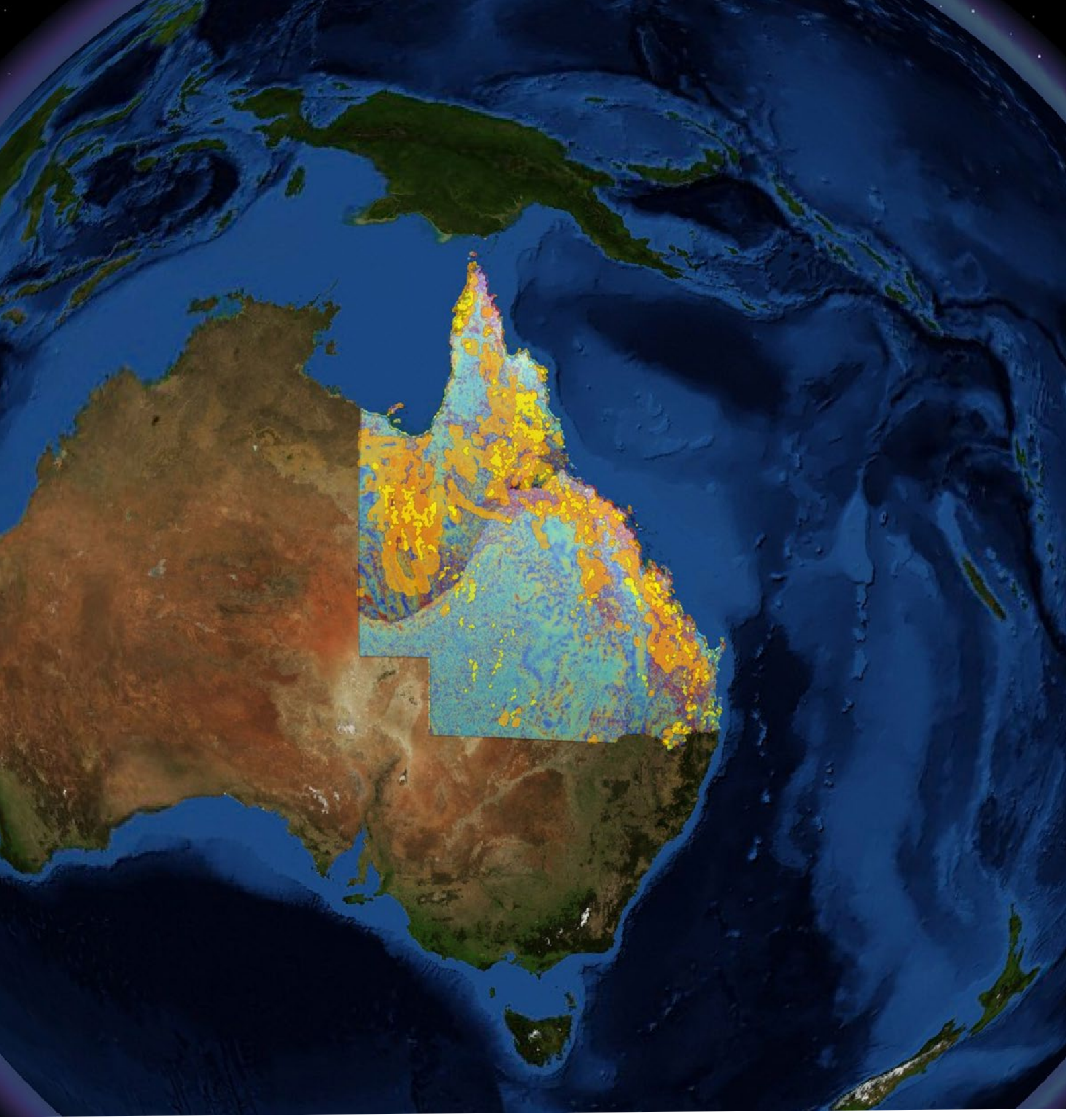

RESEARCH AND DEVELOPMENT PRIORITIES

# FOR MINERALS IN QUEENSLAND

queensland exploration council

THE UNIVERSITY OF QUEENSLAND AUSTRALIA

QUEENSLAND resources COUNCIL

Queensland Government

CS9776 4/20



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Cover image: provided by Geological Survey of Queensland.

# Introduction

Queensland is home to one of the world's most vibrant and productive mining Research and Development (R&D) ecosystems. Globally significant innovations, some of which are outlined in this publication, are coming to life thanks to the expertise of mining companies, Mining Equipment, Technology and Services (METS) companies, universities, research organisations and government. These innovations make an important contribution to the modern mining industry and Queensland's standing as an innovative place to invest.

In 2017, the Queensland Government released 'A Strategic Blueprint for Queensland's North West Minerals Province'[1]. The blueprint identified a need to support further innovation through the formation of a strategic, industry-led analysis of the research and development priorities for minerals (excluding coal) in Queensland. This publication, delivered in collaboration with the Queensland Resources Council, the University of Queensland and the Queensland Government, delivers on that commitment.

The R&D priorities outlined in this publication were developed through a series of first hand interviews with mining companies, METS companies, explorers, researchers and government staff. The fundamental question being 'what should the minerals industry look like in the future and what are the major challenges?' Further information about the methodology and key contributors are outlined later in this publication.

Through this consultation, six research themes emerged:

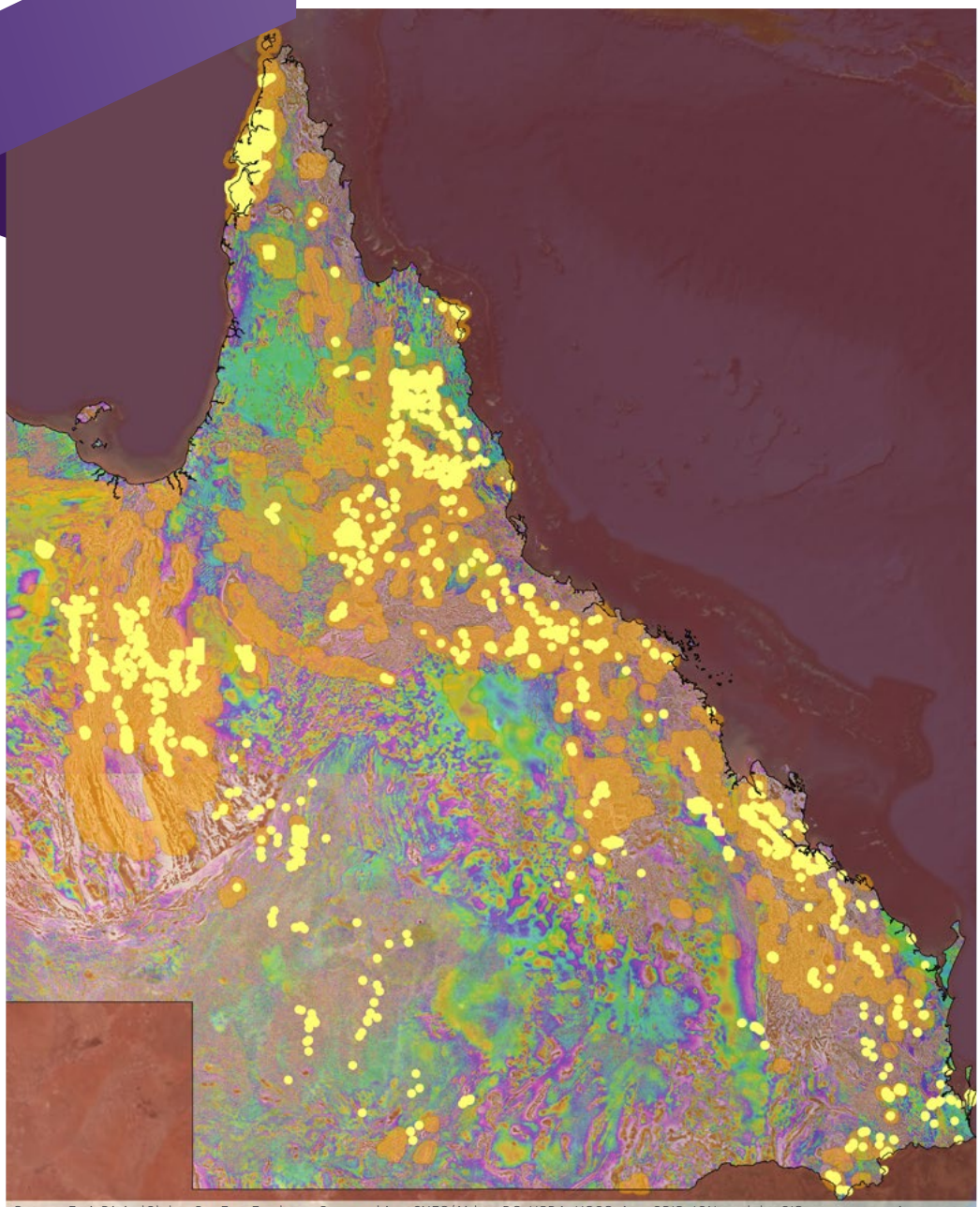
- Commercial drivers—adapting to and capitalising on the fast pace of change in business and the workforce.
- Digital transformation—using innovation in artificial intelligence, sensing, control and communication to create a cost efficient, sustainable industry.
- Finding, mining and extracting—continued innovation to lower costs and improve discovery.
- Footprint—unlocking mineral production by identifying innovative solutions to environmental, social and governance challenges.
- New horizons—supplying the minerals needed for the batteries, panels, electric motors and other strategic technologies of the future.
- Health and safety—continually innovating to ensure the health and safety of the mining workforce.

Under each research theme a series of short and medium-term priorities were identified. These priorities provide the future direction for research and development efforts across the R&D ecosystem. Government, METs companies, Universities, research organisations and mining companies can confidently and collaboratively pick up the challenge of finding solutions to these problems to bring about further transformation and success for the sector.

Queensland is endowed with an abundant supply of mineral resources. This, combined with a culture of innovation and collaboration between government, academia and industry sets Queensland up to take advantage of a growing world demand for these valuable resources.

# Contents

## Queensland's rich endowment of resource wealth and significant mineral potential, 2020



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS user community

The yellow areas represent known mineral resources and operating mines. Considered high to very high mineral potential.

The orange areas show high to moderate mineral potential based on existing exploration tenures, significant mineral occurrences and within mineralised geological terranes.

The underlying colour image shows the merged regional scale airborne geophysical magnetic surveys carried out across Queensland.

The darker shaded areas represent boundaries of the broad structural geological framework in Queensland.

# Ministerial foreword

Some of the essential minerals that can help the world transition to a low emissions economy and meet the increasing demand for advanced technologies, are found in Queensland.

As a responsible government, we are taking charge of the supply of these materials and will ensure Queensland remains a competitive destination for investment in mineral operations.

Research and development in the minerals sector is robust with Queensland's mining equipment, technology and services (METS) sector being an innovative global leader in the ecosystem alongside university and research centres, industry organisations and government centres such as the Geological Survey Queensland and SIMTARS.

Across the active ecosystem breakthroughs are being made in exploration processes, geophysics and geoscience, mining techniques, material handling and transport and logistics through to mine safety and rehabilitation.

This publication highlights a small collection of these success stories and provides a roadmap for future innovation.

Industry consultation led to the identification of six research and development themes, with 'Finding, mining and extracting' just one. The remaining five show our commitment to being a socially responsible state, one that values transparency, interaction with communities, and worker safety.

Feedback demonstrates that industry sees how essential new supply chains are to meet sudden and rapid demand growth. There is also recognition that we need to minimise the environmental footprint of our operations and attract investment.

We know we need to find new deposits to develop a pipeline of projects well into the future. As a result, in November 2019, the Queensland Government committed $9 million to better collect and share data, improve scientific understanding and supply data to undertake high-tech analysis and modelling for complex geophysical work. This includes $3.5 million in industry grants will support new and innovative exploration activities.

We also announced $4.8 million to support research into re-examining old mine tailings as part of the New Economy Minerals initiative. The demand for new minerals is high and industry is looking to get more out of old mine tailings and waste.

There is no doubt Queensland is up for the challenge. We have a strong culture of innovation and we collaborate well between government, academia and industry. This publication strengthens that focus of working together and provides a roadmap to ensure we can each play our part with confidence.

**Dr Anthony Lynham**,
Minister for Natural Resources,
Mines and Energy

# Industry foreword

It is a lesser known piece of Queensland history that prospector James Nash saved the fledgling state from bankruptcy in 1867 when he discovered 75 ounces of gold at Gympie in six days.

Since then, Queensland has earned a reputation as a resources powerhouse headlined by major discoveries such as Mount Morgan, Mount Isa and the Bowen Basin.

Today mining remains a cornerstone of the Queensland economy and a driver of regional growth but there is no escaping an evolving global marketplace and higher social and environmental expectations.

Queensland Mining's R&D Roadmap is an important step towards ensuring that Queensland continues to reap the rewards of its world-class natural resource endowment through innovation.

As this report confirms, we have a solid base upon to which to build a sustainable mining future with the support of the state's world-class R&D institutions, internationally successful technology providers and governments committed to fostering new investment and discovery.

Innovation will play a leading role in the future of Queensland mining just as it has in the past through the advent and uptake of new technologies and tools.

Data science, machine learning and artificial intelligence will become as common in the mining lexicon this century as headframe and jumbo were in the last. Traditional mining roles are also expected to expand to include a skills base of robotics, electronics, computing, mathematics and statistics.

Other variables paint a challenging and fascinating future. The minerals of the 'new economy' such as cobalt, vanadium, scandium, tungsten, molybdenum and rare earth elements have been confined until now to periodic tables. They could be found in commercial quantities under 'deep cover' or in the tailings of abandoned workings.

This roadmap points to exciting times ahead for mining in Queensland and the means to get there.

**Ian Macfarlane**
Chief Executive
Queensland Resources Council

**Kim Wainwright**
Chair
Queensland Exploration Council

# Queensland mining innovation—some facts and figures


Brisbane ranked number 2 out of the world top ten mining start-up cities

Greater than 800 METS Companies operating in Queensland

Queensland ranked number 2 in Australian mining-related patent applications

Greater than $300m in R&D funding directly relevant to Queensland minerals since 2016

58% of mining-related disciplines rated 'well above world standard' in Queensland universities, and 92% 'above world standard'

METS generates $7bn in revenue and $2.5bn to the Queensland economy

# Innovation examples

| Innovation | Innovator | Impact |
|---|---|---|
| Albion Process | Mount Isa Mines | Low environmental footprint extraction of gold from refractory ores |
| Cave Mining research | UQ (SMI) | Innovations allowing successful implementation of underground mass mining in otherwise inaccesible orebodies |
| Deswik software | Deswik | 10 year growth to major market share in mine planning software market. 150 mines in 50 countries. |
| G-MIRM | UQ (SMI) | The international standard intensive safety risk training program for mining industry employees |
| Grade Engineering | CRC-ORE | A suite of approaches designed to revolutionise grade productivity in metal mines |
| Groundprobe | UQ | Precision ground monitoring making mining safer and more profitable |
| Hovermap | CSIRO | Advanced autonomous mapping of underground mines using drones |
| Isasmelt,Isamill, and Jameson Cell | Mount Isa Mines | Globally-significant innovations to improve the efficiency and cost of base metal ore processing |
| JKSimMet and JKSimFloat | UQ (SMI) | Premiere tools for simulation of mineral processing, used all over the world |
| Mine to Mill and Geometallurgy | UQ (SMI) | A suite of tools and methodologies that maximise returns from the full minesite value chain |
| Mineral Liberation Analyser | UQ (SMI) | A Scanning Electron Microscope system for automated mineralogy - improving mineral recovery |
| Smartcap | Mining3 | Improvement of safety through the elimination of microsleeps |
| Toowong Process | Xstrata | Removal of deleterious elements such as arsenic from mineral concentrates |

# Research themes

## Commercial drivers

Adapting to and capitalising on the fast pace of change in business and the workforce.

## Digital transformation

Using innovation in artificial intelligence, sensing, control and communication to create a cost efficient, sustainable industry.

## Finding, mining and extracting

Continued innovation to lower costs and improve discovery.

## Footprint

Unlocking mineral production by identifying innovative solutions to environmental, social and governance challenges.

## New horizons

Supplying the minerals needed for the batteries, panels, electric motors and other strategic technologies of the future.

## Health and safety

Continually innovating to ensure the health and safety of the mining workforce.

# Recommendations for researchers

Things to consider when forming research and development plans related to the industry priorities outlined in this publication.

Recommendations include:

- show a business case, and be clear on benefit/change for the company
- ensure the problem you are working on is actually a problem faced by industry
- the value must be large enough for the company to get distracted
- researchers should strengthen contact with operations to ensure relevance of their research
- industry work experience in area or specialisation is important
- improve uptake by targeting message to the technical level of your audience
- there is an increasing need for researchers to train and mentor industry professionals
- investigate all possible grants and awards for support and visibility
- ensure that your solution is safe, economic, and environmentally and socially acceptable
- consider the possibility that your innovation has a broader market than the mining industry.

# Future directions for research—a summary by theme and timeframe

| Theme | Commercial drivers | Digital transformation | Finding, mining, extracting |
|---|---|---|---|
| **Potential for short term impact**<br><br>**(1-2 years)** | • Global best practice in environmental regulation of mining activities and equitable and timely management of shared land access.<br>• Establishment of a shared database of mine development information to aid companies, communities and government to understand case histories and best practices.<br>• Investigation of global best practice in the area of infrastructure delivery for remote mining.<br>• Research into the changing nature of resource deals and associated challenges and opportunities.<br>• In the business of mining - what areas are truly competitive and what areas could benefit from cooperation. | • Analysis of future skill sets; microcredentials; curriculum; human factors and interfaces.<br>• Methodologies for sharing and anonimisation of data.<br>• Investigation of new ways to deliver contracts using new technologies such as blockchain.<br>• Research into new regulation frameworks required by automation.<br>• Research into workforce implications of automation - training, skill, job requirements.<br>• Research considering bottlenecks and compromise solutions for operating mines without capital for full transformation.<br>• Ways to facilitate and incorporate real-time remote communication into mining operations.<br>• Development of mine and process control methodologies which combine data analytics and sector knowledge. | • Technologies to decrease water usage in mining and processing; technologies to capture and recycle water; methodologies to monitor water usage.<br>• Technologies and approaches to increase deposit knowledge in a way that will allow lower cost and more flexible processing.<br>• Innovation to reduce energy usage of existing technologies and technologies with potential for transformative reduction in energy usage. |
| **Potential for longer term impact**<br><br>**(2-5 years+)** | • Research into the relative value of innovations within companies, documenting quantitative and qualitative impacts and providing an improved basis for assessment of R&D opportunities.<br>• Research into innovative models of mining-related personnel, training, and work.<br>• Innovative ways to facilitate feedback between companies, operations and communities.<br>• Digital interfacing people and processes and changing the education system to suit. Developing people without a four-year time lag - in real time for real need. | • Improved systems for remote completion of mining-related tasks.<br>• Development of systems which incorporate assessment of the entire value chain in decisions and analysis.<br>• Staged and/or modular systems for partial upgrade on legacy mine and mill sites.<br>• Improved and standardised protocols for sharing of data between mine/mill control and measurement machinery.<br>• New methods of exploration targeting using a combination of mineral system knowledge and AI, machine learning and data analytics. | • Technologies and approaches that can lower mining and processing costs to improve the economics of low grade or otherwise challenging orebodies.<br>• Technologies and insights to aid mineral exploration under cover.<br>• Continued compilation of legacy exploration data; innovative methods for analysis of both structured and unstructured exploration data.<br>• Cheaper, faster and more reliable exploration technologies. |
| **Desired Impact** | • More upstream and value-additive processing.<br>• Mitigation of infrastructure challenges.<br>• Companies and communities will interact in closer and more constructive ways.<br>• New models will exist to incentivise company innovation expenditure. | • Safer, more effective and more efficient exploration, mining and processing.<br>• Positive and productive workforce transition to new digital transformation models.<br>• Orderly transition for legacy mines. | • Increased discovery rates.<br>• Flexible mining and processing.<br>• Transformative technologies move from concept to implementation.<br>• Successful production from lower grade deposits and mine wastes. |

# Future directions for research—a summary by theme and timeframe

| Theme | Footprint | New horizons | Health and safety |
|---|---|---|---|
| **Potential for short term impact**<br><br>**(1-2 years)** | • Study of mining stakeholder relationships to gain a deeper understanding of drivers and opportunities for change.<br>• Research activities which improve the fundamental understanding of the relationship between mining and associated communities, leading to improved company performance and outcomes in this area.<br>• Reduction of mining-related emissions. | • Review of known New Economy Minerals projects to assess their amenability to innovative mining and processing.<br>• Compilation of all available exploration information relating to Critical Metals/New Economy Minerals, combined with regional framework studies similar to those completed for base and precious metals in the state.<br>• New analyses of the content of new economy minerals in known prospects, mines and waste facilities.<br>• Synthesis of information relating to new economy minerals with respect to the nature and degree of their downstream integration, to give explorers and developers a better understanding of the technical hurdles and opportunities associated with such projects. | • Research aimed at improving the targeting of site-based information collection in order to better predict incidents and minimise risk.<br>• Investigation of means to pool safety resources and information in a way that can ensure that practices, risks, knowledge and insight are shared across the industry.<br>• Comparative studies investigating safety approaches from other industries and their potential for application in the industry.<br>• Application of modern data science to analyse safety data in order to improve the prediction of safety risks or systemic failings before they occur. |
| **Potential for longer term impact**<br><br>**(2-5 years+)** | • Research into improved methodologies for storage and treatment of tailings and waste from all relevant viewpoints including geotechnical, contamination and capture of economic value.<br>• New approaches and technologies which can improve interactions with mining-affected communities in terms of communication, participation and compensation.<br>• Research into lower cost and more efficient methods of dry processing and dry tailings storage.<br>• Methodologies for characterisation and processing of mine wastes.<br>• Further research into innovative means of carbon sequestration. | • Support for exploration and development projects focusing on these commodities.<br>• Development of practical process models and exploration models for targeting exploration.<br>• Support for innovative approaches to processing and productions. | • Research into the issues, causes and controls around exposure of workers in the mining industry to particulate matter, leading to insights into ways to better manage and minimise this exposure.<br>• Development and testing of enabling technologies to reduce exposure of workers to risk and to better integrate workers with the growing amount of automated equipment in the industry.<br>• Investigations into the extent to which the advent of automation will require a new set of safety standards both for the automated equipment and for interactions between personnel and that equipment. |
| **Desired impact** | • Mining refedined as a clean, high technology industry playing a key role in an equitable, low emission future.<br>• Lower environmental footprints.<br>• Carbon neutrality.<br>• Sustainability and social performance will become core issues equal in importance to health and safety. | • Development of a world-class new economy mineral mining portfolio and knowledge base in Queensland.<br>• Development of downstream new economy minerals Industry. | • Transformational improvement in safety performance.<br>• World-class training and research capability. |

# Commercial drivers

The mining industry faces a constant challenge to adapt to the external forces applied by the ongoing evolution of society and technology. Automation and digitalisation are beginning to take hold in the industry, and are provoking fundamental changes in the way mines operate. In the area of human resources, industry is simultaneously facing a skills shortage and a change in the mix of required personnel skills for effective operation. At the same time, investors and society are increasingly joining regulators in setting the standards for environmental and social performance.

These challenges are acting as a driver for mining companies to become more innovative and react more quickly to external changes. There is a growing need for companies to collaborate in areas of mutual benefit and to seek solutions to some of the barriers or traditional ways of doing things that are affecting their operations. They are also being forced to contemplate cultural and organisational changes that reflect the shifting expectations of their workforces and communities.

In addition, Industry is experiencing an increasing emphasis on the entire mining value chain. This is driving the need for new types of commercial deals that will indirectly reflect the value and/or liability associated with the better management of minewaste.

In 2016 METS Ignited identified the following Industry Knowledge Priorities which are still relevant today:

- understanding successful innovation
- determining what is slowing implementation of innovation
- advancing knowledge and understanding of business optimization methods
- managing businesses in cyclical markets
- transformative business models to deliver value from new technology
- skills—attraction, retention, requirements within an emerging technical environment.

In a Queensland context, significant challenges exist in the areas of infrastructure cost and remoteness, regulatory requirements that aren't keeping pace with change, personnel, and organisational structure.

## Challenges identified by interviewees:

- for researchers, targeting innovation to areas that will maximise potential for performance improvement
- for companies, seeking financial support for innovations, the 'valley of death' between proof of concept and commercial readiness
- in exploration, the limited window of opportunity afforded by season, funding and market support
- perceived overly restrictive environmental regulation of mine developments and operations
- regulation that is not keeping pace with technological change
- challenges in the time and regulatory complexity of gaining land access for exploration
- costs of infrastructure such as water, power and rail transport, as well as the need to accept sub-optimal and long term commercial arrangements due to lack of competition
- attracting and retaining staff with the appropriate skills, in an environment when required skill sets are changing and there is a resistance to moving to remote locations
- existing R&D tax incentives are no longer attractive due to perceived unreasonable compliance risk
- finding ways to improve industry-wide collaboration in areas which are not competitive between companies
- infrastructure challenges relating to the remoteness of operations
- identifying and executing innovative corporate and asset deals which reflect the changing nature of resource opportunities.

*'If we try to innovate everywhere, we are going to innovate nowhere' (Mining Company Senior Executive)*

*'I have been building mines since 2004 and it is just getting harder and harder' (Mining Company CEO)*

*'We need to focus innovation where we can change the dial' (Mining Company Senior Executive)*

## Future state suggested by interviewees

- In an optimistic future, more upstream and value-additive processing will take place in Australia, and more specifically Queensland.
- The mix of energy sources powering remote mines will change, with more emphasis on renewables and flexibility.
- Companies and communities will interact in closer and more constructive ways.
- New models will exist to incentivise company innovation expenditure.
- Demand for metals will continue to be strong.
- Smaller explorers will be squeezed due to the time and financial challenges of exploration under cover.
- Companies will improve investor and community support through increased transparency in their supply chains.
- The prevalence of equipment as a service will increase.

## Future directions for research:

- research into the relative value of innovations within companies, documenting quantitative and qualitative impacts and providing an improved basis for assessment of R&D opportunities
- global best practice in environmental regulation of mining activities and in equitable and timely management of shared land access
- establishment of a shared database of mine development information to aid companies, communities and government to understand case histories and best practices
- investigation of global best practice in the area of infrastructure delivery for remote mining
- research into innovative models of mining-related personnel, training, and work
- in the business of mining - what areas are truly competitive and what areas could benefit from cooperation
- research into the changing nature of resource deals and associated challenges and opportunities
- innovative ways to facilitate feedback between companies, operations and communities
- digital interfacing people and processes and changing the education system to suit. Developing people without a four-year time lag - in real time for real need.

## Case Study—CMBI

The Centre for METS Business Innovation aims to help Mining and METS companies to maximise the value of new technologies to their businesses. They work directly with Mining and METS companies to understand the business, organisational, management and eco-systemic factors which influence their degree of success in adoption and implementation of new technologies and other innovation. 'We work with engineers and scientists on the uptake of technologies,' says Professor Rachel Parker, Director of CMBI. 'Engineers are good at measuring the impact of their technology, but they are often not as good at understanding barriers around adoption of those technologies. In some cases they are also subject to short term Key Performance Indicators which act to to discourage experimentation and innovation.'

The CMBI has programs focused on speeding up innovation:

- improving company structures and cultures to drive innovation;
- helping to understand how firms can develop more competitive business models; and
- making improvements in supply chain coordination.

The CMBI works directly with industry and government to develop solutions in a collaborative way to improve performance in these areas. The Centre also works with researchers from CSIRO, CRC Ore and Mining3 to support the adoption of, and realisation of market value from the technologies they have developed.

The Centre began operation in late 2015, and has been funded through support from the state government, Mining3 and CRC ORE.

# Digital transformation

Over the past decades, the world has been going through a digital transformation which has made fundamental changes to the way we live and the way we do business. The mining industry is also going through a digital transformation, with the aim of improving efficiency, reducing costs, and improving safety in the industry.

The World Economic Forum (2017)[2] estimated the following potential value realisations from the implementation of digital mining:

- a 3-4% increase in revenue benefit to industry, customers, society and the environment
- a 2.7% increase in revenue and 9% increase in profit for mining and metals companies
- 610 Mt abatement of worldwide CO2 emissions over 10 years estimated to be worth $30bn to society and environment
- a 10% decrease in fatalities and a 20% decrease in injuries due to removal of staff from high-risk tasks.

In Queensland, METS-Ignited identified several priority areas in their 2016 Industry Knowledge Priorities document, including the necessity to improve the connectedness and operability of sensors; improvements in data analytics across the mining value chain, and continued development and streamlining of the human-machine interface.

The transition to a digital mine is likely to have important impacts on the roles and skill sets of a typical mine work force. The promise of benefits associated with the digital transformation will come with a need to carry out the training and research required to ensure that mining continues to play its positive role in regional Queensland. Effort in this area has the potential for positive benefits across the digital economy.

## Challenges identified by interviewees:

- changes to the composition of the mine work force in staff numbers, skill sets and work location, with a likely move away from remotely-based roles and an increase in required skills in the areas of electronics, programming and communications
- means to incorporate innovative new approaches to commercial transactions using tools such as blockchain.
- the staged upgrading and replacement of legacy assets with digital-capable infrastructure
- update of the regulations around the operation of new automated assets, as well as their interface with humans
- slow bandwidth to remote sites resulting in difficulties with sharing of data as well as problems with latency which makes offsite work tasks more difficult to execute in real time
- difficulties with the interoperability of automation and control systems installed in different parts of the operation
- challenges around partial transformation in the sense that this level of transformation could be more challenging than no change at all
- the need to improve the incorporation of the entire mining value chain into decisions relating to the operation.

*'The Digital Transformation will take longer than we think, and then happen faster than we expect' (Mining Company Senior Manager)*

*'Data mining is probably the next big thing, but how do we do it effectively?' (Mining Company Senior Executive)*

*'Mines are in the dark ages from a data perspective' (Mining Company COO)*

## Future state suggested by interviewees

- Machine Learning and Artificial Intelligence will become part of the normal mining operation workflow.
- There will be fewer traditional roles, and more roles relating to robotics, electronics, computing, mathematics and statistics.
- Legacy mines are likely to go through a process of hybrid digital solutions rather than a single and complete conversion.
- More employees will be based offsite in less remote population centres.

## Future directions for research:

- analysis of future skill sets; micro credentials; curriculum; human factors and interfaces
- improved systems for remote completion of mining-related tasks
- methodologies for sharing and anonimisation of data
- development of systems which incorporate assessment of the entire value chain in decisions and analysis
- investigation of new ways to deliver contracts using new technologies such as blockchain
- staged and/or modular systems for partial upgrade on legacy mine and mill sites
- research into new regulation frameworks required by automation
- improved and standardised protocols for sharing of data between mine to mill control and measurement machinery
- research into workforce implications of automation - training, skill, job requirements
- research considering bottlenecks and compromise solutions for operating mines without capital for full transformation
- ways to facilitate and incorporate real-time remote communication into mining operations
- new methods of exploration targeting using a combination of mineral system knowledge and Artificial intelligence, Machine Learning, Data Analysis
- development of mine and process control methodologies which combine data analytics and sector knowledge.

## Case study—Petra Data Science

Petra Data Science Pty Ltd, (PETRA) is a Brisbane- based software company using machine learning and mathematical optimisation to learn from years of mine site data. It analyses the mine value chain; from resource engineering to processing plant set-point optimisation. Dr Penny Stewart, the CEO of PETRA, says this approach works because it provides a way to incorporate geological uncertainty into mining and processing and to dynamically feed these learnings into orebody knowledge, mine planning, ore processing, energy efficiency and asset productivity.

The company combines strong capabilities in the area of AI and software development with deep sector expertise in mining, mineral processing and energy efficiency. Their industry leading MAXTA digital twin model software uses machine learning and mathematical optimisation to learn how mining operations achieve their best performance - determining how they achieved their best performance for variable geological characteristics. The digital twin models are used for prediction, simulation and optimisation. For example; drill and blast engineers use digital twin simulation and optimisation to determine which drill and blast design yield the most efficient and productive downstream processing. 'We understand engineering workflows,' says Dr Stewart, 'and we know that the most effective digital transformation leverages existing systems, processes and workflow'.

The group started in 2015, and has built up a list of 16 customers worldwide, with over half of their business being exports. The core of their business is Software-as-a-Service purpose built for mining applications. Their cloud hosted software provides automated operational decision support, either as an installed solution and/or as a cloud hosted web service.

# Finding, mining and extracting

It is well-understood that the challenges facing the traditional core skills of the mining industry are substantial. In the area of exploration, it is becoming more and more difficult to make discoveries in exploration settings in which the targets are either not outcropping or covered by younger sediments, and as a result the rate of discovery is below that required to replace depleting resources. In fact, over the past several years exploration has become value-destructive as an investment. At the same time, the average grade of known orebodies is continuing to drop, and other technical challenges such as variability and deleterious elements are compounding.

In addition to these challenges, the costs and availability of essential components to the mining value chain such as energy, water and transport infrastructure are increasing.

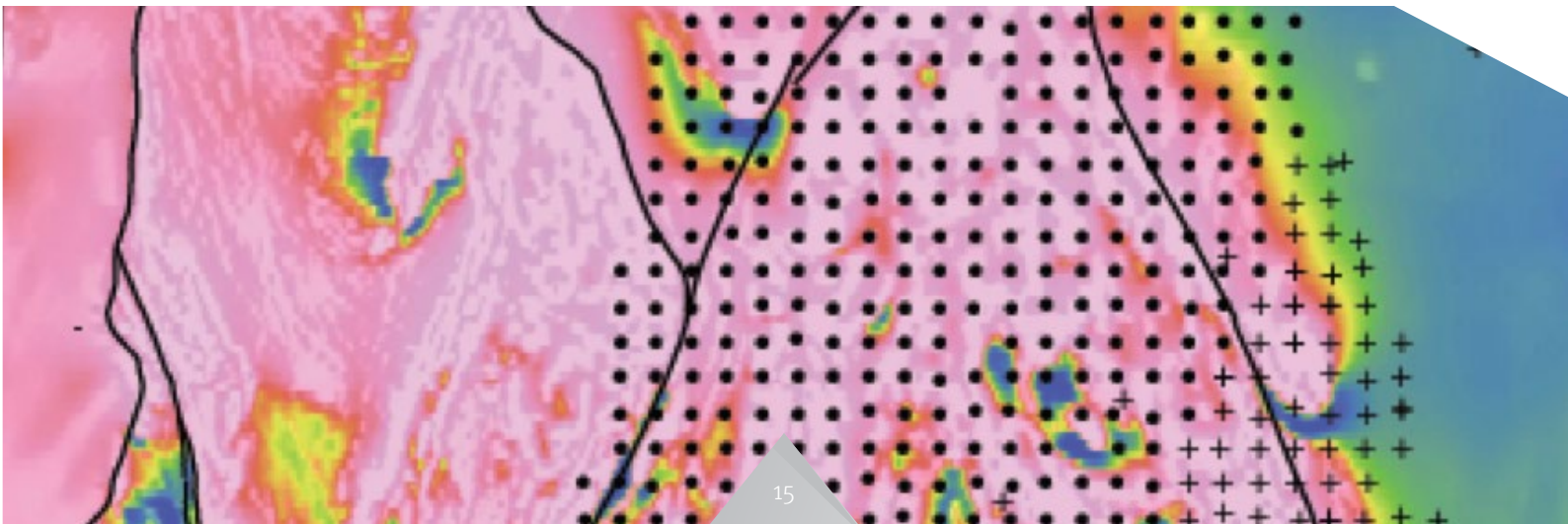
The 2017 'A Strategic Blueprint for Queensland's Northwest Mineral Province[1]' highlighted a special focus on 'developing new technologies to support mineral extraction, processing and site rehabilitation' in the region. Subsequently, the 2019 'Queensland Minerals Research Barriers and Priorities[3]' report identified four key priority areas under this theme:

- finding more resources
- expanding the mining envelope
- increasing recovered value
- improving productivity.

These challenges exist in the local Queensland context, and are compounded by the fact that many of the state's large metal mines are moving towards the later stages of operation.

## Challenges identified by interviewees:

- upscaling innovations to operational level
- declining grades and increasing challenges associated with orebodies in mines reaching the end of their operational life
- energy – many mines are energy-intensive and remote parts of Queensland have relatively high energy costs. How do we reduce these costs and take advantage of opportunities presented in the Queensland context?
- water - insufficient amount; lack of technology to manage and recycle it; lack of mining and processing technologies that minimise water usage
- improving discovery – exploration under cover is still challenging, expensive and technically risky
- data availability – the need to ensure that all relevant past exploration data is easily available as a resource for current explorers
- the need for support for exploration in all parts of the state
- for bulk commodities, the challenges around the transport and sale of mine products both in terms of cost and in terms of contracting complexity
- the cost of discovery due to the increasing technical challenges in new areas as well as the now higher fixed costs associated with exploration
- learning lessons from other jurisdictions that may inform new operations in Queensland.



*'In the end it is all about discovery' (Mining Company Exploration Manager)*

*'Materials science has evolved a lot. Could Australia find a way to do more upgrade processing?' (Innovation Company CEO)*

*'The map clearly suggests that deposits should continue into covered areas, but no one is finding them' (Mining Company CEO)*

## Future state suggested by interviewees

- In an optimistic future, more upstream and value-additive processing will take place in Australia, and more specifically Queensland.
- Automation and Artificial Intelligence will be increasingly integrated into normal operations.
- The METS sector will continue to play an increasingly important role in mining.
- Methodologies will be developed to obtain production from smaller, 'stranded' deposits.
- Flexible mining and processing will grow in importance in relation to the traditional economies of scale approach.
- The extent of outsourcing of all aspects of mining operations is likely to increase.
- Transformative technologies such as in-situ recovery will move from concept to implementation.
- A greater proportion of production will come from lower grade deposits and mine wastes.

## Future directions for research:

- technologies and approaches that can lower mining and processing costs to improve the economics of low grade or otherwise challenging orebodies
- innovation to reduce energy usage of existing technologies and technologies with potential for transformative reduction in energy usage
- technologies to decrease water usage in mining and processing; technologies to capture and recycle water; methodologies to monitor water usage
- technologies and insights to aid mineral exploration under cover
- continued compilation of legacy exploration data; innovative methods for analysis of both structured and unstructured exploration data
- cheaper, faster and more reliable exploration technologies
- technologies and approaches to increase deposit knowledge in a way that will allow lower cost and more flexible processing.

## Case study—Core Resources

Core Resources is an innovation-based company which provides integrated metallurgical test work, process engineering and technology solutions.

The company is an outgrowth from a laboratory facility opened by Mount Isa Mines Ltd in 1982, but has been operating as an independent company for the past 13 years. 'We are good at solving complex metallurgical problems,' says Dr Rob Coleman, CEO of Core Resources since August 2018. 'Everybody in the company enjoys the complex task of finding solutions to these problems and fundamental thinking goes behind everything'.

Core Resources' main areas of activity include the development and implementation of innovative technologies such as the Toowong Process, for removal of arsenic and other contaminants from mineral concentrates; and as a resource development partner for small and mid-size mining development clients, helping them to understand and optimise their project development options in the area of metallurgy.

The company was recently awarded the 'Australian Mining Monthly' Future of Mining 2019 Award for METS Exporter of the Year, as well as the overall Future of Mining 2019 Award for the best of the best in all the categories. 'Such awards are an important vote of confidence in the company,' says Dr Coleman. Approximately 60% of Core's business is with overseas clients, and they continue to develop a strong pipeline of new technologies and business through a growing and innovative team.

# Footprint

Environmental, social and governance considerations are continuing to be recognised as important components of the mining eco-system. Company performance in these areas is increasingly being driven by investors and communities in addition to the traditional regulatory authorities.

In the area of environmental performance, companies are increasingly being expected to minimise or eliminate the footprint of their operations on the regions surrounding their mines. This is driving efforts to minimise the use of water, reduce the escape of contaminants by air or water, minimise the impact of tailings and waste, and to devise realistic and rigorous closure plans.

Many industry surveys now place social performance at the top of industry concerns. According to Kemp and Owen (2019)[4], companies are under increasing pressure to:

- meet international, national, and local obligations
- develop transparent and meaningful relationships with their associated communities and stakeholders from local to regional scale
- understand, anticipate and respond to social change in a proactive way
- build internal teams with a skill set appropriate to these tasks.

In the governance and regulatory areas, mining and exploration companies are being required to operate under a set of rules which give local stakeholders and permitting authorities significant control over the cost, time and restrictions associated with site activity.

Most metal mining companies in Queensland feel that they are positively viewed by their local communities.

However, many company representatives have expressed concerns around negative societal perceptions of the industry at a state level, and around land access and permitting issues.

## Challenges identified by interviewees:

- responding to the increased environmental performance expected by investors, communities, regulators and society
- management of tailings and waste
- working with land stakeholders and regulators to achieve equitable and timely land access
- the need to understand and better manage stakeholder relationships from local to state scale
- changes to company cost structures in response to additional regulatory requirements
- finding ways to improve Company-Community relationships
- achieving lower footprint transformations (eg renewables) in an environment in which there are few incentives to do so
- finding ways to reduce mine closure financial provisions by carrying out staged rehabilitation in a way that is not detrimental to the economics of the operation
- the overarching need to improve the perception of mining in society.

*'The industry's social license to operate has gone' (Mining Company Senior Executive)*

*'Water is our most precious resource and a limiting factor for many Northern Australian developments' (Mining Service Company Senior Executive)*

*'We are happy to be part of cleaning up [our legacy sites] over time' (Mining Company CEO)*

## Future state suggested by interviewees

- Safety and environmental performance will have to improve.
- Community expectations will increase in terms of communication, participation and compensation.
- By necessity, mines will need to have lower environmental footprints.
- Mines will need to move towards the achievement of carbon neutrality.
- Investors will increasingly set environmental, social and governance standards.
- Dry tailings and dry processing will become increasingly prevalent.
- Sustainability and social performance are core issues equal in importance to profitability, health and safety.
- Mine waste retreatment projects will become more prevalent, and means will be found to incorporate the value of progressive rehabilitation into accounting frameworks.
- Mining redefines itself as a clean, high technology industry that plays a key role in providing the global mineral supply required to achieve an equitable, low emission future.

## Future directions for research:

- research into improved methodologies for storage and treatment of tailings and waste from all relevant viewpoints including geotechnical, contamination and capture of economic value
- study of mining stakeholder relationships to gain a deeper understanding of drivers and opportunities for change
- research activities which improve the fundamental understanding of the relationship between mining and associated communities, leading to improved company performance and outcomes in this area
- new approaches and technologies which can improve interactions with mining-affected communities in terms of communication, participation and compensation
- reduction of mining-related emissions
- research into lower cost and more efficient methods of dry processing and dry tailings storage
- methodologies for characterisation and processing of mine wastes.

## Case study—Voconiq

Voconiq is a company whose aim is to help mining companies to improve their interaction with stakeholder communities. The company has developed a new approach which combines traditional social science with more quantitative analysis in order to achieve a nearly real-time conversation between the mining company and the associated impacted communities. 'We are helping companies to step forward into the space between the mine and its communities,' says Dr Kieren Moffatt, CEO of Voconiq. 'The biggest driver of trust and acceptance is being heard and seeing the company respond to concerns.'

The company was founded on the basis of a research and development program that began at CSIRO, and was aimed at addressing the shortcomings of traditional models of company-community interaction. 'Companies often lack the information necessary to allow them to decide where to focus their resources, and their engagement teams are often under-resourced,' says Dr Moffatt. 'at the same time, communities often feel that they have no voice, and will find other ways to show disapproval if they feel they are not being heard.'

Voconiq has developed a methodology which involves engagement with the site team and company and an 'anchor survey' which attempts to build both qualitative and quantitative understanding of the community. Following this, Voconiq works with the company to develop a regular 'pulse' survey which allows the company to better understand and address community issues before they become serious. The company is working with a range of major Australian clients as well as building an overseas presence.

# New horizons

'New Economy Minerals' (NEMs)[5] is an umbrella term for a range of metals and mineral elements used in many emerging technologies including electric vehicles, renewable energy products, low-emission power sources, consumer devices, and products for the medical, defence and scientific research sectors.

These metals and elements overlap strongly with Critical Minerals which have generally been defined on the basis of the likelihood and impact of supply disruption as well as the environmental implications of their supply.

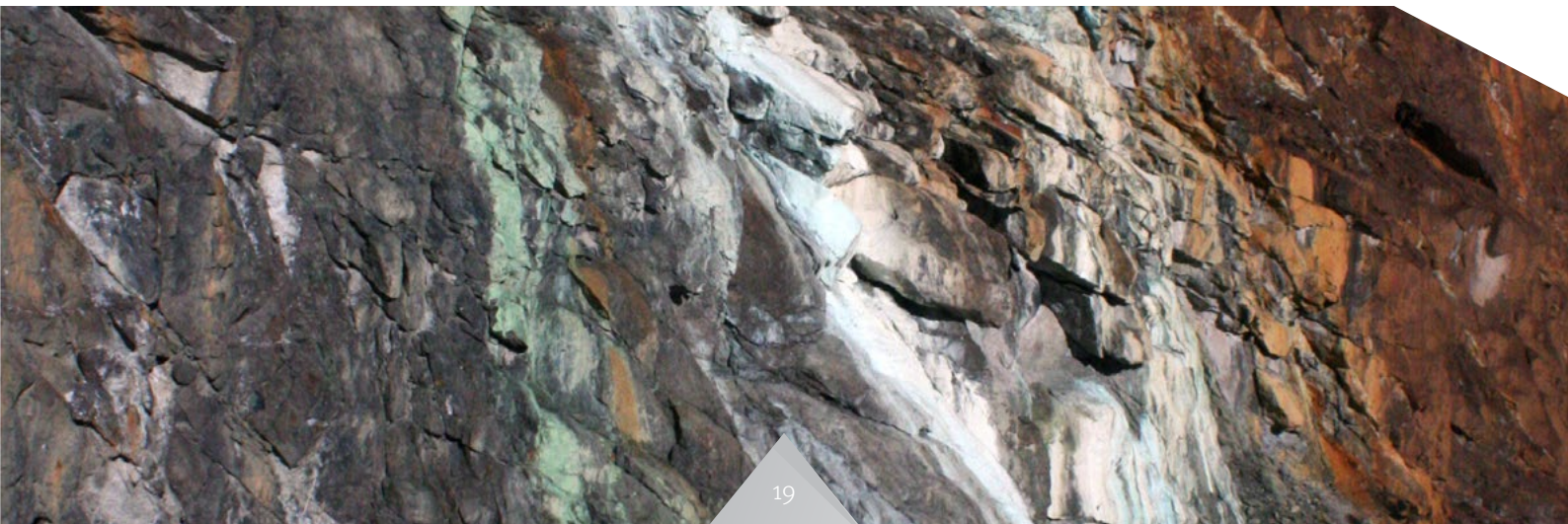
Minerals, metals and elements which are defined as New Economy Minerals in Queensland include:

| | | |
|---|---|---|
| Bauxite | Molybdenum | Tantalum |
| Cadmium | Niobium | Tellurium |
| Cobalt | Nickel | Tungsten |
| Copper | Rare earth elements | Tin |
| Gold | Rhenium | Titanium |
| Graphite | Selenium | Vanadium |
| Indium | Silica | Zinc |
| Magnesite | Silver | Zirconium |

Potential for these minerals exists in Queensland in existing operating mines, undeveloped prospects, and in tailings and mine wastes. The lack of previous attention to these elements has led to a situation in which the level of available information lags behind that which is available for base metals, precious metals and bulk commodities. There is also significant potential for upstream processing with the existence of infrastructure such as the Townsville Zinc refinery as well as significant processing expertise.

## Challenges identified by interviewees:

- uptake and funding of new technologies for processing of new economy minerals
- implementation of new market instruments to support critical metals developments
- relative lack of information relating to exploration, mining and processing of critical minerals
- the relative lack of 'development-ready' opportunities in new economy minerals
- the need for exploration and development success in this area to demonstrate the viability of the sector going forward
- lack of exploration data for critical minerals
- lack of processing knowledge relating to critical minerals
- lack of market understanding of critical minerals opportunities
- interconnectedness of specialty mineral developments which requires knowledge of demand, processing, downstream, and marketing to a greater extent than is required for traditional base metals, precious metals and bulk commodities.



*'Battery minerals may have briefly overshot but the potential for growth is definitely there' (Exploration Company Senior Executive)*

*'Specialty metals are different - they require a very specific understanding of demand, processing, downstream, and marketing' (Mining Company Senior Executive)*

*'If you don't know how to process what you are mining, then you are just a quarry' (Technology Company CEO)*

## Future state suggested by interviewees

- In a positive future, upstream processing in Australia will become a reality.
- The importance of battery and critical metals will continue to increase in response to global trends.
- Decarbonisation of industry will lead to a huge demand for many metals including copper and steel.
- Some commodities will definitely be coming from sea bed Mining - not from Queensland as a jurisdiction, but perhaps to the benefit of Queensland companies and innovators.

## Future directions for research:

- review of known New Economy Minerals projects to assess their amenability to innovative mining and processing
- support for exploration and development projects focusing on these commodities
- compilation of all available exploration information relating to Critical Metals/New Economy Minerals, combined with regional framework studies similar to those completed for base and precious metals in the state
- development of practical process models and exploration models for targeting exploration
- new analysis of the content of New Economy Minerals in known prospects, mines and waste facilities
- support for innovative approaches to processing and production of New Economy Minerals
- synthesis of information relating to New Economy Minerals with respect to the nature and degree of their downstream integration, to give explorers and developers a better understanding of the technical hurdles and opportunities associated with such projects.

## Case Study—Pure Battery Technologies

Pure Battery Technologies (PBT) is a Brisbane-based company developing a technology for cleaner and lower cost extraction of nickel and cobalt battery materials from products derived from intermediate products of nickel and cobalt ores. 'We are making tomorrow's batteries for cars and for energy storage better, cheaper and more environmentally friendly,' says Bjorn Zikarsky, CEO of Pure Battery Technologies. 'We are a technology company that occupies the space between mining and batteries and we are in a market that is taking off.'

PBT's Selective Acid Leaching (SAL) technology was originally developed at the University of Queensland, and has a number of advantages over existing technologies for extraction of nickel and cobalt from Mixed Hydroxide Precipitate (MHP) – an intermediate product derived from mining and processing of lateritic nickel-cobalt ores. The process is projected to have significantly lower capital and operating costs than other technology options and will have a much lower environmental footprint by avoiding the use of toxic solvents and producing less waste and tailings.

While he acknowledges the significant challenges associated with funding and managing the transition from a proven concept to full implementation, Mr Zikarsky is confident in the potential of the technology. 'Over 20 years of experience, you get a little bit of a feel for what's worthwhile chasing and what's not, and this is something I wanted to be part of from the very first moment. This makes a lot of sense.' PBT is working on plans for a pilot processing facility in Townsville which could produce up to 25,000 tonnes of nickel annually.

# Health and safety

Health and Safety has long been a focus of the mining industry, and management of hazards and risks is an ongoing high priority that requires constant vigilance. As with other themes, the current changes taking place in the industry have implications for health and safety systems which need to be taken into account in order to ensure that all hazards and risks are accounted for and addressed.

A mine fatality in July 2019 marked the sixth death in twelve months in the Queensland mining industry. This prompted a number of actions, including a 'Safety Reset' aimed at refocusing the industry on health and safety as the highest priority. A safety forum involving approximately 60 participants from the mining industry was held in July of 2019, and many of the challenges and suggestions under this theme are drawn from feedback received in this forum.

The Brady Review[6] of 2019 highlighted the observation that the Queensland mining industry has closely followed a 20-year trend that predicts approximately 12 fatalities over any five year period, and cautioned that fundamental changes are necessary for significant and sustained improvements to this outcome. Recommended areas of improvement included better training and supervision, more effective safety controls, organisational changes and more effective incident reporting.

Current changes in industry also present exciting possibilities, with technologies such as machine vision, automation, artificial intelligence, smart sensors, ubiquitous communication and many others potentially yielding opportunities to lessen and sometimes eliminate risks to workers. They also provide an opportunity for faster and greatly-enhanced analysis of large safety-related datasets.

## Challenges identified by interviewees:

- driving further improvement in safety performance will require a step-change in the risk management approach
- a growing realisation of the risks surrounding particulates in a mining context
- inability to take full advantage of available technology in the health and safety area
- can the industry pool safety resources and information in a way that can ensure that practices, risks, knowledge and insight are shared across the industry?
- the need for better training across industry, particularly in light of the increasing number of inexperienced workers and contractors – can the Queensland Mining Industry learn lessons from other industries such as the aeronautical industry?
- the need for prioritisation of controls and reduction of the complexity of safety systems
- senior leaders across industry need to be more engaged in safety processes to foster an industry-wide mature safety culture
- the current Site Senior Executive system places too much pressure on one individual
- the large amount of safety-related paperwork and procedures that characterise the current system may be a hindrance to safety performance
- industry needs to continually challenge its systems approach if continuous improvements in health and safety outcomes are to be achieved.

*'The industry should recognise that it has a fatality cycle' (Brady Review, December 2019)*

*'90% of safety problems are behavioural' (Mining Company COO)*

*'a significant proportion of people spoken to expressed the view that the large amount of paperwork (relating to safety) … is a major challenge (Brady Review, December 2019)*

## Future state suggested by interviewees

- Standards around safety performance and reporting will continue to tighten.
- The advent of automation will require a new set of safety standards both for the automated equipment and for interactions between personnel and that equipment.
- Increasing expectations around transparency of safety reporting and risk analyses.
- A need for faster analysis of High Potential Incidents and better analysis of leading indicators of safety risks.
- Expectations of real-time access to safety data across the industry.

## Future directions for research:

- research aimed at improving the targeting of site-based information collection in order to better predict incidents and minimise risk
- research into the issues, causes and controls around exposure of workers in the mining industry to particulate matter, leading to insights into ways to better manage and minimise this exposure
- development and testing of innovative enabling technologies to reduce exposure of workers to risk and to better integrate workers with the growing amount of automated equipment in the industry
- investigation of means to pool safety resources and information in a way that can ensure that practices, risks, knowledge and insight are shared across the industry
- comparative studies investigating safety approaches from other industries and their potential for application in the industry
- investigations into the extent to which the advent of automation will require a new set of safety standards both for the automated equipment and for interactions between personnel and that equipment
- application of modern data science to analysis of safety data in order to improve the prediction of safety risks or systemic failings before they occur.

## Case Study—SmartCap Technologies

SmartCap Technologies is a Brisbane-based company with a product designed to detect fatigue in drivers. The company has produced a system that starts with a 'LifeBand'–a headband which the user attaches to their head ware. The headband passively measures an EEG and can communicate with an app on the user's phone or tablet, but it also carries a machine learning algorithm which can measure alertness in the user and let them know when their level of fatigue is becoming a risk. The system also carries out cloud-based analysis separately for each client, allowing them to monitor their overall performance and take actions if necessary.

The technology, developed as part of the Mining CRC (now Mining3), was commercialised through SmartCap Technologies and is now installed in mining operations all over the world. 'Over 70% of our business is overseas,' says Tim Ekert, CEO of SmartCap, 'and we have never had a fatigue-related incident in a site equipped with the system. The data generated by the system shows that every customer sees an overall drop in their average fatigue levels across a deployment over time, resulting in a reduced fatigue risk.'

To date the company has focused on the mining market, but sees opportunities for growth into larger markets such as the USA trucking industry. SmartCap is on track for another year of greater than 100% revenue growth in 2019, but still needs to make sure it retains focus on its R&D priorities. 'Sometimes we want to do a new feature because it's cool,' says Mr Ekert, 'but we have to focus on where we are going to get the biggest bang for our R&D buck.'

# Methodology

The study supporting this publication was carried out through a series of 28 first hand interviews of between 30 and 90 minutes, with most having a duration of one hour. Some additional feedback was also included from group discussions and/or public presentations.

## Research themes

There have been numerous attempts to categorise areas of mining R&D into themes. These were collated and distilled into six themes

| Areas of mining | Themes | | | | | |
|---|---|---|---|---|---|---|
| | Commercial drivers | Digital transformation | Finding, mining and extracting | Footprint | New horizons | Health and safety |
| METS Ignited | Improving speed of innovation, collaboration and business models<br>Business development, optimisation and growth | Ubiquitous sensing, digitalization and data analytics | Excellence in finding, mining and extracting | Reducing mining's footprint | Operating in a global marketplace | |
| CSIRO-METS | | Data driven mining decisions<br>Mining automation and robotics | Exploration under cover<br>Advanced extraction | Social and environmental sustainability | | |
| Neuchatel 2019 | Investment<br>attraction,<br>workforce | Innovation, productivity | Find more resources<br>Expand the mining envelope<br>Increase recovered value<br>Improve productivity | Environmental | Develop new products and markets | Safety |
| Queensland Government | | Digital transformation | Promote and fast track new discovery<br>Transition energy needs and increase efficiency<br>Increase productivity across the supply chain | Minimise the physical footprint and waste of mining. Achieve improved rehabilitation outcomes and community support | Support the maturation of new and emerging supply chains for tech minerals | Reduce risk to miners from hazardous environments |

## Interview questions

How important is R&D/innovation to your organisation?

What keeps you awake at night? Name three major challenges for your organisation

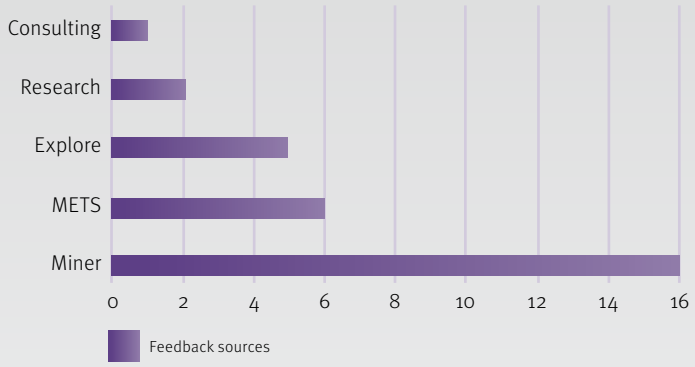
What do you think the mining industry is going to look like in 10-15 years time?

What is your awareness of mining R&D/innovation in Queensland? Any highlights for you? Is there a Queensland innovation that stands out for you and/or your company?

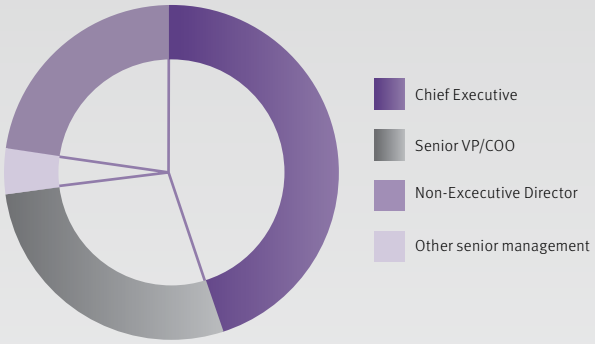
Is there an example you have been involved with where innovation has played an important and positive role in your company?

What would your advice be to Queensland groups involved in mining-related R&D and/or innovation?

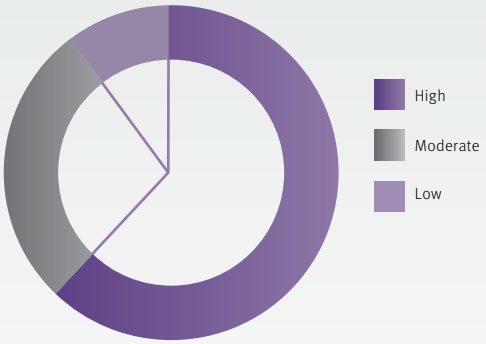
### Feedback sources




### Role of interviewee




### Importance of innovation (all respondents)




### Importance of innovation (Miners only)

# Acknowledgements

Thank you to the following people for their participation:

**Aeris Resources**
Ian Sheppard, COO

**BHP**
Rhonda O'Sullivan, Principal Geologist
Strategy and Planning

**Capricorn Copper**
Brett Fletcher, CEO

**Centrex Metals**
Simon Slesarewich, CEO

**Core Resources**
Rob Coleman, CEO

**Evolution Mining**
Bob Fulker, COO

**EY**
Paul Mitchell, Global Mining & Metals Sector Leader

**Glencore Copper**
Matt O'Neil, COO
Dan Brooks, Head metallurgy (former)

**Glencore Technology**
Mike Hourn, General Manager

**Glencore Zinc Qld**
Denis Hamel, EGM Zinc Operations

**Heathgate Resources**
Joe Potter, Principal Geologist Business Development

**Metro Mining**
Simon Finniss, CEO

**Minotaur Resources**
Glen Little, Exploration Manager

**MMG Limited**
Pierre Malan, GM Operations Australia

**Nautilus Minerals**
Glenn Withers, CFO
Anthony Manocchio, Offshore Exploration Project Manager
John Parianos, Manager Exploration and Polymetallic Nodules

**Neuchatel Partners**
Jon Loraine, Chairman

**New Century Resources**
Michael Pitt, Head of Strategic Development

**Newcrest Mining**
Briggite Seaman, Principal Metallurgist

**Oceana Gold Ltd**
Tom Cooney, General Manager Project Development and Studies

**Panaust**
Scott Cowie, GM Tech Services

**Petra Data Science**
Penny Stewart, CEO

**Pure Battery Metals**
Bjorn Zikarsky, CEO

**QUT Centre for METS Innovation**
Rachel Parker, Director

**Red River Resources**
Mel Palancian, MD
Donald Garner, Executive Director

**SmartCap Technologies**
Tim Ekert, MD

**SMI-JKMRC**
Tim Napier-Munn, Emeritus Professor

**SMI-MISCH**
Brett Garland, Director

**South32**
Vanessa Torres, Chief Technology Officer

**Tartana Resources**
Steve Bartrop, Executive Chairman

**Terrasearch**
Simon Beams, MD

**Various**
DNRME Safety Forum attendees

**Voconiq**
Kieren Moffatt, CEO

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