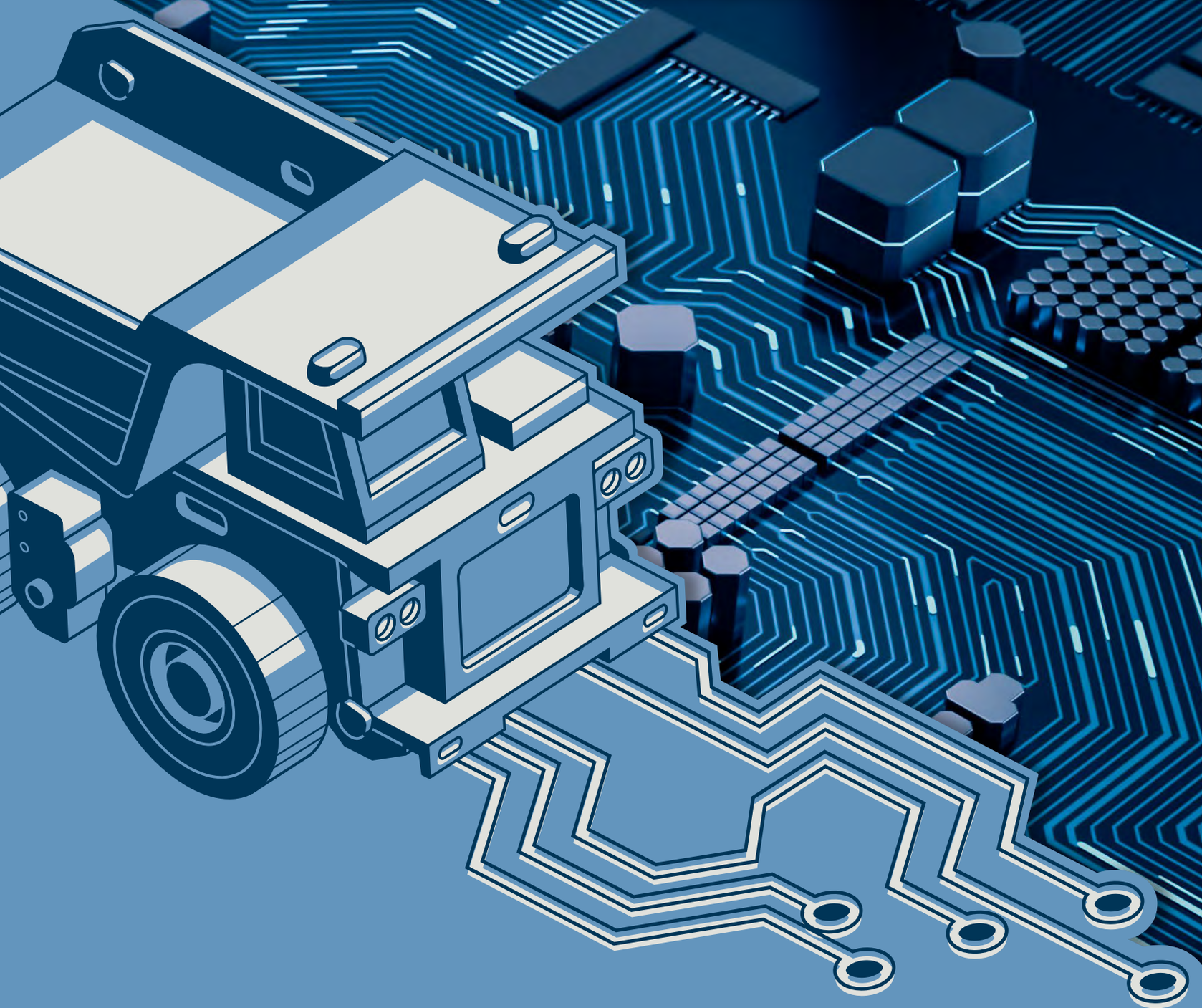

A review of Australia's mining innovation ecosystem

the DIGITAL MINE

Minerals Council of Australia

The evolution_

Productivity, safety and sustainability are driving the unprecedented rate of technological change across the mining industry.

PAGE 10

The innovators_

The innovation ecosystem includes Australia's miners, original equipment suppliers, university-led research and government agencies.

PAGE 16

The technologies_

Advanced and emerging technologies are being used across the lifecycle of a mine and throughout the mining value chain.

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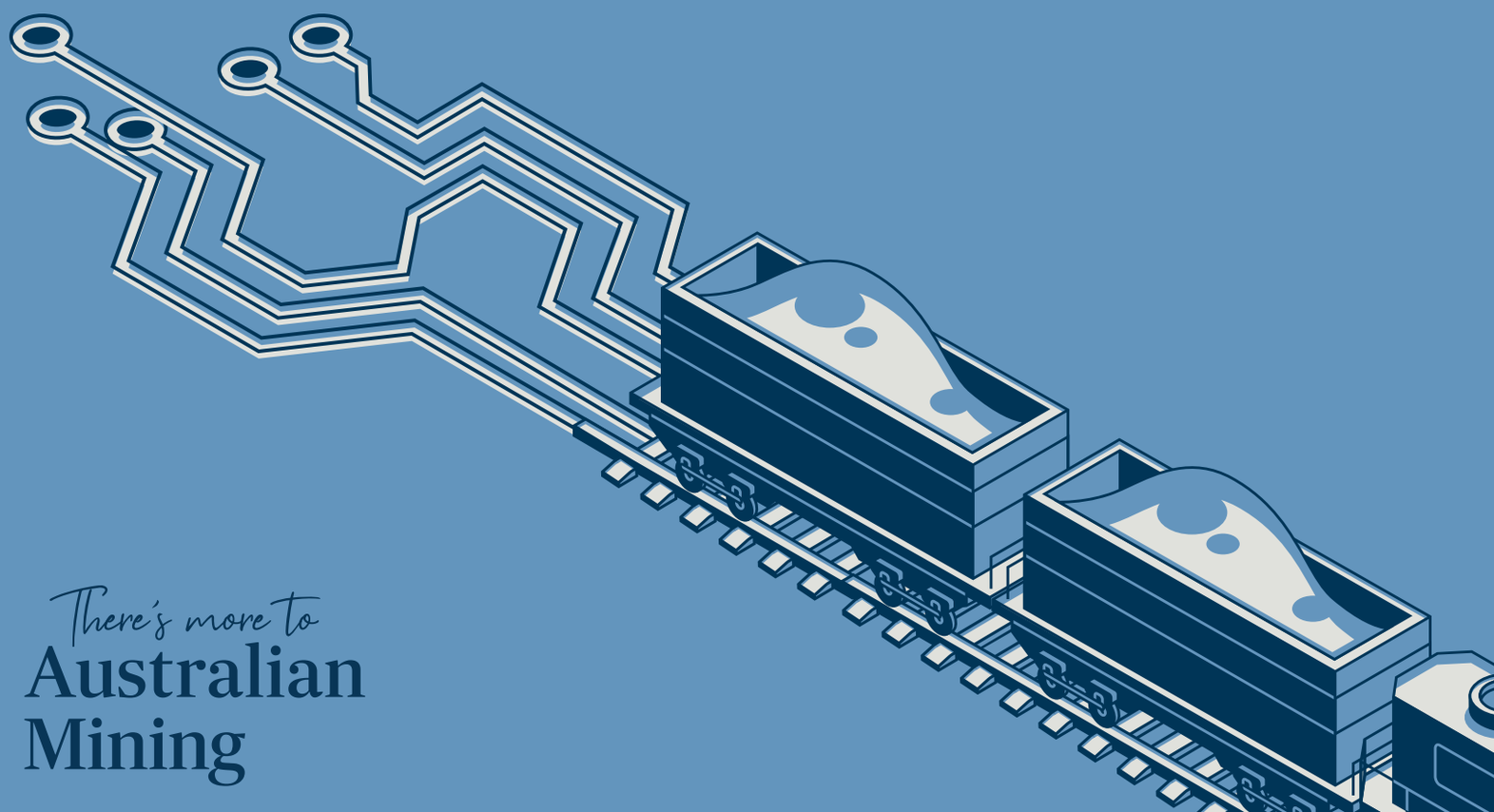

There's more to

Australian Mining

Warning Please be aware this guide may contain the names or images of Aboriginal and/or Torres Strait Islander people who may now be deceased.

September 2022

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the DIGITAL MINE

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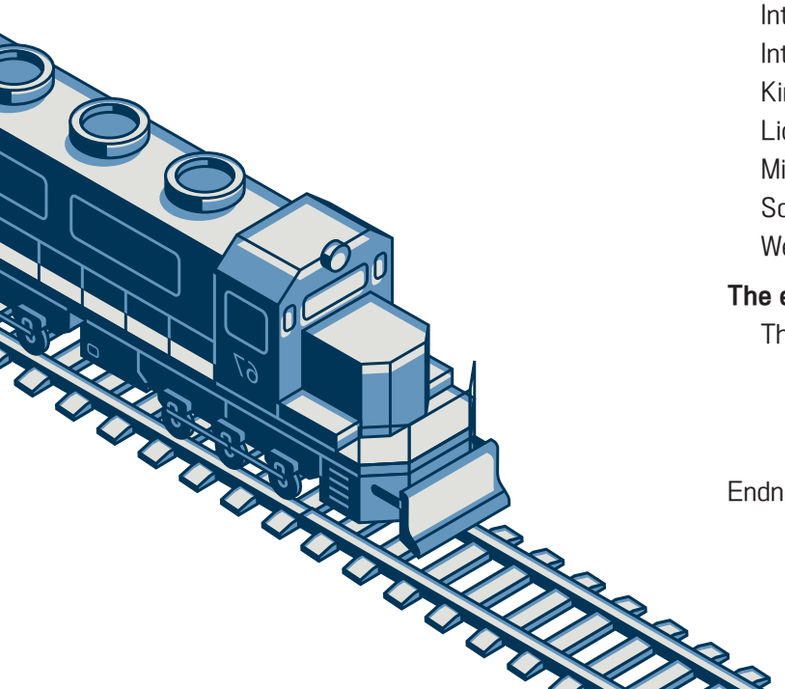


the DIGITAL MINE

The unrivalled success of Australia's mining industry has long relied on technology and innovation to improve safety, drive greater productivity and deliver better sustainable development.

The mining industry has also become an increasingly critical driver of broader industry development and innovation.[1]

However, this innovation imperative can deliver more with a cooperative focus and a policy framework that encourages creativity and application. This publication, *The Digital Mine*, addresses that goal.

Australia's minerals industry is essential for modern life and will contribute the raw materials needed for the global transition to a net zero economy. Building solar photovoltaic plants, wind farms and electric vehicles is more minerals-intensive than their hydrocarbon equivalents. Traditional commodities continue the quest to reduce emissions in extraction and use.

Technology is removing people from potentially hazardous situations, helping predict and model operational changes that improve safety and enhancing training so that the workforce is better equipped to perform work safely.

Productivity enhancing technology not only assists in discovering new resources but has the capacity to make existing resources more economic with the same level of inputs. Improved data and artificial intelligence are also making operations more efficient.

At a site-by-site level, electrification and fuel switching are reducing emissions in support of the industry's ambition to achieve net zero emissions by 2050.

These technology-driven improvements are occurring through the mining lifecycle from exploration, development and operations to closure and rehabilitation. Technology is even enhancing commodity marketing and trading by improving integrity in transactions and supply chains.

The innovators driving this transformation include miners, the mining workforce, the Mining Equipment, Technology and Services (METS) sector, original equipment manufacturers (OEMs), university-led mining research institutions, Cooperative Research Centres (CRCs) and CSIRO-led research collaboration.

A catalytic and external benefit of the technology transformation is a highly skilled workforce. Australia's minerals industry has invested significantly in training and reskilling the workforce to fully utilise new technologies in mining.

The MCA has played a leading role in identifying the future skills challenge. Australia's miners and OEMs are rising to the challenge to develop this workforce of the future.

While some roles will be replaced, many new highly skilled, highly paid roles are being created and other roles are being enhanced by technology. This technologically advanced workforce is building new capabilities for Australia.

The success is tangible.

Since 2005, Australia's mining industry has invested more than $30 billion in research and development, sitting in the top four (occasionally top two) of all industries. Australia is a top three jurisdiction for mining patent filings and four Australian universities are in the top five world rankings for mining engineering.

Utilising international benchmarks, *The Digital Mine* reviews the mining innovation ecosystem and makes a number of recommendations to improve STEM workforces, industry-orientated research and innovation, and regulatory settings to support technology pilots and drive the innovation performance to the top of the rankings.

Australia's mining industry is embracing technology-led innovation at an unprecedented rate, but this transformation cannot be taken for granted. It requires coordinated action and a shared commitment by industry and government to develop and maximise the substantial opportunities that exist to reaffirm Australian mining's position as a global leader.

Tania Constable
Chief Executive Officer
Minerals Council of Australia

Recommendations

1

Improve collaboration to boost women in STEM

The challenge

Based on the 10-year trend, it will take until 2099 to achieve a gender balance in university science, technology, engineering and mathematics (STEM) programs.

The recommendation

Government, industry and universities should work together on a comprehensive range of new initiatives to boost enrolments of women in STEM courses. In recognition of the growing role of digital skills in the Australian workforce and that a key objective is to improve diversity in the workforce, action is needed to improve diversity in critical education pathways.

Priority initiatives

- Expand successful programs such as James Cook University's program to improve STEM outcomes through diagnostic tests to determine missing elements of curriculum concepts
- Work with state and territory governments on initiatives to boost teacher quality – a key determinate to STEM student outcomes
- Support initiatives to inspire the next generation, such as the International Mathematical Olympiad which Australia is hosting in 2025.

2

Identify and formalise new skills in digital transformation for the existing mining workforce

The challenge

Formally recognising the skills and knowledge acquired through training on proprietary equipment.

The recommendation

Government should work with industry to identify new skills acquired by existing workforces as part of the digital transformation of mining and allied industries. The new skills should be recognised by a formal qualification that supports transferability and deepen the skills in Australia's labour force. Priority allied industries should include civil construction, manufacturing, agriculture and defence industries.

Priority initiatives

- Develop a skills passport so that people have a secure and central repository of their qualifications
- Fund programs to formally recognise skills acquired through on the job training to enhance portability
- Support micro-credential course development in emerging skill sets.

3

Maintain and grow support for industry-orientated research and innovation

The challenge

International innovation rankings identify Australia has a weakness in university-industry R&D collaboration.

The recommendation

The Australian government should support next generation university-industry R&D collaboration initiatives such as the Trailblazer initiative, which better integrates research between universities and industry. This is in addition to maintaining support for industry-orientated research initiatives such as the university-led mining research institutes, CRCs and CSIRO-led initiatives.

Priority initiatives

- Support the Curtin University-led Resources Technology and Critical Minerals Trailblazer hub
- Continue to support CRCs that focus on improving industry safety, productivity and sustainability
- Develop initiatives to progress new technologies through the readiness levels.

4

Prioritise the recognition of new occupations by the Australian Bureau of Statistics

The challenge

Delays in recognising emerging occupations is impeding comprehensive workforce planning.

The recommendation

The Australian government should work with industry to recognise emerging occupations more quickly. An annual process would be appropriate given the dynamic nature of occupation changes through the digital transformation of Australian industries.

Priority initiatives

- Annual program to update the occupations list
- Incorporate new occupations in a comprehensive national workforce plan.

5

Leverage strength of the tertiary education sector to guarantee a pipeline of mining engineers

The challenge

International innovation rankings identify Australia has a weakness in engineering graduates as a proportion of total university graduates.

The recommendation

Government and industry should work collaboratively to promote careers in engineering and leverage the benefit of Australia's globally recognised strengths in university education. Given the critical role of mining engineers in the industry workforce, the acute shortage of mining engineers and the exceptionally high ranking of Australian universities that teach mining engineering, priority must be given to supporting a future pipeline of mining engineers.

Priority initiatives

- Allocate at least 2500 of the 20,000 promised new university places to engineering disciplines
- Promote engineering qualifications as critical for innovation
- Expand successful programs, such as James Cook University's program and the Australian Indigenous Engineering School, to improve STEM outcomes and diversity in the STEM pipeline.

6

Sustainable safeguard mechanism reform

The challenge

Substantial efforts and progress is being made to develop and deploy technology to reduce emissions at industrial facilities.

The recommendation

The Australian government should provide certainty and stability through the transition to net zero by 2050 by ensuring reform of the safeguard mechanism is done in close consultation with those industries and facilities affected. Reform should ensure tailored treatment for emissions-intensive trade exposed and affected industries. This should be based on the principle of comparative impact, ensuring that exporters remain competitive.

Priority initiatives

- Work with industry on the design of the safeguard mechanism to provide clarity and certainty
- Increase funding for CCUS technology development to reduce emissions in electricity generation and manufacturing
- Maintain the Research and Development Tax Incentive.

7

Establish regulatory sandboxes for mining innovation

The challenge

Regulatory processes are delaying the deployment of new technologies, especially in the pilot phase.

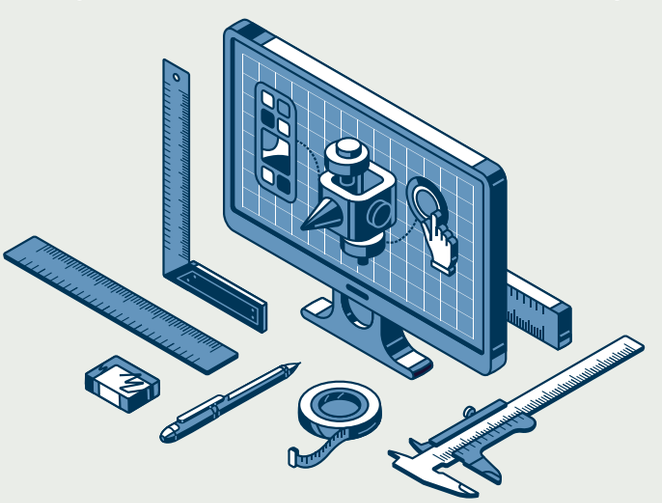
The recommendation

Governments should establish regulatory sandboxes for the mining industry so that innovative concepts can be tested at a reduced scale, on a time-limited basis and with appropriate safeguards. This would assist the evolution of game-changing technologies that are being developed.

Priority initiatives

- Create a regulatory sandbox to trial expanded use of drones
- Create a regulatory sandbox to trial new electrified equipment
- Provide government technology offices with a case management function to support regulatory reform to support new technology and innovation.

Collaboration between industry and government is needed to strengthen the mining innovation ecosystem, which will be critical to meeting the raw material challenge.



The digital evolution

To appreciate the digital evolution and innovation ecosystem of the Australian minerals and mining industry requires an understanding of the diversity of the sector.

Mining involves the extraction of a diverse range of mineral commodities. Deposits are distributed unevenly in terms of geography and grades and require a variety of extraction and processing techniques.[2]

Figure 1 provides a simplified overview of the mining value chain. It begins with exploration, continues through development and production, and ends with closure and post-mining land use.

The purpose of mineral exploration is to discover mineral deposits amenable to economic extractive operations now or in future. Mineral exploration is a high risk activity; the risk of failure is great and the cost is high.[3] The typical lead time from exploration through to mine development is 12 to 15 years or more.

Mining a mineral or metal deposit requires long-term planning to optimise production. Mining operations often incorporate transportation facilities, including trucks, trains, conveyor belts or other means, to deliver the minerals or ores for processing or shipping to downstream locations.

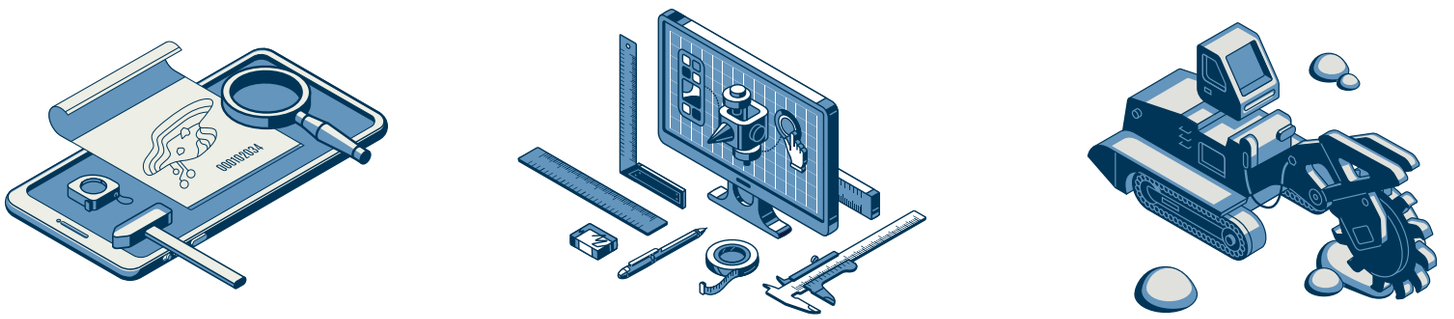
At the end of a mine's economic life, activities such as mine closure and site rehabilitation come to the forefront.

Ores that are mined generally go through initial processing or beneficiation at the mine site. These initial processes include comminution (crushing and grinding), sizing (screening or classifying), separation (physical or chemical), dewatering (thickening, filtration, or drying), and hydrometallurgical or chemical processing.

The processing of mined ores produce a more concentrated material that is then transformed into a final metal or mineral product through metallurgical processes.

FIGURE 1

An overview of the mining value chain



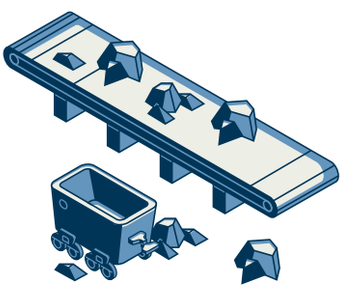
Prospecting **Resource estimation** **Mine planning** **Mine development** **Extraction**

Exploration **Mine operation**

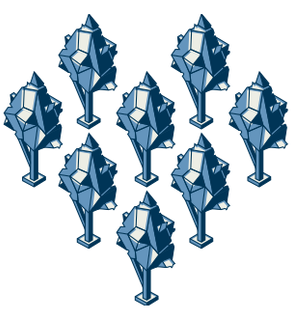
The world's first autonomous water trucks at Rio Tinto's Gudai-Darri iron ore mine in the Pilbara.

Autonomous mines

Rio Tinto's Gudai-Darri iron ore mine in the Pilbara is among the world's most technologically advanced. Officially opened in June 2022, Gudai-Darri boasts autonomous trucks, trains and drills, as well as the world's first autonomous water trucks, and a robotic ore sampling laboratory. It also features a 34 MW solar farm – another step towards Rio Tinto's ambition of developing 1 GW of renewable energy by 2030.

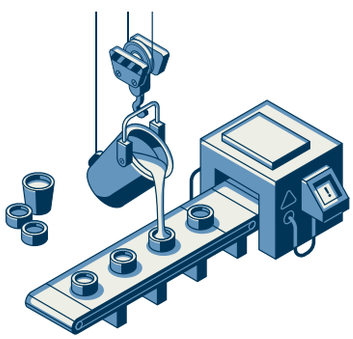


Ore processing



Transportation

Mine closure



Metallurgy

Refining

Minerals production

The raw material challenge

More metals and minerals are required to help the global economy transition to net zero emissions. Electrification will drive increased demand for copper, nickel, cobalt and lithium needed for battery electric vehicles (EVs), neodymium for permanent magnets and steel for critical infrastructure.

Leading analysts have forecast that demand for some raw materials, such as rare earth metals, could increase by a volume of ten times or more the current market size.[4]

Road transport and power generation alone will fuel a huge increase in demand for metals and minerals. A battery EV produces 60 per cent less emissions on a CO_2 equivalent per kilometre basis but requires nearly twice the metals and minerals of a car with an internal combustion engine.[5]

Excluding steel and aluminium, an internal combustion engine car requires 33.9 kg of minerals but an EV requires 207 kg of minerals.[6] This will increase demand for copper, lithium, nickel, manganese, cobalt, graphite and rare earth minerals.[7]

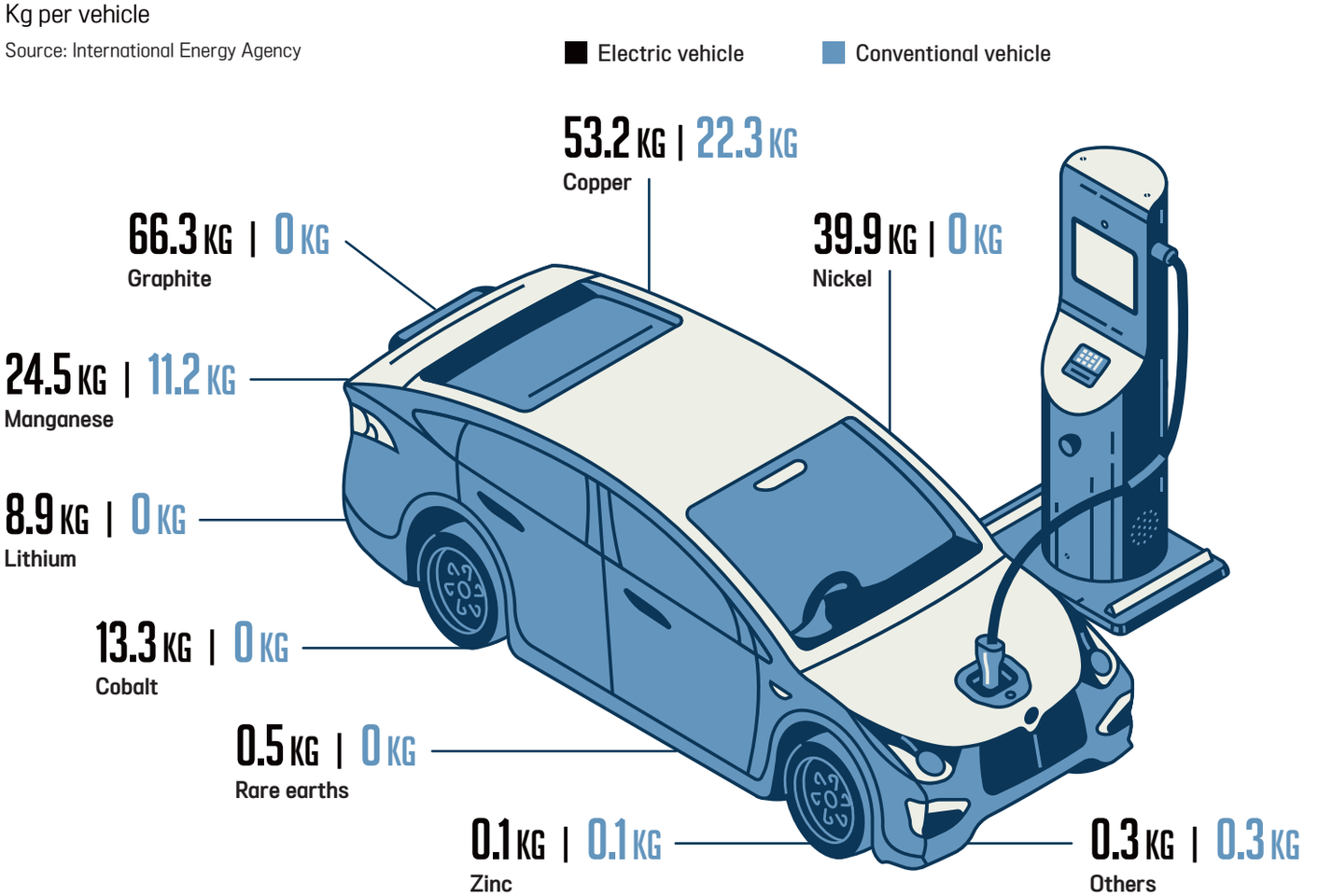
When it comes to renewable energy generation, a four-fold increase in metals is required to generate the same megawatts from wind and solar energy generation as a coal or gas-fired power station.[8] Demand for electricity is projected to triple by 2050 as sectors electrify and hydrogen and hydrogen-based fuels become more available as the economy decarbonises.[9] Again, this will increase demand for metals and minerals.

FIGURE 2

Minerals used in electric vehicles

Kg per vehicle

Source: International Energy Agency



There may be changes in the actual metals and minerals demanded based on different and emerging technologies, but overall more raw materials will be required to meet global demand, not less.[10]

Meeting this demand will be essential in keeping emerging technologies cost competitive. If mining globally cannot supply competitively priced metals and minerals, substitutions will be made. The most obvious substitution is energy-intensive recovering and recycling of existing materials.

These circumstances provide both a challenge and an opportunity for Australia and its world-class mining industry – how to become safer, more productive and more sustainable while meeting this booming raw material demand.

Whole-of-industry technological innovation and application is one way that Australia's mining industry can retain its status as a resource superpower.

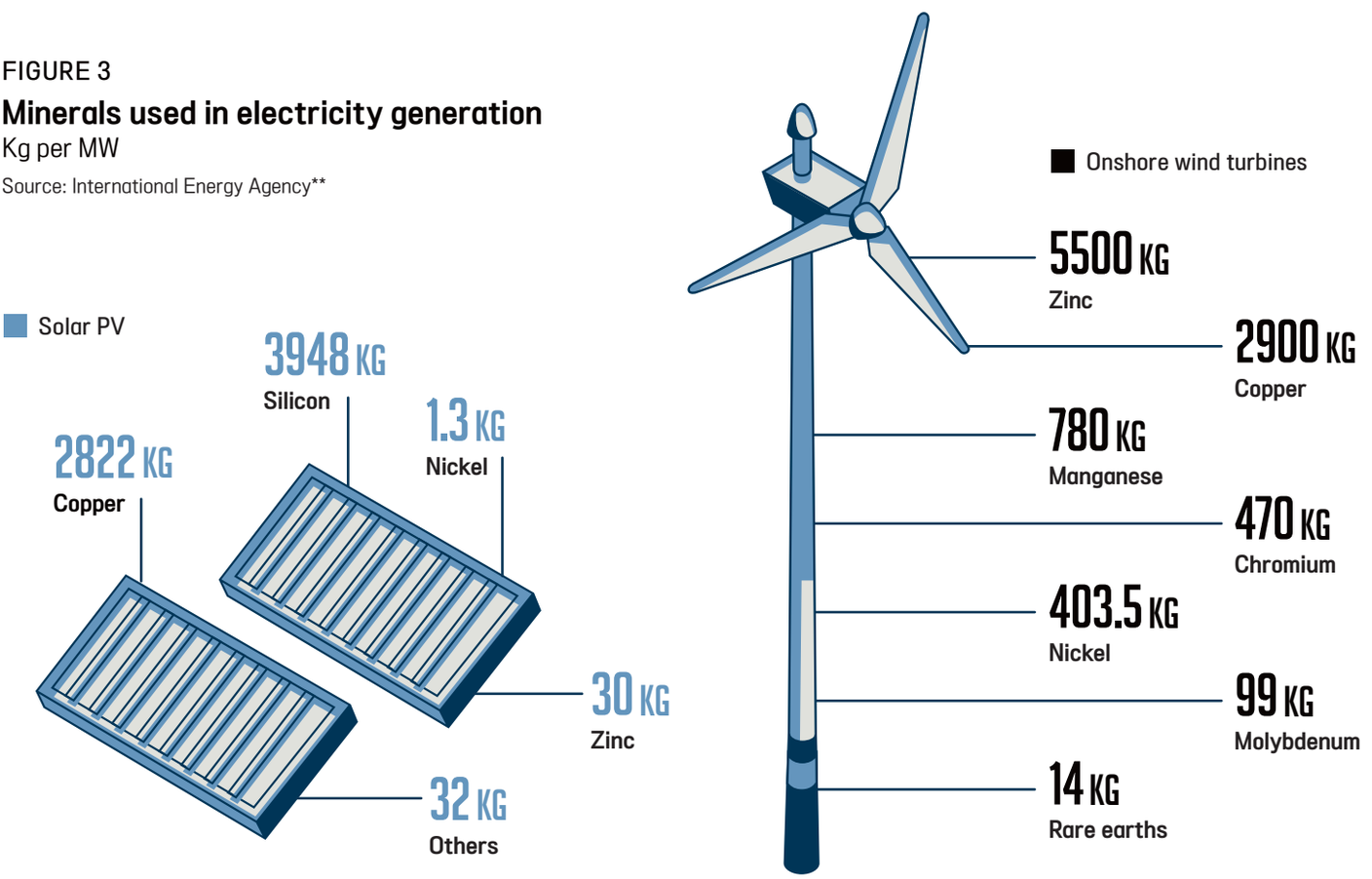
Over 400 tonnes of coking coal is needed to produce the steel in a 5 MW wind turbine.*

FIGURE 3

Minerals used in electricity generation

Kg per MW

Source: International Energy Agency**



Generation type (Kg per MW)	Copper	Chromium	Cobalt	Manganese	Molybdenum	Nickel	Rare earths	Zinc	Others
Offshore wind	8000	525	0.0	790	109	240	239	5500	6
Nuclear	1473	2190	0.0	147.69	70.8	1297.4	0.5	0.0	94.28
Coal	1150	307.5	201.46	4.63	66.25	721.04	0.0	0.0	33.9
Natural gas	1100	48.34	1.8	0.0	0.0	15.75	0.0	0.0	0.0

* Calculation based on 120–180 tons of steel per MW (Arcelor Mittal), and 770 kg of coal to make 1 tonne of steel (BHP).

** Steel and aluminium not included. Offshore and onshore wind are based on the direct-drive permanent magnet synchronous generator system (including array cables) and the doubly-fed induction generator system respectively. The values for coal and natural gas are based on ultra-supercritical plants and combined-cycle gas turbines.

What drives mining innovation?

Australia's mining sector is diverse. It covers many minerals and geographies, but also activities that occur adjacent to and in parallel with mining, such as exploration and ore processing. What virtually all subsectors of the industry have in common is that they operate in an intensely competitive environment in which minerals commodities are supplied and traded globally.

Broader trends relevant to the Australian mining industry include:

- Shifting demand for certain mineral commodities as countries around the world raise their living standards and move to low carbon sources of energy
- Access to minerals that are gradually becoming less accessible over time
- A far greater emphasis on the health and wellbeing of the mining workforce including a continuous improvement culture when it comes to safety
- Concerns about the impact of mining on natural resources such as water and the local environment, as well as the carbon footprint of the mining sector.

These competitive pressures and constraints set the framework for the spectrum of innovations that the mining industry has generated and continues to generate, in order to improve its productivity and remain competitive while at the same time meeting higher expectations for worker safety and environmental sustainability.

Productivity

In the production of mineral commodities globally, high grade minerals that can be extracted most cost effectively are generally extracted first. Over time, as mineral reserves closer to the surface are depleted, remaining deposits tend to be of a lower grade, in more remote locations, deeper in the ground, mixed with more impurities, or subject to other factors that make extraction more difficult and costly.

This trend has also been confirmed in Australia, including for the production of coal, uranium, iron ore, manganese, bauxite, mineral sands, copper, gold, lead-zinc-silver, nickel and diamonds.[11]

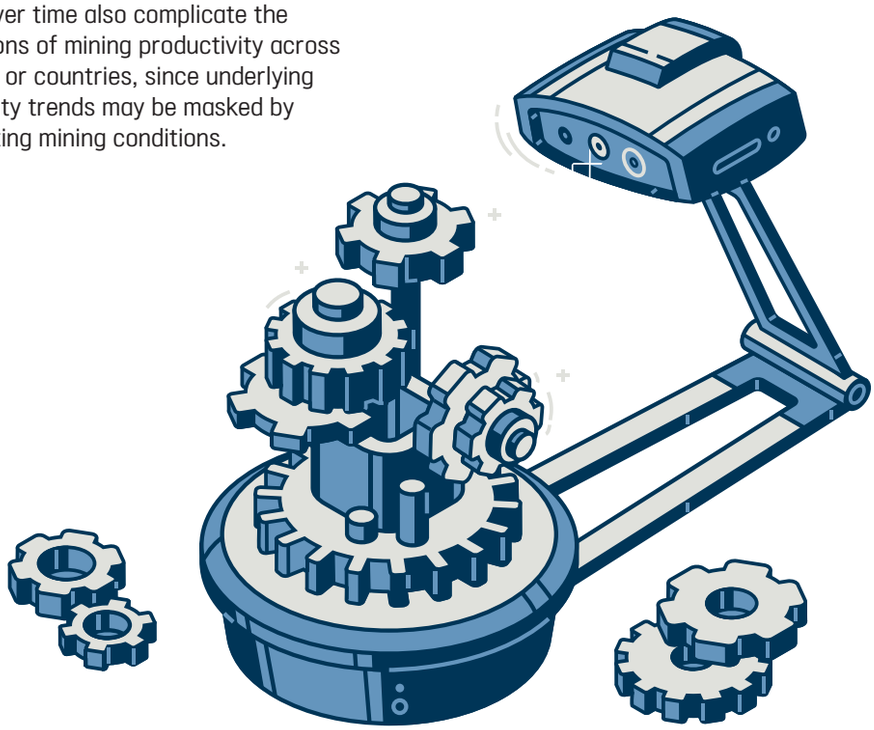
Declining and more complex ore bodies have significant implications for the productivity of a mining operation, since productivity growth must overcome these adverse effects before making any real progress.[12]

Ore bodies that become more difficult to mine over time also complicate the comparisons of mining productivity across industries or countries, since underlying productivity trends may be masked by deteriorating mining conditions.

Safety

Mining fundamentally takes place in a harsh and often hostile environment. Miners work in conditions that are hazardous, sometimes in confined spaces and often in remote locations. Across all mining activities, hazards are posed by machinery, gases, dusts, chemicals and noise in the work environment, as well as from working in extreme temperatures.

As processing technologies move toward finer and finer particle sizes, the health effects on workers of these particles (but also resulting environmental concerns) are becoming increasingly important. Additional health hazards arise from chemicals used in mining or in the processing of ores.



The first solar panels installed at BHP's Leinster nickel operation in Western Australia.

Renewable energy

BHP is forging ahead with its first large scale off-grid renewable energy project that will help power its Nickel West mining and concentration operations in Western Australia. More than 71,000 solar panels will be installed at Leinster and Mt Keith, along with a battery energy storage system, as part of the Northern Goldfields Solar Project.

Sustainability

Potentially adverse environmental impacts of many types of mining operations are well known and have led to significant changes in how the industry operates and is regulated. Australian mining is a global leader in terms of meeting and exceeding high environmental standards.

The MCA announced the adoption of Towards Sustainable Mining (TSM) in 2021, an award-winning accountability framework which helps mining companies evaluate, manage and communicate their sustainability performance. Established by the Mining Association of Canada in 2004, TSM provides sustainability tools and indicators to help companies responsibly manage environmental, social and governance performance and record and drive performance.

The framework's guiding principles and protocols cover three core areas:

- Communities and people, including health and safety, Indigenous and community relationships
- Environmental stewardship, including biodiversity, tailings management and water management
- Climate change, an area where the focus of mining businesses has increasingly turned in recent years.

Adopting the independently verified TSM system will reinforce the sector's commitment to continuous improvement in safety, environmental and social governance.

Another area where significant challenges to the mining industry arise is the growing pressures on countries and businesses to reduce carbon emissions. As established in the raw material challenge, Australian mining will play a critical role in supplying the metals and minerals to achieve net zero emissions by 2050.

However, mineral resource extraction and processing are energy intensive and a significant source of greenhouse gas emissions. Australia's minerals industry supports a measured transition to a low emissions global economy via a combination of short, medium and long-term market-based policy measures, and through the adoption of the MCA's Climate Action Plan.

Who are the mining innovators?

Innovation occurs across the mining value chain within what can be called the mining innovation 'ecosystem'.[13] The mining innovation ecosystem includes mining firms and other stakeholders contributing to mining innovations such as:

- Businesses providing mining equipment, technology and services (METS sector)
- International suppliers of specialised mining equipment
- Publicly-funded universities and research organisations, such as the CSIRO, as well as CRCs and other government-funded agencies.

As the case studies throughout this report demonstrate, collaborations are the norm rather than the exception when it comes to enabling mining sector innovation.

Miners

Australian mining businesses are at the forefront of advanced and advancing technologies. Innovative mining firms tend to be larger and produce a high proportion of their own processing technologies, such as those at Rio Tinto's new Gudai-Darri iron ore project in the Pilbara.

Rio Tinto opened its most technologically advanced mine in June 2022. Gudai-Darri features an unprecedented deployment of industry-leading technology, including the use of robotics in the ore sampling laboratory as well as autonomous trucks, trains and drills, now standard across many Rio Tinto mines in the Pilbara.[14]

Gudai-Darri also features a full digital processing plant replica which allows teams to monitor and respond to data collected from the plant, and provides a rich, interactive 3D environment for virtual reality training.[15]

R&D expenditure trends

A leading investor in research and development, Australia's mining industry has invested more than $30 billion in R&D since 2005.[16]

R&D expenditures by the mining sector have varied significantly over the years, from a high of around $4.3 billion in 2008-09 to around $900 million in 2019-20. Whereas the mining sector was ranked second behind manufacturing in 2008-09, it is now ranked fourth behind financial and insurance services, and professional, scientific and technical services.[17]

Around 40 per cent of mining R&D relates to exploration and other support services. Exploration expenditures positively correlate to the commodity cycle and the discovery of new deposits. Exploration expenditure reached $950 million in December 2021 compared to less than $300 million in March 2016, while new deposit expenditure was more than $300 million in December 2021 compared to less than $90 million in March 2016.[18]

However, using R&D as a sole indicator of innovative mining industry activity is problematic for a number of reasons:

- R&D expenditure fails to consider broader innovation efforts that mining businesses typically engage in, such as engineering development and plant experimentation to optimise processes
- R&D measures, such as direct expenditures, ignore the R&D which is embodied in capital goods and intermediate inputs, including the contribution of new technology from other industries to the mining industry
- R&D expenditure does not include exploration expenditures, which involves extensive use of high-tech equipment and often innovative approaches.

R&D investment figures may also not capture the true extent of investment occurring on behalf of the mining industry in Australia, as this investment is often made by, or in collaboration, with:

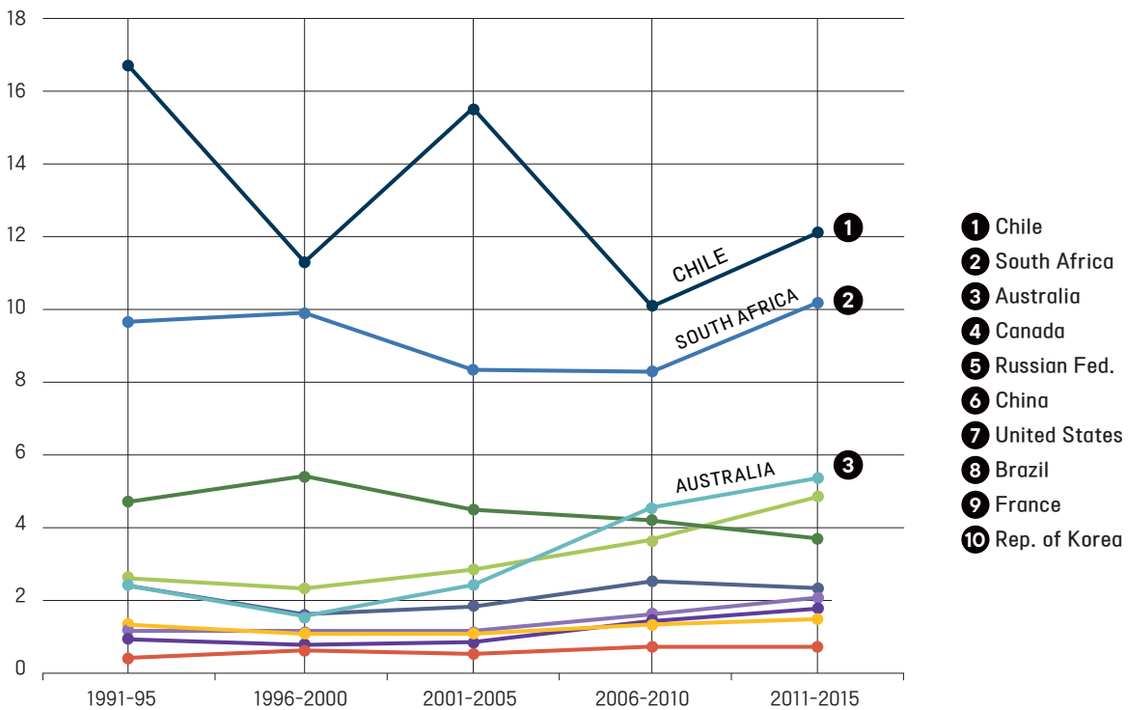
- Firms in the METS sector, which play a key role in innovating across all aspects of exploration, mining and minerals processing
- Leading technology suppliers such as Caterpillar, Komatsu, Epiroc, Hastings Deering and Sandvik who develop new equipment in close coordination with their mining customers, focusing particularly on automation and electromobility
- Research agencies such as CRCs, universities and crucially, the CSIRO.

FIGURE 4

Mining patent registrations by country

1990 – 2015 (Share %)

Source: World Intellectual Property Organisation



Patent trends

There has been a global surge in new technology patent applications across the mining sector over the last 10 years.[19] While patent data gives an overview of technological developments related to the mining industry, it also has some limitations. For instance, not all mining innovation is patented and trade secrets and tacit knowledge are an important part of mining innovation.

Nonetheless, the share of patents originating from the Australian mining sector is high (Figure 4). Australia has increased its share of patents across all elements of the mining value chain from exploration, blasting, mining and processing to refining, metallurgy and transportation.

Australia's mining industry has also sought to improve sustainability outcomes through innovation. Australian mining is ranked sixth globally in terms of patents issued from 1990-2015 in relation to environmental services.[20] These patents have focused on the treatment of waste water or soil, waste disposal, or on land reclamation, with 2446 patents registered.[21]

Australia's top three mining patent filers – Rio Tinto, BHP and CSIRO – contributed 15 per cent of total mining sector filings, around 60 per cent of which related to metal refining technology.[22] Figure 5 shows a breakdown of patents by components.

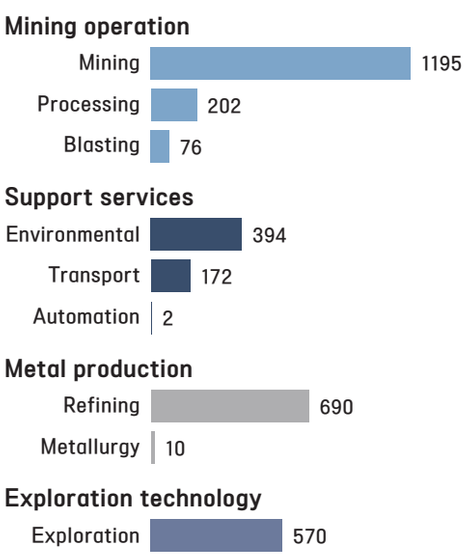
- Mining operation technologies account for 45 per cent of all patents filed
- Metal production account for 21 per cent of all patents filed
- Exploration technologies account for 18 per cent of all patents filed
- Support services account for 17 per cent of all patents filed.

FIGURE 5

Patent filings by technology

1997–2017

Source: World Intellectual Property Organisation



Mining workforce

Australia's mining and minerals workforce is responsible for driving innovation and making the nation a global resources powerhouse. The workforce continues to go from strength to strength – it has trebled since 2005 and more than 70 per cent of employees hold a qualification.[23]

Technology is changing the nature of work and the workforce is responding. In 2018, the MCA commissioned a first-of-its-kind report into the changing role of working in mining as a result of digital technology. The report found that 77 per cent of mining jobs have been enhanced or redesigned by technology, delivering better health and safety outcomes as well as higher productivity.[24]

New roles commensurate with the continued evolution of the sector are also emerging, such as automation engineers, integrated remote operating centre controllers, remote operations port controllers and autonomous mine systems controllers.

This digital transformation provides workforce opportunities and challenges.

New and changing occupations are becoming more accessible to more people. The barriers of fly-in, fly-out work are being reduced and centralised operation centres allow people in metropolitan areas to support operations in remote parts of the country. This is helping the mining workforce improve its diversity with more roles becoming more accessible to women and people with a disability.

Digital transformation also provides the opportunity for existing workforces to transition into higher skilled roles. People with experience in mining are highly valued and as plant and equipment is replaced, original equipment manufacturers deliver onsite upskilling for experienced workers.

Training of this nature ensures that employees are able to use the equipment safely in their current role, as well as provides a transferable skill that can be used to obtain future roles. The challenge for governments is ensuring that this upskilling is appropriately recognised through accredited qualifications.

In addition to recognising new skills through formal qualifications, the system to recognise new occupations must be more responsive.

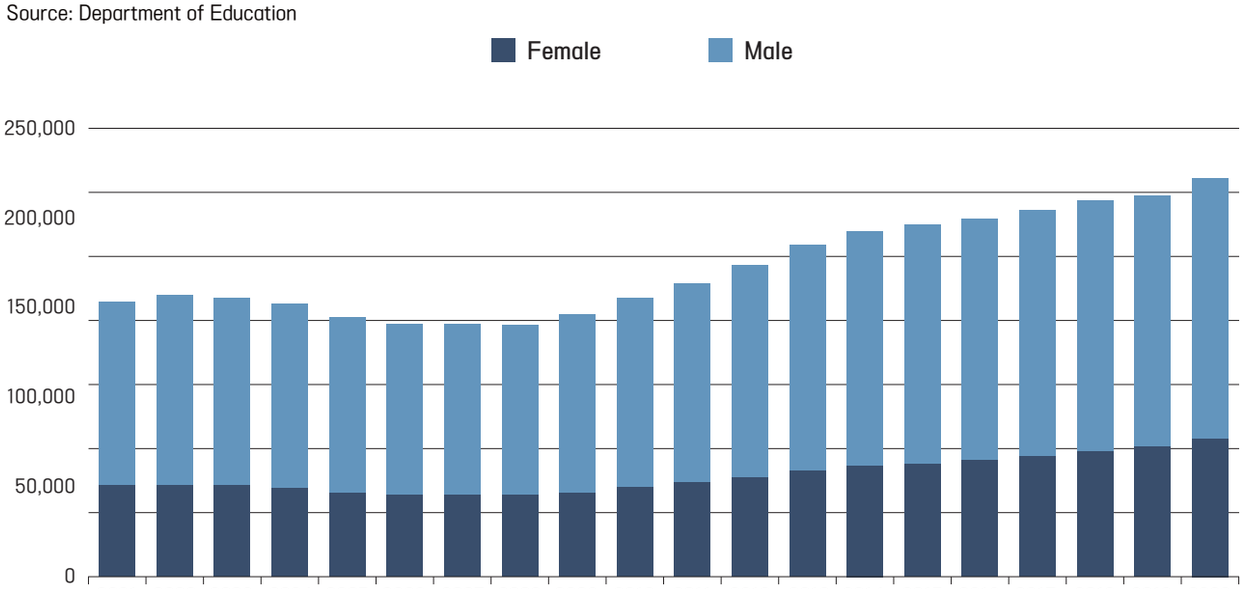
An example of the inertia of the current occupation recognition system was that in 2019 the Australian government announced that data scientists would be classified as 'information and organisation professionals NEC' – a group that also includes electoral officers and lobbyists – because this emerging and in-demand occupation was not previously classified by ANZSCO.[25]

FIGURE 6

Domestic STEM students by gender

2001–2020

Source: Department of Education



Rio Tinto launched Australia's first accredited automation qualification in 2019.

Investing in skills

Rio Tinto launched Australia's first accredited automation qualification in partnership with South Metropolitan TAFE and the WA government in 2019. The Certificate II looks at data driven processes in an autonomous workplace and the human-machine interface. Technology is transforming mining skills with traditional mining trades increasingly incorporating elements of computing, and new career paths, such as mechatronics alongside virtual reality, advancing the digital ambitions of mining companies.

Formal recognition of new and emerging occupations is required to:

- Enable accurate labour market data essential for workforce planning
- Promote career pathways
- Ensure skills and training package development and qualification recognition
- Ensure that skilled migration pathways, which are occupation rather than skills based, are included.

While the pace of digital transformation across the mining sector is unprecedented, other industries are also undergoing a similar transformation. This is increasing competition for technology professionals in all industries. Tech sector jobs have grown by 66 per cent since 2005 – almost double the growth rate for all jobs in the Australian economy.[26]

Ensuring a diversity of tech professionals working in Australia's mining industry is just as significant as ensuring the workforce keeps pace with future demand.

The Australian mining industry is taking action to achieve a gender balance across the workforce. A risk to achieving this goal is the current diversity trends within education pathways.

Although enrolment growth is stronger in university STEM programs for women, gender imbalances inherent to the current pipeline remain. Based on a 10-year compound annual growth rate to 2020, it will take until 2099 to achieve a gender balance in the STEM university pipeline.[27]

It will take until 2099 to achieve a gender balance in the STEM university pipeline based on the current rate of growth.[27]

METS sector

Australia is recognised globally as the market leader in mining equipment, technology and services (METS) across many different technology platforms and commodity segments.

According to METS Ignited (part of the Australian Government's Industry Growth Centres), the METS sector contributes $92 billion in gross value to the Australian economy and employs around 500,000 people directly.[28]

A key driver and enabler of innovation in mineral resources, METS organisations accounted for around 75 per cent of all patents filed in the Australian mining sector between 1994 and 2011.[29]

The METS sector is expected to play three important roles in the mining sector in the context of the industry's future digital transformation:

- A driver developing and bringing new innovations to the mining sector
- A translator converting scientific and technological breakthroughs into operational-ready solutions
- An integrator bringing disparate technologies together and making them work in a unique or novel way.[30]

BHP's Supplier Innovation Program and CORE Innovation Hub are examples of the role the METS sector plays in terms of generating innovations.

Supplier Innovation Program

BHP crowd-sources solutions to technical challenges through its Supplier Innovation Program Challenges. Its November 2021 Challenges were launched in collaboration with Austmine (the METS sector industry association).[31] Suppliers were asked:

- How visibility can be improved on tyre handling machines
- How the jacks used with dozers in maintenance workshops can be modernised to make the process of raising the 100+ tonne machines safer and more efficient
- How diesel-powered haul truck fleets (which account for around 80 per cent of a mine's total emissions) can be electrified in a sustainable and efficient way. This challenge resulted in eight winning concepts from countries including Australia, Switzerland, Japan, Denmark, the UK and North America.

Differing from traditional tender methods, this approach gives BHP access to a broader range of unique and innovative solutions. It also makes it easier for the METS sector to access opportunities for ongoing work with BHP while retaining their intellectual property. To date, 10 Supplier Innovation Program Challenges have been launched, with pilot solutions running at BHP's coal mining operations, at its Western Australian iron ore operations, and at Olympic Dam in South Australia.

CORE Innovation Hub

In 2021, CORE Innovation Hub and BHP announced the launch of the first centre of excellence in Newman, Western Australia. CORE Innovation Hub facilitates growth for resources and energy-based start-ups and SMEs.

The METS specialist hub, co-working and education space will support the surrounding region and be powered by BHP. The initial 12-month project aims to increase the viability and access to local businesses along the METS supply chain, helping diversify the regional economy.

The Newman hub will also aim to stimulate employment opportunities and facilitate the sharing of innovative ideas to grow the METS industry capabilities.[32]

FIGURE 7

Regional impact of METS and mining

Source: METS Ignited

$38B

Pilbara Region

Western Australia

Representing 88% of total regional economic activity.

$18B

Bowen-Surat Region

Queensland

Representing 63% of total regional economic activity.

$15B

Hunter Region

New South Wales

Representing 34% of total regional economic activity.

Glencore's Murrin Murrin operation will supply General Motors with cobalt for battery cathodes.

EV batteries

Glencore has signed a multi-year agreement to supply General Motors (GM) with cobalt from Glencore's Murrin Murrin operation in Western Australia. Cobalt is a critical metal for the production of most EV batteries. The cobalt processed from Australia will be used in GM's Ultium battery cathodes to power EVs such as the Chevrolet Silverado EV, GMC HUMMER EV and Cadillac LYRIQ.

Original equipment manufacturers and technology suppliers

Technologies developed by third parties are another way the mining industry innovates, hence the historical importance of specialist suppliers, especially machinery and equipment suppliers, in mining nations such as Australia, Canada and the USA.[33]

Collaboration can take different forms – outsourcing, open source, alliances, and joint ventures – depending on the type of technology to be developed, the development timeframe, as well as the underlying incentives for development.

BHP's long-term alliance with Caterpillar, for example, is a partnership to develop and deploy zero emissions mining trucks to reduce operational emissions. To support progress towards its goal, BHP will have early access to zero emissions equipment developed by Caterpillar and Caterpillar will facilitate hands-on learning opportunities to ensure successful deployment of the trucks at BHP sites.

The collaboration will help shape the processes, technology and infrastructure required to support zero emissions machines and the mine sites of the future. Another critical element of the collaboration will be to extend the parties' efforts to support a more inclusive mining industry through the development of machines that can be operated and serviced by a broader range of the workforce.

Rio Tinto's alliance with Komatsu is another partnership fast tracking the development and implementation of zero emissions mining haulage solutions, including haul trucks. Rio Tinto will conduct a pre-production trial of the new equipment at a Rio Tinto site and have the option to purchase some of the first trucks from Komatsu once they are commercially viable.

Rio Tinto has also joined Komatsu's newly launched Greenhouse Gas Alliance, which aims to advance Komatsu's power agnostic truck concept for a haulage vehicle that can run on a variety of power sources, including battery power and hydrogen.

Another notable example of a recent local collaboration involving equipment suppliers and mining businesses is the Electric Mine Consortium. Established by 14 companies, including Sandvik Mining and Rock Solutions, South32, OZ Minerals, IGO, Gold Fields, Barminco and led by State of Play, the consortium aims to find solutions to help reduce scope 1 and 2 emissions in line with global objectives.[34, 35]

Electrification is considered to be a gamechanger for the mining industry as it drastically reduces emissions and exposure to diesel particulates underground, as well as being a key technical foundation for the automation of mining equipment.

University-led research

The university research sector supports Australian mining industry innovation by educating the next generation of mining engineers and scientists, undertaking scientific research in fields such as geology and chemistry, as well as more targeted industry-facing research to address specific engineering problems.

Such research efforts are jointly funded by the Australian government, which awards grants to universities, and the mining firms themselves. The level of collaboration between mining and universities is very high and involves not only direct funding but on-site collaborative research, use of machines, equipment and computing power, and training for early career academics.

Australian universities dominate global rankings for mining-related disciplines. Curtin University, the University of New South Wales (UNSW), the University of Western Australia (UWA) and the University of Queensland (UQ) are ranked in the top five universities for mining engineering and are similarly highly ranked for mining research.[36] This report has identified 24 university-led mining research institutions in Australia. The largest include:

- Newcastle Institute for Energy and Resources (NIER) at the University of Newcastle, which hosts 19 research centres, collaborates with 173 industry partners and supports 257 PhD students
- Sustainable Minerals Institute (SMI) at the UQ, which houses seven research centres and one commercialisation entity
- Institute for Geoscience Research (TIGeR), which houses five research groups, and the Western Australia School of Mines based at Curtin University
- Australian Critical Minerals Research Centre at the University of Adelaide, which hosts three programs related to discovery, mineral chemistry and mineral processing
- Mining Research Centre (MRC) and the Centre for Infrastructure and Mining Safety (CIPMS) at the University of Wollongong, which are focused on the coal mining industry
- Sydney Centre in Geomechanics and Mining Materials (SciGEM) at the University of Sydney, which undertakes world-leading research in geomechanics, geotechnical engineering and granular mechanics
- University of Tasmania's Centre for Ore Deposit and Earth Sciences (CODES), which focuses on locating ore deposits, geo-metallurgy, tectonics and volcanic processes, and its Transforming the Mining Value Chain (TMVC), which has a focus on the efficient discovery of new ore zones around current mine infrastructure.

Cooperative Research Centres (CRCs)

The Cooperative Research Centre Program is an integral part of the Australian industrial research and innovation landscape. CRCs are designed to support Australian industrial innovation by connecting academic research institutions to industry, drawing on both private and public funding and sharing intellectual property, insights, experience and best practice.

Established in the early 1990s, the CRC Program has grown over two decades to average $167 million per year in nominal terms. Commonwealth funding for the Program in 2021-22 was $189 million.

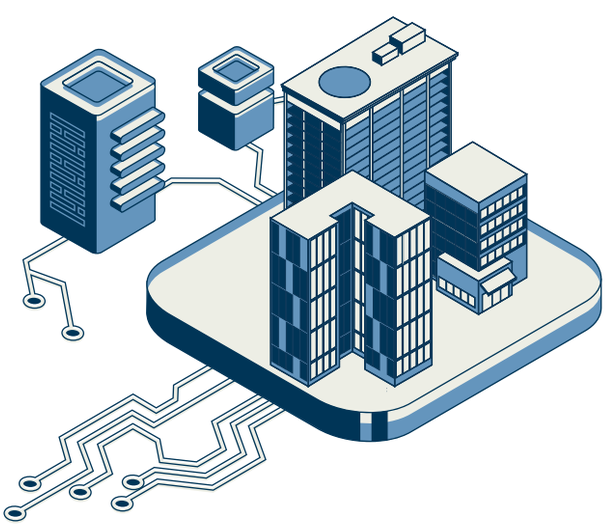
CRCs generally have a limited lifespan of seven to 10 years, after which many transform into privately funded research entities or commercial spin-offs.

There are currently four CRCs directly related to mining and a further two indirectly related CRCs including:

- Transformations in Mining Economies (TiME) CRC, which aims to develop innovative solutions to mine closure and post-mine economic transitions
- The CRC for Optimising Resource Extraction (CRCORE), which ended its government-funded term in June 2021. CRCORE's research program focused on productivity, energy and water use in mining has continued under the Future Research Program in collaboration with the CSIRO
- Mineral Exploration CRC (MinEx), which is focused on innovation in drilling, including locations and definitions of mineral deposits
- Heavy Industry Low Carbon Transition (HILT) CRC, which is focused on 'green' minerals processing (e.g. green iron products from magnetite) and utilising low carbon energy sources such as hydrogen, solar thermal and biomass.

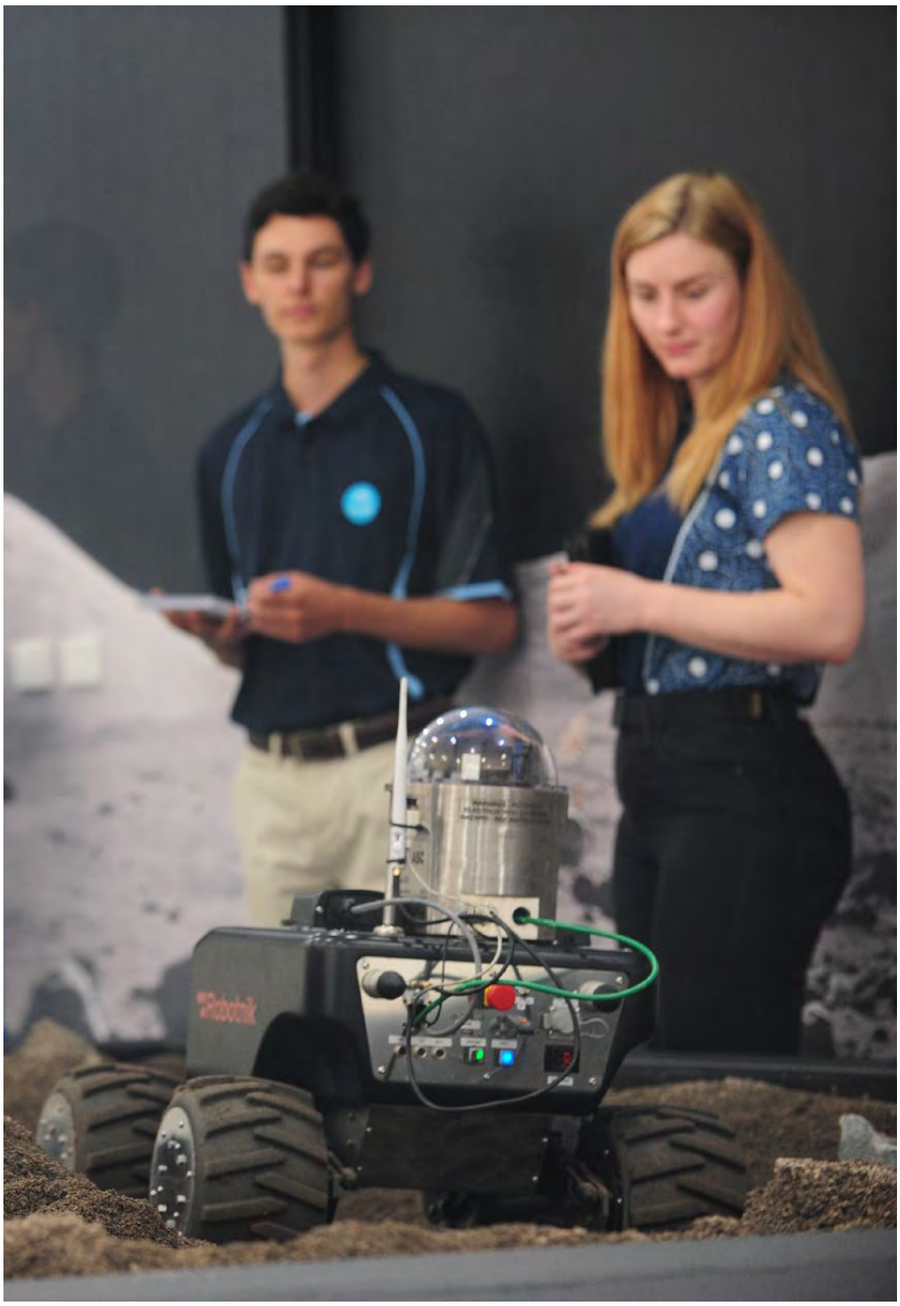
The two CRCs indirectly related to mining research and innovation are:

- Future Fuels CRC, which is focused on the demonstration and optimisation of low carbon fuel technologies for Australian conditions
- The CRC for Reliable Affordable Clean Energy (Race for 2030), which is focused on decarbonisation of industrial processes and maximising energy productivity for industrial use.



CSIRO's In-situ Resource Utilisation (ISRU) Facility

The ISRU Facility is shared with mining, automation and AI experts and includes a mission control room, a sealed area that houses a reconfigurable landscape, significant amounts of lunar regolith simulant, and dedicated areas for payload and subsystem testing.



CSIRO-led research collaborations

CSIRO is the Commonwealth Government's principle scientific and industrial research organisation. More than four decades old, the CSIRO has made a significant contribution to mining research and innovation.

CSIRO partners with other Australian and international research institutions and mining firms. Total CSIRO funding in 2020-21 was $961 million, and it is estimated that up to $100 million per year is invested in mining-related research.

At any given time, CSIRO is actively involved in hundreds of industrial research projects, and while many do not achieve stated objectives, or only have marginal benefit, some projects transition to highly successful commercial ventures.

FIGURE 8

Successful CSIRO mining research projects

Source: CSIRO

Drill core research

CSIRO developed a $7 million unique drill core lab to facilitate multiple disciplinary techniques for visualising and classifying geochemical data from drill holes and cores. The only facility of its kind in Australia, the lab will help unlock Australia's critical minerals by extracting more data from drill core analyses.

Laser analysis

Laser Induced Breakdown Spectroscopy (LIBS) is a rapid chemical analysis tool used to detect and characterise materials. CSIRO, in partnership with Australian gold producer Northern Star Resources, will use the LIBS technology to generate highly detailed, accurate mineral maps from core sample data.

NextOre

NextOre's ore sorter is able to detect the magnetic resonance signatures of many minerals, including the most common economically significant iron and copper-bearing minerals. It also has the ability to detect arsenic-bearing minerals that are often positively correlated with gold in sulphide ore deposits.

Longwall automation

CSIRO's longwall shearer automation, which was developed from early space industry technologies, has been adapted and is now being used in underground coal mines around the world. The research improved underground longwall coal mine productivity by around 5 per cent.[37]

Strengthening the innovation ecosystem

If Australian mining is to maintain its position as a global innovation leader, a supportive innovation ecosystem is required. In the same way technology rapidly develops, so too should the innovation ecosystem.

Since 2007, the World Intellectual Property Organisation has compiled the Global Innovation Index (GII). Using 81 indicators across seven categories, the GII ranks the innovation ecosystem in 132 countries and provides comparative analysis of countries with a similar income standard.[38]

According to the GII, global innovation leaders in 2021 were Switzerland, Sweden, and the United States. Australia ranked 26th globally, 25th compared to other high income countries and 6th in the Indo-Pacific region.

Nevertheless, Australia's performance was considered above expectations for our level of development. Some of the strengths of Australia's innovation ecosystem are:

- Institutions with high scores
- A competitive regulatory environment and indicators highlighting the relative ease of starting a business
- Government funding as a percentage of gross domestic product for secondary schools
- Strong QS World University rankings
- Market sophistication with a strong performance on ease of access to credit and trade tariff reform.

A number of indicators highlight several weaknesses in Australia's innovation ecosystem. Australia is ranked:

- 88th in pipeline of university graduates in science and engineering
- 87th in labour productivity growth
- 66th in infrastructure, with low scores for capital formation as a percentage of gross domestic product
- 77th in ecological sustainability, with low gross domestic product for energy use.

Relative to other high income countries, Australia's other weaknesses include:

- Lack of university-industry R&D collaboration (based on the World Economic Forum's executive survey)
- Shrinking research talent in business in terms of researchers engaged in the conception or creation of new knowledge, products, processes, methods and systems in firms.

Mining engineers

The other area of concern for the innovation ecosystem, and the industry more broadly, is the shortage of mining engineers. Mining engineers plan and manage all engineering aspects of locating and extracting metals and minerals from the earth.

The National Skills Commission Skills Priority List 2021 found mining engineers were in national shortage and forecast strong future demand.[39] Around 300 graduate mining engineers are required each year to sustain the industry, according to estimates.[40] Demand for mining engineers will increase by 21 per cent from 3900 in 2020 to 4732 in 2040.[41]

There has been a significant downward trend in graduates since 2016, with only 87 graduating in 2021.[42]

FIGURE 9

Mining engineer graduates by university

2009 - 2021

Source: Professor Peter Knights, School of Mechanical and Mining Engineering, University of Queensland

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
University of WA	14	18	23	22	32	46	51	40	29	10	13	16	19
Monash University							11	10	12	8	6	10	6
Federation University							4	9	18	6	3	2	0
University of Wollongong	16	27	23	34	49	24	35	31	30	29	12	12	6
Curtin University	61	43	69	61	71	52	56	53	36	26	22	20	27
University of Queensland	45	57	50	44	46	73	65	53	40	22	14	18	12
University of NSW	50	53	50	54	52	50	78	68	86	58	32	21	14
University of Adelaide		36	34	39	47	42	33	33	26	19	7	3	3

Image: Trevor Collens, *The West Australian*

Future Battery Industries Cooperative Research Centre Chief Executive Shannon O'Rourke.

Cathode pilot plant

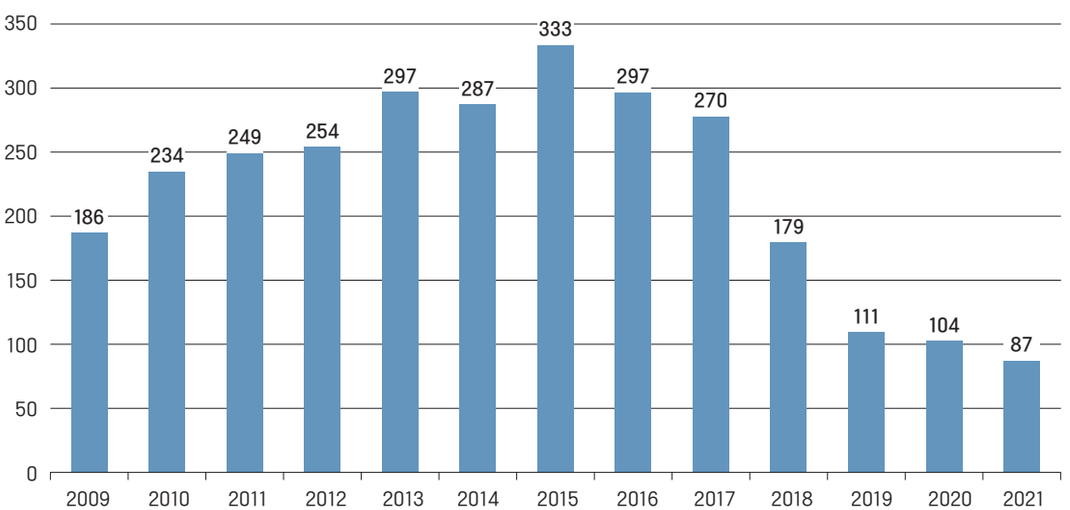
The Future Battery Industries Cooperative Research Centre (FBICRC) launched its Cathode Precursor Production Pilot Plant in 2022. An Australian first, the pilot plant will establish the technology and capabilities to design and build cathode precursor manufacturing facilities on a commercial and industrial scale. Working with industry, research and government partners, FBICRC is working to expand Australia's presence in the global battery value chain.

FIGURE 10

Australian mining engineer graduates

2009 – 2021

Source: Professor Peter Knights, School of Mechanical and Mining Engineering, University of Queensland



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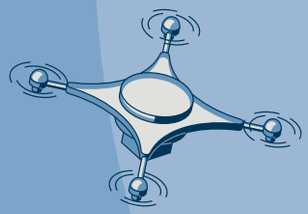
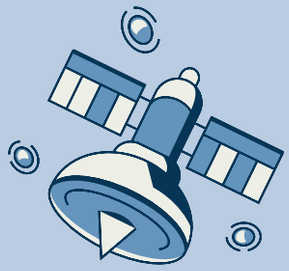


DRONES

Drones are used to survey, monitor and inspect mine operations and rehabilitation, providing real time data.

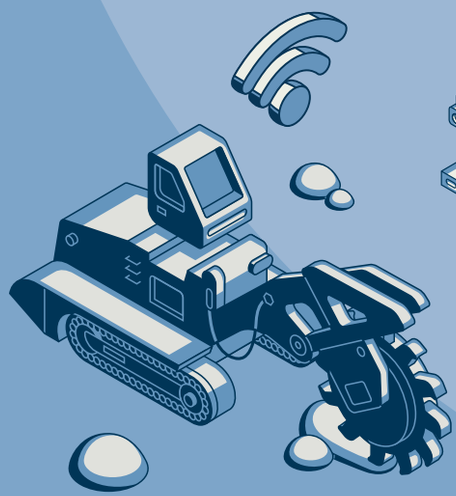


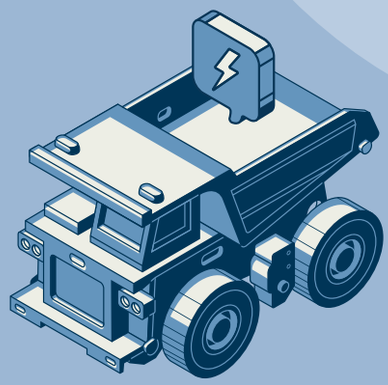
ELECTRIC HAUL TRUCKS

Electric trucks are replacing diesel trucks on some mine sites. Miners are also researching hydrogen powered haul trucks.

3D IMAGING

3D imaging is used to target exploration efforts for greater efficiency.



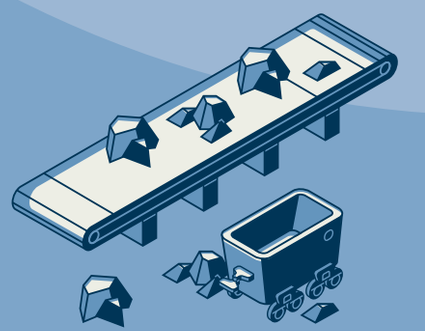


AUTONOMOUS MACHINES

From trucks to trains to drills, autonomous machines can be operated remotely, removing humans from harms way.

INTEGRATED OPERATIONS CENTRES

IOCs monitor and analyse data from across an operation to provide real time actionable intel.



ORE SORTING SENSORS

Sensor-based ore sorting reduces waste and improves efficiencies, maximising mineral recovery.

WEARABLE TECH

From health diagnostics to maps and schematics, smart helmets, glasses and other wearable tech is improving safety and productivity.

the DIGITAL MINE

There's more to

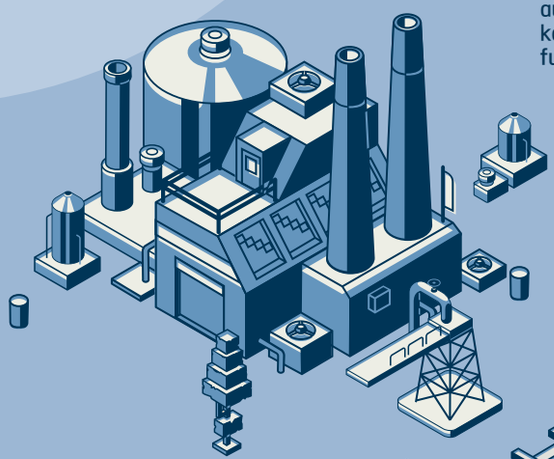
Australian Mining

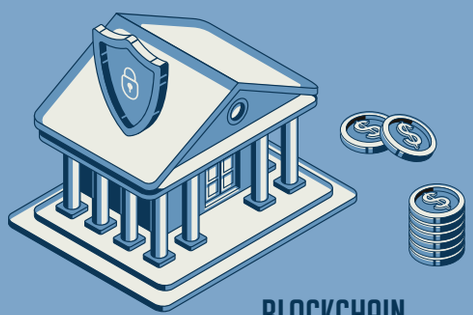
PRECISION MINING

GPS technology informs every aspect of an operation from pit to port, for greater safety, effiency and productivity.

VIRTUAL REALITY

From skills development to remote maintenance, virtual and augmented reality is used to keep workers safe and machinery functioning efficiently.



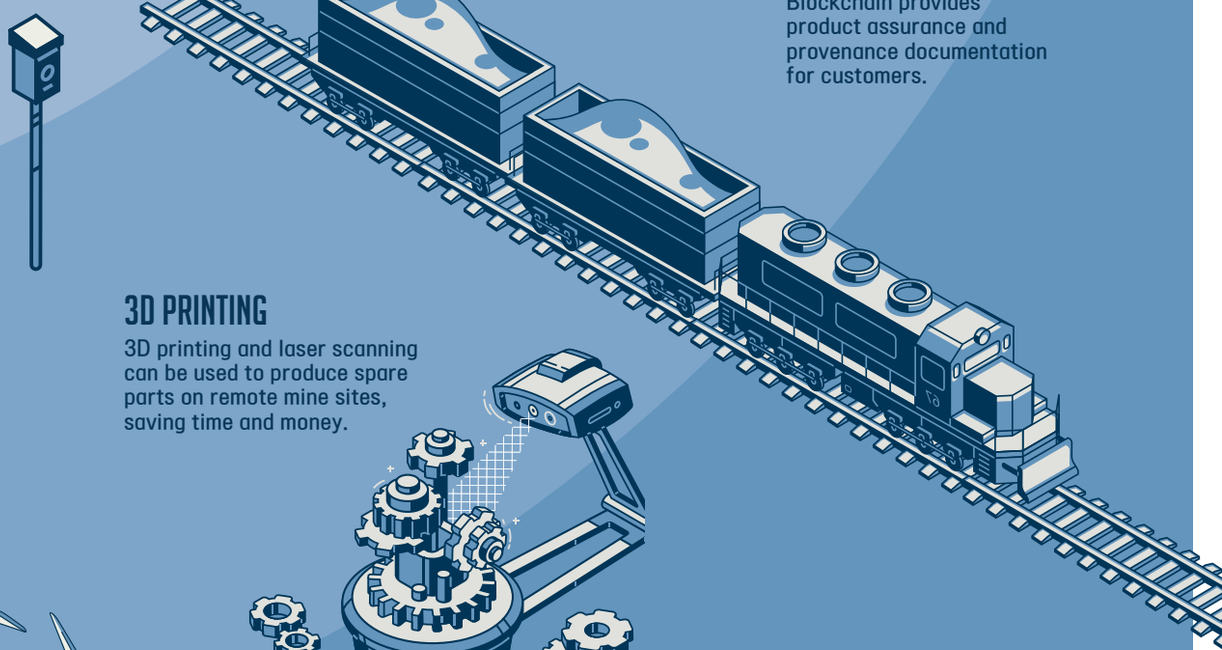


BLOCKCHAIN

Blockchain provides product assurance and provenance documentation for customers.

PREDICTIVE MAINTENANCE

Maintenance schedules are optimised from data collected from a complex network of equipment sensors.

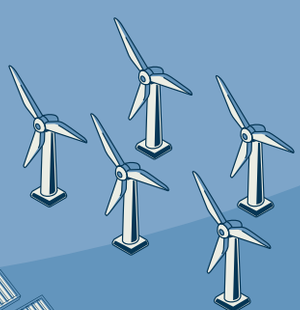


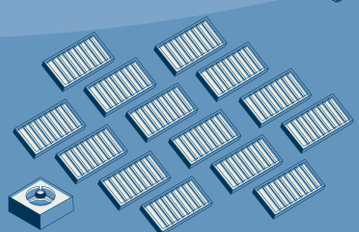
3D PRINTING

3D printing and laser scanning can be used to produce spare parts on remote mine sites, saving time and money.

ALTERNATIVE ENERGY

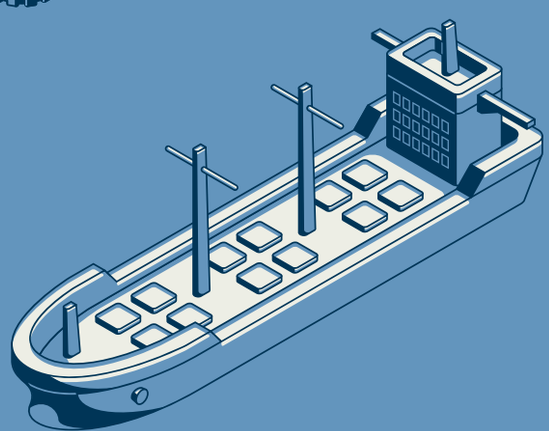
Miners are turning to wind and solar energy, as well battery storage, to reduce emissions and power off-grid operations.





LOGISTICS

Blockchain along with AI and machine learning support commodity and financial markets, facilitating faster transactions and more informed decisions.



ARTIFICIAL INTELLIGENCE

AI technology is embedded across the mining industry, integrating real-time data and analytics to improve worker safety, enhance decision-making and optimise processes.

Applications in mining:

Advanced algorithms and improvements in computing power make it possible for AI machines to learn from experience and perform human-like tasks.[43] There are three ways in which AI machines learn:

- **Unsupervised Learning** whereby the program looks for patterns in data
- **Supervised Learning** whereby a person trains the AI to understand and optimise it's environment
- **Reinforcement Learning** whereby the AI trains itself.[44]

This technology opens up new possibilities to analyse big data sets to solve problems and optimise operations. It has a range of applications in the mining industry, from analysing geological and exploration data, performance data from machinery, safety data and production process data. AI is making mining safer, more productive and more sustainable.

The ability to reanalyse decades and decades of exploration data has significant potential in terms of improving the industry's productivity, profitability and sustainability.

By creating new geological models, discovering new deposits, and optimising new exploration activity in the most prospective areas, AI technology is a critical component in ensuring that historical data is analysed in the most productive way. Perhaps most significantly, all of these operations can be completed without a single new drill hole being dug.

Asset optimisation is also greatly enhanced by using AI to analyse data from machines, enhancing productivity and sustainability and eliminating inefficient operations. For example, Rio Tinto has an ore crusher at an iron ore processing plant that can talk to trucks and let them know when it needs more ore.

AI is also an important tool improving mine safety, analysing real time data from sensors and other analytics to better understand when changes in factors such as temperature or vibrations can lead to danger. Warnings can be issued in advance to machine operators and drivers, thus preventing accidents and injuries.

BHP partners with AI explorer KoBold Metals

BHP has partnered with Silicon Valley based minerals explorer KoBold Metals to find the next wave of minerals critical for the manufacture of EVs and renewable energy, such as copper and nickel.

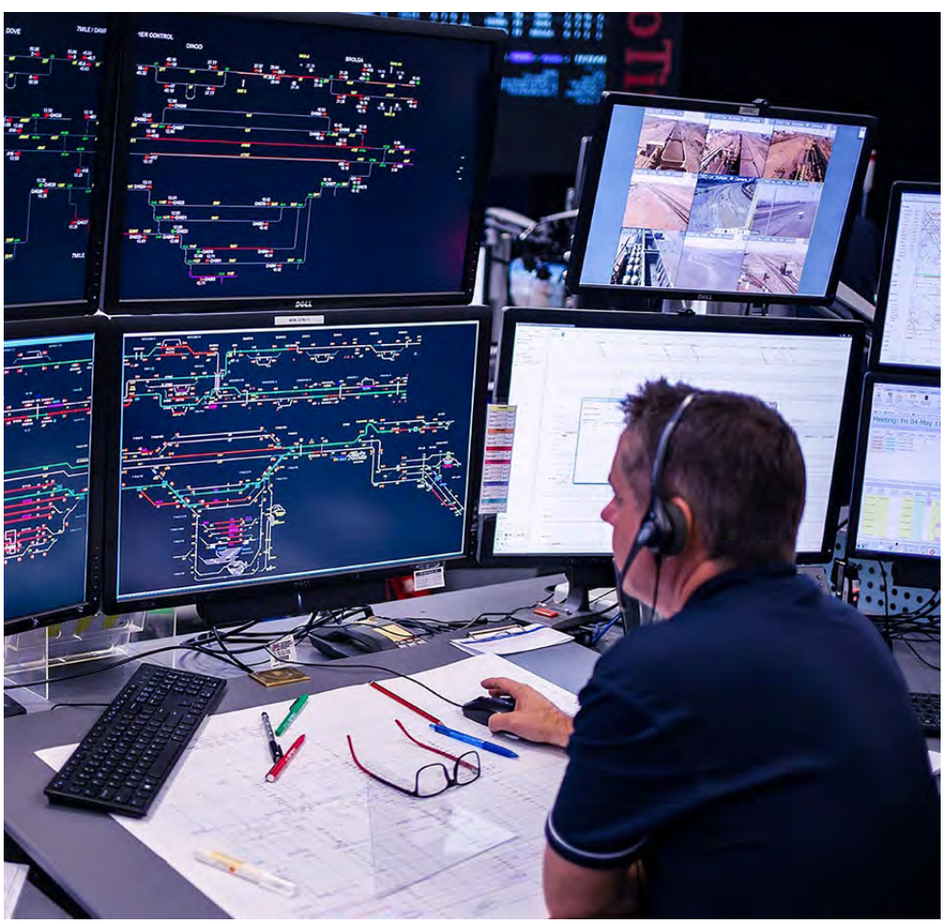
Kobold Metals is using machine learning and AI to analyse historical exploration data drawn from an area greater than 500,000 km² in Western Australia.

Deploying new technologies to analyse existing data is helping explorers discover previously overlooked mineral deposits. As shallow resources have been mined, AI is particularly important to discover remaining resources deeper underground.

KoBold Metals' billionaire investors include Microsoft's Bill Gates, Bloomberg's Michael Bloomberg and Amazon's Jeff Bezos.

BHP and KoBold Metals have teamed up to unearth battery minerals in Western Australia.

ARTIFICIAL INTELLIGENCE



Rio Tinto wields AI like a Jedi master

Rio Tinto is one of Australia's most innovative miners and is leading the way in the utilisation of AI to make better and faster decisions. Mine controllers at integrated operations centres use AI insights to better manage and maintain all manner of equipment often located on mine sites thousands of kilometres away.

Rio Tinto's AI system is so advanced it provides insights into what may happen up to 45 minutes in the future by merging real time data with historical data across 20 systems. In a 12-hour shift, more than 6 million data points can be analysed. The system's predictive modelling capabilities can simulate 400 decisions and resulting impacts in just 60 seconds, and select the most likely outcome in 300 milliseconds – a third of the time it takes to blink.

AI is not replacing human controllers but instead provides a tool to enhance decision making while removing the burden of undertaking low-value repetitive tasks.

AI helps controllers at Rio Tinto make decisions, sometimes thousands of kilometres from the mine site.

AUGMENTED & VIRTUAL REALITY

Augmented and virtual reality technologies enhance the physical world by superimposing digital data like sounds, images and text on the real world.

Applications in mining:

Augmented and virtual reality technologies offer an immersive digital experience which replaces the real world with a simulated one. The first AR head-mounted display was developed in 1968 by Harvard computer scientist Ivan Sutherland. Since then the technology has been advanced by universities, companies and government agencies for applications ranging from aviation, military and industrial purposes, as well as mining.

Humans have five senses but the way in which information is processed from these senses is completely different. Sight is perhaps the most significant sense in terms of information access by humans. An estimated 80 to 90 per cent of the information humans receive is accessed through sight. AR is a powerful support tool to enhance and enable these processes.

The mining industry is increasingly utilising AR and VR technology in many forms:

- Schematics which can be delivered as interactive 3D holograms, guiding people through complicated tasks
- Deployed in the cabins of machinery through heads up displays or smart glasses to optimise operator performance.

When integrated with other advanced technologies, operational data can be extracted from these systems and analysed to improve safety, productivity and performance.

VR is frequently used to train people in tasks that involve hazardous or remote environments. Mining companies use VR simulators to train machine operators from the safety and comfort of high tech consoles, often in metropolitan areas.

A key enabler of deploying VR for real world training is Light Detection and Ranging (LiDAR) technology that uses a pulsed laser to collect measurement. From these measurements virtual models can be made. LiDAR technology can be deployed on drones to survey large areas quickly and relatively cheaply.

Advanced simulators guide new employees

New employees at New Hope's Bengalla coal mine in the Hunter Valley clock hours in an advanced VR simulator before they climb into the driver's seat of a 500 tonne, seven metre high Hitachi dump truck.

Mine site roads, stop signs and other infrastructure are programmed into the simulator to provide a highly realistic, safe, modern and effective training platform.

Large touch-screens allow trainees to do a virtual 'walk-around' of their machines, looking for maintenance and other issues and learning the difference between worn and damaged parts.

Employee training in Australian mining is world-leading, with immersive technologies used by many mining companies to ensure workforce safety and efficiency.

Bengalla safety trainers help new employees learn the ropes in an advanced VR simulator.

AUGMENTED & VIRTUAL REALITY

Komatsu uses AR to improve safety

Leading original equipment manufacturer Komatsu has deployed semi-automated teleoperation equipment capabilities to reduce cycle times and combat operator fatigue. The system displays real time feedback on movements by the machine based on the production plan.

Using the machine's on-board sensors, each load moved is calculated and data is collected to provide insights on how to improve productivity, safety and reduce operating costs. The system also provides 360 degree views to improve visibility of objects and potential hazards.

Data collected through the system is used for online real time coaching as well as offline coaching. To complement the technology, an operator guidance and coaching function is also under development leveraging AR technology.

Komatsu's semi-automated teleoperation is an example of technology enhancing existing roles rather than replacing them.

Komatsu's real time teleoperated excavator in action.

BIG DATA ANALYSIS

Big data analysis helps mining companies make good use of the vast amounts of data collected from equipment and machinery daily to optimise safety, supply and productivity.

Applications in mining:

Big data goes beyond the collection of lots of data. It is about the value that can be extracted from data, the way data is harvested from different sources, and the way new and innovative analyses can be applied to existing data in order to better understand the information that has been collected.

There is an abundance of sensors, instruments and processes that make up modern life. Big data is working in the background analysing this constant stream of data to inform a myriad of decisions impacting every aspect of our lives. Whether its data about the physical world, commodities, financial markets, social media or historical data, big data systems are able to identify trends and help predict the future.

When applied to mining, big data has the ability to facilitate faster and more informed business decisions enhanced by predictive analytics. Virtually no part of the mining value chain cannot be enhanced by big data systems. It leverages and amplifies the benefits of AI, machine learning, IoT and sophisticated sensors.

One of the most impactful applications of big data in the mining industry is in the exploratory phase of minerals extraction. By combining large databases that include mineral evolution data, geospatial information, mineral occurrence frequency, as well as historical datasets and modelling on exhausted deposits, data scientists and geologists are able to generate models to predict mineral occurrence with greater accuracy and certainty.

Much like AI, big data has the potential to significantly improve the productivity, efficiency and sustainability of exploratory operations, while also minimising disruptive exploratory practices in and around potential minerals deposits.

Data science reshaping career pathways

Big data is driving new occupations and skills development across the mining industry. Employees at South32's silver and lead Cannington mine in Queensland are helping develop the next generation of scientists, engineers and coders.

The STEM4Schoolkids workshop at St Laurence's College in Brisbane provides hands-on activities to demonstrate the role STEM plays in the minerals and energy sector. Data analysis and data and digital literacy are two of the fastest growing mining skill sets.

Mining companies will recruit thousands of data scientists over the next decade to support mining's digital transformation. Data scientists will work alongside geotechnical engineers, mining engineers, geologists, metallurgists and process technicians in the future workforce.

Technology is reshaping traditional mining careers.

BIG DATA ANALYSIS

Data analytics making mining more productive

Geoscience Australia has released a magnetotellurics (MT) model that uses electrical conductivity to analyse mineral compositions from tens to hundreds of kilometres beneath the Earth's surface. The model is part of the $225 million Exploring for the Future program which could uncover future critical minerals deposits, such as copper, nickel and rare earth elements.

The model produced from newly collected data covers more than one million square kilometres of northern Australia and reveals distinguishing electrical conductivity features that can be used to indicate previously undiscovered mineral deposits.

New models and better data analytics are making mining more productive by increasing the resource identification per metre drilled. This also means less disturbance to the environment, land holders and local communities.

For more information: eftf.ga.gov.au

Geoscience Australia's Dr Wenping Jiang deploying MT instrumentation.

BLOCKCHAIN TECHNOLOGY

Blockchain is an open, decentralised digital public ledger that can record transactions between two parties in a verifiable and permanent way.[45]

Applications in mining:

Blockchain guarantees digital transactions are authentic and unaltered, and is increasingly finding favour in the mining industry to support efforts to demonstrate the provenance of sustainably mined minerals.

Blockchain works by storing data in blocks, connected through cryptography. New data forms a new block, and is subsequently chained to the previous block, leaving a permanent record that cannot be deleted.

While blockchain's applications are not yet widespread, its applicability and future impact has the potential to completely redefine the transaction process.[46] Current applications for blockchain in mining include mineral provenance, as well as business input sources and improved transactions.

The ability to trace the origin of metals and minerals is important for ESG certification, particularly as more and more companies make commitments to responsible sourcing. Australian mining has recently adopted the award winning Towards Sustainable Mining (TSM) accountability framework which helps minerals companies evaluate, manage and communicate their sustainability performance.

Adoption of TSM may allow for accreditation under international standards. Mining companies are also using blockchain to ensure the origin of inputs such as energy are authenticated and in line with corporate commitments.

The business of mining involves a significant number of transactions, both international and domestic. While many of these transactions are still paper based, such as commodity shipping, blockchain can enable the digital exchange of data which improves efficiency and accuracy. In some circumstances, blockchain can also be used to automate transactions.

The former federal government invested $3 million in a pilot program in the 2021–22 Budget to increase competition, simplify processes and reduce costs to support the critical minerals sector in Australia.[47] Queensland company Everledger was supported to research how blockchain technology can provide a digital certification for critical minerals across the supply chain.

Tracing emissions from nickel used in EVs

In a recent pilot, BHP traced a nickel shipment from its Nickel West mine in Western Australia to Tesla's Gigafactory in Shanghai. Blockchain technology was used to confirm the provenance and quality of the nickel.

BHP's Nickel West asset has one of the world's lowest operational carbon emissions intensities for nickel mining.

This initiative will help support traceability and sustainability for end customers across the battery supply chain.

As well as a more ethical supply chain, miners are increasingly looking to blockchain technology to mitigate supply issues, improve transparency, accuracy and efficiency of transactions, as well as support decarbonisation initiatives.

BHP's Nickel West mine has one of the world's lowest operational emissions intensities.

BLOCKCHAIN TECHNOLOGY

Rio Tinto's Yarwun alumina refinery in Central Queensland.

From mine to market it starts with blockchain

Rio Tinto has set a new standard in transparency and traceability with the launch of blockchain platform START, a 'nutrition label' for the transparent and responsible production of aluminium.

START will help customers meet consumer demand for greater transparency on where and how the aluminium products they purchase are made. The START sustainability label is now available for aluminium purchased from Rio Tinto managed operations globally.

Customers receive a digital sustainability label – similar to a nutrition label found on food and drink packaging – containing key information about the site where the aluminium was responsibly produced, including carbon footprint, water use, energy sources and recycled content.

START helps end-users differentiate between end products based on their ESG credentials, enabling them to contribute to a more sustainable future.

DIGITAL TWINS

A digital twin is a virtual copy of an object or system that is updated with real-time data and uses powerful simulations and machine learning to enhance decision making.

Applications in mining:

Digital twin technology was pioneered in the 1970s by NASA, and first utilised during the Apollo 13 Program. At the time, engineers in mission control needed to be able to analyse and simulate impacts on the spacecraft from the extreme conditions in space. This was done using a combination of physical and mathematical models.

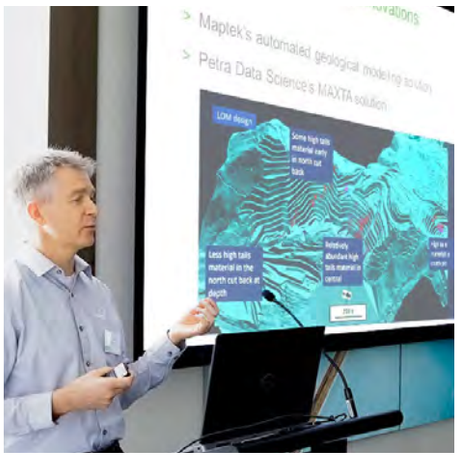
Today, with the aid of drones, big data, sophisticated sensors, 4D visualisation, AI, machine learning and IoT, a digital render can be produced with precision and updated as real time data is continually added.

In the mining industry, digital twins are used to improve productivity and safety on mine sites, as well as ensuring operations are fully integrated from pit to port and working efficiently with minerals processing facilities.

Similar to automation, digital twins do not replace the critical decision making role of people; instead it is tool to facilitate improved decision-making by people. Decisions are informed by virtual simulations which in the past could have increased the risk of damage to production processes.

Bottlenecks are able to be identified and removed, and the impact of potentially unsafe or inefficient scenarios can be tested in a virtual world without any disruption to operations.

Digital twins also enable greater collaboration between people right across a company. There is no tyranny of distance in the digital world, which makes this technology a major gamechanger for an industry that operates in remote regions.



Digital tools to meet the raw material challenge

Maptek has partnered with PETRA to develop digital twin ore bodies to optimise mine design and resource recovery. The technology provides miners with a new planning tool where petrographic and geochemical studies are not definitive.

Digital twin simulations enable engineers to virtually adjust 'levers' showing future scenarios around mine planning, blasting, metallurgy and process control to optimise resource recovery. Machine learning is also used to conduct mathematical optimisation to identify which factors lead to the best resource recovery rate.

This technology is making previously uneconomic deposits more economically viable and will help Australian miners to meet the global raw material challenge.

Maptek and PETRA are optimising mine design and resource recovery.

DIGITAL TWINS

Digital twin improves productivity at Telfer

Newcrest has deployed digital twin technology to improve productivity at its Telfer mine in the Great Sandy Desert. The virtual copy of the copper flotation circuit allows for simulations to occur in parallel without impacting operations.

Operating a copper flotation circuit is traditionally a complicated task. Not only is performance measured in grade, but also recovery objectives. This involves many pieces of equipment and hundreds of data sensors that require constant management. Once calibrated, the digital twin supports constant monitoring by alerting operators to deviations.

Copper is a key mineral for electrification and making copper mining and processing more productive is critical to meet the raw material challenge.

Newcrest is also constructing a digital replica of its Cadia gold, copper, silver and molybdenum mine near Orange in New South Wales using real-time data from sensors to help plan changes and maintenance.

Digital twin technology is boosting productivity at Newcrest.

HYDROGEN ENERGY

Hydrogen has the potential to support the decarbonisation of mining operations by storing renewable energy to generate electricity and power mine vehicles and trucks.

Applications in mining:

Hydrogen is an energy carrier which, when consumed in a fuel cell, produces only water and warm air. Hydrogen can be produced from energy sources such as gasified coal, natural gas, nuclear energy, gasified biomass and renewable electricity. Hydrogen can also be generated through electrolytic processes, solar driven processes and biological processes.

The benefit of hydrogen is its near zero greenhouse gas emission output when paired with abated energy sources like carbon capture and storage for gasified coal, natural gas or gasified biomass. Fuel switching from diesel to hydrogen in equipment, light vehicles and trucks can significantly reduce emissions in mining.

Anglo American launched a prototype of the world's largest hydrogen powered mine haul truck in May 2022. The 2 MW hydrogen-battery hybrid truck generates more power than its diesel predecessor and is capable of carrying a 290 tonne payload.

Part of Anglo American's nuGen™ Zero Emission Haulage Solution, nuGen™ provides a fully integrated green hydrogen system, consisting of production, fuelling and haulage, with green hydrogen to be produced at the mine site.

Hydrogen use today is dominated by industry, and is mainly used for oil refining, ammonia production, methanol production and steel production. Hydrogen also has the potential to replace coal or coke in steel manufacturing to create 'green steel'.

Significant research is also underway to help decarbonise the steel industry by using hydrogen as an energy carrier and reducing agent.

The Australian government has already identified seven priority prospective hydrogen hubs: Bell Bay (Tasmania), Pilbara (Western Australia), Gladstone (Queensland), La Trobe Valley (Victoria), Eyre Peninsula (South Australia), Hunter Valley (New South Wales) and Darwin (Northern Territory). These hubs are a mix of existing manufacturing regions and new manufacturing areas, offering renewal and new economic opportunities, like jobs for regional communities.

Hydrogen provides an opportunity for Australia to develop a new export industry, as well as decarbonise fuel sources for operations and manufacturing processes.

H2-powered freight trains on horizon for QLD

Anglo American and Australia's largest rail freight operator Aurizon are working together to assess the introduction of hydrogen-powered trains for bulk freight in Queensland.

A feasibility study will explore the application of Anglo American's proprietary hydrogen fuel cell and battery hybrid power units in heavy haul freight operations. If successful, the agreement could be extended to further phases of collaboration, which could include detailed engineering and development of a hydrogen -fuelled heavy haul locomotive prototype.

Anglo American has taken a global lead in the development of green hydrogen solutions as part of its commitment to carbon neutral mines by 2040.

Anglo American and Aurizon are assessing the viability of hydrogen-powered heavy haul trains.

HYDROGEN ENERGY

Collaboration in action on hydrogen future

Hatch, Anglo American, BHP, and Fortescue have formed a Green Hydrogen Consortium to investigate ways of using low emission hydrogen to help decarbonise their operations. The collaboration includes undertaking research, technology and supply chain development, as well as piloting green hydrogen technologies to de-risk and accelerate their update.

Hydrogen has traditionally been carbon-intensive to produce, either because of the emissions associated with steam methane reformation or from the electricity required to split the water molecule into hydrogen and oxygen through electrolysis. Green hydrogen is produced using electrolysis powered by renewable energy, hence there are no associated operational emissions.

The Consortium has been established for a term of three years and the members review progress every six months. A detailed scope of work and a roadmap of initiatives will be developed.

Anglo American unveiled a prototype of the world's largest hydrogen-powered haul truck in May 2022.

INTEGRATED AUTOMATION

Automation refers to machines which are able to mimic human tasks and repeat set actions which have been defined as a part of the machine's ruleset.[48]

Applications in mining:

Integrated automation maximises productivity and efficiency by enabling humans to undertake more high value, high skilled tasks and roles while machines undertake mundane, routine and repetitive tasks.

There are many phases of automation, from partly automated to locally automated, connected and optimised; collaborative and mobile automation through to autonomous and economic optimisation. The later stages of these automated technologies embed other technological inputs such as the Internet of Things, as well as big data, to control and coordinate automated machinery.

While automated drills, haul trucks and trains are used across the mining industry, the technology is also used for corporate functions like accounting. The result of this technologically-embedded approach to innovation means that safety, production, predictive maintenance and environmental monitoring are all enhanced.

Drilling is an essential part of mining operations. In the past, teams of workers were needed to operate a single drilling rig. From exploration holes to production drilling to plant explosives, workers were often required to perform physically demanding manual tasks outside and when operating, around the clock.

Today with autonomous drill systems, a single operator in a climate controlled room can control multiple drills from a single console. That console could be proximate to the drill rig or thousands of kilometres away. Autonomous drill systems allow for increased safety, accuracy and consistency – all while delivering significant productivity gains.

Autonomous trucks and trains that can be remotely controlled and monitored have also removed humans from potentially hazardous situations. The performance and operations of haul trucks can be more easily optimised using machines, alongside AI and digital twins. By reducing maintenance and fuel costs, these operations are more efficient and sustainable, while also being much safer for the operators.

Some mining companies have reported productivity gains of up to 30 per cent following the introduction of automated technology across some or most parts of their operations.[49]

From pit to port with autonomous trains

Rio Tinto launched the world's largest robot in 2019. AutoHaul is the first fully autonomous, long distance, heavy haul rail network in the world.

The 2.4 km long trains are remotely monitored by operators at Rio Tinto's integrated operations centre in Perth and travel across a vast network of 1700 km of track in outback Western Australia.

Once the train controller sets the route, a network of computers make decisions about safe speeds and collision avoidance to ensure safe, efficient haulage to port.

The trains have safely travelled more than 4.5 million kilometres autonomously since they were first deployed in 2019, delivering iron ore from 16 mines to ports in Dampier and Cape Lambert.

Rio Tinto's autonomous heavy haul network launched in June 2019.

INTEGRATED AUTOMATION

Autonomous haul truck fleet at Boddington

Newmont's Boddington operation became the world's first open pit gold mine with an autonomous truck fleet in 2021. Newmont invested $150 million in its Autonomous Haulage System (AHS) to improve safety and productivity and extend mine life.

The autonomous haulage fleet of 36 trucks – 29 new Cat 793F haul trucks and the conversion of another seven 793F vehicles already operating at the site – reduces fuel usage and associated emissions by using lower and more constant revs. Caterpillar reports these trucks have hauled close to 68 million kilometres without a lost-time injury and in some cases boosted overall mine productivity by close to 30 per cent.

Newmont operations, maintenance and support systems personnel are learning new skills to support adoption of the AHS technology at the nearby WesTrac Technology Training Centre in Collie and the WesTrac Institute in South Guildford.

Autonomous haul trucks at Newmont's Boddington gold mine in Western Australia.

INTEGRATED OPERATIONS CENTRE

Integrated operations centres are centralised control hubs, often located in metropolitan areas, able to oversee and control all aspects of a mining operation remotely.

INTEGRATED OPERATIONS CENTRE

Applications in mining:

Integrated operations centres come in the form of remote operating centres, integrated remote operating centres, unified operating centres or even processing excellence centres.

There is enormous value in having the ability to monitor and control operations that normally span vast distances. It allows for a consolidation of subject matter experts who can provide input into multiple operations from the same location, increasing capability and collaboration.

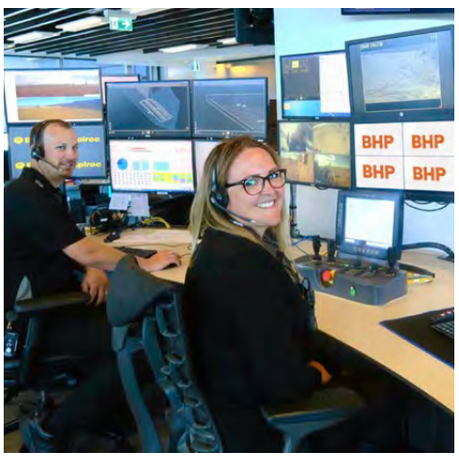
Cross function teams are also able to be deployed more effectively, seamlessly combining onsite and centrally-located team members. Better collaboration and team performance with system wide data integration also enhances decision making and productivity.

Integrated operations centres do not replace the need to have people onsite. However, the centralised location of employees can be in less hazardous zones. Integrated operations centres have been shown to result in better emergency and incident response. Additionally, they provide a redundancy in case of remote outages or health hazards that impact people onsite (such as COVID-19).

An integrated operations centre in Perth, for example, may be able to monitor operations in a cyclone zone or ensure continuity of a site's operational capacity which otherwise would have resulted in an interruption to site operations because of unavoidable workforce absenteeism.

Importantly, integrated operations centres also provide opportunities for more diverse workforces by breaking down barriers of working in remote locations on fly-in fly-out rosters. To reduce time away from family and friends, many people with onsite experience transition to roles in integrated operations centres.

A diversity of workplace options enables intra-organisational workplace mobility, ensuring that employees with onsite experience and expertise are not lost to other industries and instead are able to transition to integrated operations centres. Diverse workplace locations also reduces the impact on social services and infrastructure in remote locations.



Remote operations centres drive productivity

BHP established an Integrated Remote Operations Centre (IROC) in Brisbane in 2016 following the success of its state-of-the-art IROC in Perth. The Brisbane facility oversees multiple aspects of remote operations from an advanced control room that operates 24 hours a day, seven days a week.

By optimising supply chains and centralising expertise, IROCs have improved safety, reduced costs and boosted productivity, making Australian mining more competitive.

New occupations have also been created through the development of integrated operations centres, such as automation engineers and mine and port control operators. These new roles make a career in mining more accessible for more people, contributing to a more diverse workforce.

BHP's Brisbane Integrated Remote Operations Centre.

INTEGRATED OPERATIONS CENTRE

End-to-end integration the goal for Newmont

Newmont is working with Caterpillar to deliver a fully connected, automated, zero carbon emitting, end-to-end mining system. The goal is a safer and more productive operation that supports Newmont's 2030 goal of more than 30 per cent emissions reductions. Newmont's ultimate goal is net zero emissions by 2050.

Under the partnership, Caterpillar will develop its first battery electric zero emissions underground truck to be deployed at Tanami by 2026. The deployment includes a fleet of up to 10 battery electric underground haul trucks, including first-of-its-kind battery electric haulage technology for underground mining in 2024, and the introduction of battery autonomous technology in 2025.

Newmont's surface and underground mining fleets are responsible for around 40 per cent of the company's carbon emissions. This collaboration will help make Newmont's mines safer and more productive while also assisting the company reach its greenhouse gas reduction targets for 2030 and 2050.

Newmont's Tanami mill in the Northern Territory.

INTERNET OF THINGS

The Internet of Things (IoT) refers to the connection of various devices to the internet and then the interconnection of those devices to each other.

Applications in mining:

Although it has been around for a couple of decades, the power of IoT continues to be amplified by technological innovation, such as more sophisticated sensors, better data capture, storage and analysis and integrated systems.

IoT devices range from household appliances to entire transportation systems and industrial processes, like mineral and metal extraction.

Devices and processes which were previously unable to communicate with each other or report key metrics are today able to work in tandem and provide users with all the necessary information in a streamlined way.

For example, advances in the development of sophisticated sensors built into critical mining equipment and other machines, and supported by big data, digital twins and AI, has the potential to improve automation, eliminate waste and extract maximum production from existing systems.

The result is the rise of the 'connected mine' where performance of plant and machinery is monitored, remote diagnostics is enabled and predictive maintenance reduces unplanned down time.

It's not just the plant and machines that can be connected. The wearable technology used by workers can be used to monitor the environmental factors like temperature, humidity and noise as well as health metrics of the worker.

The connectivity created through IoT makes mine sites far safer by removing workers from close proximity to operating machinery, which is a major onsite hazard.

Sensors generate more data than Apollo 11

From pit to port, mining operations have never been more interconnected thanks to the power of IoT. An autonomous haulage truck, for example, collects data from around 180 sensing points.

Data is collected every five seconds, generating an enormous amount of information. One autonomous haulage truck, for example, collects around 2500 gigabytes of data every day.

For comparison the guidance computer on Apollo 11 had 2048 words of memory Random Access Memory. Each word comprised 16 binary digits (bits), with a bit being a zero or a one. This means that the Apollo computer had 32,768 bits of RAM memory or 0.000004096 gigabytes.

The science of analysing big data is becoming an increasingly important area in the digital mines of the future.

An autonomous haulage truck generates around 2500 gigabytes of data per day.

INTERNET OF THINGS

Underground drone a world first at Cannington

Drones are widely used in mining to provide comprehensive visual and spatial data quickly and efficiently. But drones are usually sent skyward – not underground.

In a world first, South32 partnered with a research team at CSIRO to successfully test an autonomous drone underground at its Cannington mine in Queensland. Some of the technical challenges that had to be overcome included navigating small spaces, lack of GPS capabilities, dust and moisture. Together, South32 and CSIRO developed the 'Hovermap System' using LiDAR laser and on-board auto pilot computer.

LiDAR is a remote surveying method that measures light pulses reflected from a target with a sensor to measure distances.

The underground drone produces 3D maps and images that are not only more accurate but also reduce the need to expose workers to potentially hazardous enclosed spaces.

South32 and CSIRO partnered to expand the application of drone technology underground.

KINETIC BRAKING

Harnessing the power of kinetic energy from a process of regenerative braking will enable haul trucks to store and reuse energy extracted during braking.

Applications in mining:

Mining is home to the world's largest electric vehicles. From electrified four wheel drive passenger vehicles to the large dump trucks with payloads of more than 300 tonnes and even locomotives that haul 28,000 tons of iron ore, powering these machines means upgrades to existing energy systems.

One of the natural advantages of some mine sites are the declines into the pit or mine shaft. Regenerative braking involves complex mechanics that turns the electric motors that make the wheels spin under acceleration into generators under braking.

Kinetic energy from this regenerative braking is then stored in the battery, ready to provide energy for acceleration. Capturing this energy reduces the need for external energy while also improving productivity through faster cycle times.

It's not only battery electric vehicles that benefit from this technology. Regenerative braking systems can be paired with hydrogen fuel cells to extend the otherwise limited range of electric vehicles. Mining companies are working collaboratively with original equipment manufacturers to develop this technology.

This involves prototypes, testing and pre-production trials before the trucks are used in operations.

On some machinery, kinetic braking systems are expected to provide a 45 per cent decrease in fuel use, reduce carbon emissions by 35 per cent and total operation costs by 10 to 15 per cent.[50] Improving efficiency improves productivity and environmental outcomes.

Regenerative braking on show at Komatsu

Komatsu's WE series of hybrid wheel loaders have delivered the mining industry several technological advancements since its first loader was unveiled in 2021.

The Switched Reluctance Hybrid Drive system is fully regenerative which means that during braking, electrical motors become generators and feed power back into the electrical system.

This means that the loader has the potential to deliver fuel savings of up to 45 per cent, as well as a considerable reduction in carbon emissions per tonne – 35 per cent fewer emissions compared to conventional mechanical loaders or hydraulic excavator machines.

The WE series also features real-time data monitoring and a feedback system.

Komatsu's WE series allows for less fuel consumption and reduces carbon emissions.

KINETIC BRAKING

Fortescue's Infinity Train project has the potential to be the world's most efficient battery electric train.

A train that doesn't need charging

Fortescue is developing a world-first regenerating battery electric iron ore train called the Infinity Train.

The Infinity Train concept will harness the gravitational energy generated on downhill sections of Fortescue's rail network to charge its battery electric system without any additional charging requirements. The train, jointly developed with Williams Advanced Engineering, has the potential to be the most efficient battery electric train in the world.

Once operational, the Infinity Train will eliminate diesel and emissions from Fortescue's iron ore trains, resulting in lower operating costs and reduced maintenance. The Infinity Train builds on Fortescue's announcement earlier this year to purchase two battery electric locomotives from Progress Rail, with the first scheduled for delivery in 2023.

A number of other mining companies are commissioning non-regenerating battery electric trains, including BHP, Rio Tinto and Hancock.

LIQUEFIED NATURAL GAS

Liquefied Natural Gas (LNG) is providing mining companies committed to decarbonisation a medium-term solution to reduce costs and cut carbon emissions.

Applications in mining:

LNG is natural gas in a liquid form. It is produced through a process called liquefaction that involves refining the natural gas and then super-cooling it to -162 degrees Celsius. LNG is then stored in cryogenic tanks.

LNG is suitable for vehicles and vessels that require longer ranges because liquid is more dense than gas and therefore more energy can be stored by volume. As the vast majority of Australian minerals are produced for overseas markets, international maritime freight is a key part of the supply chain for mining.

In September 2020, BHP awarded a tender to the world's first LNG-fuelled Newcastlemax bulk carrier with the aim of reducing greenhouse gas emissions intensity by more than 30 per cent per voyage. Rio Tinto has also signed agreements for LNG-fuelled bulk carriers.[51]

In 2018, the International Maritime Organization adopted a strategy to reduce greenhouse gas emissions from ships, as well as a vision to reduce emissions from international shipping.[52] Given a vessel that enters service in 2030 will likely still be in service in 2055 and beyond, it is critical that the transition to low-emissions fuel alternatives begins now.

The collaborative efforts on R&D to move away from diesel and to improve operations on a site by site basis should be recognised and supported. This transition will take time and will need to be tailored to the specific circumstances at each site.

In time, lower carbon fuels such as LNG will be replaced by zero carbon fuels. Some potential zero carbon fuel sources include green ammonia, hydrogen, methanol, biofuels and batteries.

LNG-fuelled carriers reduce emissions

BHP has chartered five LNG-fuelled Newcastlemax bulk carriers to transport iron ore between Western Australia and Asia from 2022.

The LNG-fuelled Newcastlemax bulk carriers have a carrying capacity of 209,000 deadweight tonnes and length of about 300 metres.To put this in perspective, a Panamax bulk carrier (which can enter the Panama Canal) has a maximum width of 32.2 metres. After canal upgrades, post-Panamax sized vessels are able to be 51.25 metres wide.

Bigger still are Q-Max Vessels, the largest LNG tankers, which are around 345 metres in length and are 55 metres wide.

The world's first LNG-fuelled Newcastlemax bulk carrier, the MV Mount Tourmaline.

LIQUEFIED NATURAL GAS

Smart design and operations reduces emissions

Fuel switching alone won't reduce emissions by enough to meet 2050 targets, which is why the design of modern freighters and their operation is focused on efficiency.

Innovation in hull and superstructure design is reducing emissions by up to 20 per cent. Similarly, modern propulsion systems and efficient energy management systems can reduce emissions by up to 15 per cent to 10 per cent respectively. Existing vessels can reduce emissions by up to 75 per cent just through speed optimisation and by up to 50 per cent through fleet management, logistics and incentives.

Better design and operational efficiencies are supported by the International Maritime Organization's Energy Efficiency Design Index that requires a minimum energy efficiency level per capacity mile (e.g. tonne mile) for different ship type and size segments.

APLNG's LNG export facility at Curtis Island, Gladstone.

MINE SITE ELECTRIFICATION

Miners are reducing their carbon footprint through increased electrification of mines, including off-grid renewable energy and battery storage and the rollout of electric vehicles.

Applications in mining:

Electrification involves replacing hydrocarbon fuel sources like diesel with electricity. The development of battery technology and solar photovoltaic plants is also supporting the transformation to electrification.

Electric engines in equipment have a number of benefits including:

- No tail pipe emissions
- Cooler and quieter to run
- Less maintenance than conventional internal combustion engines
- Reduced financial exposure to increases in diesel prices
- Technological improvements in electricity generation means electric engines are becoming cheaper to operate.

These attributes provide a number of advantages in the mining industry, especially when operating in underground environments. Increases in diesel prices and technology improvements in electricity generation also means electric engines are becoming cheaper to operate.

Some mining companies and technology providers are also looking at utilising overhead trolley systems to provide equipment like hybrid diesel electric haul trucks with access to additional electricity when climbing up grades.

This can also be provided as a retrofitted system supporting the transition to electrification. Some systems are reporting fuel and engine costs are reduced by more than 90 per cent when haul trucks are operated on the trolley.[53]

The electrification of diesel engine-powered technology is not just limited to trucks and machinery – remote heavy rail operations have also been considered as a part of this process.

Rio Tinto and BHP have announced trials of battery electric locomotives in their iron ore operations in Western Australia.[54] It is estimated that the electrification of all locomotives could reduce supply chain emissions by 30 per cent annually.[55]

Undergound electric haulage trial a world first

AngloGold Ashanti Australia, in partnership with Sandvik and Barminco, is trialling the world's largest battery electric underground mining truck at its Sunrise Dam gold mine in Western Australia.

The Sandvik TH655B prototype, which has a 65 tonne payload, is another practical step towards net zero emissions mining operations. Replacing a comparable diesel-fuelled vehicle, the new electric machine is expected to have a significant positive impact on underground productivity and air quality, a major factor in improving health and safety outcomes.

Switching to battery electric is becoming more cost competitive and has the added benefit of reducing exposure to diesel fuel price fluctuations and supply chain issues.

AngloGold Ashanti is trialling the Sandvik TH655B at Sunrise Dam gold mine in WA.

MINE SITE ELECTRIFICATION

Gold mine sets sights on electric future

Agnico Eagle's Fosterville gold mine in Victoria is investigating the feasibility of transitioning the operation to a fully electric mine. Agnico Eagle has identified substantial benefits to removing diesel emissions and reducing heat in its underground gold mine.

Electric equipment is also proving to outperform diesel equipment. Agnico Eagle is using Sandvik's 18 tonne electric loader which has the highest capacity in underground loaders and the smallest emissions footprint.

Switching from diesel powered equipment to battery electric equipment substantially improves underground air quality and reduces other hazards such as heat, noise and vibration from combustion engines. When battery electric equipment is paired with renewable energy it further reduces total carbon emissions making mining more sustainable.

The operation room at Agnico Eagle's Fosterville gold mine in central Victoria.

SOLAR PHOTOVOLTAICS

Solar photovoltaics are increasingly being used to power remote mine sites, making mining operations more self-sustainable, and all without producing CO_2 emissions.

Applications in mining:

Photovoltaic technology converts light into electricity. Some materials exhibit a property known as the photoelectric effect that causes them to absorb photons of light and release electrons.[56] Albert Einstein's Nobel Prize in physics was awarded for his discovery of the photoelectric effect.[57]

Although the first photovoltaic cell was built almost half a century after Einstein's discovery, the space industry utilised the technology and helped advance the technology by improving efficiency, reliability and reducing costs.

Photovoltaic technology is widespread in both domestic and industrial areas in the form of solar panels. Solar panels consist of a thin semiconductor wafer which is specially treated to form an electric field. When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material.[58] These electrons are captured to produce an electric current.

The remote location of many mine sites means localised power generation is often relied on to maintain operations. Solar panels provide mining with the opportunity to generate power at the point of consumption, increasing efficiency by reducing energy losses through significant transmission distances.

Solar panels also require less maintenance than diesel engines and generators due to the elimination of moving parts. Similarly, the abundance of space in remote locations means there is room to accommodate vast arrays of solar panels.

Many of Australia's mining companies, such as Bravus Mining and Resources, BHP, Rio Tinto, Newcrest and Glencore have deployed solar panels to power remote operations.

One of the limiting factors to more solar panels is storage capacity, particularly for mine sites which require power 24 hours a day. Improvements to battery technology in terms of reliability, efficiency and cost will help the further utilisation of solar photovoltaic plants in mining. This will support electrification, reduce diesel fuel use and ensure industry continues to reduce emissions.

Rio Tinto triples Weipa solar and adds storge

Rio Tinto's new solar farm and battery storage at Weipa in Queensland will more than triple the local electricity network's solar generation capacity and help provide cleaner power to Rio Tinto's operations.

The new solar farm and battery storage, expected to be completed by late 2022, will complement the existing 1.6 MW solar farm at Weipa completed in 2015.

The 4 MWh battery system will be built next to the existing Weipa power station and will help provide a stable power network for Rio Tinto's Weipa Operations bauxite mines and the Weipa township.

The combined solar capacity and battery will provide about 11GWh of energy annually and help to reduce Weipa Operations' annual CO_2 emissions by about 20,000 tonnes.

Rio Tinto's solar farm and battery storage project at Weipa in Queensland.

SOLAR PHOTOVOLTAICS

Adani Renewables' 65 MW Rugby Run solar farm near Moranbah.

Adani Renewables partner with grazing sheep at Rugby Run

Adani Renewables Australia has developed one of Queensland's most successful 'agri-solar' arrangements, working with local farmers to conduct a sheep grazing trial at its Rugby Run solar farm near Moranbah.

The sheep manage the grass which removes the need for mowing and slashing equipment within the solar farm, reducing dirt and dust on the solar panels. The panels also provide shade during the day for the grazing sheep.

The solar farm has more than 247,000 panels that track the sun, producing 65 MW which goes into the grid to power 23,000 homes and business.

Innovation and ingenuity doesn't end with sheep. Adani Renewables has partnered with local manufacturing firm SMW Group to develop a custom solar panel cleaning machine. This innovation earned Adani Renewables and SMW a nomination as a finalist in the productivity category of the 2022 Queensland Mining Awards.

WEARABLE TECHNOLOGY

Wearable tech like smart helmets, smart vests, smart glasses and boots are just some of the wearable tech making mining safer and more productive.

Applications in mining:

When integrated with internet connectivity and diagnostics sensors, wearable tech is an effective analytics tool improving safety and productivity on mine sites. The beneficiary of advanced connectivity technologies, wearable tech is keeping workers safer, working smarter and better connected than ever before.

From smart helmets to smart glasses to smart boots, sophisticated sensors communicating wirelessly among teams or across operations are able to measure and protect against adverse health and injury risks. Some of the functions of various wearable pieces of technology include:

- Smart helmets that provide 360 degree views of the mine site from the user's location and support communication with other workers
- Smart vests able to track location, body temperature, pulse rates and other key health diagnostic measurements
- Smart glasses that give people access to maps, plans or schematics to support tasks, as well as the functionality of taking photos
- Smart boots that can ensure exclusion zones are observed and alert other workers in the event of a fall or a trip.

Wearable tech is further enhanced by 5G, the fifth generation mobile network. Technologists have proposed that 5G will ignite a fourth industrial revolution as technologies drive productivity and growth across many industrial applications. 5G is up to 100 times faster than 4G, reducing latency and allowing for more data to be transferred more quickly.

The technology offers the mining industry new productivity boosting applications for automation and predictive maintenance, digital twins, VR, AR and IoT-type systems.

Wearable tech helps prevent ergonomic injuries

Soter Analytics in partnership with the mining industry has developed wearable tech that uses AI to coach employees to self-correct and avoid ergonomic injuries.

The Soter device measures and captures data from the wearer helping workplaces reduce the risk of exposure to movements that can cause injuries and pain. A companion app connected to the device provides actionable insights in real time.

Developed for the mining industry and adaptable to any personal equipment, the solution can be adopted by all industries that involve manual handling tasks.

Preventing musculoskeletal injuries protects the workforce and increases labour productivity. ACIL Allen estimates that implementation of the Soter device may result in industry cost savings of up to $26.6 million over a 10-year period.

The Soter device was developed in partnership with the mining industry.

WEARABLE TECHNOLOGY

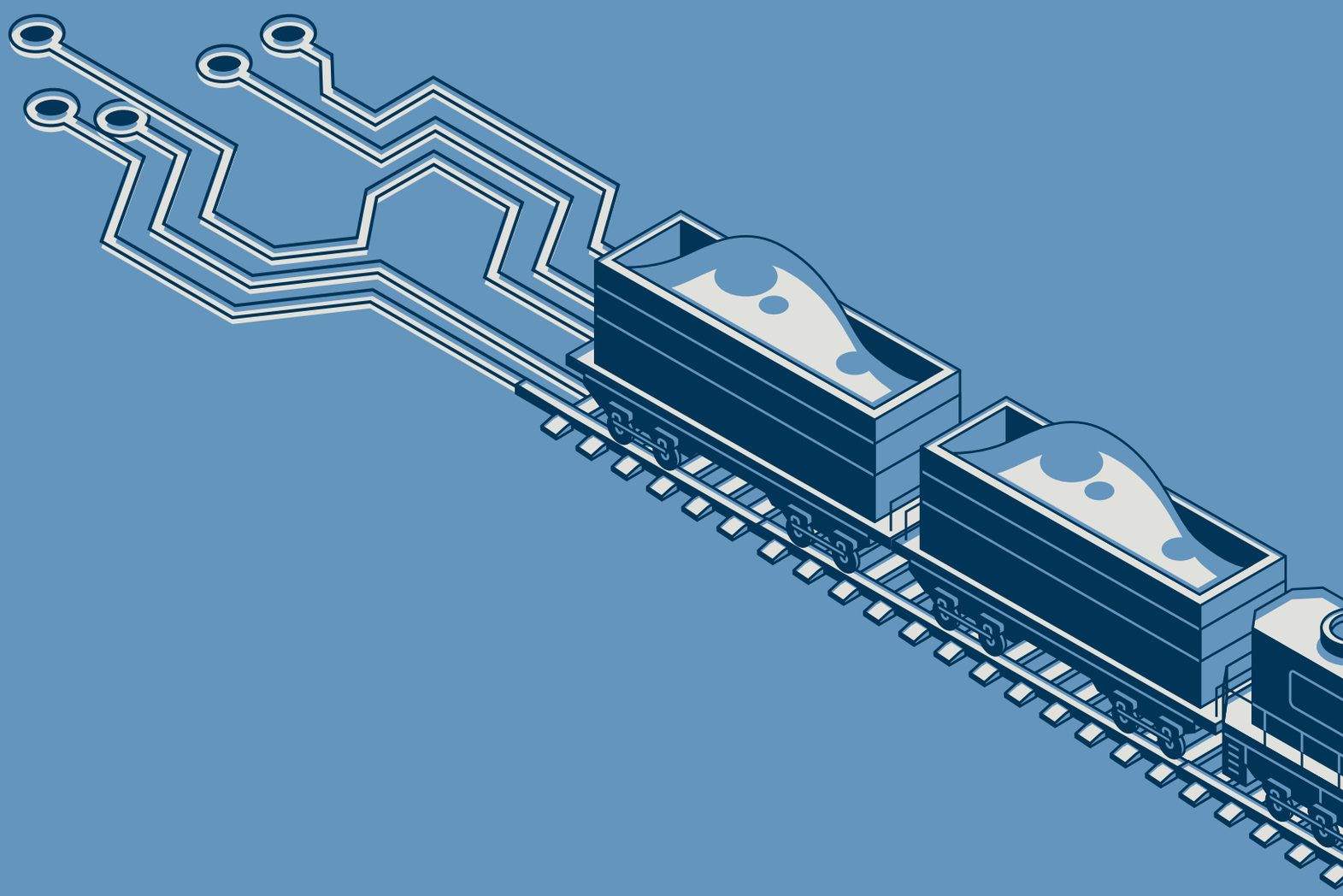
Caterpillar Smartband combats worker fatigue

Worker fatigue can be a major hazard in the mining industry due to 24-hour, 7-day a week operations and rostering arrangements at mine sites in remote Australia. Caterpillar's Smartband, similar to a fitness band, captures sleeping data that is 93 per cent as accurate as the results of a laboratory study.

This Smartband can predict when the wearer's fatigue level will become a safety risk by utilising non-invasive actigraphy to measure motion with an internal 3-D accelerometer. Data is downloaded into an analytics program that demonstrates how sleep patterns are impacted by shift schedules and how sleep debt affects an individual's effectiveness during work hours.

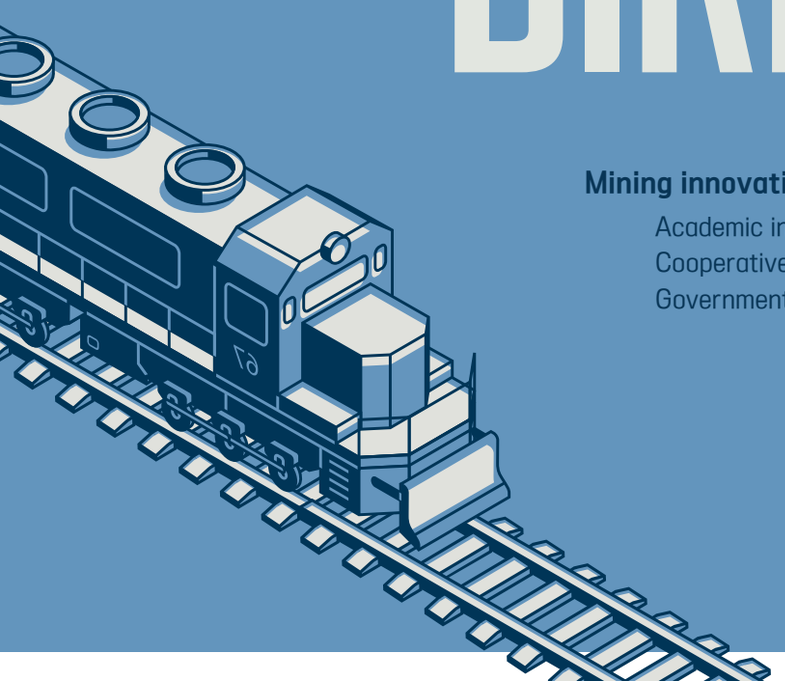
Visibility into sleep levels not only helps operators cut down on fatigue-related accidents, but it can also indicate deeper health issues like sleep apnea or even increased risk for heart disease.

Fatigue management is critical to the health and safety of the mining workforce.



Mining innovation ecosystem

the DIRECTORY



Mining innovation partners_

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Mining research led by

ACADEMIC INSTITUTIONS

The Institute for Geoscience Research (TIGeR)

Curtin University

At TiGER, researchers are focused on locating large mineral deposits and the efficient extraction and recovery of precious metals.

Related centres and facilities:

- John de Laeter Research Centre
- Digital Mineralogy Hub Facility
- 3D Imaging Hub
- Timescales of Mineral Systems Research Group
- Sustainable Engineering Group at Curtin
- Curtin Corrosion Centre
- Drilling Mechanics Group
- Mining Rock Mechanics group
- Gold Technology Group
- Bankwest Curtin Economics Centre
- Curtin University Oil and Gas Innovation Centre
- Centre of Excellence for Core to Crust Fluid Systems
- Trace and Environmental DNA Laboratory

Areas of focus:

- Geoscience for exploration
- Environmental assessment
- Mining engineering
- Resource economics
- Workforce participation and safety
- Optimisation
- Asset management and decommissioning
- Site restoration

Industry partners:

- Lynas Corp
- IGO Ltd
- BHP
- Iluka Resources
- Creasy Group
- FMG
- Atlas Iron
- Anglo American

Government partners:

- CSIRO

University partners:

- ARC Centre for Mine Site Restoration
- WA School of Mines: Minerals, Energy and Chemical Engineering
- Centre for Transformative Work Design
- ARC Industrial Training Centre for Transforming Maintenance through Data Science
- Future of Work Institute
- ARC Industrial Transformation Training Centre for Mine Site Restoration

CRC partners:

- MinEx CRC
- FBICRC

Sustainable Minerals Institute (SMI)

University of Queensland

SMI hosts more than 100 researchers across six research centres, an international centre of excellence and the technology transfer company JKTech.

Related centres and facilities:

- Centre for Mined Land Rehabilitation
- Centre for Social Responsibility in Mining
- Centre for Water in the Minerals Industry
- International Centre of Excellence in Chile
- Julius Kruttschnitt Mineral Research Centre
- Minerals Industry Safety and Health Centre
- W.H. Bryan Mining and Geology Research Centre
- JKTech Ltd

Areas of focus:

- Land rehabilitation
- Communities, governance, cultural heritage
- Water
- Health and Safety
- Floatation chemistry
- Energy transformation
- Minerals processing and complex ore bodies
- Digital transformation and process automation
- Sustainable closure

Industry partners:

- AMIRA International Ltd
- CRC Ore Ltd
- JKTech Pty Ltd
- Anglo American

Government partners:

- CSIRO

University partners:

- University of Newcastle
- University of Cape Town, South Africa
- Hacettepe University, Turkey
- University of Rio de Janeiro, Brazil
- McGill University, Canada
- Chalmers University of Technology, Sweden
- China University of Mining and Technology, China

Mining Research Centre (MRC)

University of Wollongong

Based in Wollongong, the MRC has maintained its traditional focus on coal.

Areas of focus:

- Coal
- Mine safety
- Geotechnical engineering and ground control
- Computer applications and operational research methods

Industry partners:

- Australia Coal Association Research Program (ACARP)
- BHP
- Glencore
- BASF International

Newcastle Institute for Energy and Resources (NIER)
University of Newcastle

NIER research centres are finding solutions for the mineral, gas and water industries as well as developing optimised energy technologies while also examining the social impacts of the energy and resources sectors for communities.

Related centres and facilities:

- ARC Centre of Excellence for Enabling Eco-Efficient Beneficiation of Minerals
- Research Hub for Advanced Technologies for Aust. Iron ore
- Advanced Particle Processing and Transport
- Frontier Energy Technologies and Utilisation
- Organic Electronics
- Bulk Solids and Particulate Technologies
- Centre for Advanced Energy Integration
- Global Centre for Environmental Remediation (GCER)
- Global Innovative Centre for Advanced Nanomaterials (GICAN)
- International Collaborative Centre for Carbon Futures
- Ironmaking Materials Research
- Multiphase Processes
- Optimal Planning and Operations
- Resources Health and Safety
- Social Research and Regional Futures (CSRRF)
- Water, Climate and Land

Areas of focus:

- Resource productivity and efficiency
- Advanced particle beneficiation
- Iron ore sintering, cokemaking and blast furnace ironmaking
- Geotechnical analysis and materials characterisation
- Bulk solids handling and transport
- Energy technologies and utilisation
- Low emission energy technologies
- Renewable energy systems, efficiency and storage
- Fuels, materials and energy utilisation
- Advanced materials for industrial innovation
- Electrochemistry and materials engineering
- Advanced nanomaterials
- Organic electronics
- Land, water, social impacts and sustainability
- Climate, soil and water
- Land use management, environmental remediation and social impacts
- Resources health and safety

Industry partners:

173 active industry partners including:

- BHP
- Bengalla Mining Company
- Jord International
- MACH Energy

Industry partners:

- CSIRO

Australian Centre for Sustainable Mining Practices (ACSMP)
University of New South Wales

ACSMP is focused on new mining practices, and the development and application of technologies and systems for sustainable mining initiatives.

Areas of focus:

- Sustainable mining practices
- Sustainability and people
- Environmental management
- Water management
- Mine waste management

Industry partners:

- Mitsubishi Development

Mine Water and Environment Research Centre (MiWER)
Edith Cowan University

The Institute for Frontier Materials is a vibrant, multicultural research institute, graduating more than 30 PhD students a year and training 80 post-docs at any given time.

Areas of focus:

- Pit lake research
- River ecology
- Wetland ecology and management
- Microbial communities
- Bio-remediation of acid mine drainage

Industry partners:

- ACARP

University partners:

- Curtin University
- Murdoch University
- University of WA
- Montana State University

Centre for Infrastructure and Mining Safety (CIPMS)
University of Wollongong

A focus on infrastructure protection and mining safety.

Areas of focus:

- Coal
- Infrastructure protection and retrofitting techniques against man-made and natural hazards
- Mining safety, impacts of severe loads on infrastructure
- Landslides risk management and protection

Industry partners:

- ARC
- ACARP
- BHP

Centre for Mining Equipment, Technology and Services Business Innovation

Queensland University of Technology

The Centre for Mining Equipment, Technology and Services Business Innovation (CMBI) is funded by the Department of State Development Manufacturing, Infrastructure and Planning, Mining3 and the Queensland University of Technology.

Areas of focus:

- Industry development
- Business Models
- Organisational culture and change
- Technology eco-systems
- Innovation adoption and diffusion
- The role of risk management in technology adoption
- Social licence to operate
- Minimising minings footprint

Industry partners:

- Mining3
- METS Ignited
- Austmine

Government partners:

- QLD Government Department of State Development

Australian Critical Minerals Research Centre

University of Adelaide

Metals and non-metals that are irreplaceable inputs for society's future, including in renewable energy systems, infrastructure, transport, high tech equipment, and defence systems.

Areas of focus:

- Discovery – critical minerals in time and space
- Mineralogy – understanding ores and mineral chemistry
- Processing – new opportunities and strategies to optimise and be sustainable

Industry partners:

- BHP Olympic Dam
- OZ Minerals
- Fortescue Metals Group
- Havilah Resources
- Glencore
- Northern Minerals
- Lynas Corporation
- Iluka Resources
- Nyrstar
- Boart Longyear
- Orica
- Bureau Veritas
- Scantech
- Maggoteaux
- Manta Controls

Government partners:

- Geoscience Australia
- State & Territory geological surveys
- ANSTO

University partners:

- University of South Australia, including its Future Industries Institute
- Australian National University
- University of Queensland
- Curtin University
- Monash University
- James Cook University

UWA Mining Innovation Network (MINe)

University of Western Australia

MINe is focussed on education and training, research and development, and community and engagement.

Related centres and facilities:

- Centre for Exploration Targeting (inc. Australian Research Council Centre of Excellence in Core to Crust Fluid Systems)
- Australian Centre for Geomechanics
- Transforming Maintenance through Data Science – Australian Research Council Industrial Transformation Training Centre
- Centre for Mining Energy and Natural Resource Law
- Centre for Environmental Economics and Policy
- Centre for Rock Art Research and Management
- CRC for Transformations in Mining Economies
- Environmental Stewardship in Mining Initiative
- Ecosystem Restoration and Intervention Ecology Group
- Centre for Sleep Science
- Centre for Energy Geoscience
- Future Tails (tailings geotechnics and geomechanics)

Industry partners:

- Alcoa
- BHP
- Roy Hill

Government partners:

- CSIRO

University partners:

- Curtin University

Australian Coal Industry Research Program (ACARP)

A mining research program established in 1992. It is 100 per cent owned and funded by all Australian black coal producers. Each year the ACARP Committees select approximately 70 projects from the 300 submitted.

Areas of focus:

- Health and safety of open cut and underground coal mines
- GHG mitigation at the mine site
- Noise and air pollution mitigation at the mine site
- Low emission coal use
- Remote control and automation
- Hydrology
- Ventilation and gas management

Industry partners:

- ACIRL Ltd
- MineRisk
- Conveyor Technologies
- Umwelt (Australia)
- Basacon Services
- Nicholas Corrosion

Government partners:

- CSIRO
- Hunter Valley Research Foundation

University partners:

- University of Adelaide (CSER Research)
- University of Newcastle
- Central Queensland University (Centre for Environmental Management)
- University of Queensland

Mining and Resources
Monash University

Partnerships with government, industry and the community to improve research across the mining value chain.

Related centres and facilities:

- Minerals Microbe and Solutions Research Group (MMRG)
- Institute of Railway Technology (IRT)
- Maintenance Technology Institute (MTI)
- IITB-Monash Research Academy

Areas of focus:

- Loop Geoscience Project (3D geological risk management)
- Mine rehabilitation
- Maintenance
- Drone technology

Industry partners:

- AGL Loy Yang Mine
- Anglo Coal
- AUSIMM
- Boral Limited
- BHP
- Fortescue Metals Group
- Holcim Australia Pty Ltd
- Karoon Gas Australia Pty Ltd
- MMG
- Newcrest Mining
- Orica
- Rio Tinto
- Roy Hill
- Woodside Energy

The Sydney Centre in Geomechanics and Mining Materials (SciGEM)
University of Sydney

SciGEM within the School of Civil Engineering was established in 2013 to capitalise on the outstanding pool of researchers with specialised skills and expertise in the field of geomechanics and geotechnical engineering. SciGEM's objective is to remain world leaders in the research fields of geomechanics, geotechnical engineering and granular mechanics.

Areas of focus:

- Granular physics
- X-ray vision of granular dynamics
- Interfacial mechanics
- Unconventional soils
- Computational mechanics

Research School of Earth Sciences (RSES)
Australian National University

RSES' research priorities include future climate change impacts, adaptation and mitigation strategies, water, mineral and energy resource security, as well as new opportunities in areas including drone and space-based observation, high pressure materials science, and data science.

Areas of focus:

- Location of critical minerals (mapping)
- Climate change
- Minerals and energy resource security

Industry partners:

- South32 (internship program)

Energy and Resources Institute
Charles Darwin University

The Energy and Resources Institute (ERI) provides high-quality research and consultancy for all aspects of energy and resources, including engineering, scientific, economic, environmental, social, community, legal, policy and digital considerations.

Areas of focus:

- Fossil-based and renewable energy
- Mineral resources
- Digitisation of energy and resources
- Energy materials
- Process safety, including fire and explosion safety
- Corrosion engineering in the energy and resources sector
- Environment protection and social mandate to operate

Government partners:

- Northern Territory Government
- Alice Springs Future Grid project

Future Regions Research Centre (FRRC)
Federation University of Australia

FRRC aims to create new knowledge and innovative solutions to the grand challenges that impact both our natural and constructed environments.

Areas of focus:

- Stable Landforms and Mine Rehabilitation: this stream aims to stabilise landscapes and mining landforms through soil conditioning and revegetation programs to address further deterioration

Government partners:

- Cooperative Research Centre for Transformations in Mining Economies

Sustainable resources
University of Melbourne

Developing new materials for advanced digital and energy technologies that will underpin renewable energy generation.

Areas of focus:

- Artificial intelligence
- Energy minerals
- Sustainable processing

Government partners:

- Future Battery Industries Cooperative Research Centre
- Centre for Excellence for Enabling Co-Efficient Beneficiation of Minerals
- Proposed Industrial Transformation Research Hub for AI in Resources

Transforming the Mining Value Chain (TMVC)

University of Tasmania

The main objective of the TMVC is to improve efficiencies within the mining value chain, focusing on areas that will have a marked impact on the value of Australia's mineral resources, thereby benefiting the nation's economy.

Areas of focus:

- Detecting proximity to ore (footprints): efficient discovery of new ore zones around current mine infrastructure
- Optimising geo-metallurgical prediction: early acquisition and modelling of geo-metallurgical parameters
- Minimising geo-environmental risks: early identification of environmental issues for ores and wastes

Industry partners:

- AMIRA
- Newcrest
- BHP
- Corescan

The Australian Centre for Geomechanics (ACG)

University of Western Australia

The ACG seeks to effectively respond to industry's needs by initiating innovative research that provides ongoing benefits and viabilities instead of quick-fix solutions.

Areas of focus:

- Stope design and reconciliation phase 2
- Probabilistic stope design
- Strainburst research project
- Safe, sustainable management of filtered tailings
- Towards a mechanistic understanding of electrokinetic in situ leaching
- Physical and numerical modelling of cave propogation
- Physical modelling of cave breakthrough
- Blast testing of ground support at Cadia mine
- An effective stress approach to mine backfill
- HEA Mesh
- Towards the elimination of rockfall fatalities
- High resolution seismic monitoring in open pit mines
- Squeezing ground task force
- Integrated monitoring systems for open pit wall deformation
- Rapid low cost mine mapping
- Metallurgical mine tailings rehabilitation
- Saline tailings disposal and decommissioning

Industry partners:

- BHP
- Master Builders Solutions
- New Concept Mining Powered by Epiroc
- Newmont Australia
- PSM
- REC Geotechnical and Tailings
- Reutech Mining
- SRK Consulting

Government partners:

- WA Government

University partners:

- Curtin University

Institute for Frontier Materials (IFM)

Deakin University

The Institute for Frontier Materials is a vibrant, multicultural research institute, graduating more than 30 PhD students a year and training 80 post-docs at any given time.

Areas of focus:

- Advanced alloys and infrastructure materials
- Carbon fibre and composites
- Electro and energy materials
- Fibres and textiles

Industry partners:

- Brown Coal Innovation Australia
- Defence Materials Technology Centre
- Transform Metals
- Weir Minerals

Government partners:

- CSIRO

University partners:

- Monash University

Economic Geology Research Centre (EGRU)

James Cook University

The EGRU connects researchers, students and government organisations to promote collaborative research and provide applied research services.

Areas of focus:

- Petrological microscopes, photo-microscope research services
- Geochemical and isotope analytical research services.

Industry partners:

- Mount Isa Mines
- South32
- Anglo American
- Evolution Mining
- Rio Tinto
- Heathgate Resources
- Map to Mine
- Terra Search

Mining research led by

COOPERATIVE RESEARCH CENTRES

Mineral Exploration CRC (MinEx CRC)

Innovation in drilling, including identifying mineral deposits.

Areas of focus:

- Drilling optimisation
- Coiled tubing drilling
- Hydraulic Fluid Drilling Processing System (HPS)

Industry partners:

- Anglo American
- BHP
- Epiroc
- Geological Survey of Western Australia
- Geoscience Australia
- Geotec Boyles
- HiSeis
- IMDEX
- LKAB Wassara
- Micromine
- Minerals Research Institute of WA (MRIWA)
- McKay Drilling
- Geological Survey of New South Wales
- Rio Tinto
- Sandvik
- South32

University partners:

- Geological Survey of South Australia
- Australian National University
- CSIRO
- Curtin University
- University of Adelaide
- University of Newcastle
- University of New South Wales
- University of South Australia
- University of Western Australia

Transformations in Mining Economies (CRC TiME)

Initiated in early 2020 through the Australian Government's Cooperative Research Centre (CRC) Program, CRC TiME provides a vehicle to enable sustained industry, research and community collaboration. CRC TiME brings together over 70 leading mining and mining service companies, regional development organisations, State and Commonwealth governments and research partners to address the challenges underpinning mine closure and relinquishment.

Areas of focus:

- Mine closures and rehabilitation

Industry partners:

- Alcoa
- BHP
- CME
- Mining3
- FMG
- Hanson
- Iluka
- MCA

Government partners:

- Geoscience Australia
- CSIRO
- Queensland Government
- MRIWA
- SA Government
- NT Government

University partners:

- Curtin University
- Flinders University
- UQ
- UniSA
- AGRF
- Federation University
- Flinders University

Cooperative Research Centre for Optimising Resource Extraction (CRCORE)

CRCORE was established in 2010 to reverse the market trend of declining mine productivity by improving operational value, commercial return, and environmental outcomes.

Areas of focus:

- Novel testing, measurement and mapping technologies to characterise and quantify waste and ore for coarse separation attributes as inputs into engineering assessment and mine planning
- Integration of operational strategies and engineering solutions to effect coarse separation in the dig and deliver interface
- New processing circuit designs, integrated simulation capabilities and operational control systems to exploit changes in grade and other physical properties resulting from feed streams
- Whole of system control and execution to manage disruptive and dynamic opportunities that coarse separation delivers

Industry partners:

- Hatch
- Orica

Government partners:

- CSIRO

University partners:

- Western Australia School of Mines, Curtin University

Heavy Industry Low-carbon Transition CRC (HILT)

HILT CRC focuses on developing technologies and methods that overcome barriers to the low-carbon transition, which include the unacceptable risks of untested innovations that could jeopardise equipment, production and/or worker safety.

Areas of focus:

- Producing green iron products
- Green alumina calcination
- Low-carbon lime and cement
- Integrating variable energy into industrial processes
- New energy sources such as electrification, hydrogen, solar, thermal, biomass
- Hybrid technology
- Capture and reuse of CO_2

Industry partners:

- Alcoa
- FMG
- Roy Hill

Government partners:

- CSIRO

University partners:

- Curtin University
- ANU
- University of Adelaide

Future Battery Industries CRC (FBICRC)

The FBICRC was established in 2019 and brings together 70 participants across 15 research projects and is the largest partnership of industry, government and researchers focused on battery industries in Australia.

Areas of focus:

- Use of batteries in mining and minerals processing, manufacturing, services and recycling and reuse of batteries.
- Transitional issues

Industry partners:

- Alpha HPA
- AnteoTech
- Ardea Resources Limited
- BASF
- BHP
- Blackstone
- Calix
- Chemx Materials
- EVM
- Igo
- Jordproxa Koppers
- Lycopodium
- Magellan Power
- Minerals Research Institute of Western Australia
- Multicom Resources
- Pure Battery Technologies
- Source Certain International
- Swordstone
- Syrah Resources
- Talga
- Ultra

Government partners:

- Northern Territory Government

University partners:

- Murdoch University
- Queensland University of Technology
- University of Melbourne
- University of Technology Sydney
- The University of Western Australia

Future Fuels CRC

Future Fuels Cooperative Research Centre is the industry focused research, development and demonstration partnership enabling the decarbonisation of Australia's energy networks.

Areas of focus:

- Future fuel technologies, systems and markets
- Social acceptance, public safety and security of supply
- Network lifecycle management

Industry partners:

- APGA
- Australian Gas Infrastructure Group
- AusIndustry
- Energy Networks Australia
- Energysafe Victoria
- GAMAA
- Jemena

Government partners:

- Australian Government
- NSW Government
- Resources Safety and Health QLD
- Government of Western Australia

University partners:

- RMIT
- South Australia
- University of Adelaide
- University of Melbourne
- University of Queensland
- University of Wollongong
- Deakin University

CRC for Reliable Affordable Clean Energy for 2030 (RACE to 2030)

Focused on customer-centred clean energy transition, the Reliable Affordable Clean Energy for 2030 Cooperative Research Centre (RACE for 2030) will drive energy innovation that aims to cut bills and carbon emissions of Australian households and businesses.

Areas of focus:

- Boosting business energy productivity (via digitalisation, electrification and value chain optimisation)
- Developing and applying new energy technologies and solutions for consumers
- Optimising Australia's electricity grid through customer distributed energy resources and network integration
- Foresighting, stakeholder engagement, capacity building, training & education

Industry partners:

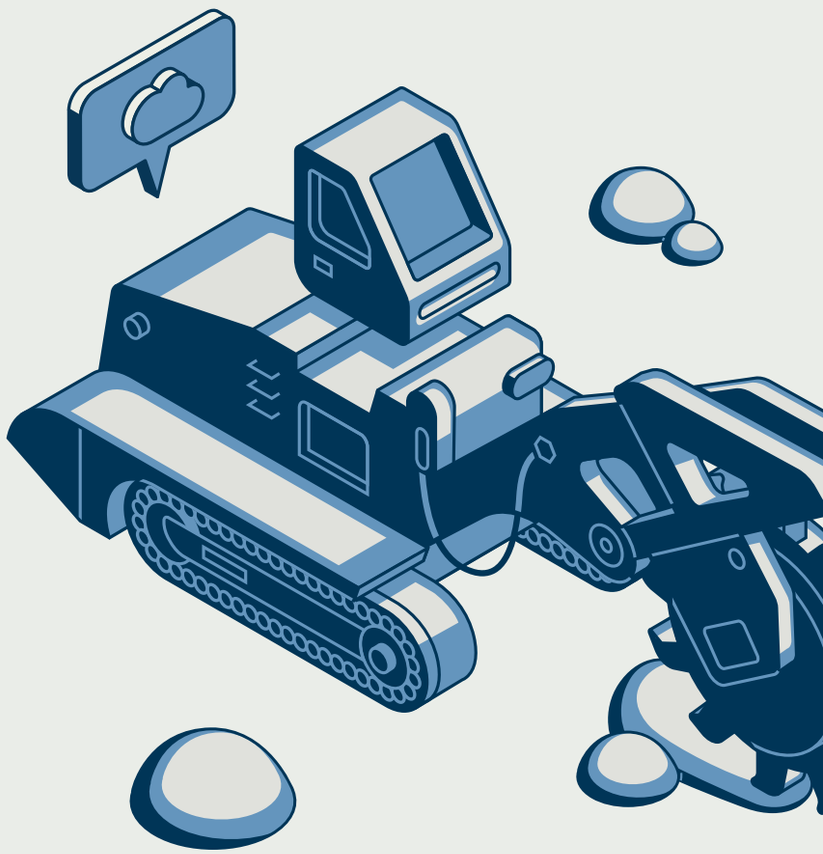
- Ausgrid
- Boral

Government partners:

- CSIRO

University partners:

- Curtin University
- Monash University
- UNSW
- UniSA



Mining research led by

GOVERNMENT AGENCIES

Commonwealth Scientific and Industrial Research Organisation (CSIRO)

Areas of focus:

- Exploration
- Ore body definition
- Extraction
- Minerals processing
- Mine safety
- Mine closure

Industry partners:

- Australian mining industry

Government partners:

- Geoscience Australia
- Commonwealth Government Department of Resources
- State and Territory mining and resources departments

University partners:

- Most Australian universities

Geoscience Australia

Areas of focus:

- Ore body location
- Ore body definition
- Auditing and reporting

Industry partners:

- Australian mining industry

Government partners:

- CSIRO
- Commonwealth Government Department of Resources
- State and Territory mining and resources departments

University partners:

- Most Australian universities

Minerals Research Institute Western Australia (MRIWA)

Areas of focus:

- Characterising cover
- WA's lithospheric architecture
- Resolving WA's 4D geodynamic and metallogenic evolution
- Distal footprints of ore deposits
- Automation and alternative methods of extraction, concentration and/or precision mining
- Economic extraction from low-grade ores
- Lower overall energy costs, reduced carbon footprint and removal of hazards from mining operations through adoption of alternative energy sources
- Co-extraction of multiple commodities to minimise waste.

Industry partners:

- Rio Tinto
- FMG
- Fortescue Metals
- Newcrest Mining
- South 32
- BHP

Government partners:

- CSIRO
- Geoscience Australia

University partners:

- Most Australian mining research institutes

CRC partners:

- FBICRC
- CRCORE
- CRCTIME
- MinExCRC

Endnotes

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3 Note: Chances of a mineral occurrence being developed estimated at around 1 in 1000 (Gandhi and Sarkar 2016).

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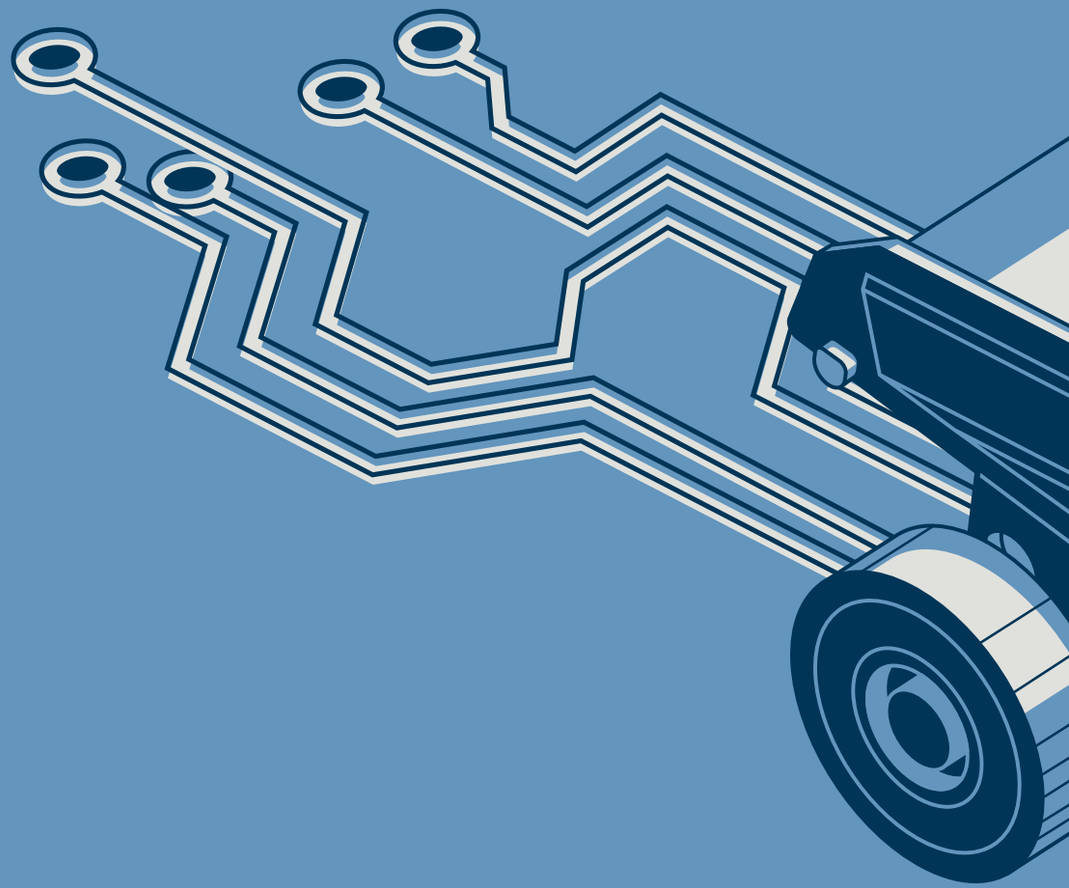

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