of coal products, reduce the environmental impact of coal consumption, and enhance the comprehensive utilization of coal resources. Some of the main trends and innovations of coal preparation technology in China are:

Developing clean coal technologies, such as coal washing, briquetting, gasification, liquefaction, and combustion, to reduce the ash, sulfur, mercury, and carbon dioxide emissions from coal use.

Developing dry coal beneficiation technologies, such as air dense medium fluidized bed, air jigging, electrostatic separation, and microwave treatment, to save water consumption, reduce tailings disposal, and increase separation efficiency.

Developing intelligent coal preparation technologies, such as online detection, automatic control, big data analysis, and artificial intelligence, to optimize the process parameters, enhance the product quality, and reduce the operation cost.

Some examples or case studies of coal preparation technology in China are:

The Shenhua Group, the largest coal company in China, has built several large-scale coal preparation plants with advanced technologies, such as the 15 Mt/a plant in Baotou, Inner Mongolia, which uses a three-product heavy medium cyclone, a banana flip-flow screen, a fine slime flotation column, and a hyperbaric filter.

The Datang International Power Generation C., Ltd, a major power company in China, has developed a dry coal beneficiation technology based on an air dense medium fluidized bed, which can separate 50-6 mm raw coal with an ash content of 36-50% into clean coal with an ash content of 8-12%. The technology has been applied to a 1.4 Mt/a demonstration plant in Hebei Province 1.

The China University of Mining and Technology, a leading research institution in China, has developed an intelligent coal preparation system based on online detection, automatic control, big data analysis, and artificial intelligence. The system can monitor the quality and quantity of raw coal and products, adjust the process parameters according to the feedback, analyze the operation data for optimization, and provide decision support for management. The system has been applied to several coal preparation plants in Shanxi Province 1.

COAL PREPARATION DEVELOPMENTS IN INDONESIA AND AUSTRALIA

Indonesia and Australia are both major coal exporters in the world, supplying mainly thermal coal to Asian markets.

However, they have different characteristics and challenges in terms of coal preparation developments.

INDONESIA

Indonesia is rapidly becoming a major coal producer of thermal coal with low ash content (typically less than 10%). There is little need for conventional coal preparation of the generally low ash coal. However, Indonesia also faces some challenges such as high moisture content (typically more than 30%), low calorific value (typically less than 5000 kcal/kg), high stripping ratio (typically more than 10:1), and environmental issues (such as deforestation, land degradation, water pollution).

To address these challenges, Indonesia has been developing and applying various coal preparation developments to improve the quality and value of coal products, reduce the environmental impact of coal mining, and enhance the comprehensive utilization of coal resources. Some of the main trends and innovations of coal preparation developments in Indonesia are:

Developing moisture reduction technologies, such as mechanical dewatering, thermal drying, or chemical treatment, to increase the calorific value, reduce the transportation cost, and improve the combustion efficiency of Indonesian coals.

Developing coal upgrading technologies, such as coal briquetting, coal blending, or coal liquefaction, to produce higher-value products, such as smokeless briquettes, blended coals, or synthetic fuels, for domestic or international markets.

Developing coal utilization technologies, such as coal gasification, coal bed methane extraction, or coal mine mouth power generation, to utilize the low-rank coals, recover the coal bed methane, or reduce the transmission loss of electricity.

Some examples or case studies of coal preparation developments in Indonesia are:

The PT Adaro Energy Tbk, the second-largest coal producer in Indonesia, has developed a mechanical dewatering technology based on a belt press filter, which can reduce the moisture content of its low-rank coals from 35% to 25%. The technology has been applied to a 1.5 Mt/a plant in South Kalimantan.

The PT Bumi Resources Tbk, the largest coal producer in Indonesia, has developed a coal briquetting technology based on a binderless process, which can produce smokeless briquettes with a calorific value of 6500 kcal/kg. The technology has been applied to a 0.5 Mt/a plant in East Kalimantan.

The PT Bukit Asam Tbk, a state-owned coal company in Indonesia, has developed a coal gasification technology based on an entrained flow gasifier, which can produce synthesis gas for various applications, such as methanol, dimethyl ether, or ammonia. The technology has been applied to a 0.2 Mt/a plant in South Sumatra.

AUSTRALIA

Australia is a well-established coal producer of both thermal and metallurgical coal with high quality (typically more than 6000 kcal/kg and less than 10% ash). There is a strong demand for conventional coal preparation of the generally high ash coal. However, Australia also faces some challenges such as declining coal prices, increasing mining costs, stringent environmental regulations, and social opposition.

To address these challenges, Australia has been developing and applying various coal preparation developments to improve the efficiency and sustainability of coal production, reduce the greenhouse gas emissions of coal use, and diversify the coal markets and products. Some of the main trends and innovations of coal preparation developments in Australia are:

Developing fine coal processing technologies, such as advanced flotation, centrifugal separation, or filtration, to recover the fine coal particles (typically less than 0.5 mm) that are lost in the conventional coal preparation processes. These technologies can increase the yield, quality, and value of Australian coals.

Developing low-emission coal technologies, such as oxy-fuel combustion, carbon capture and storage, or integrated gasification combined cycle, to reduce the carbon dioxide emissions from coal-fired power plants. These technologies can enhance the competitiveness and acceptability of Australian coals.

Developing diversified coal products, such as activated carbon, carbon fiber, graphene, or carbon nanotubes, to produce high-value products from low-rank coals or coal by-products. These products can create new markets and applications for Australian coals.

Some examples or case studies of coal preparation developments in Australia are:

The BHP Billiton Mitsubishi Alliance (BMA), the largest metallurgical coal producer in Australia, has developed a fine coal processing technology based on a reflux classifier, which can separate fine coal particles based on density and size. The technology has been applied to several plants in Queensland.

The Callide Oxyfuel Project, a joint venture between CS Energy, Glencore, Schlumberger, and Japanese partners, has developed an oxy-fuel combustion technology based on burning coal with pure oxygen instead of air. The technology can capture up to 90% of the carbon dioxide emissions from a 30 MW power plant in Queensland.

The Australian National Low Emissions Coal Research and Development (ANLEC R&D), a partnership between the Australian Coal Association Research Program (ACARP) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO), has developed a diversified coal product based on graphene oxide membranes, which can filter water or gas molecules with high selectivity and permeability. The product is made from low-rank coals or fly ash.

Application of pre-splitting and roof-cutting control technology in coal mining: a review of technology

According to the development requirements of green mining of coal resources, it is imperative to improve the extraction rate of coal and the application of safe and efficient mining technology. Pre-splitting and roof cutting technology is widely used in reducing residual coal pillars and safe pressure relief mining, which has become the crucial technology for pillar-free mining methods. Therefore, it is essential to review and discuss the research hotspots, innovative methods, principles of action, and application areas of the development of this technology. Above all, the research data on pre-splitting and roof-cutting development in the past ten years are summarized and outlined. The research's hot spots are pressure relief technology and gob-side entry retaining technology. Then, the functional forms of pre-splitting and roof cutting technology are discussed and compared, including explosive blasting (directional energy gathering blasting, liquid explosive blasting, and composite blasting), hydraulic fracturing, liquid CO2 gas fracturing, and mechanized roof cutting (chain arm saw machine and directional cutting roof rig). Through the analysis of field application cases, the application field is divided into three major areas: non-coal pillar mining (gob-side entry driving with narrow coal pillar, gob-side entry retaining with the filling body, completely gob-side entry retaining, and "N00" construction method), pressure relief at working face (thick and hard main roof cracking and end area hard roof cracking), and pressure relief at roadway (gob-side roadway pressure relief and blasting pressure relief technology for roadways). By detailing the process of each application technology one by one, the principle and mode of pre-splitting in each technology are expounded. Finally, the development prospects of pre-splitting and roof cutting in new technical methods, deep pressure relief mining, intelligent unmanned mining, and green and efficient mining are prospected, providing references for similar projects.

In Chinese coal mining, high-intensity mine pressure in the roadway and working face has been the critical factor that endangers the average coal production. In the past 30 years, with the rapid development of computer science and sensor technology, the study of mine pressure in the coal mining process has become more profound and transparent. Theoretical models of mine pressure in mining fields and roadways have been proposed and gradually recognized by field engineers, such as the structural model of "masonry beam", the mechanical model of "plate structure" of the stope, the theory of slip line of roadway floor, and the theory of butterfly plastic zone. Many scholars have profoundly and extensively studied the location and causes of stress concentration areas in the mining field and the roadway through pressure monitoring in the field and numerical calculations by computer. Among them, the stability and movement of the roof after coal mining are closely related to the regional stress concentration condition of the mining field and the roadway. Especially for the coal mining face with a hard roof, composite roof,

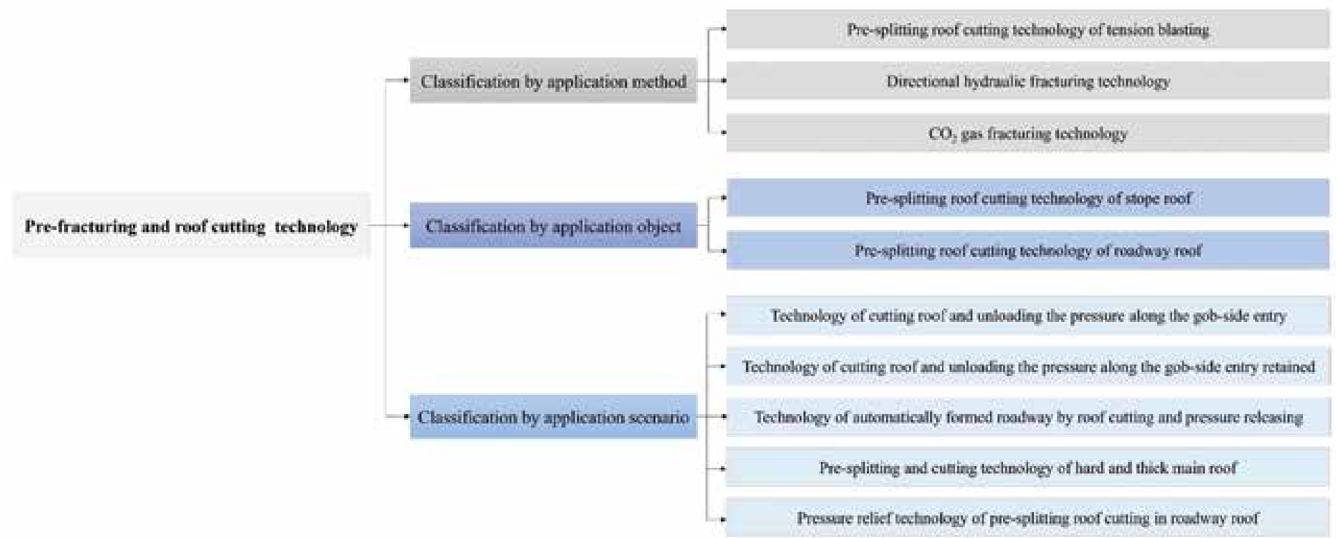

Figure 1: Category of pre-splitting and roof-cutting technology.

and thick roof, when it adopts usual mining methods, many problems such as support crushing, large deformation, and strong disturbance will occur. Simultaneously, the increase of the buried depth makes the surrounding rock conditions of the roadway increasingly bad. Under the complex surrounding rock environment, it is difficult to maintain the stability of the roadway only by support, and the application of pressure relief technology is urgently needed. Based on this, pre-split or cutting off the roof before working face mining is gradually being implemented to study pressure relief in mining fields and roadways.

Pre-splitting and roof-cutting control technology refers to the directional pre-fracturing or cutting off of the roof of the mining field and roadway by explosive blasting or high-strength hydraulic fracturing. As shown in **Figure 1**, according to its application method, it can be classified into directional blasting roof cutting technology, directional hydraulic fracturing technology, and liquid CO_2 gas fracturing technology. According to its application object, it can be classified into pre-splitting control technology of mining field's roof and roadway's roof. According to its application scenario, it can be classified into the technology applied to roof cutting and pressure releasing of gob-side entry driving, roof cutting and pressure releasing of gob-side entry retaining, roof cutting for self-forming roadway technology, hard main roof cracking, and pressure relief on the surrounding rock of the roadway.

With the development of roof cutting and pressure relief theory, pre-split means, and supporting equipment, pre-splitting and roof-cutting technology has become essential to realize pressure relief and no pillar mining. Based on this technology, the recovery rate of coal mining increases and the roof disaster decreases, which is conducive to producing high-quality and efficient green coal mining. The research application of pre-splitting and roof-cutting technology in the coal mining field in the past five years is analysed by VOSviewer, as shown in **Figure 2**.

By counting more than 300 papers on pre-splitting and roof-cutting in the global mining industry in the past five years, we can get that the research hotspots are: Pre-splitting roof applied to the stability study of working face and roadway roof; Analysis of the mechanical mechanism of pre-cracked roof effect, including mechanical model and pressure release principle; Process design and optimization of support means of pre-fractured roof technology; Numerical simulation analysis study of pre-fractured roof technology, including the evolution of its plastic zone, stress, and deformation; Application of pre-fractured roof technology, including hard-roof cracking and pressure relief, no pillar mining (gob-side entry driving and gob-side entry retaining), and self-forming roadway

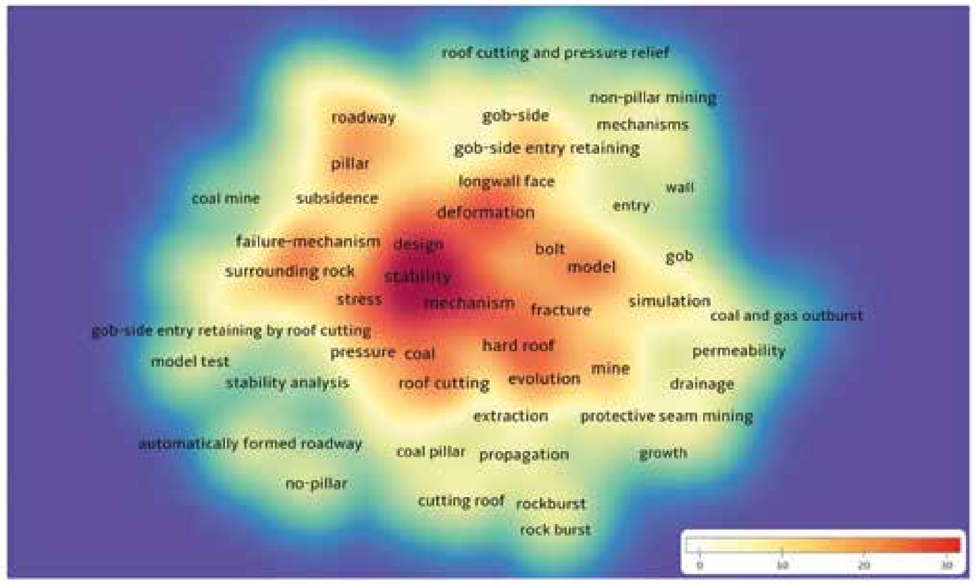

Figure 2: Research hotspot map of pre-splitting and roof-cutting technology.

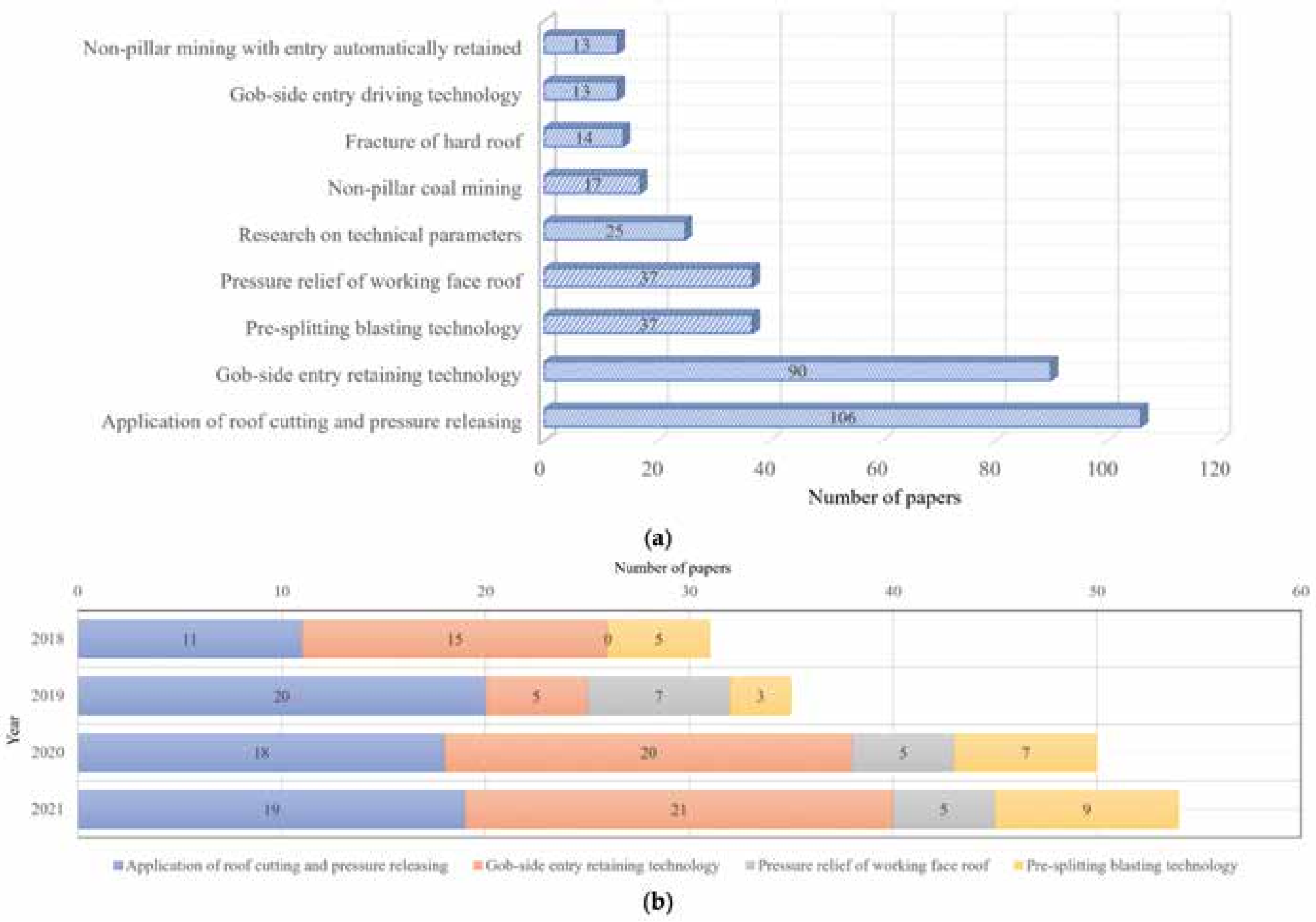

Figure 3: Category of pre-splitting and roof-cutting technology. (a) Nine research hotspots (b) Research trends in the past four years.

technology; Research on gas and rock explosion in the process of the pre-fractured roof.

China is the technological powerhouse country in coal underground mining. Pre-splitting and roof-cutting technology is extensively implemented in Chinese coal mines. By searching the keywords "pre-splitting and roof-cutting" in CNKI (China National Knowledge Internet), 180 related papers were obtained in the past 10 years. As shown in **Figure 3**, the subject terms of these research papers are roof cutting and pressure relief application, gob-side entry retaining technology, pre-split blasting technology, working face pressure relief mining, technical parameter study, non-pillar mining, hard roof cracking, gob-side entry driving technology, and non-pillar self-forming roadway. Among them, the study of gob-side entry retaining through roof-cutting technology is the hot spot of research, which accounts for 56%. The deformation of the roadway along the gob is extensive and challenging to maintain. By cutting the roof, the intense stress concentration of the roof can be released, thus significantly improving the stress environment of the roadway along the gob. In addition, in the past four years, research on pre-splitting and roof-cutting has been at the forefront of the industry in the field of gob-side entry retaining and pressure relief mining at the working face. As the geological conditions of applied coal mine working faces become more diverse and complex, scholars have begun to improve the traditional pre-splitting and blasting technology, and the research on the effects of directional energy-gathered blasting has gradually increased.

With the more widespread application of pre-splitting and roof-cutting technology by Chinese and foreign scholars and engineers in coal mining sites, the technology has been comprehensively developed in the coal mining field. Furthermore, four major application scenarios have gradually been derived: roof cutting and pressure releasing for gob-side entry driving and gob-side entry retaining, non-pillar self-forming roadway, cracking of hard and thick layer roof, and pressure relief of working face and the roadway; this paper presents a comprehensive summary of this technology in coal mining in recent years and systematically describes the basic methods, technical principles, mechanical mechanisms, and application scenarios. Currently, underground coal mines advocate the development of safe and green mining technologies with high recovery rates; this technology is widely used to increase recovery rates by reducing or eliminating pillars. Therefore, this paper takes the pre-splitting and roof-cutting technology that helps coal achieve efficient and green mining as the research object of the review and comprehensively analyses the current situation and development prospect of the application of this technology; it provides reference suggestions for the project experts who need this technology in the mining field to be applied more effectively in green coal mining.

Underground explosives equipment.

FORMS OF PRE-SPLITTING TECHNOLOGY FOR THE ROOF

The technology of pre-splitting and roof-cutting is to destroy the roof of the working face and roadway in advance to achieve the effect of releasing its stress concentration, and its core is to fracture the roof successfully. In the field, there are four primary forms of this technology: blasting pre-split technology, hydraulic fracturing technology, liquid CO_2 gas fracturing technology, and mechanical roof-cutting technology.

Pre-Splitting Roof Technology of Explosive Blasting

Directional Concentrated Blasting Technology

Drill-hole blasting applied in roof-cutting is different from regular blasting. As shown in **Figure 4**, the blast wave and energy of ordinary blasting spread from the centre of the hole to the surrounding area. Due to the anisotropy of the rock mass, the cracks around the hole are randomly extended after blasting. Although this is locally fractured in hard roof, the blast holes are not effectively connected and do not achieve the "cut-off" effect. Therefore, most field applications of bidirectional energy-gathered tensioning and forming blasting technology. The basic principle of this technology is to control the transmission of blasting shock and stress waves through the energy-gathering pipe, which generates high-pressure gas to stretch the fracture expansion directionally. Each blasting hole is blasted simultaneously, and the rock layer is cut off by producing directional fissures.

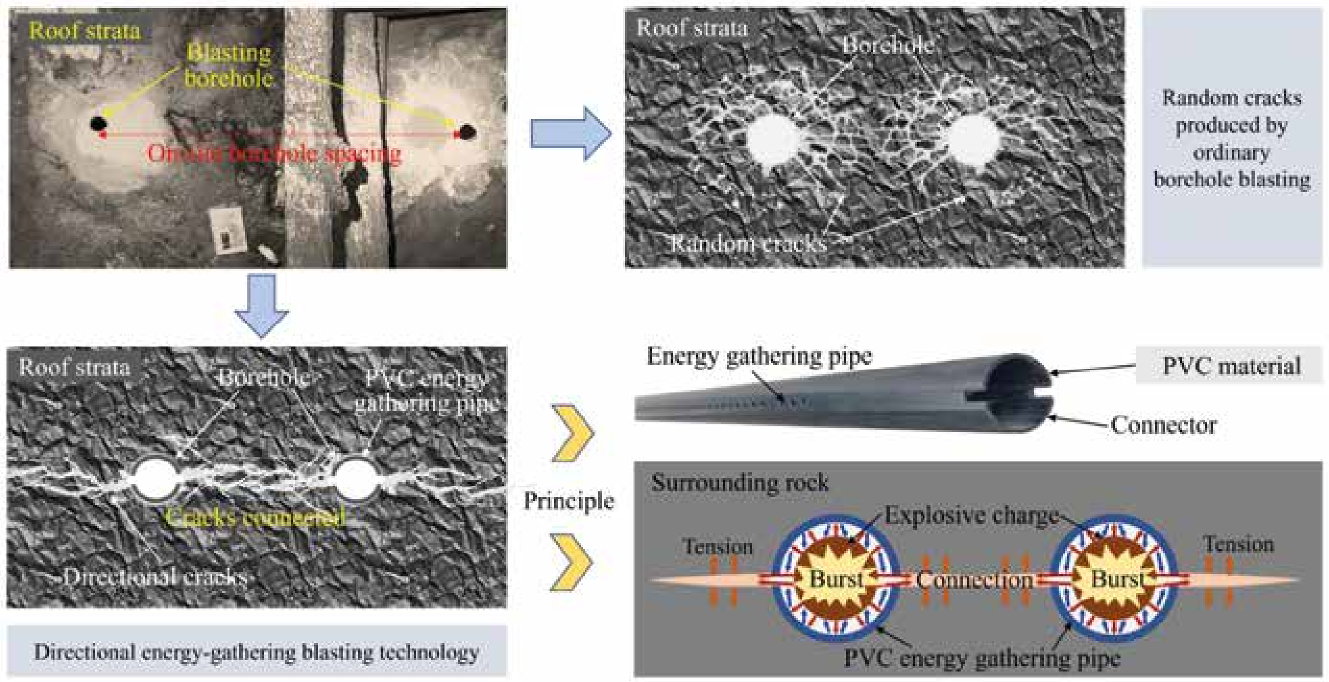

Figure 4: Directional concentrated blasting technology.

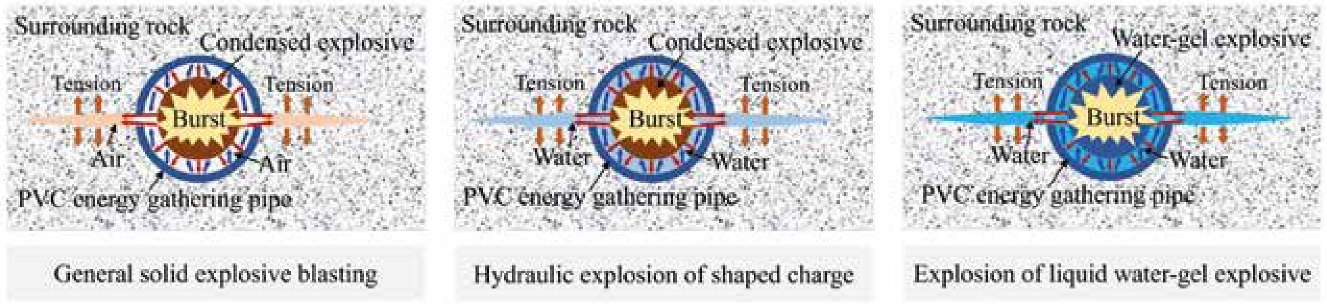

Figure 5: Charge structures of different blasting methods.

In ordinary directional energy-gathered blasting, the explosive is in a dry explosive environment, and its shock wave propagates in the air medium during blasting. Applying this method in underground coal mines generates lots of dust and toxic gases, which is not conducive to the green mining of coal. In order to overcome this drawback, the energy-gathered charge hydrodynamic blasting technology is gradually applied; it is the application of the water medium filled with explosives, the use of water to spread the explosive energy, which reduces the generation of coal dust and toxic gases while enhancing the blasting effect, and it becomes a green and safe method for directional roof-cutting.

Directional Pre-Splitting Technology of Liquid Explosive

Ordinary solid explosives dry blasting drawbacks, improved for water-filled pressure blasting, which is effective in gas and dust control, but still shows the explosive explosion instant power and cracking range is not enough. Therefore, liquid explosives blasting technology gradually developed, the structure of the three as shown in **Figure 5**.

Liquid explosives to achieve the pumping method of filling the blast hole, the explosive blast energy in the fracture during the explosion is continuously supplied, the rock breaking load in the seam is robust and long duration, conducive to the full development and expansion of rock fractures. In addition, compared with hydrogel explosives and emulsion explosives, the fracture density of the borehole wall of the surrounding rock after blasting is large, and the fractures are evenly distributed. Therefore, liquid explosives in coal mines with blasting the energy gathering pipe can achieve coupled charging in the pipe while playing the flow characteristics; its directional blasting fracturing effect and environmental protection are much better.

Directional Seam-Making Technology of Composite Blasting

In the actual roof-cutting work, the problem of precise and continuous fracturing of the hard and thick roof is often encountered, which requires the composite means of multiple blasting methods. For this reason, the composite blasting directional fracturing technology, which includes energy-gathered injection and high-pressure splitting, is gradually being applied in the field. The core device of this technology is a high-energy perforating gun, which needs to be installed at a certain depth of the blast hole, to be sealed after the excitation of the detonating cord to detonate the perforating bullet; its explosion also stimulates the rapid detonation of the composite propellant to produce high-pressure gas secondary splitting. The result is a radially continuous fracture surface with the fusion of holes and seams to achieve precise control of rock collapse of the roof.

Hydraulic Fracturing Pre-Splitting Roof Technology

Hydraulic Fracturing Principle

The roadway roof is drilled according to a certain elevation angle, and the radial cutting groove is prefabricated on the

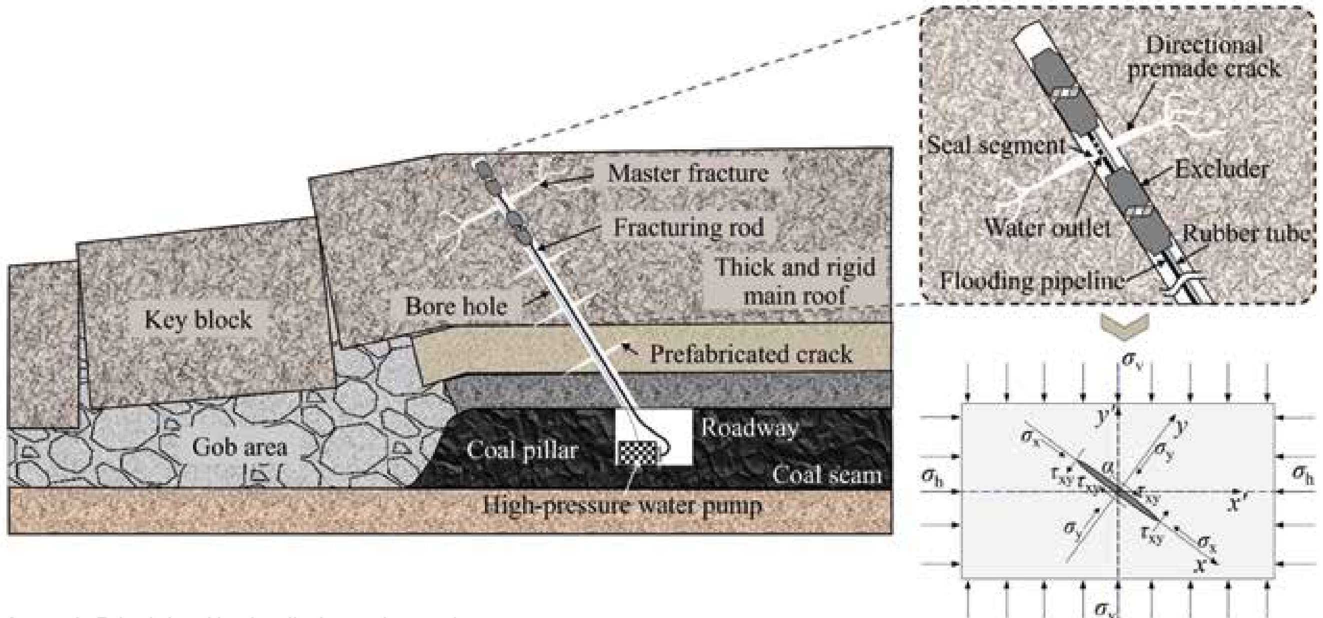

Figure 6: Principle of hydraulic fracturing rock.

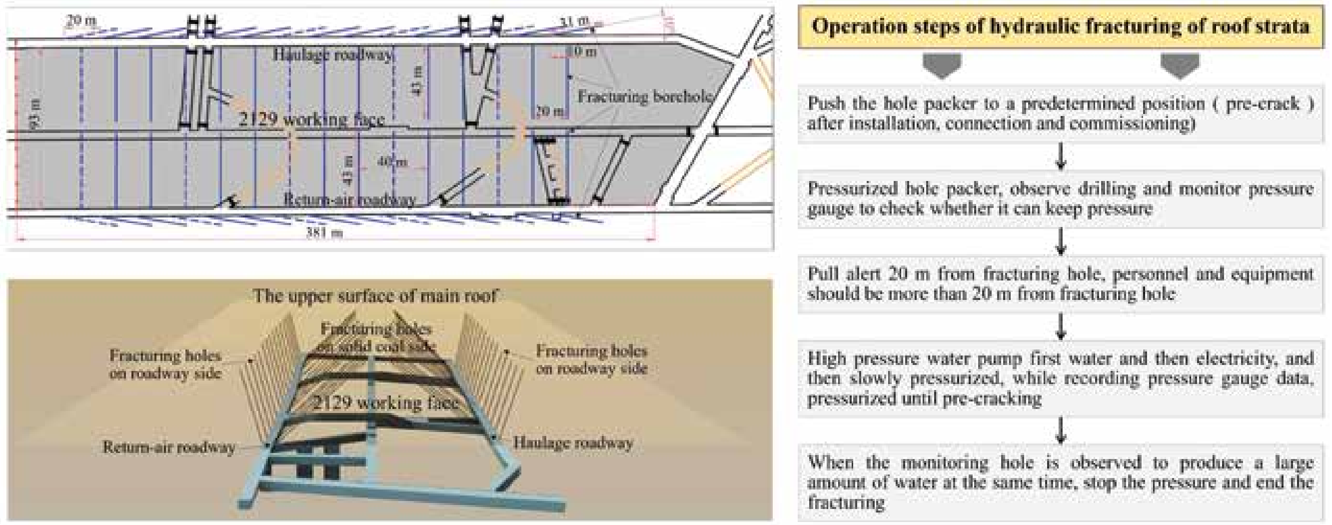

Figure 7.: Hydraulic fracturing technology for roof cutting.

inner wall of the borehole. After that, the hole is sealed, and the high-pressure water pump is used for water injection fracturing. The roof rock layer cracks and expands, and the crack generated by other boreholes is connected to achieve the effect of cutting off the roof; its core is that the surrounding target rock is pre-cut and fractured by high-pressure pre-water injection, thus weakening the overall strength.

As shown in **Figure 6**, for the pre-splitting surrounding rock, the pre-cutting groove is drilled first, and then the two sides of the groove are sealed by the packer, and then the high-pressure water is injected into the sealing fracturing section to realize fracturing of the surrounding rock. Concerning the fracture initiation mechanism, through the force analysis of the coin-shaped crack section, the initial conditions of the coin-shaped fracture in the water-saturated and natural state are obtained:

where *a* is the radius of coin-type fracture, mm; σV and σh are vertical stress and minimum horizontal principal stress, respectively, MPa; α is the elevation angle of the borehole, α∈(0°~90°); K_{ICW} and K_{ICN} are the type-I fracture toughness values under full water and natural state; PW and PN are the water pressure of groove initiation, MPa; μW and μN are Poisson's ratio; for parameter k, σV > σh takes an even number, and vice versa takes an odd number. As a result, the trench inclination or borehole elevation angle α, which is most favourable for fracture initiation in hydraulic fracturing, can be calculated under different surrounding rock and stress environments.

Application of Hydraulic Fracturing Technology

The hydraulic fracturing technology includes fracture hole drilling, hole trenching, hole sealing, roof hydraulic fracturing, and effect monitoring. As shown in **Figure 7**, the 2129 working face has a thick and hard main roof rock layer, designed to be hydraulically fractured to the full extent of the top slab prior to its mining to attenuate the impact of solid rock pressure from the hard roof.

The straightforward steps of the hydraulic fracturing process: firstly, drilling is carried out with a geological drilling rig, and after the drilling is completed, the drilling team will proceed with the next drilling operation. Then a sealer is installed in the completed hole, and the hole is sealed with a manual pump and an energy reservoir. Finally, a high-pressure pump is connected for fracturing. The fracturing of the coal seam to be mined and the hard roof above the roadway is achieved, after which the working face can be advanced and mined; this method is safe, does not produce toxic gas and dust, and is gradually being more widely accepted at coal mine sites.

Liquid CO2 Gas Pre-Splitting Roof Technology

CO_2 gas phase pre-fracturing refers to the rapid conversion of CO_2 from liquid to gas by a high-pressure detonation head and its instantaneous volume expansion pressure to fracture rock along the fracture face.

As shown in **Figure 8**, liquid CO_2 is stored in a storage tank, which requires an environment with p > 7.35 MPa and T < 31°C to maintain the liquid form. The volume of liquid CO_2 in the fracture expands 600 times in 20 ms under the action of the heating device, creating an expansion pressure of 80-270 MPa to fracture the rock. Quick steps of liquid CO2 blasting: After the heating device is activated, the liquid CO2 in the storage tank expands and destroys the fixed pressure shear sheet. CO2 is released sharply and generates low temperature and high-pressure gas to act on the pre-fractured part to realize pre-fracture blasting [58]; this method has excellent continuity, does not quickly produce a lot of dust and sparks, has apparent safety and environmental advantages, and is currently being applied in complicated rock fracturing in the excavation and recovery workings.

Mechanized Directional Roof-Cutting Technology

Continuous Cutting Technology of Chain Arm Saw Machine

The continuous cutting machine with a chain arm saw cuts the rock in a specific direction and inclination with low-speed chipping; it considers both ductile and brittle cutting methods, and the cutting head can make extrusion and shear damage to the rock body, thus forming a continuous through-cutting slit and achieving precise directional cutting of the top slab.

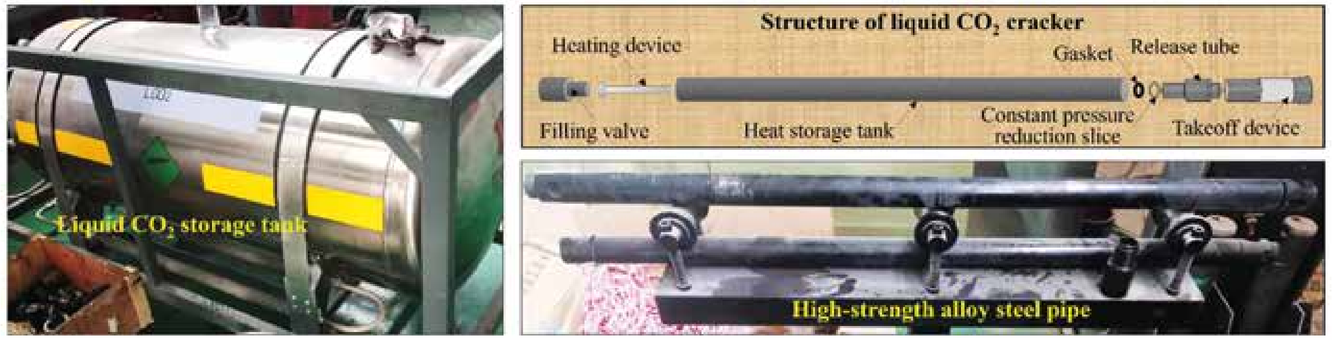

Figure 8: Liquid CO_2 storage tank and cracker.

This method has a high degree of mechanization and can directly cut the roof by remote directional control, and continuous operation reduces the time of cutting the roof. The low-speed chipping way avoids spark generation and does not consume much water; the mechanical cutting is highly accurate, and the cut surface is smooth and flat. The development of mechanized roof control is an essential step to intelligent mining in coal mines, and the continuous cutting technology of chain arm saw gives an application idea.

Application of Directional Cutting Roof Rig

The directional roof cutting drilling rig is the mechanized roof cutting equipment developed by Academician He Manchao's "N00" construction method; it has the crucial technology of simultaneous drilling in multiple holes and dynamic adjustment in multiple directions, which realizes multi-hole with the same surface and efficient cutting. According to the field test, it effectively cuts off the stress transfer between the goaf's roof and the roadway's roof so that the roof of the roadway is in a specific range to form a short arm beam structure. The method is being gradually improved, popularized, and applied.

PRE-SPLITTING AND ROOF-CUTTING TECHNOLOGY FOR NON-PILLAR MINING

The method of non-pillar mining can significantly improve the coal recovery rate and reduce the waste of coal resources, which is in line with the concept of high-efficiency and green mining and has been extensively applied in the field.

Application in Gob-Side Entry Driving

Gob-side entry driving means that a narrow coal pillar (3~8 m) is set on one side of the last working face to drive the roadway of the next working face.

As shown in **Figure 9a**, the main roof break appears "O-X" shape in the plane when the working face is mined. The roadway and narrow coal pillar are under the "triangle" key block in gob-side entry driving. According to the support practice of gob-side entry on-site, the gob-side

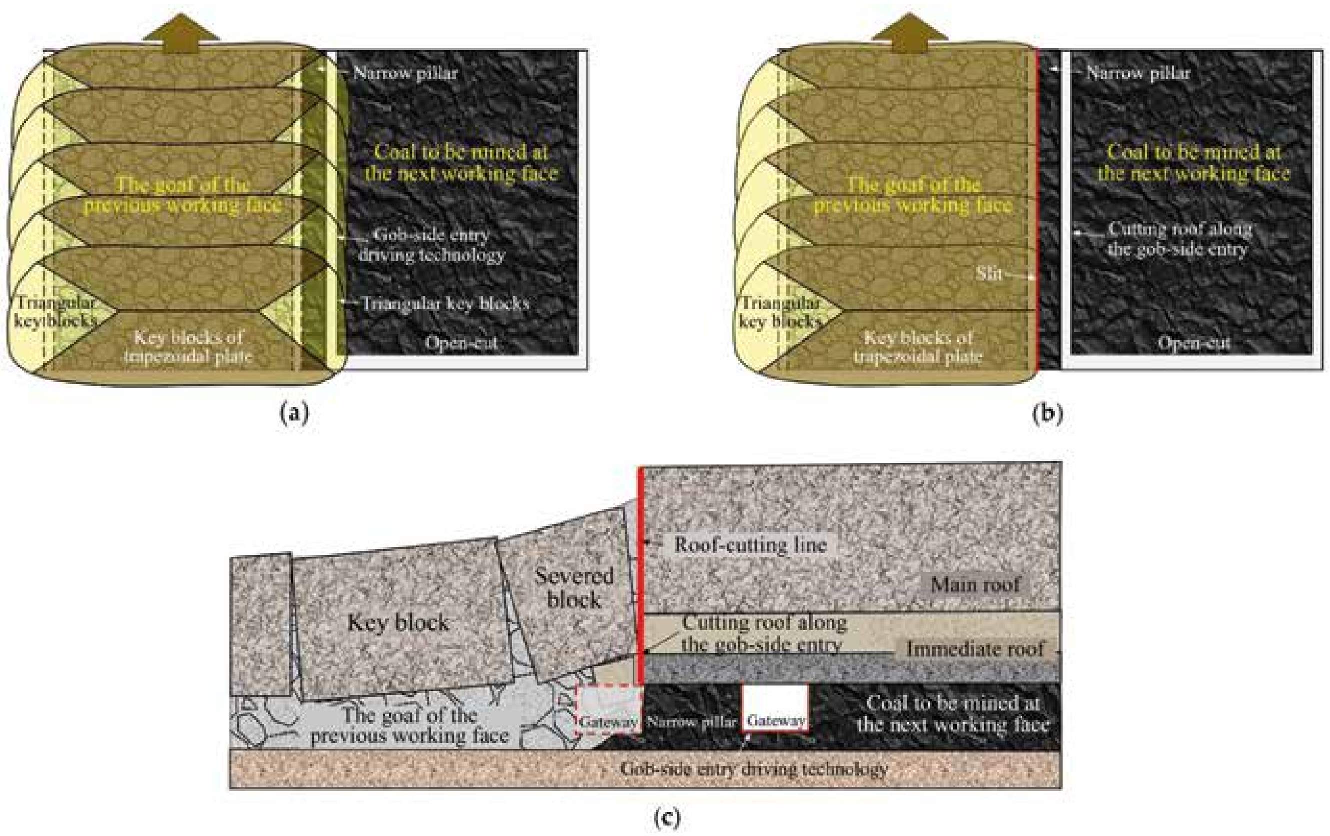

Figure 9: The schematic diagram of roof-cutting for gob-side entry driving. (a) Roof structure without roof cutting (b) Roof structure after roof cutting (c) Cutting roof and unloading the pressure along the gob-side entry.

ROOF CUTTING CONTROL

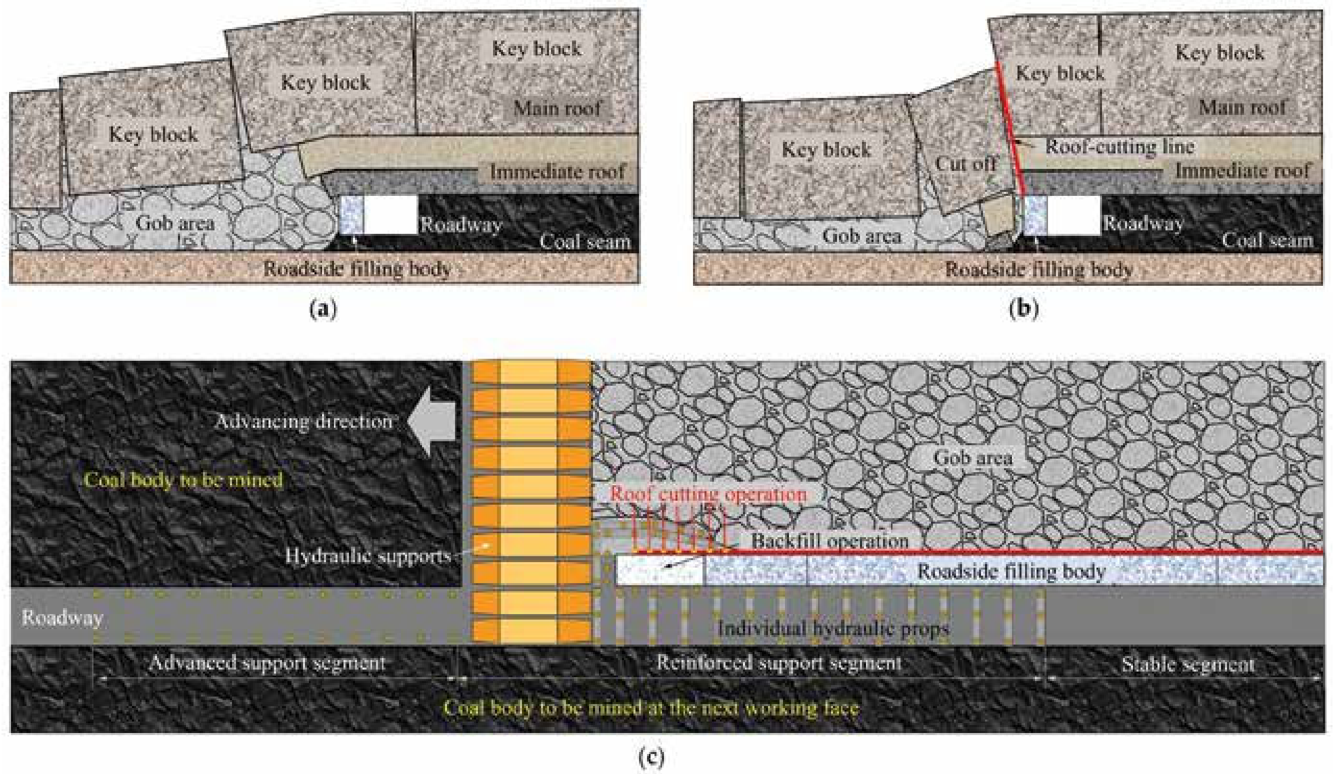

Figure 10: Delayed pre-splitting and cutting roof for gob-side entry retaining. (a) Gob-side entry retaining with backfill (b) Cutting roof on goaf side (c) Working methods of roof-cutting and gob-side entry retaining with backfill.

entry is disturbed strongly by the superimposed stress, and its maintenance is quite tricky. The key influencing factor of mining pressure behaviour in gob-side entry driving is the fracture position of the "triangle" key block. The unfavourable fracture position directly leads to large deformation of the roadway and roof collapse. Therefore, it is necessary to actively control the fracture location of critical blocks to alleviate the concentrated stress in the roadway, as shown in **Figure 9b**.

As shown in **Figure 9c**, in the mining face, the subsequent mining face side of the roadway driving along the goaf to carry out the pre-splitting operation, the location of roof cutting is in the narrow coal pillar side of the roof. When a section of the roadway roof cutting operation is completed, and the roof collapse in the goaf is stable simultaneously, the roadway digging operation along the goaf. Attention should be paid to the replacement relationship between the mining operation of the previous working face and the tunnelling operation of the next working face to ensure that the safety distance is maintained. According to the field practice, the stress concentration degree along the empty roadway of this method is small, and the roadway support effect is practical, ensuring the roadway roof's safety.

Application in Gob-Side Entry Retaining

The gob-side entry retaining technology realizes the succession of the completely non-coal pillar between working faces, an efficient and green mining technology that is booming and applying.

Gob-Side Entry Retaining with the Filling Body

This gob-side entry retaining method uses an artificial filling body as a narrow coal pillar in gob-side entry driving. The filling bodies include high water material, paste material, and concrete.

Delayed pre-splitting and cutting roof

As shown in **Figure 10a**, the force on the filling body is similar to that on the narrow coal pillar in the gob-side entry driving. At this moment, the roof structure and fracture state of the gob-side entry is similar to that of gob-side entry driving, which still leads to roadway maintenance difficulties. In order to reduce the pressure of the filling body and make the roof entirely collapse, pressure relief blasting technology with circular shallow holes is used, as shown in **Figure 10b**. After mining, a row of round holes is drilled towards the goaf next to the filling body about 20 cm to carry out energy-accumulating blasting. As a result, the roof above the mining area collapses, falls, and then compacts and continues to support the overlying rock layer, as shown in **Figure 10c**.

The disadvantage of this method is that it interferes with the parallel operation of mining and filling of the working face, which cannot realize the fast and high-intensity operation of the comprehensive mining face.

Advance pre-splitting and cutting roof

The method of roof-cutting along the side of the roadway to be mined is the most commonly used in the field before mining the working face. As shown in **Figure 11a,b**, setting the filling body in the roadway for gob-side entry retaining, the main roof structure above the roadway and the filling body is more integral and stable after cutting the roof in advance. According to the size of roadway and backfill, ample ventilation, and laneway equipment size, roadway expansion measures are often taken to ensure that the roadway size is reasonable, as shown in **Figure 11c**; this

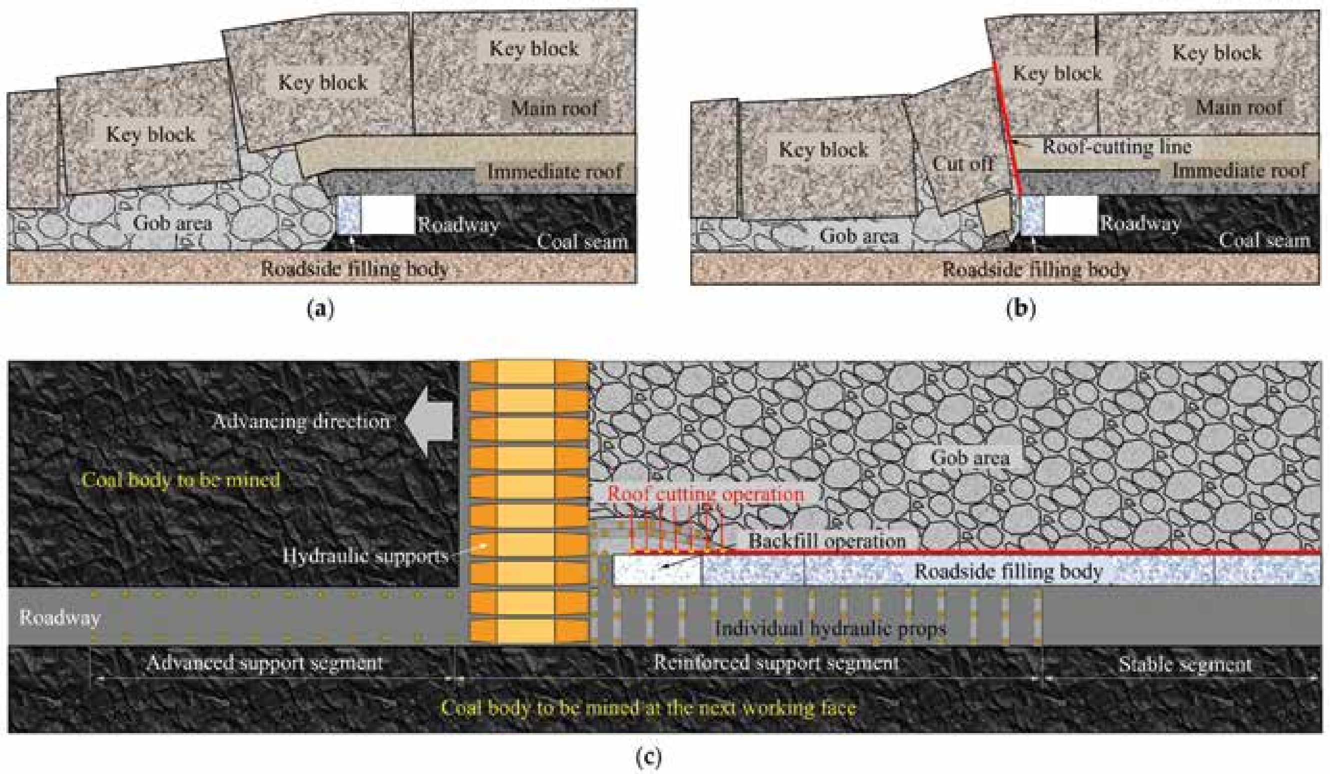

Figure 11: Advance pre-splitting and cutting roof for gob-side entry retaining. (a) Gob-side entry retaining with backfill (b) Roof cutting operation in advance (c) Working methods of roof cutting in advance and gob-side entry retaining with backfill.

method can be applied in thick coal seams, soft rock, and deep high-stress environment.

Completely Gob-Side Entry Retaining

The method of fully gob-side entry retaining means not leaving the roadside filling body, using a specific prop or single pillar to support the roof of the goaf side, and setting up gangue protection and Air leakage prevention device. Compared with cutting the roof of retaining roadway leaving narrow coal pillar and roadside filling body, this method is more straightforward; it fully uses mining pressure and rock mass fragmentation to realize automatic lane formation.

Cutting roof for retaining roadway with advance pre-splitting

During the working face mining period, pre-fracturing and roof-cutting are overrun along the solid coal side in the roadway to weaken or release the physical-mechanical connection between the roadway's roof and the gob's roof, as shown in **Figure 12a,b**; it is supported by a temporary prop (portal prop) with a single pillar to provide upward support resistance. The roof of the gob area is cut down as a whole by using mining pressure and artificially created roof-cutting cracks in advance. The roadway is under a complete and stable cantilevered structure, as shown in **Figure 12c**. According to the mechanism of roof-cutting and roadway-retaining, the site is usually divided into three operational phases: the pre-cracking and roof-cutting stage, the reinforcement support stage, and the stabilization stage of the left roadway. The three stages correspond to various locations, so parallel operations are realized between the processes, which will significantly improve the efficiency of the left roadway. Since this method does not require the setting of a filling body, this has negligible effect on the advancing speed of the working face; this method is being applied under the conditions of different coal seam thickness, burial depth, dip angle, and roof conditions, and it has become a hot spot in the research of no pillar mining methods.

Combined support for cutting roof retaining roadway

For special roof conditions (e.g., thick direct roof), the pre-fracturing and roof-cutting can be re-optimized. For the working face with a thick immediate roof, the roof breaks down and collapses after working face mining. Due to the fragmentation of rocks, the collapsed rock can adequately fill the goaf. At this time, the combined support can be used to achieve roof cutting and roadway retaining, that is, to strengthen the support of the roadway to be retained in advance; it mainly includes the firm anchoring of the deep hole of the high-strength bolt cable on the roof and the support on the goaf side (π-shaped steel, the cross-hinged roof beam, and the single pillar of the gob-side entry retaining); they provide robust support resistance and use the mining pressure of the working face to realize the cutting of the immediate roof of the goaf side and fill the goaf to complete the roadway retaining operation. The overall approach covers four technologies: combined support roof-cutting technology, advanced-area reinforcement support technology, prevention, control technology of gangue in goaf, and beam-column auxiliary support technology of roadway [81,82].

This method directly eliminates the process of over-advance pre-fracturing and roof-cutting; meantime, it avoids the impact on the working face advancement efficiency due to blasting or hydraulic fracturing, which realizes the efficient retention of the roadway with the rapid advancement of the

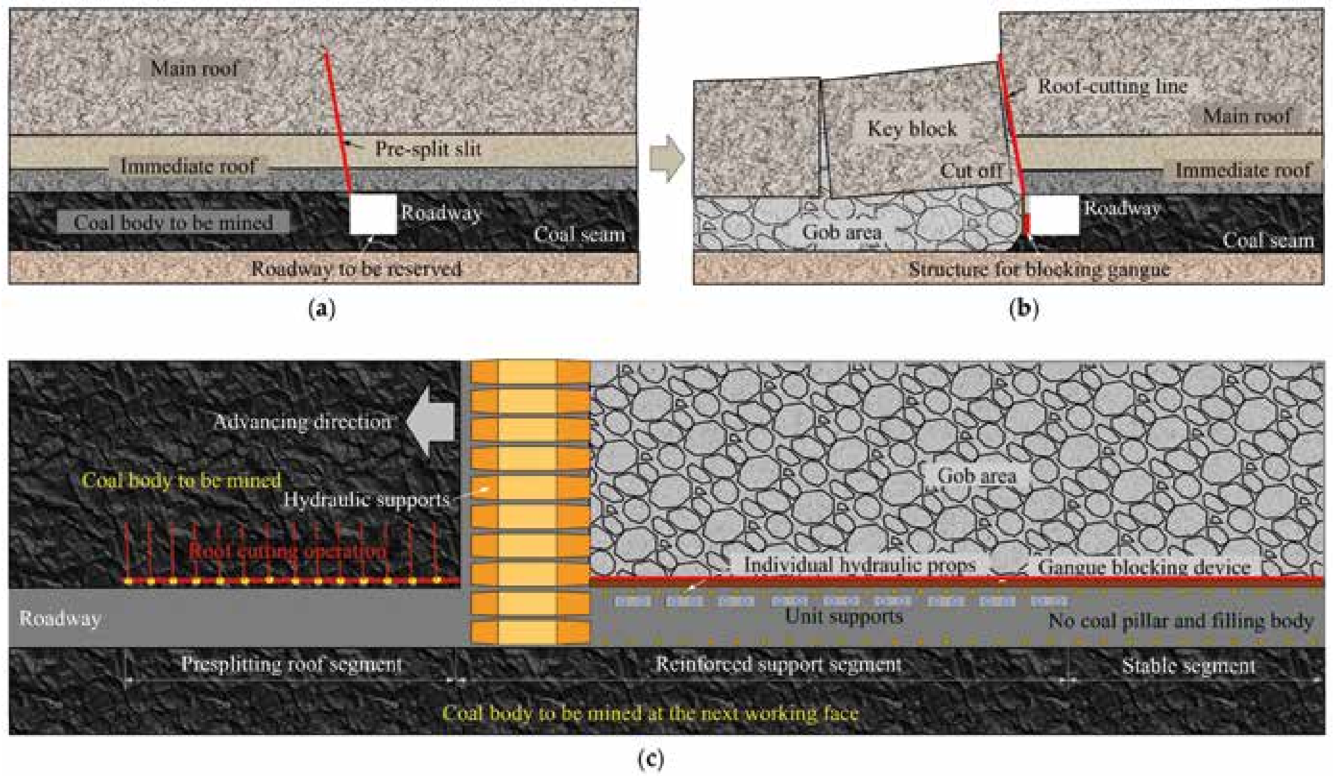

Figure 12: Gob-side entry retaining technology without coal pillar and filling body. (a) Pre-splitting roof in advance of the working face (b) Cutting roof to form roadway automatically (c) Working methods of roof cutting in advance and gob-side entry retaining with no-pillar.

working face. Although its application conditions are still limited at present, its method indicates the future need to develop a mechanized way of cutting the roof and leaving the roadway without blasting.

"N00" Construction Method

The "N00" coal mining method efficiently combines the working face mining and roadway tunnelling to realize the mining of N working faces, the tunnelling of 0 roadways, and the retaining of 0 district sublevel coal pillars, as shown in **Figure 13** [32]. In this method, the working face is mined to form the next working face's roadway, and the roadway's roof along the goaf is treated by pre-splitting and roof cutting. The directional cutting method, such as energy-accumulating blasting, was successful at the initial test stage; however, due to the large-scale blasting operation behind the working face, there are hidden dangers to safety. After that, the team researched and developed the supporting equipment for the "N00" method and developed a directional roof-cutting rig, which is located on the side of the left-over roadway and follows the hydraulic support of the working face to push forward the roof-cutting operation.

In addition, with the roof-cutting prop to support the roof on the side of the mining area of the roadway, to achieve automatic mechanical connection of coal mining, roadway formation, roof-cutting and pressure relief, support, and other processes of the working face; this method is being gradually improved and promoted in the field, providing a complete set of solutions to achieve coal pillar-free automated mining in new mining areas ultimately.

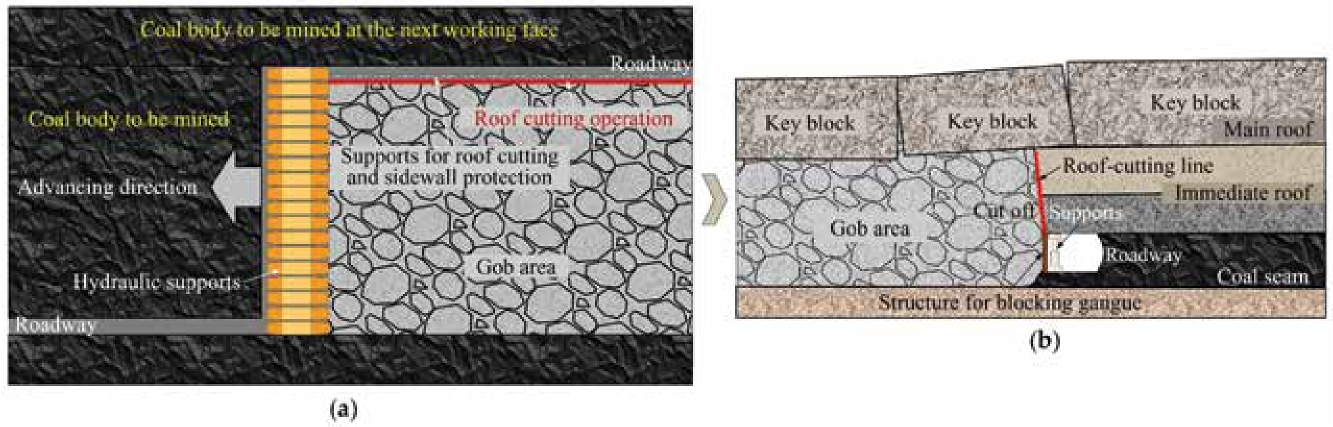

Figure 13; Cutting roof and retaining roadway technology in the "N00" construction method. (a) Plane diagram of "N00" construction method (b) The diagram of the retained roadway.

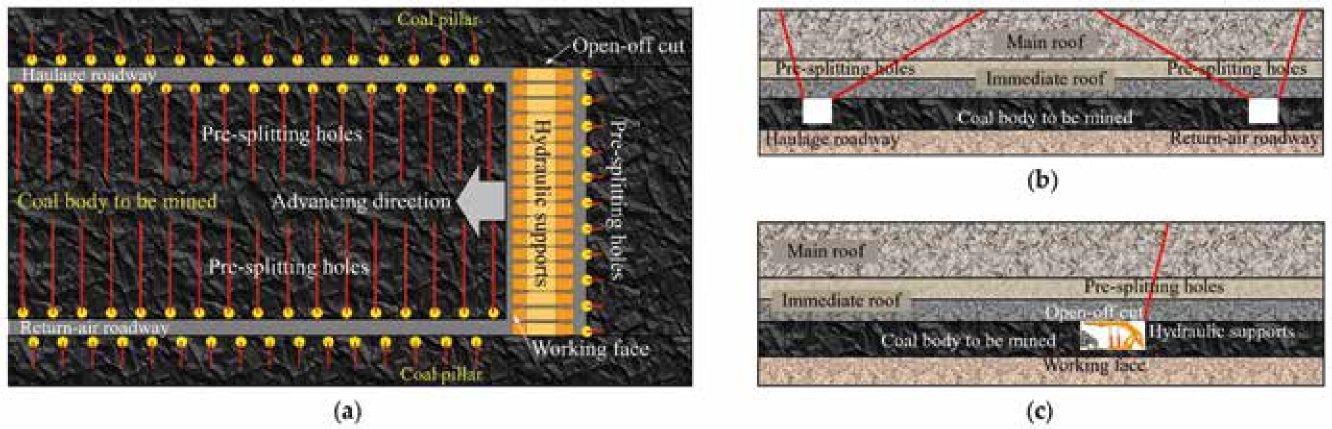

Figure 14: Fracturing operation of the thick and hard main roof. (a) Plane diagram of pre-splitting drilling hole (b) Side view of boreholes in roadway (c) Side view of boreholes in the open-off cut.

PRE-SPLITTING AND ROOF-CUTTING TECHNOLOGY FOR PRESSURE RELIEF MINING OF WORKING FACE

The hard roof is often encountered when the long wall working face is mined. The hard roof is difficult to collapse, and the support of the working face continues to bear the high load, which requires pre-cracking and unloading the roof.

Fracturing Operation of Thick and Hard Main Roof

The physical and mechanical properties of the main roof above the coal seam directly affect the smooth mining of the longwall working face. With the increase of mining depth, the stress level during coal seam mining gradually increases. For the coal seam with a thick and hard main roof, the weighting step and pressure of the main roof increase significantly when the working face is mined. The intense pressure threatens the safety of equipment and workers, such as hydraulic support in the working face. Therefore, the pre-splitting operation is usually carried out before the mining face for the thick and hard main roof.

As shown in **Figure 14**, the main roof rock is pre-cracked by hydraulic fracturing, and the crack location includes the roof of the coal body to be mined, the roof of the roadway on both sides, and the roof of the working face's open-off cut. After the main roof's pre-splitting, the working face's

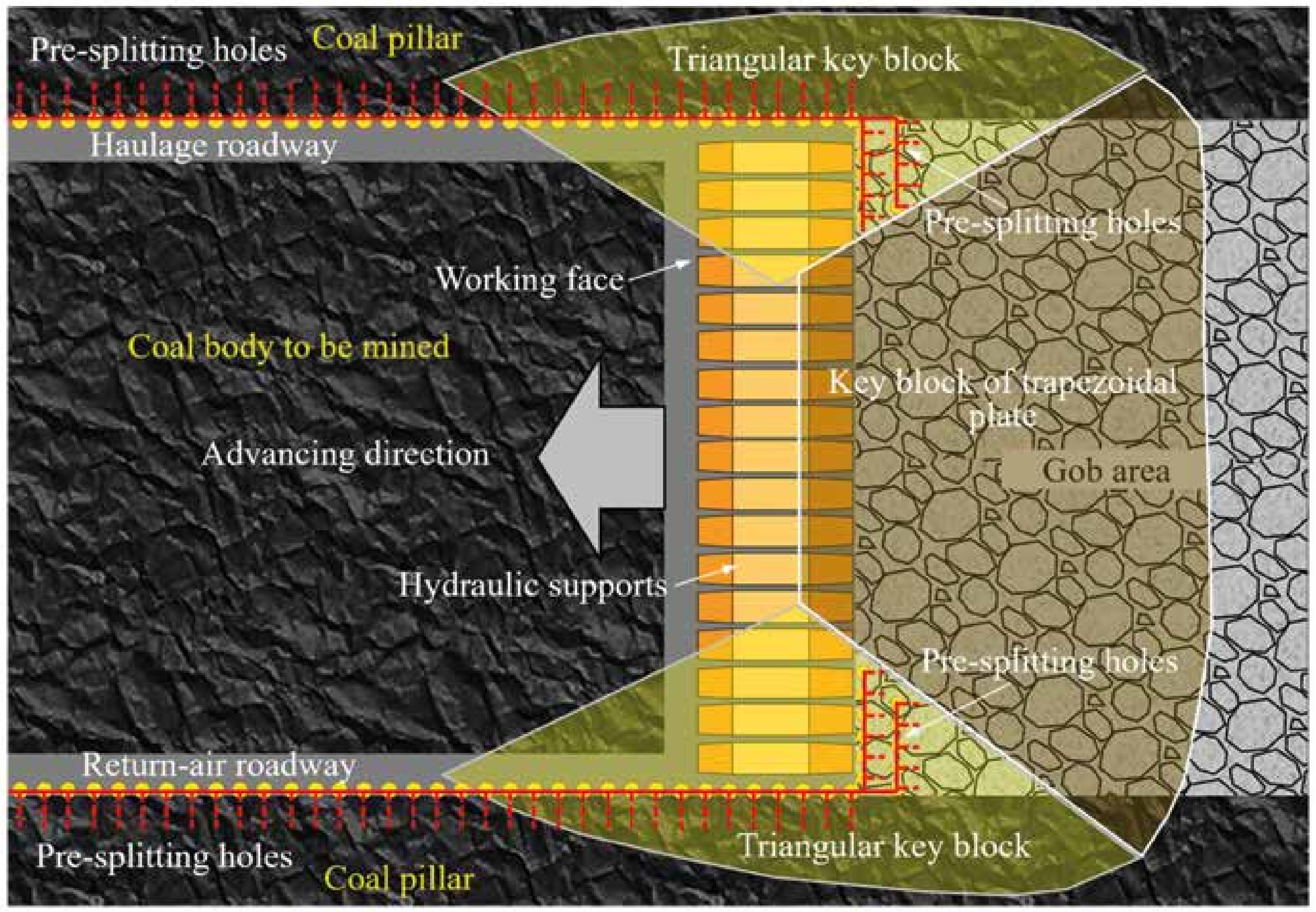

Figure 15: Fracturing operation of a hard roof at the end of the working face.

coal wall pressure is slight during the waiting period. The shrinkage of the pillar is minor, and the roof collapse is closely followed by the support, indicating that the main roof activity is not intense during the fracturing; this method has been widely used in pressure relief mining of working faces with the thick and hard main roof.

Fracturing Operation of Hard Roof at the End of the Working Face

For the broken roof of the longwall working face, there is a "triangle" key block structure in the end area. When the roof of the working face is hard, it is often challenging to collapse on both sides of the roof, resulting in an excessive hanging roof area. Improper treatment will cause air leakage in the working face, gas accumulation in the goaf, and sudden caving of the sagging roof. Therefore, the hard roof at the end side should be cracked in time, and the borehole layout is shown in **Figure 15**. Due to the goaf behind the end support, there is a risk of explosive blasting, and hydraulic fracturing is generally used to crack the roof. According to the field practice, in the subsequent mining process, the end top plate, after cracking, is no longer suspended but gradually collapses with the advance of the end support, which dramatically reduces the pressure of the support and achieves a good pressure relief effect.

PRE-SPLITTING AND ROOF-CUTTING TECHNOLOGY FOR ROADWAY'S PRESSURE RELIEF

For gob-side entry, tunnelling entry, and deep roadway with a high-stress environment, standard support methods are often tricky to work, and active pressure relief is needed for the position of a continuous deformation.

Large Deformation of Roadway along Goaf

When one side of the working face is being mined, the phenomenon of large deformation occurs in the local area of the roadway along the goaf of the adjacent digging face, especially in the roadway section within the influence of the working face mining, which rate is speedy and challenging to control. In order to reduce the influence of mining-induced stress on gob-side entry as much as possible, pre-splitting and roof-cutting operations are designed in the adjacent roadways of this working face. The borehole layout is shown in **Figure 16**. By cutting the roof in advance, the continuous structure between the working face and the roof of the gob-side entry is severed, hindering mining-induced stress transmission. Thus, the surrounding rock stress environment of the roadway along the goaf is improved, and the stability of the roadway can be successfully maintained by reinforcing the support means. Pre-splitting and cutting the roadway's roof in the overhead section of the working face to unload the pressure for the roadway along the goaf is commonly implemented in the field, which has become an important method to control the large deformation of the roadway along the goaf.

Blasting Pressure Relief Technology for Roadways

The deformation characteristics have apparent continuity and persistence for the deep high ground stress and robust rheological environment of the roadways. The general reinforcement support method cannot prevent the rheological characteristics of the surrounding rock, and the roadway needs to be expanded and repaired many times. At this point, the key to controlling deformation is to relieve pressure and cut off the transmission path of continuous high stress. As shown in Figure 17, illustrates three blasting methods to relieve pressure to cope with substantial deformation of the roof, gangs, and floor. Blasting to relieve pressure means creating cracks by blasting to destroy the integrity and continuity of the rock to release the concentrated stress and cut off the stress transmission path to control the rheology of the surrounding rock in the roadway.

For the pressure relief of the roadway under the complex high-stress environment, concentrated drilling is often carried out in the surrounding rock of the complex high-stress area. The small-scale pressure relief and fracture area are generated through the deformation and collapse of the drilling hole. At present, directional pre-splitting and roof-cutting pressure relief technologies such as concentrated energy blasting and hydraulic fracturing have been widely applied. According to different surrounding rock environments and the mechanical properties of rock mass, a reasonable pressure relief method is selected to better realize the stability of the roadway under complex conditions.

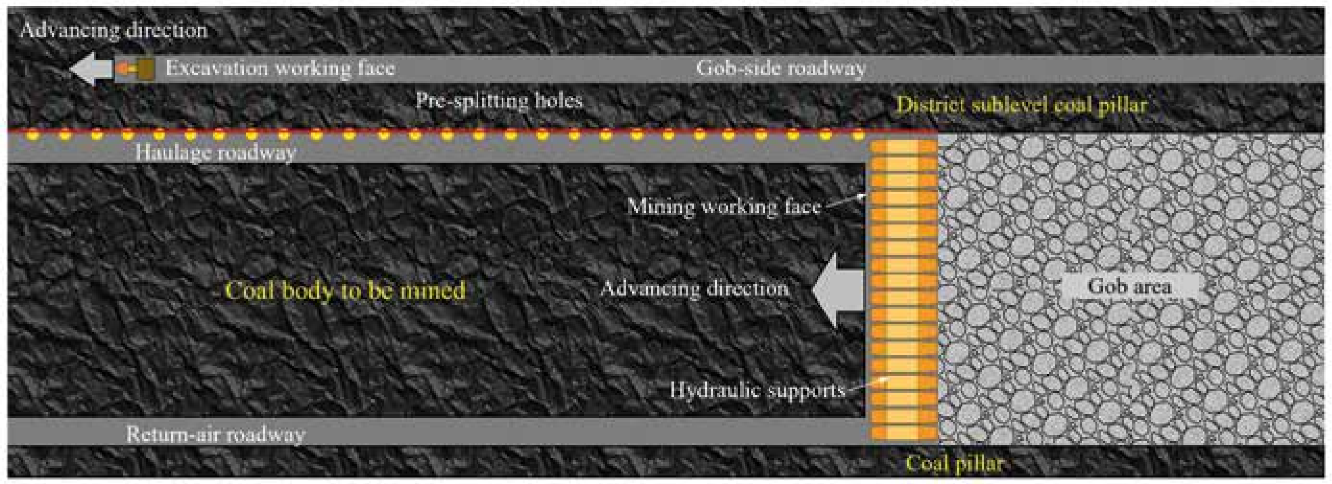

Figure 16: Pressure relief technology of roof-cutting for large deformation of roadway along goaf.

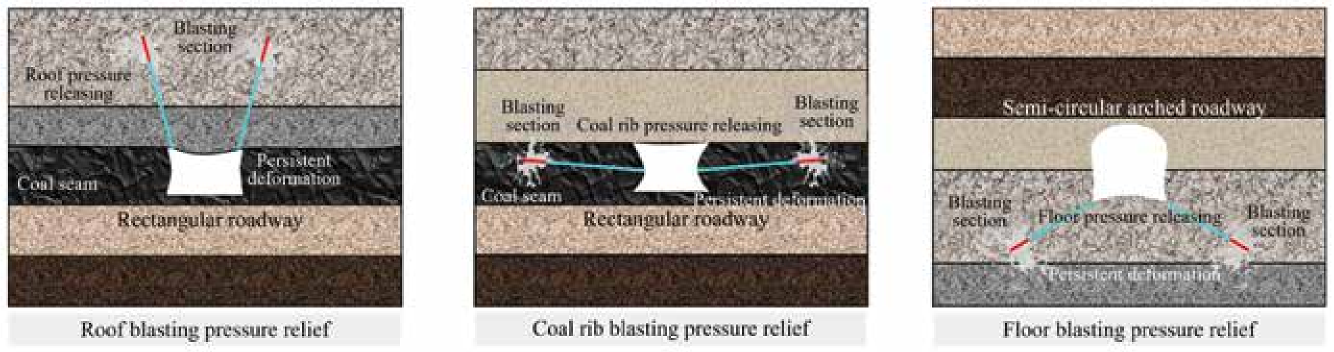

Figure 17: Blasting pressure relief technology for roadways.

With the development of the method, the internal pressure relief method and hydraulic pressure relief method of roadway surrounding rock are gradually evolved, which have achieved outstanding field application effect in controlling deep continuous deformation roadway.

DISCUSSION

This paper summarizes the four forms of application of pre-splitting and roof cutting technology (explosive blasting, hydraulic fracturing, liquid CO_2 gas fracturing, and mechanized roof cutting) and elaborates its process in three major fields (non-pillar mining, working face's pressure relief, and roadway's pressure relief). The following conclusions and prospects are obtained:

1. The pre-splitting method of explosive blasting has gradually developed to low pollution, low dust, high precision, and high safety. The methods of water-filled pressure blasting, liquid explosive blasting, and liquid CO2 gas phase blasting improve environmental protection and safety significantly. The composite blasting form is committed to establishing a continuous fracture surface to achieve precise roof cutting.
2. Hydraulic fracturing technology is gradually becoming increasingly widespread in the application of hard-roof fracturing, especially in roof pre-splitting near the working face and the goaf; this method does not produce toxic gas and dust, which has high application safety for gas mines.
3. The research hotspots of pre-splitting and roof cutting focus on pressure relief technology and gob-side entry retaining technology. For deep high-stress mining environments, applying roof pre-splitting technology will be more widely, including the safe replacement of deep coal seam working face, deep hard roof cracking, and deep roadway pressure relief.
4. As an essential step of non-pillar mining, pre-splitting and roof cutting technology is also developing towards mechanized roof cutting, while the mining method is mechanization and automation. The research, development, and application of the chain arm saw machine and directional cutting roof rig are representative; it is anticipated that the future pre-splitting and roof-cutting technology will balance precision, automation, and greening, which will help the development of intelligent and unmanned mining.

Outlined below is a sample of references provided with this article, should you wish to seek further references please use the link provided: Application of Pre-Splitting and Roof-Cutting Control Technology in Coal Mining: A Review of Technology (mdpi.com)

REFERENCES

1. He, M.; Wang, Q.; Wu, Q. Innovation, and future of mining rock mechanics. J. Rock Mech. Geotech. Eng. 2021, 13, 1-21.
2. Yu, B.; Tai, Y.; Gao, R.; Yao, Q.; Li, Z.; Xia, H. The sustainable development of coal mines by new cutting roof technology. R. Soc. Open Sci. 2020, 7, 191913.
3. Ma, Z.; Wang, J.; He, M.; Gao, Y.; Hu, J.; Wang, Q. Key Technologies, and Application Test of an Innovative Noncoal Pillar Mining Approach: A Case Study. Energies 2018, 11, 2853.
4. Wang, E.; Xie, S. Determination of coal pillar width for gob-side entry driving in isolated coal face and its control in deep soft-broken coal seam: A case study. Energy Sci. Eng. 2022, 10, 2305–2316.
5. Xie, S.; Gao, M.; Chen, D.; Sun, Y.; Pan, H.; Su, H.; Lan, S. Stability influence factors analysis and construction of a deep beam anchorage structure in roadway roof. Int. J. Min. Sci. Technol. 2017, 28, 445-451.
6. Xie, S.; Pan, H.; Zeng, J.; Wang, E.; Chen, D.; Zhang, T.; Peng, X.; Yang, J.; Chen, F.; Qiao, S. A case study on control technology of surrounding rock of a large section chamber under a 1200-m deep goaf in Xingdong coal mine, China. Eng. Fail. Anal. 2019, 104, 112-125.
7. Chen, D.; Wang, E.; Xie, S.; He, F.; Wang, L.; Zhang, Q.; Wu, X.; Jiang, Z.; Li, Y.; Shi, S. Roadway surrounding rock under multi-coal seam mining: Deviatoric stress evolution and control technology. Adv. Civil Eng. 2020, 2020, 9891825.
8. Kang, H.; Zhang, X.; Wang, D.; Tian, J.; Yi, Z.; Jiang, W. Strata control technology and applications of non-pillar coal mining. J. China Coal Soc. 2022, 47, 16-44.
9. Qian, M.; Miao, X.; Xu, J. Theoretical Study of Key Stratum in Ground Conrol. J. China Coal Soc. 1996, 21, 2-7.
10. He, S.S.; Xie, S.R.; Song, B.H.; Zhou, D.Q.; Sun, Y.D.; Han, S. Breaking laws and stability analysis of damage main roof in close distance hypogynous seams. J. China Coal Soc. 2016, 41, 2596-2605.
11. He, F.L.; Chen, D.D.; Xie, S.R. The kDL effect on the first fracture of main roof with elastic foundation boundary. Chin. J. Rock Mech. Eng. 2017, 36, 1384-1399.
12. Chen, D.D.; Guo, F.F.; Wu, Y.Y. Study on the first fracture of the main roof plate structure with one side goaf and elastic-plastic foundation boundary. J. China Coal Soc. 2021, 46, 3090-3105.

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Unpleasant plumes: dust control at the conveyor load zone

When tons of raw or processed coal hit a moving conveyor belt, three things happen: fines scatter in random directions, cargo shifts and dust becomes airborne. The impact creates turbulent air pressure inside the chute that seeks to escape from any gap it can find, carrying dust and fines with it. A properly designed enclosure will manage bulk solids, allow cargo to settle in the center of the belt and contain most of the dust inside a settling zone enclosure.

Well-designed conveyor loading zones keep walkways clear from spillage, control dust emissions and allow hazard-free inspections and maintenance. Operators need only take a broad look at the expense that fugitive material contributes to a system to realize the full cost that accompanies inefficient transfer point designs. Problems such as improper belt support, badly sealed chutes, damaged idlers and uneven cargo distribution all result in spillage and belt mistracking, contributing to increased costs for maintenance and cleanup, the potential for injury and compliance issues.

THE COST OF SPILLAGE

If left uncontained, fugitive material in the form of dust and fine particle spillage will increase labor costs for cleanup, foul equipment, potentially encapsulate the belt and pose a serious safety hazard.[**Figure 1**] A dirty and dusty environment also discourages workers from doing regular maintenance on the problem area and negatively affects morale.

Since trips and falls are regularly among the most common workplace accidents, Occupational Safety and Health Administration (OSHA) as well as Mine Safety and Health Administration (MSHA) inspectors are constantly on the lookout for those hazards. Spillage surrounding the loading zone is an easy violation to spot, in severe cases blocking access to the system and exacerbating the hazards of working near a moving belt.

Dust levels are also strictly regulated by OSHA, and permit violations are often accompanied by fines and potential

Figure 1: With the proper enclosure design, dust volumes can be lowered to below regulatory levels.

downtime. In many industries known for dust generation, workers wear personal dust monitors to measure particulate levels throughout their shifts. Working within proximity of poorly designed loading zones can cause monitored levels of PM10 (particulate material <10 microns in size) to exceed allowable limits.

SEALED CHUTE COMPOSITION

A well-designed loading zone typically consists of a combination of components. These include:

1. An *enclosed transfer chute* should be long enough to give dust and fines time to settle.
2. A *heavy-duty belt support system* absorbs impact, protects the belt and can handle rapidly shifting heavy material.
3. *Closely spaced idlers* help avoid sags in the belt that allow gaps where fines can escape and ease material disruption from bouncing.
4. *Externally adjustable or self-adjusting skirting* contains fine particles and adapts to fluctuations in the belt plane. [**Figure.2**]
5. *Easily serviced wear liners* can be changed from outside the chute without confined space entry.
6. *Dust curtains* set strategically throughout the enclosure control airflow and help settle dust.
7. *Dust bags or mounted air cleaners* collect tiny, highly active particles.
8. *A sealed tail box* protects the tail pulley from the backflow of fines, dust and spillage.
9. *Exit curtains* prevent fugitive dust from escaping from the end of the chute.

Dust and spillage are top concerns for many safety professionals. Field tests have shown that enlarged skirtboards and engineered settling zones promote dust settling and reduce fugitive material. [**Figure 3**]

CASE STUDY

A mine in north central Mexico was experiencing excessive spillage and dust emissions at the loading zone of its tower-mounted conveyor transporting gold, silver, zinc oxide, copper, lead, and molybdenum. Despite installing various transfer and loading chute components, workers found that dust filled the tower and chunks of material 2-3 in. (51-76 mm) in diameter spilled from the transfer chute onto the stairs, partially blocking access to the area and creating a potential workplace hazard. [**Figure 4**] Twice per month operations had to be disrupted for 12-24 hours so that a 4 to 5 person team could clean spillage and return it to the cargo flow. Cleanup and downtime raised the cost of operation and lowered efficiency.

Technicians from Martin Engineering Mexico were invited in, and after a thorough inspection designed a plan based on the principles of Production Done Safely®. It addressed all aspects of the bulk handling process for properly guiding the cargo through the transfer chute. Impact Cradles were installed to center the material and help prevent belt damage, improving performance as well as safety by pulling out for external maintenance, a system invented by Martin Engineering. The project also included skirting and

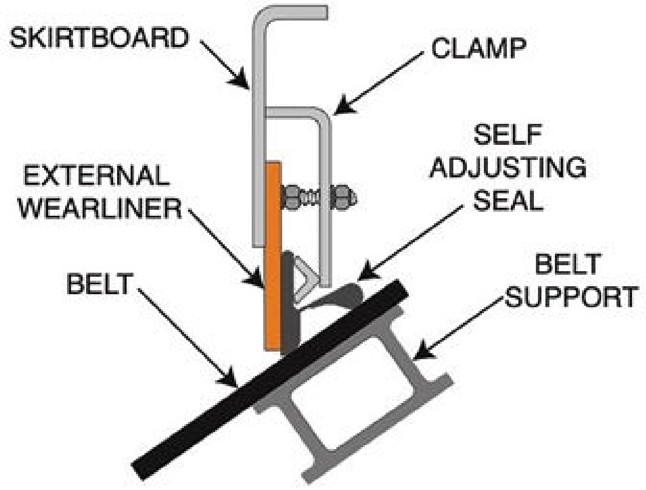

Figure 2: External wear liner and dual self-adjusting seal with belt support.

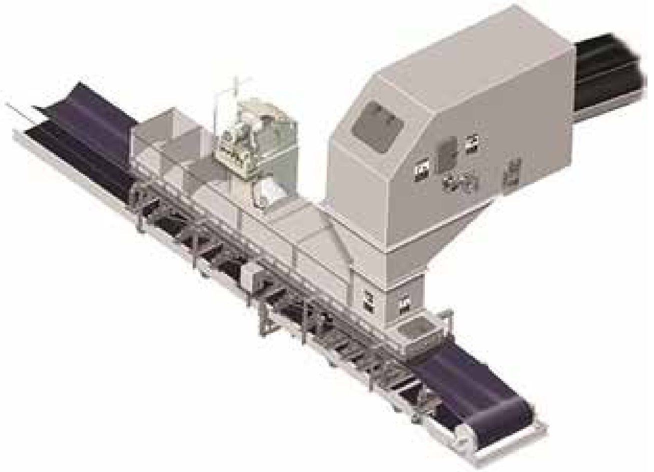

Figure 3: Modern loading zone design has elements that focus on safety for both personnel and equipment.

Figure 4: Bulk material drops onto a moving conveyor belt, creating dust and spillage.

Figure 5: The reconfigured conveyor controls emissions for improved safety and easier maintenance.

dust bags to contain emissions and spillage throughout the settling zone. Strategically placed belt trackers maintain belt alignment along the entire path. Heavy-duty primary and secondary cleaners that can be pulled out for easy service were installed at the discharge zone to reduce carryback and promote safer blade replacement. The entire system was designed with innovative safety features and ease of maintenance in mind. Each of the components works together to deliver a comprehensive bulk handling solution that promotes efficiency and a safer workplace. [**Figure 5**]

Following installation, fugitive material was significantly reduced and spillage no longer blocked access to the area. The air around the transfer point and throughout the tower was much clearer. "We no longer need scheduled shutdowns just for cleaning," said an operations manager. "We're very happy with the work done." The customer cited the expert service from the Martin Engineering team, a thorough understanding of the mine's needs and the quality of the equipment.

CONCLUSION

With some fairly simple calculations, cost-minded managers can see the negative impact of labor costs for cleanup and maintenance on the bottom line. Combined with the expense of fouled equipment replacement, potential OSHA violations and unscheduled downtime, the expense of a chute redesign can become an essential capital expense. Using the technologies described here, even poorly-performing conveyors need not be replaced, but merely modified and reconfigured by knowledgeable and experienced technicians installing the right equipment. These improvements help operations improve efficiency, reduce risk and facilitate regulatory compliance[1].

REFERENCES

1. Swinderman, Todd: "The Payback of Safety and Justifying Expenditures for Safety Improvements," paper presented at the 2017 SME Annual Conference and Expo; CMA 119th National Western Mining Conference.

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

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