Mining Equipment, Technology and Services

A Roadmap for unlocking future growth opportunities for Australia

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CSIRO Futures is the strategic advisory and foresight arm of Australia's national science agency.

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ACKNOWLEDGEMENTS

CSIRO would like to acknowledge the METS Ignited Industry Growth Centre and Austmine for their input and support in the development of this report.

We are also grateful for the time and input of industry representatives consulted throughout this project and the many researchers who provided invaluable review and feedback on this report.

CSIRO Foreword

Australia's Mining Equipment, Technology and Services (METS) businesses are recognised as a great Australian success story, with global companies and countries looking to Australia for innovation. In this down cycle, METS businesses now need to be investing in the science and technology they need to navigate an uncertain future and emerge on top as the market turns. In response to these challenges, CSIRO is investing in research to catalyse innovation in the sector, including advanced exploration and deep earth imaging, rapid resource characterisation, intelligent mining and ore management, processing options, improved environmental performance solutions and new technologies for responsible and efficient metal production. This research and development is driven by deep collaboration and partnership with businesses and industry bodies such as the METS Ignited Industry Growth Centre and Austmine.

CSIRO's Strategy 2020 is to be Australia's Innovation Catalyst, which will help us work closely with industry to create new value by translating world-class science into innovative products to help the METS sector become more globally competitive. 'Customer First' is the first pillar of our strategy, and we've prioritised the way we work side-by-side with our customers and partners to tackle the big challenges facing their industries. We're committed to responding with agility and creativity to find the right solutions for unique projects, and spending more time understanding the specific requirements of industries and businesses. This customer-centric approach doesn't just extend to how we work with our partners; it is also reflected in our broader research agenda.

CSIRO uses science to conceptualise, predict, and model the major trends shaping Australia's future, including the Australia 2030 Report, Our Future World: Global Megatrends report, and the Australian National Outlook. We believe the METS sector has a bright future in this country. Working closely with METS Ignited, this Industry Roadmap identifies five opportunities that could secure the future competitiveness and success of METS businesses in Australia. But building this future relies on a collaborative approach from the research, education, government, business and investor communities. CSIRO is committed to continuing to channel resources into this effort, including bringing our world-class science and solutions to the table.

Responding to the disruption facing every part of the Australian landscape requires nothing short of deep collaboration to drive breakthrough innovation. We are proud to stand shoulder-to-shoulder with METS Ignited and the other Industry Growth Centres as they further map out their roads to success. These Industry Roadmaps work inextricably with our Science Roadmaps to ensure alignment for national benefit. Together, we can apply world-class scientific and technological expertise to our unique Australian challenges and chart a course for long-term sustainable prosperity for our nation.

Dr Larry Marshall
CSIRO Chief Executive

METS Ignited Foreword

I am delighted to introduce and endorse CSIRO's METS Industry Roadmap for its contribution in shaping the sector's future. CSIRO has long been involved in Australian mining research and innovation and is an integral part of the industry ecosystem.

When the METS Sector Competitiveness Plan was launched in late 2016, it laid the strategic foundations for sector success over the next decade. The vision for the industry was one of smarter relationships and collaborative leadership. CSIRO's METS Industry Roadmap complements this piece of work by identifying and unlocking opportunities for METS companies to become globally competitive.

It was a pleasure to work collaboratively with CSIRO on the development of this Industry Roadmap and the Sector Competiveness Plan.

In developing the Sector Competitiveness Plan, METS Ignited, CSIRO and Austmine engaged with more than 600 participants in the METS, mining, government and research communities. CSIRO played an important role in researching trends impacting and shaping the future of the mining and METS sectors as part of the consultation process.

The core message we received during the consultation for the Sector Competitiveness Plan focused on improving collaboration practices and platforms in the industry that allow for faster commercialisation, and the effective development and implementation of knowledge and skills.

The Australian METS sector needs scale and speed to stay abreast of global changes. As outlined in this Industry Roadmap, the increasing dependencies on technologies and the specialised skill required to support them are both opportunities and threats for our sector. The METS sector is technologically advanced but must develop faster Intellectual Property transfer and build better relationships within our helix of stakeholders to take industry capability to the next stage.

The collective economic footprint of the METS and mining sector in Australia is significant. We are a world-class sector that embodies an entrepreneurial spirit that drives innovation. We must use CSIRO's Industry Roadmap and the Sector Competitiveness Plan to work together as a nation to create and sustain our competitive advantage if we are to secure jobs and prosperity.

Ric Gros
METS Ignited Chief Executive Officer

METS IGNITED

Executive Summary

Executive Summary

Australia's Mining Equipment, Technology and Services (METS) sector has an important role to play in the continued success of Australia's mining industry.

However, the mining industry's increasing dependence on specialist technologies, combined with a changing global landscape is creating new opportunities and threats for the future of Australia's METS sector.

This Industry Roadmap, through a process of sector consultation and analysis, aims to support this decision making process. It explores global mining megatrends and Australia's comparative advantages and identifies five opportunities where Australian METS companies can be internationally competitive. These opportunities are supported by a discussion of the underlying science and technology investments and management skills, culture, processes and business models required to unlock them.

Global mining megatrends are reshaping the METS sector, requiring Australian companies to re-evaluate their role in the industry's future.

The changes are challenging the viability of conventional practices and technologies, creating opportunities for new business models and reducing barriers to entry for new players. Australian METS companies need to ensure that their strategy is aligned with the trends that are set to drive change in the industry over the next 20 years.

FIGURE 1: GLOBAL MINING MEGATRENDS

RETHINKING OUR RESERVES

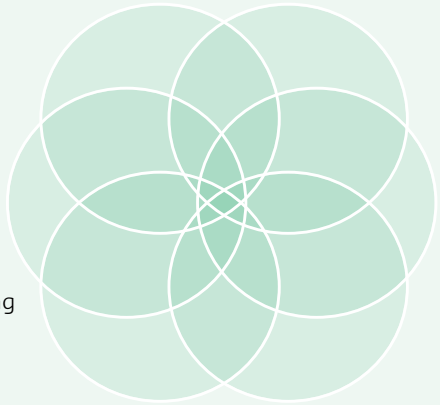
Rates of discovery for high-quality and accessible ores are declining and not keeping up with depletion. Solutions that help exploration under cover, extend the life of a mine and optimise recovery, combined with social expectations for recycling, re-use and urban (or above ground) mining are all playing a role in changing what is deemed economic.

THE INNOVATION IMPERATIVE

A drop in commodity prices, along with rising costs, declining ore grades and concerns about decreasing productivity are compelling the mining industry to focus on operational costs. The mining industry requires creative and innovative solutions to become more productive, sustainable and achieve financial growth.

THE KNOWLEDGE ECONOMY

As emerging economies continue to develop their mining sectors, support in developing applicable skills, services and technologies will be required for efficient and sustainable exploitation of mineral reserves. In advanced economies, increased adoption of specialised digital technologies are resulting in greater collaboration, new business models and fierce competition for talent.



PLUGGED IN AND SWITCHED ON

Digital technologies, data analytics and automation along with greater mobility and increasing connectivity are creating exciting opportunities for the mining industry. These connected technologies are improving safety and environmental outcomes, increasing productivity and driving disruptions across the mining value chain and life cycle.

NEW SUPPLY, NEW DEMAND

Increasing urbanisation and rapid development of emerging economies will continue to spur demand for mineral resources, which will be supplied from developing nations and new geographic domains through technology advancements. Rapid adoption of new consumer technologies is also changing demand for high value, low volume metals and minerals.

THE ERA OF ACCOUNTABILITY

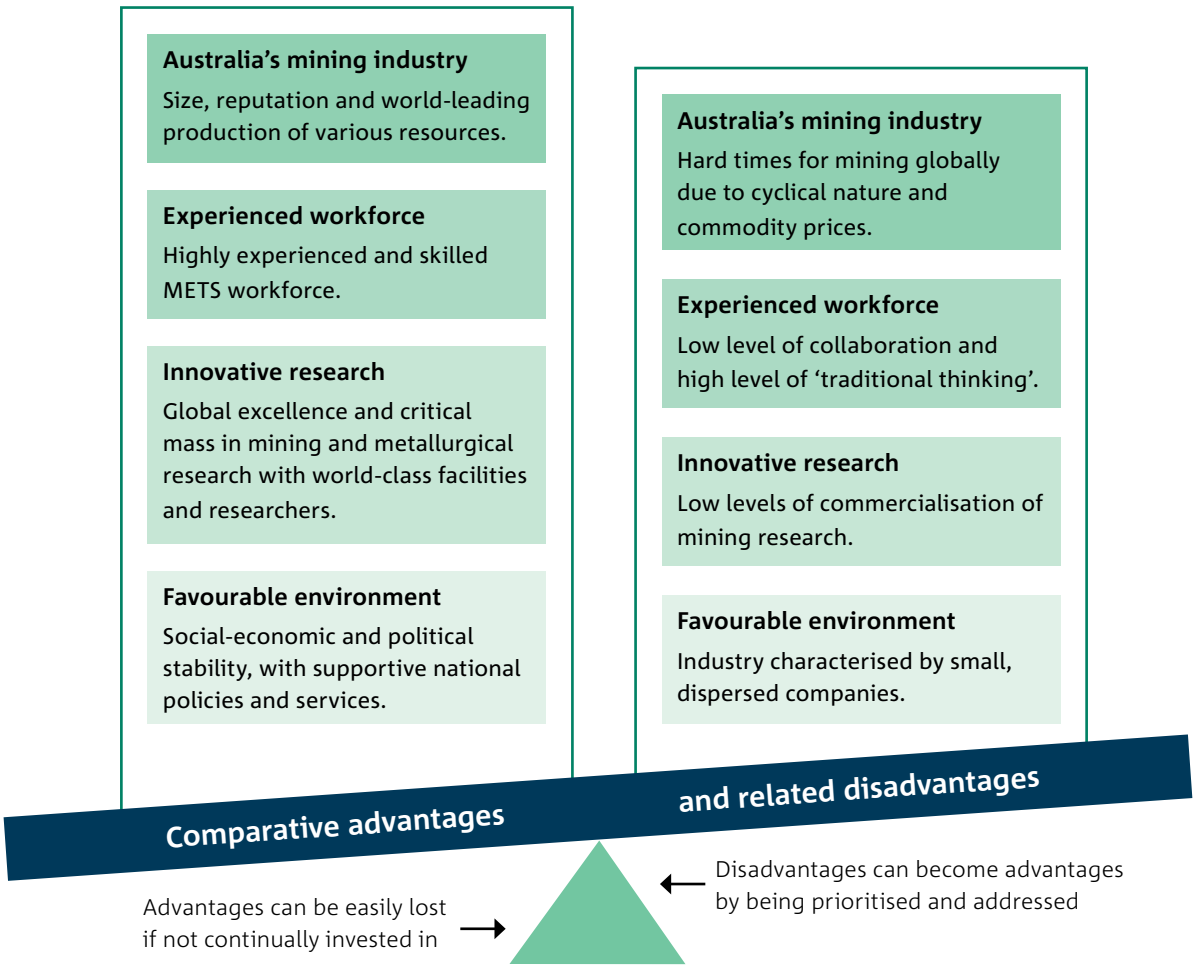
Mining companies will move forward as good corporate citizens, where accountability and environmental success exceeds expectations, strengthening community engagement and support for existing and new projects into the future.

The METS sector has comparative advantages that can be lost if not nurtured, and disadvantages that can become advantages if prioritised.

Australia's METS sector is underpinned by a number of unique comparative advantages that help improve its competitiveness on a world stage. These advantages have related disadvantages that the sector needs to be cognisant of because, despite not being uniquely Australian, they will impact the future competitiveness of the sector if not addressed.

Continued success for Australian METS companies is not guaranteed, as high rates of digital and technological change in the mining sector no longer create a strong barrier to entry. Observations of change and disruption from other industries, such as automotive and aerospace, are hard to ignore. As such, METS companies must prepare for increased competition from within and outside of the sector and focus on innovative and creative solutions to provide greater value and ensure continued success and future growth.

FIGURE 2: AUSTRALIA'S COMPARATIVE ADVANTAGES AND RELATED DISADVANTAGES

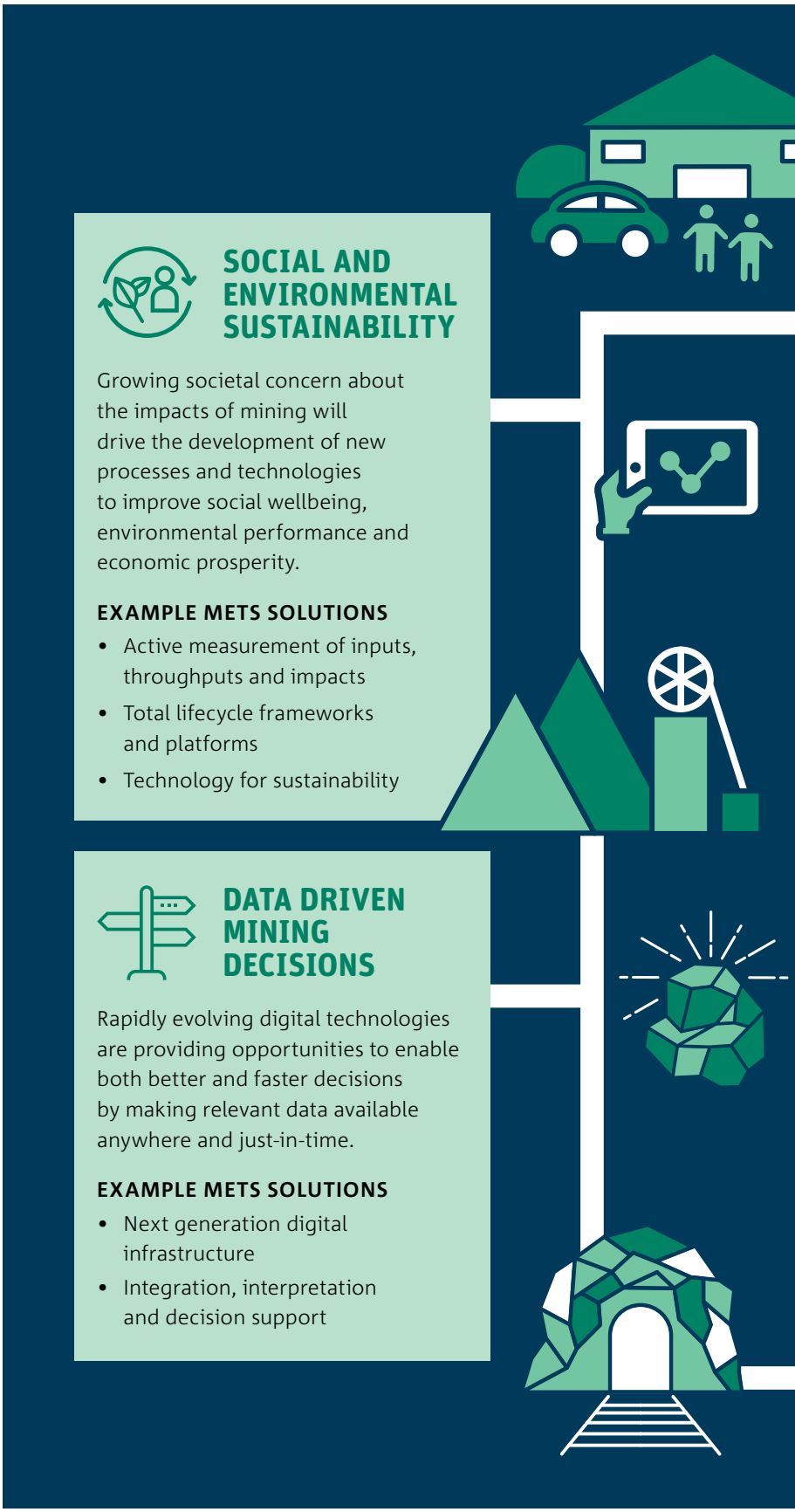


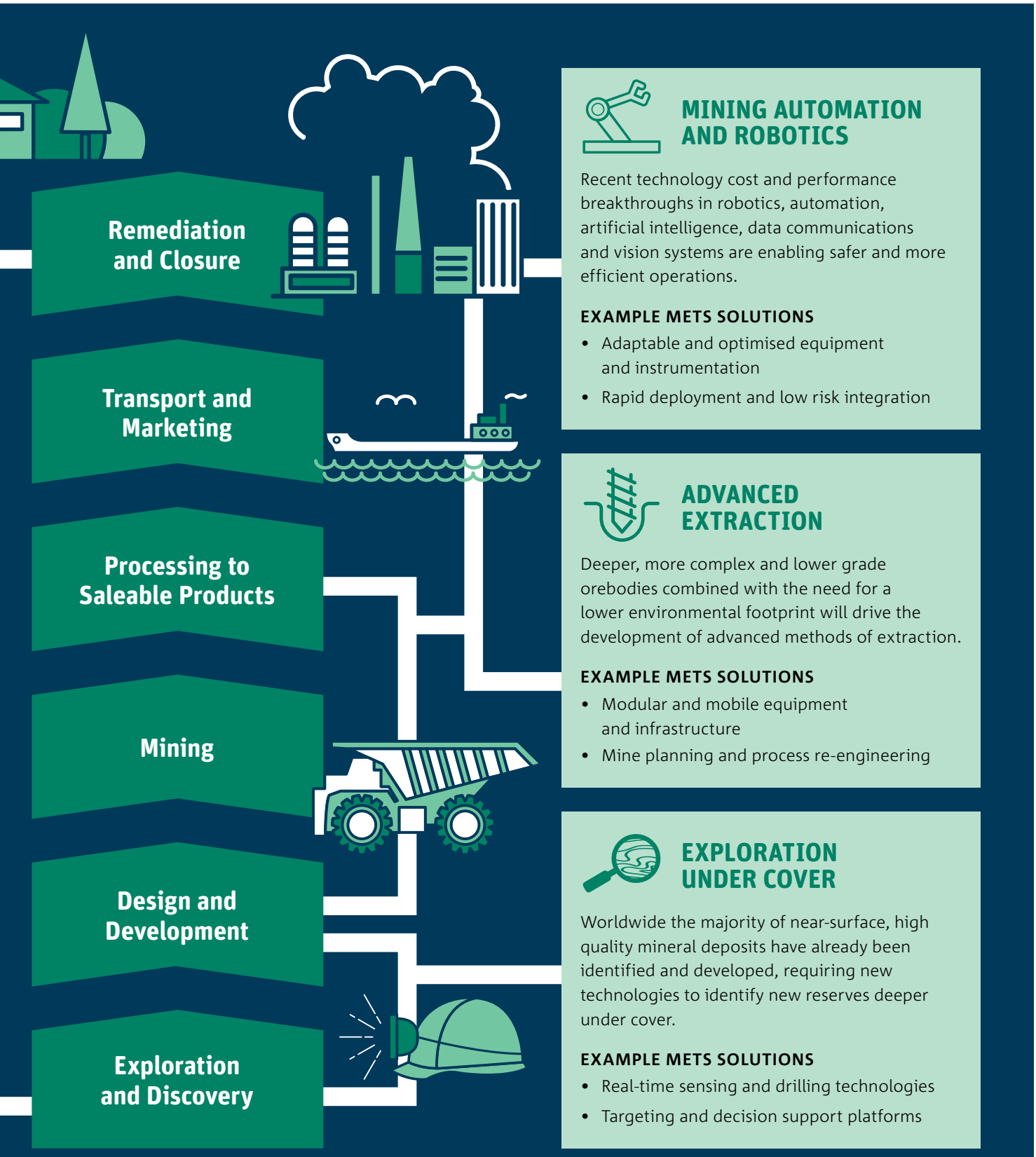
There are many opportunities, however Australian METS companies need to prioritise the right solutions to be internationally competitive.

The culmination of the Roadmap process is the identification of five opportunities to support the continued growth of the Australian METS sector. These opportunities span the mining value chain with the Data Driven Mining Decisions and Social and Environmental Sustainability opportunities playing a pivotal and enabling role across the other opportunities. Each opportunity is supported by example METS solutions that could be taken to market, which aim to help businesses identify and prioritise potential areas of specialisation and differentiation within each opportunity.

*The five opportunities for growth are not considered to be an exhaustive list of opportunities available to the METS sector.

FIGURE 3: IDENTIFIED OPPORTUNITIES FOR THE AUSTRALIAN METS SECTOR





MINING AUTOMATION AND ROBOTICS

Recent technology cost and performance breakthroughs in robotics, automation, artificial intelligence, data communications and vision systems are enabling safer and more efficient operations.

EXAMPLE METS SOLUTIONS

- Adaptable and optimised equipment and instrumentation
- Rapid deployment and low risk integration

ADVANCED EXTRACTION

Deeper, more complex and lower grade orebodies combined with the need for a lower environmental footprint will drive the development of advanced methods of extraction.

EXAMPLE METS SOLUTIONS

- Modular and mobile equipment and infrastructure
- Mine planning and process re-engineering

EXPLORATION UNDER COVER

Worldwide the majority of near-surface, high quality mineral deposits have already been identified and developed, requiring new technologies to identify new reserves deeper under cover.

EXAMPLE METS SOLUTIONS

- Real-time sensing and drilling technologies
- Targeting and decision support platforms

Businesses must take action to unlock opportunities, investing in business transformation and new science and technology capabilities.

In order to unlock the various growth opportunities, Australian METS companies should consider the following actions:

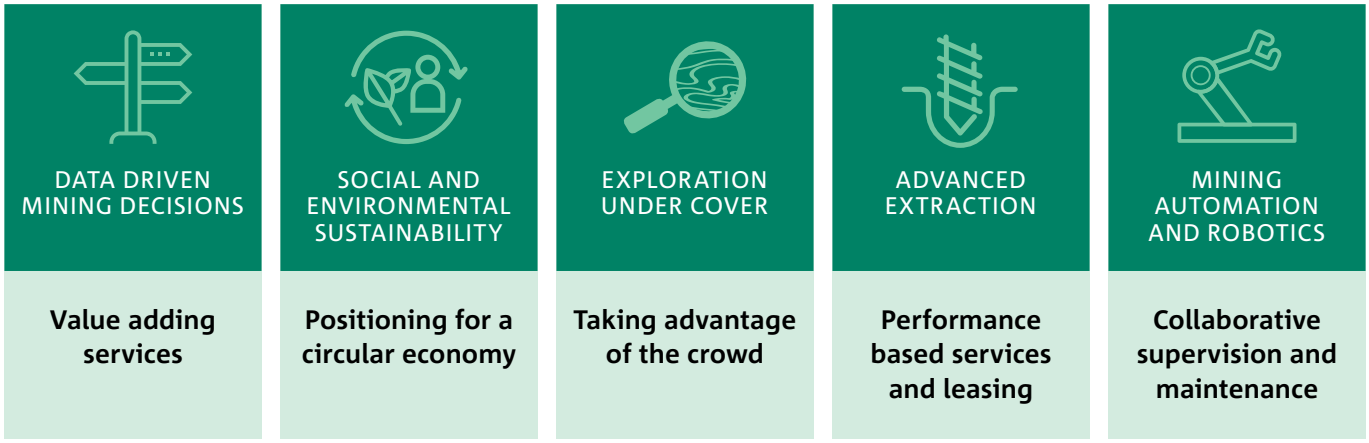
FIGURE 4: SUMMARY OF CHANGES PER GROWTH OPPORTUNITY

	BUSINESS ENABLERS			ENABLING SCIENCE AND TECHNOLOGY
	PEOPLE AND SKILLS	CULTURE AND COLLABORATION	PROCESS AND STANDARDS	
Data driven mining decisions	Foster skills to improve interpretation, modelling and decision making using big and small datasets.	Improve how the business uses and responds to data, moving from reactive to proactive.	Address interoperability and integration issues, working with industry and research to implement appropriate data standards.	• Sensors and the Internet of Things • Analytics and optimisation • Visualisation • Cyber security
Social and environmental sustainability	Establish cross-disciplinary skills – engineering, financial, social, environmental and economic – to better demonstrate the long-term value proposition of triple bottom line solutions.	Connect miner, government, social and environmental groups to support and improve technical and regulatory decision making processes.	Assess operational and regulatory barriers that may limit social and environmental monitoring and reporting, and the associated liabilities.	• Monitoring and sensing • Decision support and stakeholder engagement • Site and equipment design
Exploration under cover	Develop geophysical and geochemical knowledge, data analysis, modelling and geographic information system (GIS) skills.	Increase multidisciplinary collaboration and support activities that improve decision making and resource governance.	Identify and promote best practice in data acquisition, processing, sharing and integration to improve data quality and reduce issues with integrating large exploration datasets.	• Next generation drilling technologies • Expanding exploration knowledge and processes
Advanced extraction	Develop skills in installing, operating and manufacturing advanced extraction technologies as well as advanced drilling, sensing, sorting and processing technologies.	Improve alignment of performance drivers and foster interdisciplinary collaboration across mining, metallurgical and geological personnel.	Support development of regulatory frameworks for advanced extraction technologies, including standards for interoperability of technologies.	• Advanced drilling and cutting technologies • Sensors and ore sorting • Integrated beneficiation technologies
Mining automation and robotics	Foster skills in the operation and maintenance of autonomous and robotic equipment; develop technical expertise in material sciences and nanotechnology.	Challenge the role of automation and robotics in mining, and use change management to address cultural acceptance of technologies.	Support sector wide actions to address interoperability issues, leveraging existing initiatives – e.g. AMIRA (P1025), EMESRT and GMSG projects.	• Machine vision, materials and robotics • Control systems and algorithms • Virtual and augmented reality

A changing business environment and evolving market creates support for a range of new business models within the METS sector.

Each opportunity identified within this report is supported by example business models that may be leveraged across a range of solutions and opportunities.

FIGURE 5: BUSINESS MODEL EXAMPLES PER GROWTH OPPORTUNITY



Long term success will be achieved by increasing collaboration across the entire Australian mining and METS innovation ecosystem.

While the identified growth opportunities and enablers largely focus on actions for individual METS businesses, long-term success requires collaboration across the entire Australian innovation ecosystem – including miners, METS, government, investors, educators and the research community.

From a science and technology perspective, the research community will need to ensure projects are well aligned to industry needs and that technologies are developed from market pull rather than technology push. This includes streamlining and improving the approach to industry partnership, ensuring the research engagement process is efficient and not overly complicated or onerous on industry.

A key vehicle for achieving this is the METS Ignited 10 Year Sector Competitiveness Plan (SCP) and the key programs of work and industry knowledge priorities (IKPs) that have been identified. This Roadmap seeks to complement the SCP and the sector's broader vision providing input into current and future IKPs. Given the cyclical nature of the industry, the report structure also provides a narrative and key questions that can be continuously applied at a company level to inform the strategic decision making process.

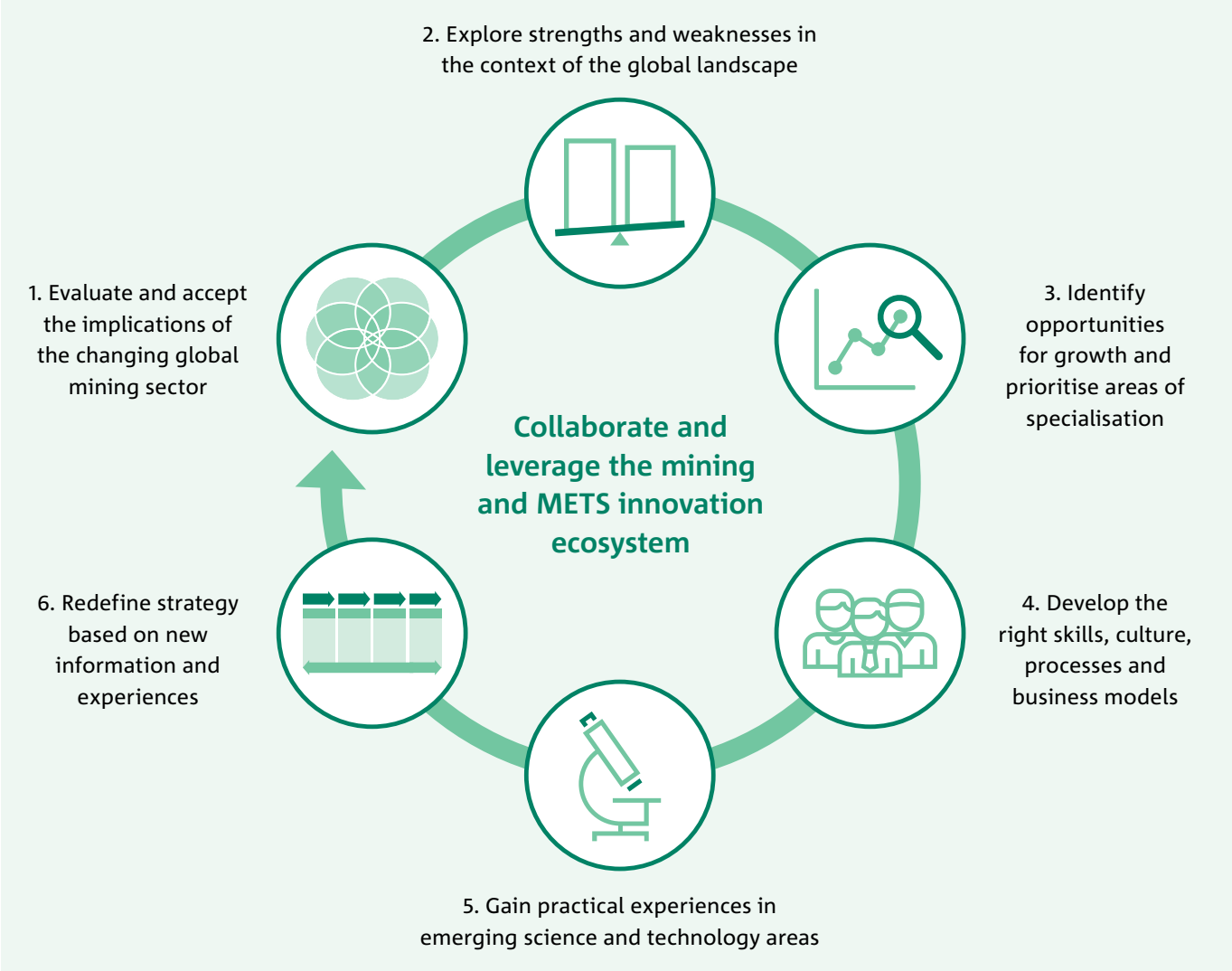
Call to action

Working together, the Australian METS sector is well placed to succeed. METS businesses will need to take calculated risks and invest in the future, and can use this Roadmap and the SCP as a tool for sustained competitive advantage (Figure 6).

METS SECTOR VISION

The Australian METS industry is an aligned, efficient and agile industry ecosystem with a high degree of collaboration, global leadership in innovation, and a growing share of the global market.[1]

FIGURE 6: USING THE METS ROADMAP



1 METS Ignited (2016). *Industry-led Growth Centre for METS.* [Online] Available from: http://www.metsignited.org/Category?Action=View&Category_id=72 Accessed 19/12/2016

Contents

Introduction

1 Introduction

The importance of Australia's Mining Equipment, Technology and Services (METS) sector and its role in the success of the mining industry is clearly reflected in its growth over the last few decades.

However, the mining industry's increasing dependence on technologies, combined with the evolving complexity and specialisation of skills required to support them, is creating new opportunities and threats to Australia's METS sector. At the same time, global mining megatrends are reshaping the sector's future, creating opportunities for new business models, challenging the viability of conventional practices and technologies, and reducing barriers to entry for new players.

As a result, Australian METS companies need to re-evaluate their role in a changing landscape and re-positioning themselves to take advantage of emerging global opportunities.

1.1 This Roadmap

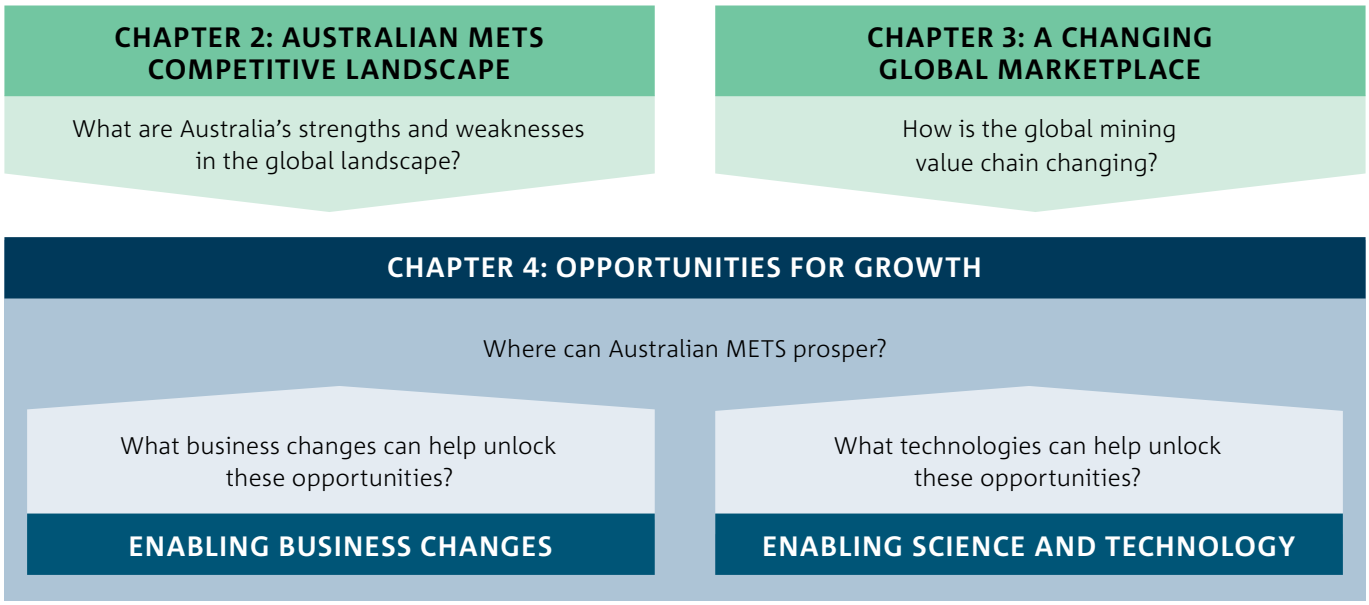
To unlock opportunities and avoid threats, METS companies will need to make decisions about the future of their businesses – ensuring that scarce resources are appropriately allocated and that strategy is underpinned with strong underlying market, business and technology assumptions.

This Roadmap, through a process of industry consultation and analysis, aims to support this decision making process by exploring five METS opportunities and the underlying science and technology investments and management skills, culture, processes and business models required to unlock them.

Each opportunity is supported by example product and service solutions that could be taken to market. These help to explore potential areas of specialisation and differentiation where METS companies can be internationally competitive. The structure of the report (see Figure 7) has been designed to outline a narrative that can be continuously applied by individual businesses and revisited as the market evolves.

While this Roadmap targets a METS business audience, this industry-led document also aims to support miners, government, investors, educators and the research community. For the research community specifically, the report seeks to identify areas where research and development can best support business to increase the chances of generating commercial outcomes.

FIGURE 7: METS ROADMAP STRUCTURE



1.2 Industry consultation

This industry-led Roadmap was developed in consultation with Australian METS companies. Local and global companies provided direction and input across all chapters.

INDUSTRY CONSULTATION

CSIRO participated in and supported the METS Ignited national consultation process which occurred between April and June 2016. This process gained feedback from approximately 400 sector participants across six states. Beyond the mining and METS companies that participated in the workshops, there was also representation from the state and federal government, and research organisations.

METS IGNITED AND AUSTMINE

As representatives of the METS sector, both organisations provided valuable input and feedback throughout the development of this report. The report references Austmine's METS sector surveys and leverages the analysis conducted by METS Ignited.

INDUSTRY INTERVIEWS

One-on-one interviews were held with additional METS businesses to supplement, test and refine the workshop outputs. This includes presenting early Roadmap findings at the METS Ignited Digital Disruption workshop, held during the 2016 International Mining and Resources Conference (IMARC).

1.3 A vision for Australian METS

VISION

The Australian METS industry is an aligned, efficient and agile industry ecosystem with a high degree of collaboration, global leadership in innovation, and a growing share of the global market.[2]

Given the breadth and complexity of the mining industry and the METS sector, this Roadmap should be considered as one component in a broader landscape of work being conducted to lift the entire Australian sector and create a stronger international METS brand.

A key vehicle for achieving the long-term vision for the METS sector is the METS Ignited 10 year Sector Competitiveness Plan (SCP).[3] The plan outlines five key programs of work, each helping to define the sector's future state and specific short and long-term activities to help improve competitiveness (see Figure 8).

Supporting the vision and key programs of work, the SCP has defined a set of METS Industry Knowledge Priorities (IKPs), which are 'outcome-focused bodies of information or skills that need to be developed to create sustainable global competitive advantage for the Australian METS sector.'

Working closely with the METS Ignited Industry Growth Centre and its partners, this Roadmap seeks to complement the SCP and the METS sector's vision by exploring emerging trends and providing input into current and future IKPs.

FIGURE 8: METS SCP KEY PROGRAMS OF WORK

PROGRAMS OF WORK	THE VISION
Aligned Strategy	Working togther the METS and mining sectors are better positioned to anticipate trends, to identify opportunities and to de-risk solutions, radically improving productivity, social and environmental outcomes and the growth and competitiveness of both sectors.
Global Brand	An umbrella positioning that has strong resonance domestically and globally and connotes high quality, knowledge intensive solutions; sets standards and expectations and attracts a price premium
Internationally Competitive	Australian METS cluster together to compete effectively in the global supply chain; their growth is enabled by a competitive and supportive capital market.
Collaborative and Innovative	Partnering from the ideation stage; working together to develop and de-risk solutions; live site testing has resulted in a reputation for quality solutions and speed to market.
Skilled for 2026	Australian METS have, or can access, the full range of skills required to realise their entrepreneurial ambitions. The industry is continually renewing itself.

Source: METS Ignited (2016)

2 METS Ignited (2016). *Industry-led Growth Centre for METS.* [Online] Available from: http://www.metsignited.org/Category?Action=View&Category_id=72 Accessed 19/12/2016

3 METS Ignited (2016). *Mining Equipment, Technology and Services - 10 Year Sector Competitiveness Plan (SCP).*

Australian METS competitive landscape

2 Australian METS competitive landscape

2.1 METS sector in Australia

DEFINING METS

This report defines the Mining Equipment, Technology and Services (METS) sector as any company that provides specialised products, technologies and services across the mining value chain from mineral exploration, development and extraction to processing, transport and remediation.

Australia's METS sector has built a global reputation for being innovative – successfully developing and commercialising high quality, cutting edge technologies for the mining sector, both within Australia and internationally. Australia's METS sector is recognised as a competitive strength and strategic priority for the country.[4]

Companies in the Australian METS sector are diverse, consisting of small start-ups through to global multi-nationals. The companies are all focussed on providing equipment, technology or services across the mining and resources value chain and many work across more than one phase of the mining lifecycle.[5] Companies involved in manufacturing mining equipment, consumables and chemicals form the largest segment of the METS sector (Figure 9). The majority of METS companies provide products or services to mining companies in the operations phase of the lifecycle (Figure 10). However, the boundary of the METS sector is constantly evolving, with new players entering from non-traditional sectors. For example, traditional oil and gas or defence services companies now provide key technologies and services to mining, and telecommunications providers have moved beyond communications to providing mining software and data services.

As a key supporting sector to the Australian mining and resources industry, METS has felt the effects of the mining downturn. In Austmine's 2015 National Survey (n=432), 79% of companies reported a decrease in revenue of, on average, 31%.[6] In the face of this decrease in revenue and alongside rising costs of operating a business in Australia, the METS sector has shown resilience by diversifying into other industries such as oil and gas, infrastructure and renewable energy.

Australian METS companies are globally focused with 66% of companies exporting products and services. Exports from the sector total approximately $15 billion annually.[7] South East Asia is a key export region for Australian METS, with growth into the future expected in North and South America, particularly the US, Canada and Chile. In addition, analysis by IP Australia shows that the top inventor location for Patent Cooperation Treaty (PCT)[8] applications for mining inventions are Japan and Germany, followed by Australia, with 537 PCT applications out of the total 4,159 PCT applications.[9]

Australian METS have strengths in bringing together technologies and integrating them appropriately to different mining operations and optimising their performance for Australian specific conditions. Given this expertise, patents may not accurately profile the intellectual property and intellectual capital of Australia's METS sector.

4 Department of Industry, Innovation and Science (2016). *Industry Growth Centres - Initiative summary,* Australian Government. [Online] Available from: http://www.industry.gov.au/industry/Industry-Growth-Centres/Pages/default.aspx Accessed 19/12/2016

5 Austmine (2015). *National METS Survey 2015 Results: New Realities, Bigger Horizons*, [Online] Available from: http://www.austmine.com.au/News/articleType/ArticleView/articleId/2724/National-METS-Survey-2015-Results-New-Realities-Bigger-Horizons#sthash.HziHD34g.dpuf

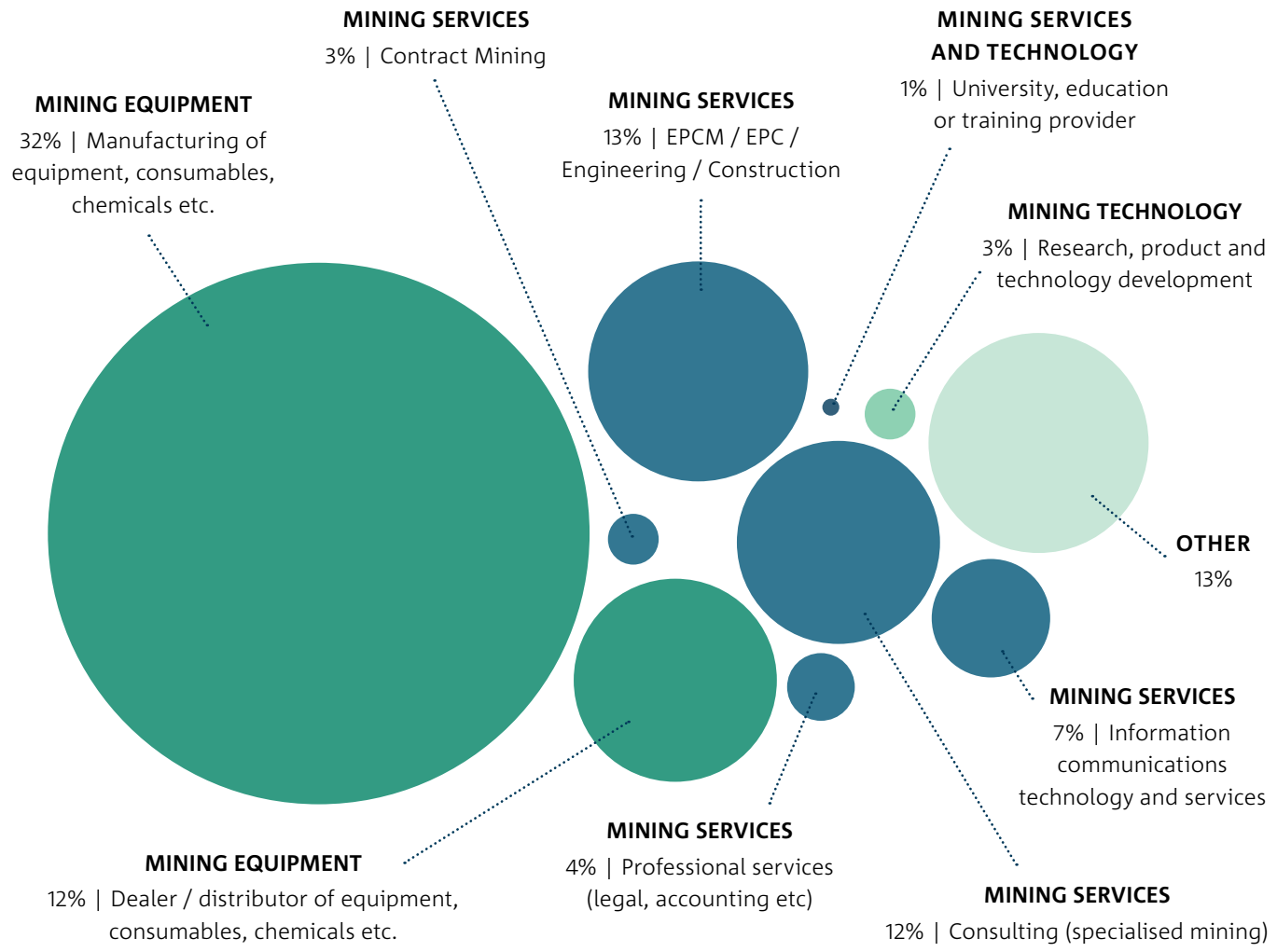
6 Austmine (2015). *New Realities, Bigger Horizons - Australian Mining Equipment, Technology and Services (METS) National Survey.*

7 METS Ignited (2016). *Mining Equipment, Technology and Services - 10 Year Sector Competitiveness Plan (SCP).*

8 Under the Patent Cooperation Treaty (PCT) applicants may also apply for what is known as an international patent application, which allows their invention to be assessed in terms of the newness and inventiveness of the invention by an international authority, after which it is published before entering processing in the jurisdictions elected by the applicant.

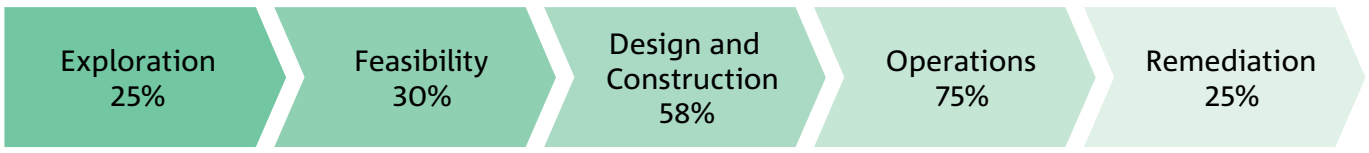
9 Francis, E. (2015). *The Australian Mining Industry: More than Just Shovels and Being the Lucky Country,* IP Australia.

FIGURE 9: BREAKDOWN OF AUSTRALIAN METS (2015)



Adapted from Austmine (2015)

FIGURE 10: PERCENTAGE OF AUSTRALIAN METS COMPANIES INVOLVED IN EACH PHASE OF THE MINING LIFECYCLE



Source: Austmine 2015

AUSTRALIA'S MINING AND METS SECTOR

400
operating mines

$133.2 billion
in direct Gross Value Added (GVA) in 2015–16

With an estimate of between
$10 to $40 billion
GVA for the METS sector*

Source: Deloitte Access Economics (2017),[10] METS Ignited (2016),[11] Austmine (2017).[12]
* METS sector GVA based on a combination of published and existing estimates.

Australia's METS Sector

Employed **386,000** highly skilled workers in FY12

3,000–4,000
METS businesses in 2013

80% of METS businesses are Australian owned

$90 billion
revenue in FY12

$15 billion
of exports

$1.18 billion
expenditure on research and development in FY14

METS organisations accounted for the **majority (~76%) of patents filed** in the Australian mining sector between 1994 and 2011

Source: METS Ignited (2016),[11] Department of Industry, Innovation and Science (2016),[13] Austmine (2013, 2015, 2017),[14 15 16] IP Australia (2015).[17]

THE CYCLICAL NATURE OF MINING

The Australian mining sector, together with the broader global mining sectors are key buyers of products and services from Australian METS businesses. Because of this, many of the trends that impact the mining sector, in turn impact METS.

Decline in the mining sector's revenue over the past five years has been influenced by falling commodity prices, weaker demand growth from industrialising economies and increased global commodity output resulting from recent investments (transitioning from construction to operation).[18] This has had flow on impacts to Australia's METS sector as companies have stalled expansion programs and are rebalancing their portfolios and implementing cost-reduction initiatives. However, companies are also looking to improve efficiency and productivity, which presents new technology development and service opportunities for Australian METS.

Given the cyclical nature of mining, the difficulties experienced by the mining sector are expected to moderate over the long term.

10 Deloitte Access Economics (2017). Mining and METS: engines of economic growth and prosperity for Australians. Report developed for Minerals Council of Australia. Deloitte.
11 METS Ignited (2016). *Mining Equipment, Technology and Services - 10 Year Sector Competitiveness Plan (SCP).*
12 Austmine (2017). Proprietary data and unpublished correspondence.
13 Department of Industry, Innovation and Science (2016). *Competitiveness at a glance,* Australian Government. [Online] Available from: http://www.industry.gov.au/Office-of-the-Chief-Economist/Publications/IndustryMonitor/section1.html Accessed 19/12/2016
14 Austmine (2017). Proprietary data.
15 Austmine (2013). *Australia's New Driver for Growth: Mining Equipment, Technology and Services.*
16 Austmine (2015). *New Realities, Bigger Horizons - Australian Mining Equipment, Technology and Services (METS) National Survey.*
17 Francis, E. (2015). *The Australian Mining Industry: More than Just Shovels and Being the Lucky Country,* IP Australia.
18 Allday, A., (2016). *Mining in Australia,* IBISWorld.

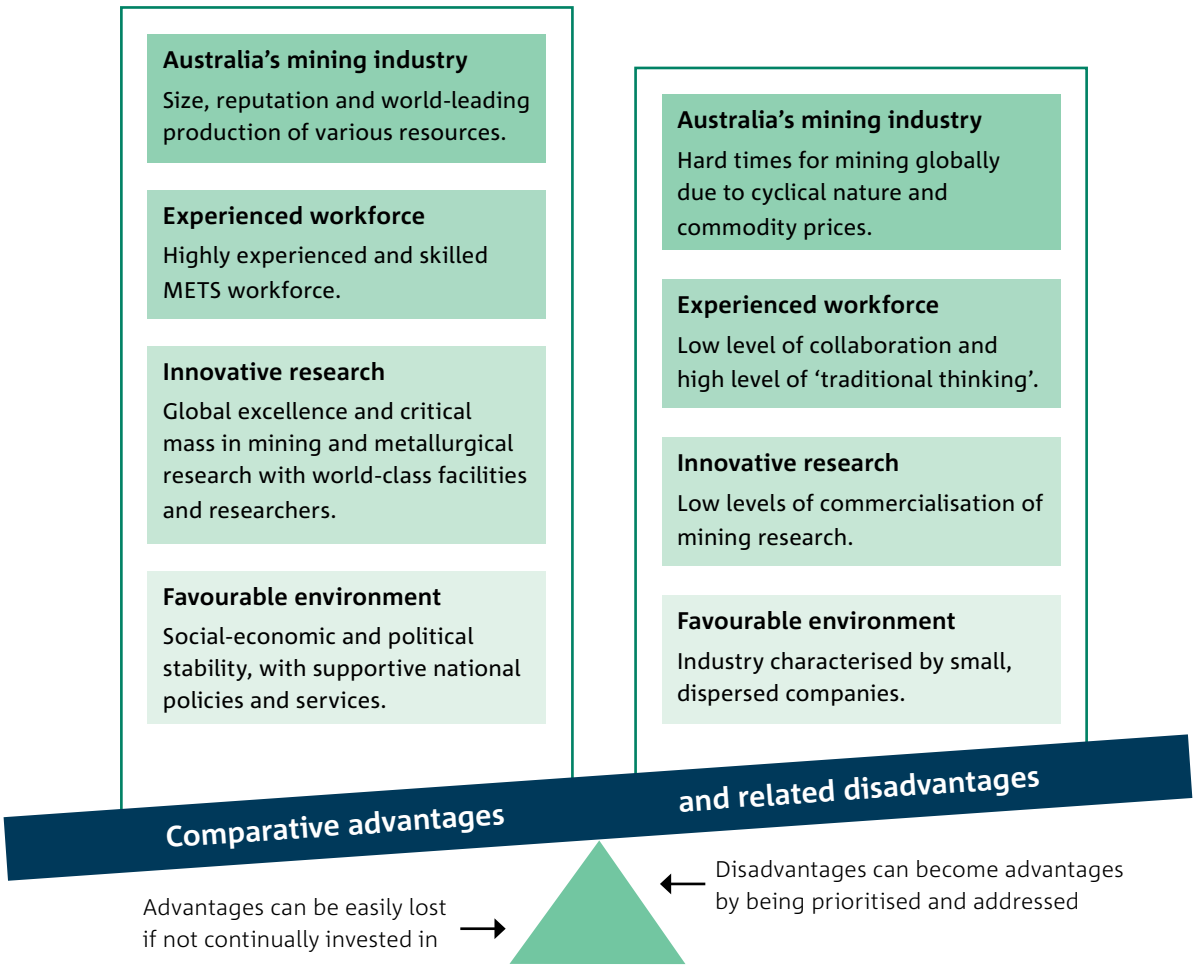
2.2 Comparative advantages and related disadvantages for Australian METS

Australia's METS sector is underpinned by a number of unique comparative advantages, helping improve its competitiveness on a world stage. These comparative advantages and related disadvantages were identified through industry consultation, and are supported by key literature. Australia's advantages represent strengths that can be built upon and exploited to secure the future competitiveness of the METS sector. While many of the related disadvantages identified are not exclusively Australian, they will impact the competitiveness of the sector if not addressed.

The advantages draw on Australia's large domestic mining industry which has provided the sector with deep domain knowledge and supported its ability to create unique solutions for global mining companies. Recognising these unique strengths, Australia now has one of the most organised and globalised METS sector anywhere in the world. This is underpinned by Local, State and Federal Government support, such as funding schemes available to Australian SMEs and start-ups (see Appendix A.2), and support via the METS Ignited Industry Growth Centre.

Australia's advantages and related disadvantages are further addressed in Appendix A.1.

FIGURE 11: AUSTRALIA'S COMPARATIVE ADVANTAGES AND RELATED DISADVANTAGES



2.3 METS sector globally

Australia's METS sector is facing increasing global competition as regions recognise the fundamental importance of METS in the future development of the mining industry. With many national economies not yet grouping mining equipment sectors together with technology and services for reporting purposes, global estimates for the METS market are limited, with the term 'METS' still uncommon. However, mining equipment, discrete from mining services and technology development has been assessed globally, with the market expected to reach revenues of US$150 billion by 2022, growing at a compound annual rate of 7.9% from 2016-2022. The Asia-Pacific is becoming the largest market for mining equipment globally.[19]

Australian METS suppliers are a reference for Chile, as they are characterised by being internationally competitive and innovative.

A number of countries have emerging METS sectors with national strategies / plans that recognise the importance of the mining and METS sectors. Key countries with growing METS sectors include Sweden, Finland, Chile, Canada, China, India, Germany, Brazil, South Africa and the USA. These countries provide both partnership opportunities and well as competition to Australia's METS sector.

Recognising Australia's world leading efforts in developing the METS sector, the Chilean Mining Technology Roadmap 2035[20] states: *'Australian METS suppliers are a reference for Chile, as they are characterised by being internationally competitive and innovative.'* The roadmap describes emulating the successful experience of Australia in the development of Chile's METS sector.

NEW ENTRANTS AND THREATS

Despite the advantages identified, success for Australian METS companies is not guaranteed. High rates of digital and technological change no longer create a barrier to entry or unique advantage for Australia – with ideas coming from anyone, located anywhere in the world.[21]

Furthermore, observations of change and disruption from other industries are hard to ignore with examples including: Waymo (formerly Google's self-driving car project),[22] a major technology player in the automotive industry, playing a leading role in the development of self-driving cars; and SpaceX (founded by Elon Musk),[23] who design, manufacture and launch advanced rockets and spacecrafts and are successfully taking on many established and world-leading defence and aerospace players.

With the threat of new entrants and global competitors increasing, innovative and creative solutions will need to be pursued by Australian METS to ensure the continued success and future growth of this great Australian sector.

19 Allied Market Research (2016). *Mining Equipment Market by Equipment Type,* [Online] Available from: https://www.alliedmarketresearch.com/mining-equipment-market

20 Alta Ley (2016). *From copper to innovation - Mining technology roadmap 2035*, Fundación Chile.

21 Edmands, P (2015). Advantage Australia: harnessing our comparative advantage in resources and the METS sector – Austmine 2015, Brisbane. Rio Tinto. [Online] Available from: http://www.riotinto.com/documents/150519_Speech_Austmine2015_Phil_Edmands.pdf Accessed 23/02/2017

22 Waymo (n.d). [Online] Available from: https://waymo.com/ Accessed 23/02/2017

23 Space Exploration Technologies Corp SpaceX (n.d). [Online] Available from: http://www.spacex.com/ Accessed 23/02/2017

A changing global marketplace

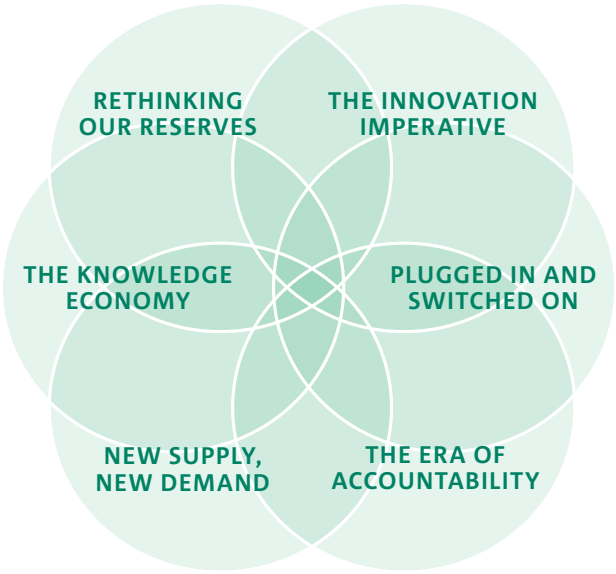
3 A changing global marketplace

3.1 Global mining megatrends

A megatrend is defined as a substantial shift in social, economic, environmental, technological or geopolitical conditions that may reshape the way an industry operates in the long-run.[24] Megatrends occur at the intersection of many trends; they are not mutually exclusive and the trends that make up one megatrend can influence or contribute to another.

CSIRO has identified six megatrends evident in global mining that will have significant impact on the METS sector over the next 20 years. These were developed by applying CSIRO's Global Megatrends[25] to the mining industry and refining the output with both research and business communities.

FIGURE 12: GLOBAL MINING MEGATRENDS



THE INNOVATION IMPERATIVE

A drop in commodity prices, along with rising costs, declining ore grades and concerns about decreasing productivity are compelling the mining industry to focus on operational costs. The mining industry requires creative and innovative solutions to become more productive, sustainable and achieve financial growth.

The fall in commodity prices has drawn significant attention towards controlling operational costs and improving productivity. However, commodity prices are merely the most recent in a confluence of intertwined challenges which include rising costs and declining ore grades.

The mining boom played a key role in masking some of the above challenges. As prices rose and demand increased (particularly from Asia), the mining industry rushed to expand production capacity, with the rate of capital spending disproportionate to the increases in production.[26] Rising costs and productivity issues were hidden or overlooked as production increased, creating an environment that was tolerant of inefficient processes.[27]

Some of the factors increasing costs have been the long-term challenges related to declining ore grades and deeper, more complex orebodies. To achieve the same production levels, miners have had to increase the quantity of ore that is extracted and processed, increasing the energy and water used, and waste generated.[28] As a result of these challenges in maintaining output, there is now a strong focus on productivity and operational costs.

24 Hajkowicz, S. (2015). *Global Megatrends – Seven Patterns of Change Shaping Our Future,* CSIRO Publishing, Canberra.
25 CSIRO Futures (2016). *Australia 2030: Navigating our uncertain future*, CSIRO, Canberra.
26 Lala, A., Moyo, M., Rehbach, S., & Sellschop, R. (2015). *Productivity in mining operations: Reversing the downward trend,* Metals & Mining Practice, McKinsey & Company.
27 Littleboy, A., Cook, H., Hajkowicz, S., Deverell, J., & Giugni, S. (2013). *Scenarios for ICT in Minerals and Energy in 2025,* CSIRO.
28 Giurco, D., Prior, T. D., Mudd, G. M., Mason, L. M., & Behrisch, J. C. (2010). *Peak minerals in Australia: A review of changing impacts and benefits.* [Prepared for CSIRO Minerals Down Under Flagship by] Institute for Sustainable Futures (University of Technology, Sydney) and Department of Civil Engineering (Monash University).

Success will require innovation combined with organisational and structural changes in the sector, such as greater collaboration, improved integration and holistic value chain assessment. A new wave of digital technologies and their subsequent integration are expected to play a major role in enabling greater levels of automation, remote operation and optimisation across the value chain. At the same time, growing energy costs and competing water demands will necessitate more sustainable processes and technologies, including the adoption of renewables across the mining life cycle and value chain.[29] Success with these innovative processes and disruptive technologies will require closer collaboration between mining companies, the METS sector, research and government.

PLUGGED IN AND SWITCHED ON

Digital technologies, data analytics and automation along with greater mobility and increasing connectivity are creating exciting opportunities for the mining industry. These connected technologies are improving safety and environmental outcomes, increasing productivity and driving disruptions across the mining value chain and life cycle.

As in many other industries, technology trends in the mining industry are heavily dominated by data and digital technology, which over the last few decades have been supported by significant improvements in the cost and power of computing, communications and storage. The result of these trends will be a future mining environment that is underpinned by smarter and more automated equipment, processes and infrastructure – improving productivity, safety and environmental outcomes.

Technology trends are also creating opportunities within and across the value chain. For example, robotics and autonomous systems are improving productivity and increasing safety by removing humans from dangerous environments. Advances in communications, sensors, mapping and monitoring technologies are allowing for real-time environmental and operational insights. Advanced materials are allowing sensors to be embedded within the materials of equipment and machinery, allowing high-resolution and multi-dimensional datasets to be created for greater predictability in areas like processing. Improvements in human-to-machine and machine-to-machine interfaces are improving the coordination and interaction of people and machines. And big data and analytics are bringing all of this information together to integrate and optimise operations and identify new opportunities for improvement across the value chain.

Beyond these opportunities, technology advances will have an impact on long-term mining workforce requirements. For example, while automated mining technologies can reduce costs and increase productivity and safety, they also reduce the requirement for local and fly-in fly-out (FIFO) on-site workers. Control rooms in centrally located cities will allow more mining sector workers to commute daily to work, switching from FIFO to log-in-log-out (LILO) models.[30]

As requirements change in the mining industry, reskilling of employees and upcoming generations will need to be a priority. The workforce will need to be comfortable with digital technologies and there will be increasing demand for more fundamental data science expertise, such as those with abilities to translate large amounts of data into trends to derive insights and high-value business related questions. In the longer term, the increasing shift towards disruptive data and digital technologies may reduce barriers to entry to the METS sector, creating threats and opportunities for existing and more traditional technology and service providers.

29 Ernst & Young (2014). *Business Risks Facing Mining and Metals 2014–2015,* Ernst & Young Global Limited.
30 Littleboy, A., Cook, H., Hajkowicz, S., Deverell, J., & Giugni, S. (2013). *Scenarios for ICT in Minerals and Energy in 2025,* CSIRO.

THE ERA OF ACCOUNTABILITY

Mining companies will move forward as good corporate citizens, where accountability and environmental success exceeds expectations, strengthening community engagement and support for existing and new projects into the future.

It is essential to the success of mining projects that companies earn and maintain community support and approval, often referred to as a 'social licence to operate'. With changing societal attitudes and policies (globally and nationally), many mining organisations are being proactive with community engagement, rather than waiting for demands to be mandated. These actions will ensure that benefits from the mine site flow to all community stakeholders through improved infrastructure, healthcare, training and employment prospects, and better community services.[31]

Mining companies are taking the opportunity to build strong relationships with the community; addressing problems together and respecting different positions to build a sense of joint ownership and commitment.[32] In addition to improving social and environmental outcomes, these relationships reduce the risk of project delays, interruptions and possibly shut down of mining projects due to public opposition and company-community conflict.

Mining strategies also ensure that projects are sustainable across their whole life cycle. This includes sustainable management practices for water, biodiversity, remediation and climate, as well as having well-considered transition plans to help economic development of local communities post-closure.[33] Into the future, mining organisations will also increase transparency, addressing external stakeholder demands for disclosure of sustainable development goals and strategies.[34] As with other industries, the need to become more accountable will propagate to secondary and tertiary mining industry providers, for example requiring equipment and services companies to improve their own practices.

NEW SUPPLY, NEW DEMAND

Increasing urbanisation and rapid development of emerging economies will continue to spur demand for mineral resources, which will be supplied from developing nations and new geographic domains through technology advancements. Rapid adoption of new consumer technologies is also changing demand for high-value, low volume metals and minerals.

While growth in China has slowed, other emerging economies are expected to play an increasingly important role in both supply and demand for major mining commodities.[35] For example, Africa, Latin America and other parts of Asia are all witnessing rapid growth and investments, and are (or are becoming) major mineral producers. While less explored than other regions, Africa is progressively developing its mining industry and will become an important source of mineral resources.[36] At the same time, technological advancements may enable resources to be sourced from new geographic domains. For example, mineral extraction at the bottom of deep seas is becoming feasible with the first mining permits recently granted in Papua New Guinea for mining of copper and gold at a water depth of 1,500 metres.[37]

From a demand perspective, population growth and urbanisation will see Asia and Africa accounting for nearly 90% of the 2.5 billion people added to the world's urban population by 2050.[38] In particular, demand for metals and minerals in Asia will be spurred by growth from India, the source of the largest projected growth globally, with India's population expected to overtake China's by 2030.[39] This will drive a critical need for new infrastructure and therefore boost demand for mineral resources, in-turn creating an emerging market for the METS sector.[40]

31 Simpson, M., Aravena, E., Deverell, J. (2014). *The Future of Mining in Chile,* CSIRO.

32 Littleboy, A. (2015). *Social capital in the life-of-mine,* The AusIMM Bulletin – October 2015.

33 Mason, L., et al. (2011). *Vision 2040: Mining, minerals and innovation – A vision for Australia's mineral future.* [Prepared for CSIRO Minerals Down Under Flagship by] Institute for Sustainable Futures (UTS, Sydney, Australia) and Curtin University (Perth, Australia).

34 International Council on Mining and Metals (ICMM) (2013). *Adapting to a changing climate: Implications for the mining and metals industry*, London.

35 Lo, C. (2014). *Where next for mining's dominant emerging markets?* Mining-technology.com. [Online] Available from: http://www.mining-technology.com/features/featurewhere-next-for-minings-dominant-emerging-markets-4401234 Accessed 19/12/2016

36 Dowra, A., et al (2016). *Creating Global Mining Winners in Africa*, Metals & Mining Practice, McKinsey & Company.

37 International Council on Mining and Metals (ICMM) (2012). *InBrief - Trends in the mining and metals industry*, London.

38 United Nations, Department of Economic and Social Affairs, Population Division (2014). *World Urbanization Prospects: The 2014 Revision*. Custom data acquired via website. United Nations.

39 Deloitte (2015). *Tracking the trends 2016 - The top 10 issues mining companies will face in the coming year*, Deloitte Touche Tohmatsu Limited.

40 Austmine (2016). *The Indian Mining Market: Insights into an Emerging Market for Australian METS,* [Online] Available from: http://www.austmine.com.au/News/articleType/ArticleView/articleId/2990/The-Indian-Mining-Market-Insights-into-an-Emerging-Market-for-Australian-METS Accessed 19/12/2016.

Similarly, growing adoption of modern electronics (smart phones, digital cameras, laptops) and renewable energy technologies (wind turbines, solar panels, batteries) is also generating demand for strategic mineral resources and rare earth elements, such as lithium and graphite. As a result of global requirements, spot lithium carbonate prices have increased approximately 10% to 15% since 2014 and lithium supply security has become a top priority for United States and Asian technology companies.[41] Despite these commodities only accounting for limited quantities when compared to the staples of mining, they do present opportunities for the supply of high importance commodities that are at risk of supply shortages.[42] These opportunities could be increased if viewed from a whole-of-value-chain perspective – driving value add from mining through to manufacturing.[43]

As the industry becomes dependent on specialised technologies, there is likely to be a greater trend towards the creation of new business models that increase collaboration between and outsourcing of key operational elements across the value chain.

THE KNOWLEDGE ECONOMY

As emerging economies continue to develop their mining sectors, support in developing applicable skills, services and technologies will be required for efficient and sustainable exploitation of mineral reserves. In advanced economies, increased adoption of specialised digital technologies are resulting in greater collaboration, new business models and fierce competition for talent.

Many of the most important mining countries are emerging economies. These economies often do not have well-developed practices, reliable geological information, skilled workers and sufficient infrastructure to support growth,[44] and frequently face challenges in turning deposits into producing mines.

While rapid increases in mining investments are helping to overcome some of these challenges, a knowledge-demand gap is being created – one that creates opportunities for suppliers in the METS sector.[45] However, past models revolved around the export of knowledge and services (often using large expatriate communities), whereas future models will need to allow local communities to capitalise on mining investments. For example, a 2014 citizen survey examining Chilean attitudes toward mining revealed that employment, improvements to regional infrastructure, and general economic benefits were the strongest positive predictors of public acceptance.[46]

As the industry becomes dependent on specialised technologies, there is likely to be a greater trend towards the creation of new business models that increase collaboration between and outsourcing of key operational elements across the value chain. Achieving best practice in automation, digitisation and data analytics in machinery, equipment and processes will, in many cases, draw on skills and thinking outside of the mining industry – introducing new METS players and fierce competition. As such, deep domain knowledge will only be part of the equation.

41 Jaskula, B. (2016). *Lithium - U.S. Geological Survey, Mineral Commodity Summaries.* [Online] Available from: https://minerals.usgs.gov/minerals/pubs/commodity/lithium/mcs-2016-lithi.pdf Accessed 19/12/2016.

42 Skirrow, R., et al (2013). *Critical commodities for a high tech world: Australia's potential to supply global demand,* Geoscience Australia, Canberra.

43 Barakos, G., (2016). *An outlook on the rare earth elements mining industry,* The AusIMM Bulletin, [Online] Available from: https://www.ausimmbulletin.com/feature/an-outlook-on-the-rare-earth-elements-mining-industry/ Accessed 1/02/2017

44 Ernst & Young (2013). Mining in Emerging Economies - Sharing the Spoils. Ernst & Young LLP.

45 Simpson, M., Aravena, E., Deverell, J. (2014). *The Future of Mining in Chile,* CSIRO.

46 Moffat, K., Boughen, N., Zhang, A., Lacey, J., Fleming, D. & Uribe, K. (2014). *Chilean attitudes toward mining: Citizen Survey – 2014 Results*, CSIRO.

RETHINKING OUR RESERVES

Rates of discovery for high-quality and accessible ores are declining and not keeping up with depletion. Solutions that help exploration under cover, extend the life of a mine and optimise recovery, combined with social expectations for recycling, re-use and urban (or above ground) mining are all playing a role in changing what is deemed economic.

Although some commodities are experiencing over supply, recent trends have seen exploration activities slow, with declines in the discovery rates of new, accessible, high grade ores.[47] Furthermore, in many parts of the world, including Australia, near-surface, high quality (tier 1) mineral deposits have already been identified, forcing the need to dig deeper to access reserves. Given the long production lead times, shortfalls in the supply pipeline can have a large impact on future growth.[48] While exploration will continue to play a key role in sustaining the industry, addressing long-term supply challenges requires new solutions.

Technology developments to extend the life of mines and optimise value recovery will play a key role in counteracting future supply risks. These developments will target and improve the extraction and processing of low grade or more complex ores – for example by taking advantage of sensors to improve large-scale ore sorting and provide greater clarity on the processing parameters for an orebody. Technology will also help to improve processing, for example, the use of improved leaching technologies will reduce capital and energy intensity and can allow for previous waste stockpiles to be economically mined.

To satisfy future demand and prevent commodity shortages, some nations are looking towards recycling (or 'urban mining'). Countries like Germany are leading the way with recycling rates for aluminium at 35%, lead at 59%, steel at 90%, and cobalt at 20% to 25%.[49] However, recycling rates are still varied due to the relatively low efficiencies in the collection and processing of discarded metal-bearing products, and the relative abundance of low-cost, primary materials. In the long term, the concept of a circular economy has the potential to result in greater levels of recycling and re-use, removing waste across global supply chains.[50] Using gold as an example, computer circuit boards and mobile phone handsets can contain up to 250 and 350 grams per tonne of gold respectively, compared to a typical open-pit mine that yields between 1 and 5 grams of gold per tonne.[51]

To satisfy future demand and prevent commodity shortages, some nations are looking towards recycling (or 'urban mining').

47 Mason, L., et al. (2011). *Vision 2040: Mining, minerals and innovation – A vision for Australia's mineral future,* [Prepared for CSIRO Minerals Down Under Flagship by] Institute for Sustainable Futures (UTS, Sydney, Australia) and Curtin University (Perth, Australia).

48 Ernst & Young (2014). *Business Risks Facing Mining and Metals 2014–2015,* Ernst & Young Global Limited.

49 German Federal Ministry of Economics and Technology (BMWi) (2010). *The German Government's Raw Materials Strategy - Safeguarding a Sustainable Supply of Non-Energy Mineral Resources for Germany.* Berlin.

50 World Economic Forum (2014). *Towards the Circular Economy: Accelerating the scale-up across global supply chains*, Geneva.

51 Owens, B. (2013). *Mining: extreme prospects.* Nature, 495(7440), S4-S6.

Opportunities for growth

4 Opportunities for growth

A rapidly changing global mining environment creates opportunities for the Australian METS sector to be the key driver and facilitator of change in the mining sector, harnessing the deep mining domain knowledge and expertise that have been established in both Australia's METS and mining sectors, and the research sector over the past few decades.

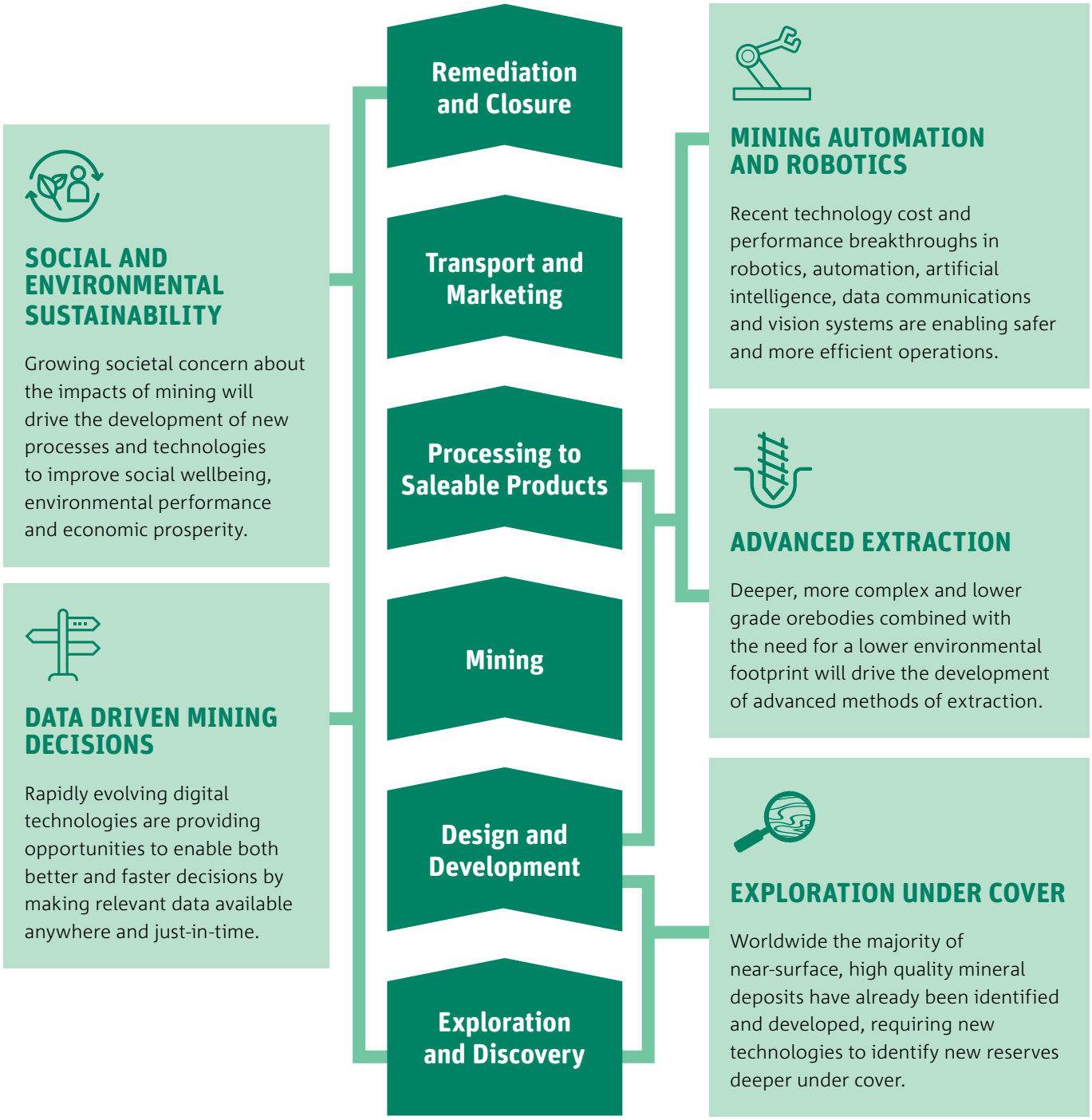
The culmination of this Roadmap process is the identification of five opportunities where Australian METS companies can clearly be internationally competitive. These strategic growth opportunities impact various parts of the mining value chain (Figure 13), and build on the METS Ignited Industry Knowledge Priorities (Chapter 1.3). Developed through a broad range of sector consultations, the opportunities identified in this Roadmap each leverage existing Australian comparative advantages (discussed in Chapter 2.2) and have the potential to deliver considerable benefits and competitiveness globally.

Given the breadth of the Australian METS sector, each opportunity discussed in this chapter is supported by example METS solutions. These examples aim to help businesses identify and prioritise potential areas of specialisation and differentiation within these opportunities, as well as explore the enabling science and technology investments and the management skills, culture, processes and business models required.

While the sector is well positioned to capture these opportunities, success for Australian METS companies is not guaranteed. Beyond Australia's disadvantages, there are a range of new entrants within and outside the traditional METS sector which will continue to challenge the competitiveness of Australian METS. Innovative and creative solutions need to be pursued by Australian companies to ensure the continued success and future growth of this great Australian sector.

Innovative and creative solutions need to be pursued by Australian companies to ensure the continued success and future growth of this great Australian sector.

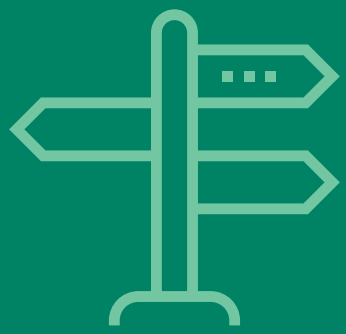
FIGURE 13: IDENTIFIED OPPORTUNITIES FOR THE AUSTRALIAN METS SECTOR ACROSS THE MINING VALUE CHAIN



*The five opportunities for growth are not considered to be an exhaustive list of opportunities available to the METS sector.

Data driven mining decisions

Rapidly evolving digital technologies are providing opportunities to enable both better and faster decisions by making relevant data available anywhere and just-in-time.



KEY DRIVING MEGATRENDS

- The innovation imperative
- Plugged in and switched on
- The knowledge economy

QUICK STATISTICS

- Advanced analytics applied to complex ore processing operations can lead to yield improvements in the order of $20-$50 billion of additional earnings globally (based on comparable applications).[52]
- By 2025, data used to improve equipment maintenance may result in 5-10% reduction in maintenance costs.[53]
- Globally, the Internet of Things (IoT) is estimated to have an economic impact of US $160-$930 billion per year on mining, oil and gas and construction industries by 2025.[53]

52 Durrant-Whyte, H. et al. (2015). *How digital innovation can improve mining productivity,* McKinsey & Company.
53 Manyika, J. et al. (2015). *The Internet of Things: Mapping the Value Beyond the Hype,* McKinsey Global Institute, McKinsey & Company.

4.1 Data driven mining decisions

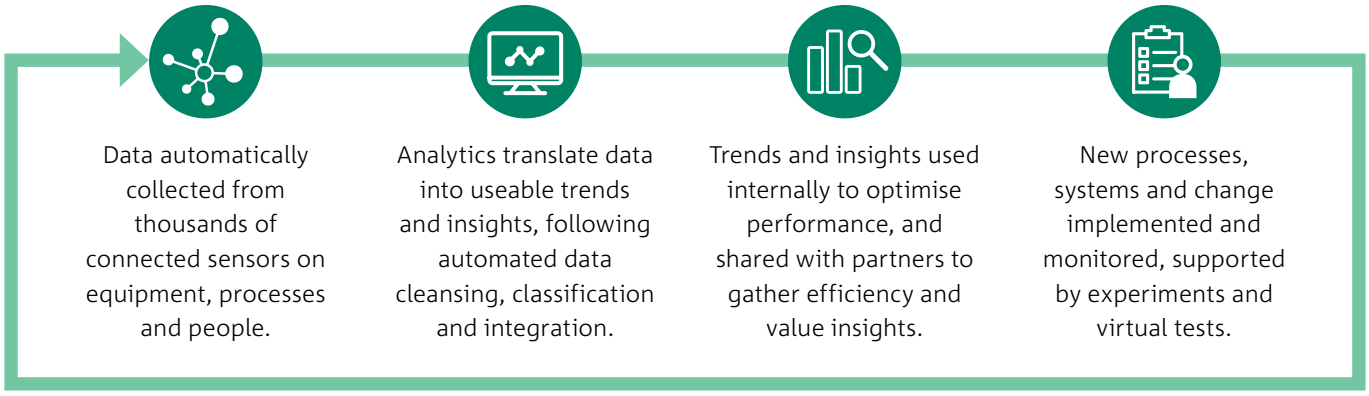
FUTURE STATE OF THE MINING CUSTOMER

The future data driven mine will optimise mining operations and reduce timeframes for making high value decisions. It will maximise the value of new and existing data, supervisory control and data acquisition (SCADA) systems, and external market information, enabling decisions based on near real-time information (hours or days) instead of using information that is months or years old.[54] Data will be used throughout the mining lifecycle to draw insights and optimise recommendations based on a multiplicity of sensors deployed throughout a mining operation, thereby acting as a key enabler to many more opportunities. Importantly, value from these insights will be achieved through a broader change process (see Figure 14), leveraging experts and disparate teams, and allowing insights to be actioned.

Long-term benefits of collecting and using mining data include:

- **Predictive maintenance** – increasing asset integrity by analysing and predicting failures based on structured data (e.g. historian and SCADA), unstructured data (e.g. maintenance and operator logs) and contextual data (e.g. weather).[55]
- **Improved decision making** – providing real-time access to data, enabling reduced timeframes for decision making and increasing efficiency.
- **Operational gains** – increasing yield and throughput, optimising use of raw materials by using data insights to break down operational silos and where appropriate embedding market-driven (e.g. commodity spot price) flexibility into operations (from quarterly to shift production schedules).
- **Greater transparency** – anonymising operational data for benchmarking to improve community and shareholder / investor engagement.
- **Improved safety** – tracking of people and assets to proactively identify hazards and prevent incidents.

FIGURE 14: APPLICATION OF DATA WITHIN A CHANGE PROCESS



54 McGagh, J (2014). *Rio Tinto Mine of the Future. Internet of Things World Forum* - Chicago. [Online] Available from: http://www.riotinto.com/documents/141014_Presentation_Internet_of_Things_World_Forum_John_McGagh.pdf Accessed 19/12/2016

55 Mudge, C (2016). *Computational informatics – next wave of innovation in our minerals industry,* ATSE AGM Seminar - Minerals Resources, Melbourne.

METS SECTOR SOLUTIONS

Australia's METS businesses will play a key role in the deployment and commercialisation of various secure digital technologies for the mining sector, including new sensors and digitally connected, communicative equipment. METS businesses will also play a role in assisting mining operators with the development of new platforms and the integration of data and information systems to support real-time decision making; driving ongoing optimisation through remote monitoring solutions and new service models.

The following provides example METS solutions that can be taken to market and is supported by Figure 15 which explores how these solutions may evolve in the short, medium and long term. The short, medium and long-term horizons are based on a mixture of maturity and capability requirements. However, the timeframes should be viewed as a guide as different mining and METS maturity levels may allow opportunities to be brought forward or set back.

EXAMPLE METS SECTOR SOLUTIONS

NEXT GENERATION DIGITAL INFRASTRUCTURE

The data driven mine will digitise all processes and assets, taking advantage of new sensors, advanced wireless communication technologies and embedded intelligent materials within fixed and mobile assets. As such, digital infrastructure and its reliability and responsiveness will become critical. For METS companies, opportunities exist to provide technologies (hardware and software) and services to develop, deliver, install, integrate and maintain this digital infrastructure. This will span new instrumentation and wireless infrastructure through to new technology architectures and cyber security services – ensuring that digital infrastructure is able to keep pace with technology trends outside of the mining industry.

INTEGRATION, INTERPRETATION AND DECISION SUPPORT

The volume and complexity of data being collected on a mine site is increasing exponentially, creating difficulties in the realisation of value. This however, creates immediate METS business opportunities for integration, analytics and decision support. As the digital maturity in mining increases, long-term leadership opportunities exist for METS businesses that are able to combine (and deepen) their engineering, digital and data science skills with existing domain knowledge. METS companies with these capabilities will help ensure that emerging technologies such as machine learning, advanced modelling and artificial intelligence are suitably adopted and focused on answering the right strategic questions in a 'top-down' design and learning based manner. They will also help to ensure that interpretation and decision support are part of a broader change process (see Figure 14) and are effectively delivered in collaboration with mining companies.

FIGURE 15: METS SECTOR SOLUTIONS

SHORT TERM (0 – 3 YEARS)	MEDIUM TERM (3 – 10 YEARS)	LONG TERM (10+ YEARS)
NEXT GENERATION DIGITAL INFRASTRUCTURE		
From solutions to manage and maintain critical digital infrastructure...		**...to solutions that redefine greenfield mines and drive world-leading digital practices**
• Advanced sensors and instrumentation technologies (deployable on fixed and mobile infrastructure) for real-time analysis and interpretation to inform production schedules. • Advanced communications and networking infrastructure for above and underground mining operations. • Smaller, low cost and durable sensors and deployment models that reduce the marginal cost of data acquisition in brownfield sites. • Cyber security offerings to improve collaboration, ensuring a system, application or individual can verify their identity and establish trust. • Algorithms, platforms and processes to reduce data cleansing and integration (ERP, MES, etc.) burden. • Multi-functional instrumentation to provide greater sensing flexibility and reduce costs. • Algorithms that are able to make data inferences from any data points that are hard or costly to measure.		• Technology architecture services that increase modularity, improve standards ('plug and play'), and simplify capital planning. • Real-time digital mine offerings allowing large-scale optimisation opportunities to be virtually tested and planned. • Embed sensing within materials used in fixed and mobile infrastructure and equipment.
INTEGRATION, INTERPRETATION AND DECISION SUPPORT		
From solutions that improve real-time data collection and analysis...		**...to intelligent solutions that enhance decision making and improve efficiency**
• Tools and services that help prioritise data acquisition to target high-value / step-change opportunities. • Analysis and integration of existing mining and METS datasets with remote operation centres, predictive maintenance, etc. • Modelling, machine learning and visualisation technologies to improve decision making in discrete and cross-cutting parts of the value chain. • Platforms and integration offerings to improve interoperability and standards for data and analytics.	• Integration services that bring together data across fragmented, large-scale and complex datasets (internal and external) that were previously not connected. • Real-time enterprise decision making tools and common mine models (e.g. multi-attribute, multi-resolution models) that create a single source of the truth. • Real-time access to data facilitating new business models including uptime guarantees for equipment, eliminating reactive maintenance.	• Solutions that codify 'invisible' (tacit) knowledge within mining and METS providers to create highly differentiated decision support and analytics offerings. • Artificial intelligence and intelligent mining software algorithms that reduce supervisory needs and automate decision making and control. • Deploying feedforward control approaches from the grinding circuits to the entire value chain.

Case study

DINGO Software

DINGO Software Pty Ltd is an innovative Australian company, headquartered in Brisbane, with offices in the US and partners across the globe. Founded in 1991, DINGO assists complex industrial customers in the mining, wind, oil and gas, and rail sectors to proactively monitor and maintain heavy equipment. Using data collected from the assets, DINGO blends expertise with industry-leading predictive maintenance software to deliver insights and actionable intelligence that improve asset health, helping to increase both productivity and useful life, resulting in material cost savings.

DINGO currently manages over $7 billion worth of assets. One of DINGO's biggest customers is one of the world's top five producers of export metallurgical coal, with operations in Australia and Canada. Across their global mining operations, this customer operates a fleet of 150 haul trucks, 80 dozers, 30 loaders, 30 hydraulic excavators and shovels, several drills and 100 underground assets. DINGO has helped this company achieve an operating cost reduction in excess of US$55 million through the use of DINGO's cloud-based condition management software system Trakka, which optimises asset performance and improves productivity.[56]

BUSINESS MODEL CONSIDERATIONS – VALUE ADDING SERVICES

METS providers usually either collect or have the ability to collect large volumes of data from existing products and services. In the short term, METS providers can leverage this data internally. For example, analysis by McKinsey & Company suggests that applying usage data to improve equipment design and pre-sale analytics may result in a 6% and a 2% revenue gain for equipment suppliers respectively, by 2025.[57]

In the long term, this data could be leveraged for value adding services – working individually or in partnership with multiple mining and METS companies. This could also lead to the creation of new METS 'as-a-service' business models that use data to optimise targets and share risk-profit with mining operators.

56 Dingo (2016). Asset Wellness for mining, [Online] Available from: http://www.dingo.com/Dingo/media/img/Page%20Hero%20Images/DINGO-Mining-Case-Study_Global-Coal-Miner-Saves-US$55M-through-Asset-Wellness_1.pdf?ext=.pdf Accessed 05/01/2017

57 Manyika, J. et al (2015). *The Internet of Things: Mapping the Value Beyond the Hype*, McKinsey Global Institute, McKinsey & Company.

ENABLING BUSINESS CHANGES

In order to unlock this opportunity METS companies will need to invest in business transformation – taking action internally and externally.

BUSINESS PRIORITIES: CREATING ADVANTAGE THROUGH CAPABILITY AND LEADERSHIP

People and skills

- Develop staff to have both domain and data / digital expertise, strengthening their comfort and ability to mathematically and algorithmically interpret, model and make decisions using big (and small) datasets.
- Tap into the skilled ageing workforce to retain globally differentiated mining expertise, particularly given the new players and low barriers to entry with disruptive digital technologies.
- Work with universities to develop '*mining and analytics 101*' courses for METS to increase industry maturity, collaboration and knowledge of specialist (but often siloed) functions. Note: This could create a METS service opportunity to miners.

Process and standards

- Work with industry organisations to address organisational and industry wide interoperability and integration issues by implementing appropriate and sophisticated industry data standards in consultation with research and global industry (e.g. through GMSG, AMIRA, EMESRT).[58]
- Develop processes (e.g. data handling, cleansing, etc.) to improve data trust and integrity.
- Involve cyber security expertise throughout the product development lifecycle.
- Review data ownership agreements and examine ability or limits related to long-term use.

Culture and collaboration

- Work with partners to develop business cases for data integration and research projects, demonstrating possible outcomes and ROI.
- Use change management to improve how staff use and respond to data. For example, many are accustomed to reacting to alerts and alarms. Instead, operators and METS staff will need to gain comfort in responding to predictive and forward looking insights and modelling recommendations.
- Address the information technology (IT) and operational technology (OT) staff divide to take advantage of technology advances and gain efficiencies from the skillsets and management approaches that have been developed.
- Use partnering and collaboration within and outside of the mining sector to fill data and digital skill / capability gaps, such as leveraging deep digital capabilities within the Australian financial services sector.
- Work with industry associations to establish collaborative agreements to maximise use of capability and national High Performance Computing (HPC) infrastructure (e.g. within research organisations and universities) to reduce risks and improve outcomes related to the modelling of large datasets.
- Challenge mining silos and closed system thinking to ensure insights are evaluated accurately and are not influenced by subconscious human bias.
- Identify opportunities to pool existing non-competitive Australian METS and mining datasets (potentially related to environment and sustainability).

58 Farrelly, C T., Ballantyne R J. (2016). Achieving Interoperability across the Minerals Value Chain, Phase 1 – Surface Mining Equipment, P1025 Summary Report, AMIRA International, Australia

Case study

MICROMINE

MICROMINE, founded in Western Australia in 1986, is an innovative software solutions provider that span the breadth of the mining lifecycle. Over the past thirty years, the company has expanded significantly and now has offices in 18 of the world's mining capitals, with MICROMINE software solutions in use at more than 2,000 mine sites in over 90 countries.

MICROMINE provides solutions that improve the collection and use of data, helping miners and explorers maximise their asset value, increase productivity and make reliable decisions. These solutions include:

- Geobank – a secure and flexible data management solution to capture, validate and manage data.
- Micromine – a comprehensive and easy-to-use exploration and mine design solution, which offers integrated tools for modelling, estimation, design, optimisation and scheduling.
- Pitram – a fleet management and mine control solution that records, manages and processes mine site data in real time, suitable for underground and surface mining, construction, development and production.

Highlighting the value of these data enabled products, MICROMINE has helped numerous companies improve their operations and data management. For example, Pitram is helping a Canadian based metallurgical coal mining company to increase production while reducing costs. Pitram helps provide a solution for the company that captures all relevant material movement, production, shift, equipment and personnel data so that the performance of both the underground and open-pit operations can be measured to provide a comprehensive view of the mine, track progress against the plan and drive efficiencies in real time. Pitram's automated data collection methods and real-time reporting has introduced operational efficiencies that have increased the mines production rates.

ENABLING SCIENCE AND TECHNOLOGY

Scientific and technological developments both within and outside of the mining industry will be key to unlocking this and many other opportunities. To stay ahead, METS businesses need to invest in developing the right capabilities and gain practical experiences in emerging areas to successfully convert leading scientific and technological breakthroughs into repeatable and operationally ready solutions.

RESEARCH PRIORITIES: CREATING ADVANTAGE THROUGH RESEARCH*

Sensors and the Internet of Things

- Low cost, combined and integrated sensors to collect multiple information types and reduce the overall number of sensors needed.
- Improved sensor durability and sensitivity to function in high temperature, harsh or remote environments with reduced maintenance, while producing reliably calibrated data.
- Self-powering sensors through battery developments such as miniaturisation, increased capacity and density, and renewable energy sources.
- Wireless connectivity of in-situ remote sensors through on-board electronics.
- Advanced materials that embed sensors directly into the materials of parts and equipment.

Visualisation

- Tools and user interfaces that improve the interrogation of data and facilitate remote collaboration and support to resolve issues and identify new opportunities.
- Advanced visualisation and virtual / augmented reality to provide real-time operational context, situational awareness and remote analysis.

Analytics and optimisation

- Improved mathematical models and algorithms to identify association and correlation across constantly growing and highly diverse datasets.
- Algorithms and / or sampling methods to improve analytics performance and minimise / avoid false positives.
- Improved systems for data storage and management that can handle the rapidly increasing amount of data captured.
- Improvements in quality of data captured and development of decision making algorithms to improve autonomy.
- Develop common mine models / representations and define interface / interoperability standards.

Cyber security

- Improved mechanisms for cyber security and data privacy to ensure data integrity and safety, and allow valuable and secure data sharing.
- Develop cyber security tools / technologies to discover unknown vulnerabilities and anomalous activity within the network.

**Draws on research areas identified during METS Ignited IKP development*

Social and environmental sustainability

Growing societal concern about the impacts of mining will drive the development of new processes and technologies to improve social wellbeing, environmental performance and economic prosperity.

KEY DRIVING MEGATRENDS

- The innovation imperative
- The era of accountability
- Rethinking our reserves

QUICK STATISTICS

- Australia has over 50,000 legacy mine sites (previously mined, abandoned, orphan, derelict or neglected sites).[59]
- Lack of social licence to operate can reduce the market value of a project by up to 70%.[60]
- On average comminution processes consume approximately 36% of the energy utilised in hard ore processing mines.[61]
- Analysis of risks related to global mining tailings dams suggests a failure rate of about three failures every two years.[62]
- A mining project with capital expenditure of between US$3-5 billion can experience lost productivity and sales due to temporary shutdowns or delay of approximately US$20 million per week of delayed production in Net Present Value terms.[63]

59 Pepper, M., et al (2014) *Mining Legacies – Understanding Life-of-Mine Across Time and Space*, Life-of-mine conference, Brisbane 2014.

60 Tarnopolskaya, T., Littleboy, A., (2015). *Towards Dynamic Financial Valuation of Social Licence to Operate under Uncertainty,* 21st International Congress on Modelling and Simulation, Gold Coast, Australia, 2015.

61 Ballantyne, G.R., & Powell, M.S., (2014). *Benchmarking comminution energy consumption for the processing of copper and gold ores*, Minerals Engineering - Volume 65, p109–114.

62 Chambers, D., & Higman, B., (2011). *Long term risks of tailings dam failure,* Center for Science in Public Participation.

63 Davis, R., Franks, DM (2014). *Costs of Company-Community Conflict in the Extractive Sector.* Corporate Social Responsibility Initiative Report No. 66. Cambridge, MA: Harvard Kennedy School.

4.2 Social and environmental sustainability

FUTURE STATE OF THE MINING CUSTOMER

The mining industry will concurrently pursue triple bottom line outcomes; meeting evolving community and shareholder expectations, and policies related to environmental and social responsibility, while maximising profits (see Figure 16). Focus will increase on ensuring mines operate with improved measurable social and environmental outcomes across the life of the mine and mining value chain. Accountability will be shared across the mining ecosystem – miners, explorers, governments, communities, researchers and METS businesses. This is expected to become more important as regulations on mining operations become increasingly tightened. The future mine will be responsive to changes in downstream sustainable metal and material demand and recycling and circular economy market trends, resulting in a lower impact on the surrounding environment and community.

From a financial perspective, benefits to mining companies in pursuing social and environmental sustainability include:

- **Reduced development and production delays** – streamlining engagement and relationships by aligning values and being transparent with traditional land owners, community, government and shareholders.
- **Increased margins** – minimising energy, waste, water, fuel and material inputs through process optimisation, re-use and recycling.
- **Additional value streams** – using the entire resource and existing waste streams to generate new sources of value.
- **Reduce risk and environmental liabilities** – using proactive management and mitigation to reduce remediation requirements and improve health and safety outcomes.
- **Minimise workforce shortfalls** – proactively developing skills and regional economies.

Case study

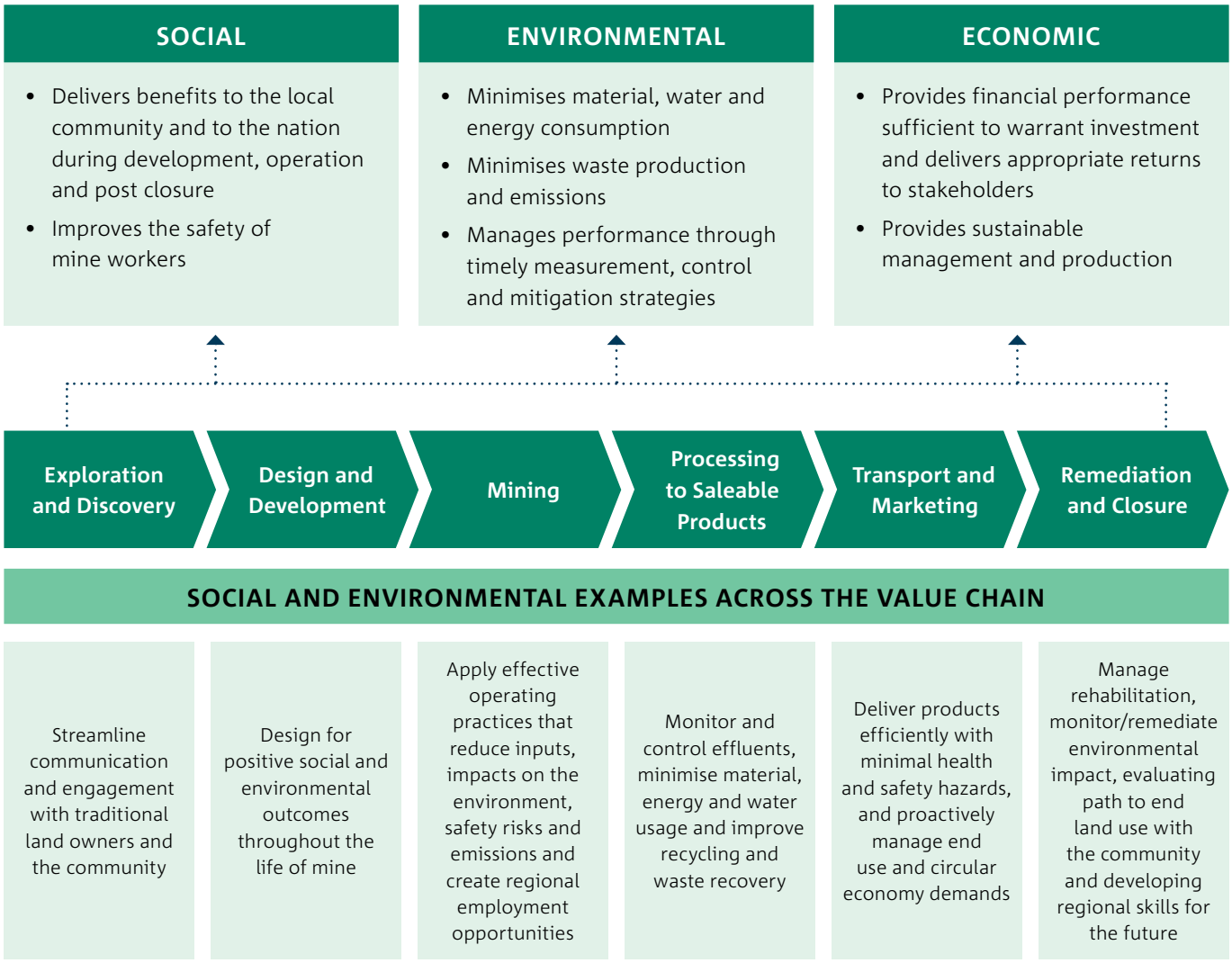
GroundProbe

With a vision to make mining safer, GroundProbe, a Queensland-based company, developed the world's first Slope Stability Radar (SSR), a system to monitor and warn of wall movement in open pit mines. Developed from research at the University of Queensland, GroundProbe commercialised the SSR in 2001 and has since expanded to have 12 global offices, with over 300 radars deployed across 27 countries.

GroundProbe's technology detects the amount, shape and degree of the wall movement in mines. Using this data, mining operators can make informed decisions to safely evacuate people and equipment, improving mine safety and maximising productivity. In one example, the SSR alarm at the Mt Owen mine, located in the Hunter Valley, provided four hours of warning prior to a 30,000,000 tonne low wall failure. This warning allowed the mine to safely evacuate all personnel and equipment prior to the wall failure.[64] Beyond helping operators ensure the safety of their workers, GroundProbe's technologies help with long-term mine planning, informing and promoting global best practice for slope stability.

64 Noon, D., (2009). *Case Studies of Slope Stability Radar used in Coal Mines*, GroundProbe Pty Ltd, Brisbane.

FIGURE 16: ELEMENTS TOWARDS MINING WITH IMPROVED SOCIAL AND ENVIRONMENTAL OUTCOMES



Case study

ReGen and WRJV

ReGen is a business division of Downer Mining, a leading diversified mining services provider in Australia. ReGen offers complete solutions for mine closure and minesite rehabilitation, including design, bulk earthworks, civil capacity, revegetation, monitoring and maintenance. Producing tailored mine rehabilitation programs, ReGen works to meet specific sustainability and post-mining land use criteria.[65]

Along with mine rehabilitation services, ReGen provides site-specific water management solutions to significantly improve water-use efficiency and address risks associated with water discharges.

Recognising the importance of partnering with the traditional owners of mined land, ReGen aims to provide sustainable opportunities for economic participation and capability development by Aboriginal communities. In 2016, ReGen and Waanyi PBC, the native title representative body for the traditional owners of Century Mine (Waanyi people), formed the WaanyiReGen joint venture (WRJV) to provide a dedicated specialist Traditional Owner rehabilitation and closure solution. WRJV combines ReGen's proven experience in mining, civil and landform construction, progressive rehabilitation and mine closure with a commitment to enabling economic, social and community development solutions for the Traditional Owners of the Waanyi lands in North Queensland.

65 ReGen (2017). *Mine rehabilitation solutions,* [Online] Available from: http://www.mineregen.com.au/ Accessed 05/01/2017

METS SECTOR SOLUTIONS

Australia is home to many mature mining operators that exhibit high standards of self-regulation within a well-established national regulatory system. METS companies have a key role to play in helping these mature mining operators develop innovative solutions that allow continued extraction of minerals with a lower impact on the environment and positive community outcomes.

The following provides example METS solutions that can be taken to market and is supported by Figure 17 which explores how these solutions may evolve in the short, medium and long term. The short, medium and long-term horizons are based on a mixture of maturity and capability requirements. However, the timeframes should be viewed as a guide as different mining and METS maturity levels may allow opportunities to be brought forward or set back.

EXAMPLE METS SECTOR SOLUTIONS

ACTIVE MEASUREMENT OF INPUTS, THROUGHPUTS AND IMPACTS

Triple bottom line (TBL) reporting and transparency will require a new generation of tools that monitor and integrate multiple environmental and social attributes. METS companies have the opportunity to embed measurement of these attributes into existing products, targeting areas that are already legislated or those that may enhance operations and regulation. In the longer term companies have the ability to develop specialist offerings (and define the respective standards required) for future TBL measurement and decision support activities. As recycling and re-use technologies and strategies are deployed, monitoring will need to go beyond unit processes and site assessments, measuring national impacts and global flows of resources.

TOTAL LIFECYCLE FRAMEWORKS AND PLATFORMS

Successfully improving the social and environmental sustainability of mining will require a fundamental shift in mindsets across the whole life-of-mine and mining value chain and all mining stakeholders – miners, explorers, governments, communities and METS businesses. For many, this will require a shift from environmental and social activities being reactionary or compliance driven, to being proactive and seen as a source of advantage, particularly when investments are made and refined over the whole life-of-mine. There is an opportunity for METS businesses to take an active role in this change by providing services, frameworks and platforms that inform decision making and help miners improve social and environmental outcomes.

TECHNOLOGY FOR SUSTAINABILITY

Many METS companies have developed solutions that support operations while reducing environmental impact, such as water-efficient products, low emissions equipment, and technologies that reduce waste streams. While high-value, these solutions are often focused on a discrete part of the value chain. Going forward, there is an opportunity for METS companies to extend their current solutions and create partnerships with other METS companies to offer state-of-the-art integrated technologies that provide improved TBL outcomes across the value chain.

FIGURE 17: METS SECTOR SOLUTIONS

SHORT TERM (0 – 3 YEARS)	MEDIUM TERM (3 – 10 YEARS)	LONG TERM (10+ YEARS)
ACTIVE MEASUREMENT OF INPUTS, THROUGHPUTS AND IMPACTS **From measurement of processes, sites and surrounds...**		**...to proactive measurement of national flows and global systems**
• Ubiquitous sensor networks and technologies to provide smarter monitoring and alerting of risks across a range of areas (noise, dust, emissions etc.). • Site based real-time monitoring, compliance and reporting offerings across energy and water usage, waste optimisation, carbon emissions, health and safety, environmental impact assessments, community perceptions and equality. • Wearables such as clothing and accessories (hats, glasses, wristbands etc.) with in-built advanced sensors and electronic technologies to improve productivity and safety of workers by monitoring fatigue, location, atmosphere and vitals. • Remediation and rehabilitation measurement offerings including those that target ecological services and biodiversity, water quality, land management systems and soil fertility post mine.[66] • Subsurface water resource measurement tools. • Contaminant monitoring, management and remediation technologies and services, including biochemical sensors for activities such as flotation.		• Data transparency and collaboration strategies that improve stakeholder trust while avoiding the release of highly competitive operational information. • Smart sensing offerings that track the flow of minerals through the economy.[67] • Proactive modelling and decision making tools that integrate cross-value chain data from environmental sensing and monitoring devices.
TOTAL LIFECYCLE FRAMEWORKS AND PLATFORMS **From improved awareness of total lifecycle mining impacts...**		**...to global lifecycle frameworks and platforms that improve decision making and lower impacts**
• Tools to assess the impact of management decisions on environmental performance and social responsibility (e.g. climate adaptation modelling and machine learning). • Multi-stakeholder social and environmental frameworks that recognise value systems and improve community-miner relationships. This includes understanding and factoring company-community conflict costs into the decision making process.[68] • Low impact mining training / education services to increase awareness and maturity across all mining stakeholders.	• Best practice low impact mining frameworks and strategies that can be applied across different commodities, mining methods and regions. • Preventive and recovery-oriented waste management frameworks and approaches that are integrated into mine planning and operations.[69] • Transition strategies and processes for economic development and environmental and community outcomes post closure.	• Redefined community engagement and procurement processes to nurture regional service hubs that meet industry standards and sustain the workforce through the cycle. • Strategies to increase responsiveness to downstream sustainable metal and material demand and recycling trends. • Platforms that anonymise operational data for benchmarking and to improve community and shareholder / investor engagement.
TECHNOLOGY FOR SUSTAINABILITY **From using discrete / siloed METS offerings to reduce inputs and waste ...**		**...to integrated METS offerings that minimise (or eliminate) inputs and waste across the value chain**
• Water and energy efficient products (e.g. reducing the slurry drag effect in the piping system with less water and energy). • Novel blast and drilling technologies that reduce comminution energy usage and increases mineral recovery. • Waste management technologies (e.g. wastewater filtration and treatment).	• Technologies to increase re-use such as extracting water from mineral tailings using ultrasound technology.[70] • Lightweight, high strength materials in equipment to reduce carbon emissions and increase fuel efficiency. • Low emissions equipment such as more efficient or hybrid haul trucks combined with route and load optimisation. • Technologies and process re-engineering services to optimise material handling and resource flow such as changing the layout of the comminution circuit.	• Closed-loop solutions that create value or secondary products from waste streams resulting in zero waste.[71] • Technologies that maximise re-use and recycling during development. • Hybrid and renewable energy technologies across the value chain (e.g. electric mine, solar farms, solar thermal, geo-thermal).

66 Mason, L., et al. (2011). *Vision 2040: Mining, minerals and innovation – A vision for Australia's mineral future.* [Prepared for CSIRO Minerals Down Under Flagship by] Institute for Sustainable Futures (UTS, Sydney, Australia) and Curtin University (Perth, Australia).

67 Florin, N., Dominish, E., Giurco, D. (2015). *Action Agenda for resource productivity and innovation: opportunities for Australia in the circular economy*, UTS.

68 Davis, R., Franks, DM (2014). *Costs of Company-Community Conflict in the Extractive Sector.* Corporate Social Responsibility Initiative Report No. 66. Cambridge, MA: Harvard Kennedy School.

69 Lèbre, É., Corder, G. (2015). *Integrating Industrial Ecology Thinking into the Management of Mining Waste,* Resources, 4(4), 765-786.

70 Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE) (2013). *Case Study: Saving water in mineral processing*, [Online] Available from: http://www.crccare.com/case-study/saving-water-in-mineral-processing

71 Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE). *CRC CARE Fact Sheet 5 - Zero waste*.

Case study

Virtual Curtain Limited (VCL)

VCL, based in Perth, provides long-term solutions for the remediation and neutralisation of sub-surface and above-ground acidic and contaminated wastewaters from the mining industry and industrial projects.

VCL is developing and commercialising patented Hydrotalcite Technology (HT) from CSIRO, which involves the synthesis and application of hydrotalcites – a layered double hydroxide mineral, primarily composed of magnesium and aluminium. As hydrotalcites form, metals become trapped and are easily removed from wastewater streams within the hydrotalcite product.

In a proof-on-concept study at the Baal Gammon Copper mine in Queensland, the application of HT was able to remediate 60Mgl of contaminated mine-pit water prior to reverse osmosis water polishing. The treatment achieved water purity to a level that satisfied discharge water quality guidelines for final discharge into the adjacent Jamie Creek.[72]

BUSINESS MODEL CONSIDERATIONS – POSITIONING FOR A CIRCULAR ECONOMY

The vision of a circular economy is encouraging re-use and recovery in mining and driving greater levels of recycling across global supply chains, supporting the feasibility of urban (or above ground) mining.

With a long-term vision, countries such as Germany and Sweden are already planning for greater levels of re-use and recycling in mining.[73] [74] For Australian METS companies, the circular economy vision opens the door to completely new business models and opportunities ranging from exploring downstream or secondary products from waste streams to increasing collaboration across sectors. For example, energy generating businesses could co-locate with energy intensive companies such as METS manufacturers and mineral processing companies, sharing energy flows and systems so that waste from one business can be used as an input in another.

72 Virtual Curtain Limited website, Case Studies, [Online] Available from: http://www.virtualcurtain.com.au/?page_id=11 Accessed 28/02/2017

73 Nordic Rock Tech Centre AB (RTC) (2013). *Strategic research and innovation agenda for the Swedish mining and metal producing industry (STRIM)*, [Online] Available from: http://www.rocktechcentre.se/wp-content/uploads/2013/06/STRIM-final.pdf Accessed 05/01/2017

74 Federal Ministry of Economics and Technology (2010). *The German Government's raw materials strategy*. [Online] Available from: https://ec.europa.eu/growth/tools-databases/eip-raw-materials/en/system/files/ged/43%20raw-materials-strategy.pdf Accessed 05/01/2017

ENABLING BUSINESS CHANGES

In order to unlock this opportunity METS companies will need to invest in business transformation – taking action internally and externally.

BUSINESS PRIORITIES: CREATING ADVANTAGE THROUGH CAPABILITY AND LEADERSHIP

People and skills

- Develop cross-disciplinary skills by combining technical and engineering knowledge with social, environmental and financial / economic training to better demonstrate the long-term value proposition of environmental and social sustainability challenges.
- Work with universities to develop new training courses that embed total lifecycle assessments into decision making and equipment design.
- Develop system thinking capabilities that account for total lifecycle and circular economy opportunities and risks across the mining value chain.

Process and standards

- Assess operational and regulatory barriers that may limit social and environmental monitoring and reporting, and the associated liabilities.
- Understand future environmental reporting needs, internal governance procedures, integration requirements and new data standards particularly in relation to recent tailings dam failures.
- Enhance development and operational processes to incorporate 'social in design' concepts, addressing any future social challenges and opportunities that may arise during adoption of new technologies.[75]

Culture and collaboration

- Connect operator, government, social and environmental groups to support and improve technical and regulatory decision making processes.
- Identify methods to ensure positive community and stakeholder support and acceptance of novel technologies (such as digital and data, robotics, automation and advanced extraction technologies).
- Engage with miners, communities and traditional land owners to foster a shared model for mining that has improved social impacts, recognising the unique differences and needs in regional communities.
- Develop a 'whole of resource' processing mindset and culture that reduces waste by extracting as much as possible from a given orebody.
- Work with industry bodies to facilitate access to demonstration site(s) for the testing of new technologies and solutions to drive environmental performance and social responsibility at mine sites.
- Collaborate with other METS providers to integrate niche and specialised solutions to address multiple social and environmental outcomes across the value chain.

75 Franks, D M., Cohen, T. (2012). *Social Licence in Design: Constructive technology assessment within a mineral research and development institution,* Centre for Social Responsibility in Mining, Sustainable Minerals Institute, University of Queensland

ENABLING SCIENCE AND TECHNOLOGY

Scientific and technological developments both within and outside of the mining industry will be key to unlocking this and many other opportunities. To stay ahead, METS businesses need to invest in developing the right capabilities and gain practical experiences in emerging areas to successfully convert leading scientific and technological breakthroughs into repeatable and operationally ready solutions.

RESEARCH PRIORITIES: CREATING ADVANTAGE THROUGH RESEARCH*

Monitoring and sensing

- Ubiquitous real-time sensing for environmental, health and safety monitoring to improve TBL outcomes, including the development of sensors that are biodegradable and / or bio-compatible.
- Advanced materials with pervasive sensing that can be applied to industry parts, equipment and infrastructure, and can monitor a range of environmental indicators.
- Improved sensing and characterisation technologies that embed social and environmental considerations in extraction and processing decision making.
- Technologies for waste and discharge water monitoring and management.
- Monitoring devices and biosensors with lead indicators and predictive mechanisms that can be incorporated into wearables to protect the safety of workers.

Decision support and stakeholder engagement

- Lifecycle analysis and risk assessment frameworks and platforms to improve measurement and management decision making.
- Improved tools for data translation and communication to increase transparency and sharing, drive environmental performance and social acceptance, help manage expectations of all stakeholders and inform policies and standards.
- Decision support tools that identify value added processing opportunities to improve downstream energy, waste, water and environmental outcomes.
- Machine learning tools that improve mining supply chain resilience to weather extremes and climate change, allowing for improved environmental performance.
- Improved technologies to support prediction of social and environmental impacts and provide management options during the life-of-mine.

Site and equipment solutions

- Improved tailings dam design factoring social and environmental risks, rising operational cost pressures and lower grades (which could increase waste).
- Advanced extraction technologies that improve the footprint of mining activities and increase recovery rates, such as in-situ recovery technologies (see Chapter 4.4).
- Technologies and processes for remediation of contaminated sites, including bioremediation processes, 'green chemistry', phytoremediation, ultrasound, etc.[76]
- Low emissions energy technology feasibility studies / integration.
- Advanced material developments focusing on light weighting and energy harvesting to reduce fuel and energy inputs.
- High performance, modular, low energy and 'wear-less' equipment and infrastructure that reduces maintenance and increases availability.
- Novel and small scale processing technologies and management tools that minimise waste, increase recycling and re-use, while reducing inputs such as energy and water.

**Draws on research areas identified during METS Ignited IKP development*

76 Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE). *CRC CARE Fact Sheet 3 - Remediation*.

Exploration under cover

Worldwide the majority of near-surface, high quality mineral deposits have already been identified and developed, requiring new technologies to identify new reserves deeper under cover.

KEY DRIVING MEGATRENDS

- Rethinking our reserves
- The innovation imperative
- New supply, new demand

QUICK STATISTICS

- Almost 60% of Australia is yet to be explored for minerals.[77]
- Low levels of global exploration 'bang per buck' – with an estimated US$140 billion spent to uncover $93 billion in value between 2005 and 2014.[78]
- 75% of new base metal discoveries are at depth of more than 300m.[79]
- The global growth potential for exploration spend is expected to increase from approximately US$15 billion in 2015 to $22 billion in 2020.[80]

77 Kachel N. (2015). *Prized exploration technology brings big bucks home,* CSIRO Blog, [Online] Available from: https://blog.csiro.au/prized-exploration-technology-brings-big-bucks-home/ Accessed 09/01/2017

78 Schodde, R. (2014). *Canada's discovery performance and outlook*, MinEx Consulting, Perth, [Online] Available from: http://www.minexconsulting.com/publications/R%20Schodde%20PDAC%20Conf%20March%202015%20FINAL.pdf Accessed 24/01/2016

79 Deloitte (2013). *Tracking the trends 2014.*

80 Schodde, R., (2014). *Uncovering exploration trends and the futures: Where's exploration going?* MinEx Consulting, presentation to IMARC 2014.

4.3 Exploration under cover

FUTURE STATE OF THE MINERAL EXPLORATION CUSTOMER

Tackling the cover challenge will reduce the uncertainty and risk associated with mineral exploration through barren cover (e.g. sediments, volcanic sequences and regolith), varying from tens to a few hundred metres and even over one thousand metres in thickness. This quest to explore under cover will support the development of new equipment and techniques, from advanced drilling equipment to improve detection under cover, to new sensing and analytical methods which can be used to provide insights on how to predict, navigate and detect resources in the sub-surface prior to drilling. It is envisaged that data science, simulation and analytics will also provide important new tools for the industry. This opportunity encompasses the planned use of real-time characterisation techniques to allow explorers to make decisions in hours or days rather than months. For the industry more broadly, improved methods of exploration under cover will:

- **Improve exploration investments** – creating positive sentiment from investors in companies that are engaging in predictive geoscience and exploration beneath cover to create wealth, countering the past decade of increasing global exploration spend without corresponding dollar value increases in discoveries.
- **Enhance sustainability outcomes** – minimising the impact on natural environments, for example, by reducing the number of drill holes required during exploration and reducing waste.
- **Unlock new mineral provinces** – improving discovery rates of new and accessible ore reserves for commodities that are otherwise likely to decline and enabling discovery of whole new mineral provinces.[81]
- **Minimise substitution threats** – reducing the risk of downstream commodity substitutes caused by market constraints and / or high prices from supply issues (noting some commodities are experiencing over supply).

Discovering new mineral resources and developing new mining provinces will be critical to maintaining Australia's position as a major producer of key commodities.

This opportunity is particularly important to the Australian economy, with national geoscience knowledge and technology investments, and industry, research and government collaboration occurring through the UNCOVER initiative.[82] In the last few decades Australia has received lower shares of global exploration expenditure due to the perception that it is a relatively mature exploration environment. With 80% of Australia's mineral production derived from mines discovered over 30 years ago, there are concerns that half of Australia's mines will be exhausted in 15 years.[83] Discovering new mineral resources and developing new mining provinces will be critical to maintaining Australia's position as a major producer of key commodities

81 Australian Academy of Science (2012). *UNCOVER: Searching the deep earth - A vision for exploration geoscience in Australia.*

82 Geoscience Australia (n.d). *UNCOVER.* Commonwealth of Australia. [Online] Available from: http://www.uncoverminerals.org.au/ Accessed 12/01/2016

83 Fitzgerald, B. (2015). *Concern over mining's future as exploration spending plunges,* The Australian. [Online] Available from: http://www.theaustralian.com.au/business/mining-energy/concern-over-minings-future-as-exploration-spending-plunges/news-story/e2a269e49f61c2027482a6231039686f Accessed 19/12/2016

Case study

Minnovare

Incubated at the Innovation Centre of WA and founded in 2012, Minnovare develops and distributes its flagship product, the Azimuth Aligner®. With no need for GPS, compasses, string lines, plumb bobs or flagging tape, the Azimuth Aligner is an autonomous drill rig alignment technology that delivers efficiency to drilling processes within the mining and construction industries.

Conventional alignment processes can take between 30 minutes and 1 hour. This reduces drilling time and negatively impacts drilling productions. Conventional methods are also prone to human error and inaccuracy, which impacts drilling quality. Using military grade North Seeking Gyro technology, the Azimuth Aligner automates a traditionally labour intensive and inefficient process to provide operators with reduced costs and improved azimuth accuracy within +/- 0.2 degree, a standard previously unheard of in the industry. The technology helps eliminate setup errors, reducing setup time and cost. The technology can be set up very quickly, reducing downtime by approximately 70-90% and reducing drill costs by 10% and labour by 33%. The product helps exploration reduce cost per drilled meter by 3-10%. For the mining and construction industries, this is a highly valuable innovation.

An example that highlights the success of the Azimuth Aligner is its use at a large poly-metallic underground mine in South Australia, where the technology delivered faster, cheaper and more accurate drilling on site.

After winning numerous mining industry awards for its initial success in Australia, Minnovare has expanded the use and distribution of the product internationally and now aims to become a leading integrated technology developer, focussed on delivering technologies and drilling products which provide greater efficiencies, safety, control and productivity for the mining, civil, and oil and gas industries.

METS SECTOR SOLUTIONS

The METS sector has a key role to play in developing and commercialising the necessary equipment and services required by explorers. With only approximately 25% of Australian METS organisations operating in exploration,[84] there is room for more METS companies to expand focus into this area and take advantage of the increasingly data driven nature of exploration. Example product and service solutions include: developing new geophysical sensors for airborne, ground and UAV surveying; geochemical detection tools, sampling methods and hand-held instrumentation; small-scale but widely deployed passive sensor systems; data management, integration, analytics and delivery methods; and new simulation and prediction services and platforms.

Success will require improvements in global collaboration and changes to existing exploration practices, bringing together multi-disciplinary teams and drawing on experts within and outside of mining.

The following provides example METS solutions that can be taken to market and is supported by Figure 18 which explores how these solutions may evolve in the short, medium and long term. The short, medium and long-term horizons are based on a mixture of maturity and capability requirements. However, the timeframes should be viewed as a guide as different mining and METS maturity levels may allow opportunities to be brought forward or set back.

EXAMPLE METS SECTOR SOLUTIONS

REAL-TIME SENSING AND DRILLING TECHNOLOGIES

There is an opportunity for METS companies to develop advanced sensing technologies, software and equipment that is able to characterise mineralogy, geochemistry, rock hardness, properties, structures and economic value under cover. Leveraging advances in material sciences, in-hole sensors and design techniques, manufacturers will be able to develop cheaper, more durable and faster drilling technologies and detection tools that minimise exploration cost and risk. Advances in geophysics and geochemistry combined with increasing miniaturisation of passive and active sensors (within and outside of mining) will lead to multi-attribute sub-surface sensing and imaging in near real time. These small scale sensors will be connected in an array, helping to facilitate new portable analysis and data treatment methods that improve the sensitivity and precision for prediction.

TARGETING AND DECISION SUPPORT PLATFORMS

Current activities to improve the accessibility and integration of large and siloed national and international datasets will create METS opportunities for targeting and decision support tools. These will span identification, prioritisation and the testing of a target to the actual discovery of the orebody. In addition to addressing greenfield challenges with exploration under cover, these tools will also greatly improve outcomes related to brownfield exploration. Success will require improvements in global collaboration and changes to existing exploration practices, bringing together multi-disciplinary teams and drawing on experts within and outside of mining.

84 Austmine (2015). *New Realities, Bigger Horizons - Australian Mining Equipment, Technology and Services (METS) National Survey.*

FIGURE 18: METS SECTOR SOLUTIONS

SHORT TERM (0 – 3 YEARS)	MEDIUM TERM (3 – 10 YEARS)	LONG TERM (10+ YEARS)
REAL-TIME SENSING AND DRILLING TECHNOLOGIES		
From discrete exploration equipment, services and componentry...		**...to integrated sensing and drilling equipment that produces real-time insights**
• New drilling, detection and monitoring technologies and drill bit designs that produce cheaper, more durable and faster drills – such as Coiled Tube Drilling to hard rock environments from the oil industry.[85] • Advanced real-time software and tools to improve interpretation, measurement and prediction. • Sensors to improve measurements while drilling. • Passive sensor deployments from across sectors. • Communication and wireless technologies and digital infrastructure to facilitate remote data collection and analysis. • Airborne and ground surveying equipment that provide high resolution imaging of mineral systems and orebodies under deep cover.	• New geophysical sensors with increased sensitivity and precision. • New hand-held geochemical / mineralogical methods. • Improved drilling materials to reduce wear and increase energy recovery opportunities. • Integrated in-hole sensing and communications with drill technologies. • Drilling technologies that define / model and monitor the chemistry of groundwater aquifers and reduce long-term rehabilitation needs. • Different field sampling approaches and in-field analysis methods. • Drilling services that take advantage of real-time data captured at the drill site.	• Sensors and drilling equipment that can conduct imaging and gather geochemical, mineralogical and structural data in one logging run. • Real-time analytics and drilling platforms that conduct analysis minutes after drilling.
TARGETING AND DECISION SUPPORT PLATFORMS		
From integration of existing and new data / knowledge...		**...to predictive modelling to improve targeting and discovery rates, with minimal drilling**
• National (and global) data integration services and platforms to bring together disparate datasets, computing resources and publications. • Measurement and prediction of uncertainty in exploration data and models. • Geostatistics and economic assessment services in early stage exploration to improve the time from discovery to development. • Software to enable scalable data sharing. • Change management and process improvement services to increase collaboration and develop new exploration techniques. • Advanced exploration education and training services in emerging mining regions.	• Data analytics, modelling, simulation and artificial intelligence offerings that leverage data to create, test and simulate new mineral analysis techniques. • Offerings that codify tacit drilling knowledge from engineers to remove trial and error activities. • Data flows from passive sensor imaging data from a dynamic earth. • New data integration, inversion methods. • Crowd sourcing services that allow non-miners to participate in data analysis processes. • Cloud-based advanced platforms that integrate historic geological and drilling data to predict areas for prospecting in developed and developing mining regions.	• Predictive exploration platforms that use analytics, modelling and simulation to identify targets in largely unexplored global regions with minimal (or no) drilling. • Global real-time updating exploration data portals. • Secure platforms for cross tenement, regional and jurisdictional data delivery that improve exploration success.

85 Deep Exploration Technologies CRC (n.d.). Coiled Tubing Drilling for Mineral Exploration. [Online] Available from: http://detcrc.com.au/programs/program-1/project-1-1/ Accessed 23/03/2017

Case study

Imdex Group – REFLEX

Imdex Ltd is an ASX listed mining technology provider to the global minerals industry, headquartered in Perth, Western Australia. The company has operations in all key mining and exploration regions throughout Asia Pacific, Africa, Europe and the Americas. Imdex develops solutions to improve the process of identifying and extracting what is below the earth's surface for drilling contractors and resource companies. Imdex aims to be a market leader in real-time subsurface intelligence solutions, through its AMC and REFLEX brands. AMC provides quality drilling fluids, specialty products and innovative equipment. REFLEX provides advanced downhole instrumentation, data management and analytical software for geological modelling.[86]

In 2015, REFLEX entered an exclusive agreement with the Deep Exploration Technologies Cooperative Research Centre (DET CRC) to commercialise the top-of-hole analysis technology, Lab-at-Rig, developed by DET CRC participants: CSIRO, Imdex and Olympus Scientific Solutions Americas. The technology allows measurement and analysis of drill hole geochemistry and mineralogy at a drill site within minutes of the drilling process, providing objective, consistent, quantitative and rapid geological data which is complementary to, and in many ways surpasses, traditional geological logging.

The technology is expected to result in significant cost savings by enabling timely decisions to be made by mineral explorers, such as whether to terminate or extend drill holes or whether to modify the location or trajectory of subsequent holes. The Lab-at-Rig technology will be developed alongside REFLEX's other Assay-While-Drilling technologies and integrated with REFLEX solutions such as the secure, cloud based REFLEXHUB-IQ, allowing real-time interrogation of drill hole assay data from any location.[87]

BUSINESS MODEL CONSIDERATIONS – TAKING ADVANTAGE OF THE CROWD

There are immediate opportunities for METS companies to develop tools and services that help challenge existing practices. For example, the Integra Gold Corp 'Gold Rush Challenge' (2016) recently applied crowd sourcing to tackle their current exploration challenge, offering public access to historic mining and exploration data and a CAD$1 million prize. The challenge received 100 submissions consisting of 1,342 participants across 83 countries working in 95 teams.[88]

In the long term, accessible, integrated and high resolution exploration data could play a role in disrupting the 'venture' value chain – shifting exploration away from being risk based[89] – which could result in completely new business and operating models for existing METS companies.

86 Imdex Limited (2016). *2016 annual report*, Perth.

87 DET CRC (2015). *Press Release: REFLEX to Commercialise DET CRC's Lab-at-Rig® Technology,* [Online] Available from: http://detcrc.com.au/2015/september-2015-det-crc-press-release-reflex-to-commercialise-det-crcs-lab-at-rig-technology/

88 Integra Gold Corp (2016). *Gold Rush Challenge,* [Online] Available from: http://www.integragold.com/goldrush/#video/0/ Accessed 09/01/2017

89 Stanway, G., et al (2016). *Innovation: State of Play – CEO Insights Mining,* VCI.

ENABLING BUSINESS CHANGES

In order to unlock this opportunity METS companies will need to invest in business transformation – taking action internally and externally.

BUSINESS PRIORITIES: CREATING ADVANTAGE THROUGH CAPABILITY AND LEADERSHIP

People and skills

- Develop geophysical and geochemical knowledge in parallel with data sciences, modelling and geographic information system (GIS) skills. For example develop statistical modelling and interrogation techniques to improve targeting using available data or gaps (uncertainties) within datasets.
- Work with universities to develop graduates that understand established geological fundamentals as well as emerging computational and analytical skills.
- Improve field skills to take advantage of real-time (or near real-time) sensing and targeting data.

Process and standards

- Improve data integration and data transfer standards to take advantage of new sensors and emerging 'big data' technologies. The geospatial data standards that have been developed over the last 20 years have been funded and adopted by government agencies and will need further work for commercial application. The pathway to developing these standards is now well defined and should be leveraged rather than reinvented.
- Identify and promote best practice in data acquisition and processing to improve data quality and reduce issues with integrating large exploration datasets.

Culture and collaboration

- Facilitate greater collaboration between Junior explorers, METS and mining companies to address market failure risks and increase recognition of innovation needs. Note: While METS and junior explorers are often treated separately, both groups have a high degree of commonality.
- Improve multidisciplinary collaboration – such as between geologists and biologists for improving operation and post-closure outcomes.[90]
- Create opportunities for sampling and analysing vegetation / geology for traces of minerals in exploration (but also for other industries like Agriculture).[91]
- Improve stakeholder and community engagement methods to reduce current barriers (e.g. raising capital, gaining licences, regulatory approvals).
- Promote the sharing and integration of exploration and geological data and leverage crowd sourcing to allow data science experts from fields other than mining to interrogate exploration data across tenement and regional boundaries.[92]
- Support activities that improve decision making related to resource geography and its potential, and develop models and predictive tools to help resource governance.[93]

90 Randell, A (2015). *Exploration Is Multidisciplinary: Exploring the Relationships Between Geologists and Biologists.* Geologyforinvestors.Com. [Online] Available from: http://www.geologyforinvestors.com/exploration-multidisciplinary-exploring-relationships-geologists-biologists/ Accessed 19/12/2016

91 CSIRO (2013). *Gilding the gum tree – scientists strike gold in leaves.* [Online] Available from: https://csiropedia.csiro.au/gilding-the-gum-tree-scientists-strike-gold-in-leaves/ Accessed 19/12/2016

92 Marketwired (2015). *Integra Gold Corp. launches Cdn $1,000,000 crowd-sourcing gold rush challenge.* Mining.com. [Online] Available from: http://www.mining.com/web/integra-gold-corp-launches-1000000-crowd-sourcing-gold-rush-challenge/ Accessed 19/12/2016

93 Nordic Rock Tech Centre AB (RTC) (2013). *Strategic research and innovation agenda for the Swedish mining and metal producing industry (STRIM),* [Online] Available from: http://www.rocktechcentre.se/wp-content/uploads/2013/06/STRIM-final.pdf

ENABLING SCIENCE AND TECHNOLOGY

Scientific and technological developments both within and outside of the mining industry will be key to unlocking this and many other opportunities. To stay ahead, METS businesses need to invest in developing the right capabilities and gain practical experiences in emerging areas to successfully convert leading scientific and technological breakthroughs into repeatable and operationally ready solutions.

RESEARCH PRIORITIES: CREATING ADVANTAGE THROUGH RESEARCH*

Next generation drilling technologies

- Development of faster, cheaper and more portable drilling technologies, including directional drilling and measure-while-drilling techniques which help to continuously target new provinces and mineral systems.
- Advancing first principles mineral system and orebody formation knowledge.
- Advancing sensing and data collection technologies and processes, including geophysical, geological, geochemical and geometallurgical sensing, exploration at depth, sub-sea exploration, and down-hole technologies.
- Improvements in exploration targeting including cheaper 3D seismic exploration in hard rock environments, passive sensor deployments to image the dynamic earth and integrated data treatment, technologies and capabilities.[94]

Expanding exploration knowledge and processes

- Characterising Australia's cover: develop first and second generation national 3D map / layer to reframe cover from an exploration impediment to an opportunity and provide knowledge that underpins future digital exploration platforms, processes and simulation techniques and tools.[95]
- Investigating Australia's lithospheric architecture: expand available data and knowledge about lithospheric architectures (the crust and the uppermost mantle of the earth), shifting the sector from 2D to 3D analysis to identify the requirements for future exploration hardware and software, which will eventually lead to new knowledge, tools, process and platforms that can be used globally.[95]
- Characterising and detecting the distal footprints of ore deposits: develop new exploration tools that improve exploration targeting processes and reduce the risk of false positives. This may include new airborne and ground surveying equipment, methodologies and analysis techniques at multiple scales and the creation of new data-analytics, integration and modelling tools that build on existing characterisation datasets.[95]
- Resolving the 4D geodynamic and metallogenic evolution of Australia: develop a 4D geodynamic and metallogenic evolution platform / map for Australia and elsewhere in the world to accelerate discoveries, further Australia's international exploration leadership and support long-term analytics and computational big data services.[95]

**Draws on research areas identified during METS Ignited IKP development and AMIRA International[95] and Deep Exploration Technologies CRC projects.[96]*

94 Deep Exploration Technologies CRC (n.d.). *3D Seismic Exploration for Hard Rock Environments,* [Online] Available from: http://detcrc.com.au/programs/program-3/project-3-1/ Accessed 19/12/2016

95 AMIRA (2015). *P1162. Unlocking Australia's hidden potential. An Industry Roadmap – Stage 1.* AMIRA International, Australia.

96 DETDeep Exploration Technologies CRC (n.d.). Deep Exploration Technologies CRC. [Online] Available from: http://detcrc.com.au/http://detcrc.com.au/ Accessed 23/03/2017

Advanced extraction

Deeper, more complex and lower grade orebodies combined with the need for a lower environmental footprint will drive the development of advanced methods of extraction.

KEY DRIVING MEGATRENDS

- The innovation imperative
- The era of accountability
- Rethinking our reserves

QUICK STATISTICS

- The mass of waste rock moved to the surface of an open pit can be 5-10 times the mass of value bearing ore.
- Underground pre-concentration methods have the potential to save 20-40% of mine operating costs.[97]
- In Situ Recovery has the potential to eliminate the combined costs of drilling, blasting, digging, hauling and crushing / grinding which have been estimated to amount to upward of 80% of all operating costs.[98]

97 Murphy, B., van Zyl, J., Domingo, G. (2012). *Underground preconcentration by ore sorting and coarse gravity separation*. In Narrow Vein Mining Conference (pp. 26-27).

98 Moström, J. (2008). *Mine Cost Drivers, Capital Markets Day,* [Online] Available from: Available at http://www.boliden.com/Global/IR%202016/Reports%20and%20presentations/Capital%20markets%20day/2008/CMD/5%20Mine%20cost%20drivers,%20Jan%20Mostr%C3%B6m%20,%20President%20Boliden%20Mines.pdf Accessed 09/01/2017.

4.4 Advanced extraction

FUTURE STATE OF THE MINING CUSTOMER

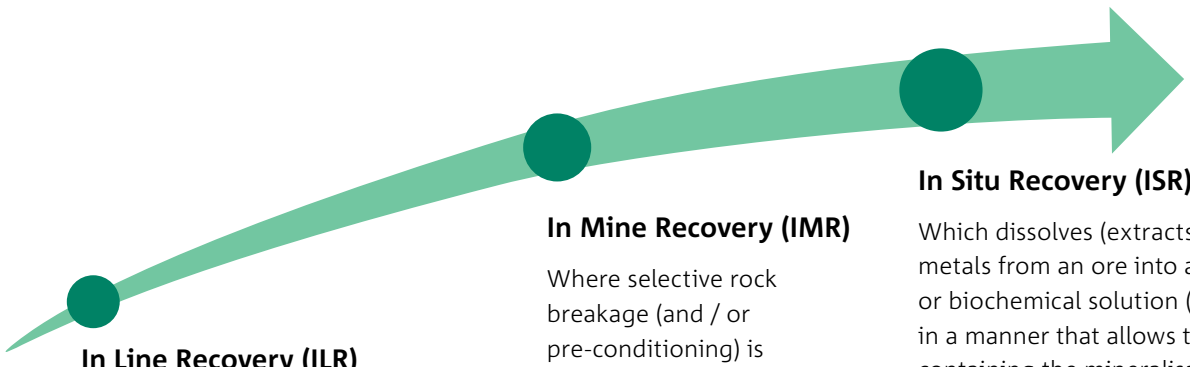
Future extraction technologies will increase selectivity in mining, materials handling and processing, reducing the movement of material transported to the surface of a mine by targeting localised ore extraction and by enabling mineral processing to occur close to, or directly at, the mining face. Key advanced extraction technologies include 'In Line Recovery' (ILR), 'In Mine Recovery' (IMR) and 'In Situ Recovery' (ISR) (see Figure 19). These technologies will take advantage of advances in automation and robotics (Chapter 4.5) and support broader low impact of mining developments (Chapter 4.2), reducing the footprint of mining and tailings dams. Compared to conventional methods, advanced extraction technologies can:

- **Dramatically reduce capital and operating costs** – by facilitating smaller on-surface infrastructure and reducing surface tailings storage facilities, as well as eliminating or reducing costs associated with extraction, comminution, haulage and processing more broadly.
- **Improve environmental outcomes** – reducing (or eliminating) tailings, greenhouse gas emissions, dust, noise, and energy required in transporting waste to the surface, and avoiding open cut or large scale excavations.
- **Improve safety outcomes** – reducing the number of workers exposed to hazards or potentially dangerous environments during mining operations.
- **Extend production** – using advanced extraction technologies may lead to lower economic grades being exploitable (over time) and an ability to economically recover stranded ore in brownfield sites.

The technologies envisaged to enhance extraction and improve selectivity are likely to support the implementation of more incremental changes in production volumes than is currently the case. For example, ISR provides flexibility by allowing operators to scale production quickly, due to the low capital and labour requirements, depending on market conditions.[99] This plausible real time flexibility contrasts with current practice where technologies are subject to the economies of scale meaning that increments must usually be large, incur a high capital cost, and operate for a very long lifetime to be able to be economic.

If technologies for greater selectivity are combined with a more detailed knowledge of the resource, the development of long-term mine plans and short-term mining schedules can be improved, leading to a more sophisticated ability to manage value, margins and cash flow, rather than simply chasing tonnes.

FIGURE 19: SELECTIVITY IN MINING, MATERIALS HANDLING AND PROCESSING



In Line Recovery (ILR)

Combining precision mining, material preparation and processing stages (beneficiation, and/or pre-concentration and/or leaching) adjacent to the mining face.

In Mine Recovery (IMR)

Where selective rock breakage (and / or pre-conditioning) is combined with leaching of materials in place with no bulk material movement.

In Situ Recovery (ISR)

Which dissolves (extracts) valuable metals from an ore into a chemical or biochemical solution (a lixiviant) in a manner that allows the rock containing the mineralisation to remain in place, while the solution is pumped through the ore, then to the surface for further processing.

99 Seredkin, M., Zabolotsky, A., & Jeffress, G. (2016*). In situ recovery, an alternative to conventional methods of mining: Exploration, resource estimation, environmental issues, project evaluation and economics,* Ore Geology Reviews, 79, 500-514.

Case study

Mining and Process Solutions (MPS)[100]

Mining and Process Solutions (MPS), established in 2014 and based in Perth, aims to transform the base and precious metals mining industry by delivering low cost, energy efficient, environmentally friendly methods to extract valuable minerals. MPS holds exclusive rights to two key technologies and are working towards having the technology demonstrated as rapidly as possible:

- Glycine Leaching process, licenced from Curtin University involves a new type of breakthrough lixivant for highly selective leaching of base and precious metal ores.
- Continuous Vat Leaching (CVL), a Canadian developed mechanical leaching process, involves cyclical gravity discharge of a lixivant to fluidise and leach metals from ore contained within a vat. It has the efficiency of a conventional tank leach with costs that are competitive with heap leaching.

MPS operates a test centre at its facility within the Australian Minerals Research Centre in Perth where they are testing the Glycine Leaching process, before demonstrating the technology at pilot scale. As a simple process that uses 'off the shelf' equipment and provides an environmentally benign solution, replacing the need for cyanide, the innovative Glycine leaching process has the potential to transform the mining industry. Many applications using Glycine leaching process have been identified, including:

- GlyLeach – helping transform orphan deposits and wastes into viable opportunities.
- GlySmelt – the application of Glycine as a method to leach concentrates, potentially disrupting the current paradigm from a mine-to-concentrate value chain to a mine-to-metal model.
- GlySlag – the application of Glycine to leach residual metals contained in slags, transforming wastes into viable opportunities.
- GlyMine – the application of Glycine as a lixivant in applications where leaching of valuable metals can be carried out by in place and in situ leaching.
- GlyCat – catalysed leach for mixed base and precious metals.

100 Mining & Process Solutions Website(n.d.). *Technology*, [Online] Available from: http://www.mpsinnovation.com.au/technology/ Accessed 18/01/2017

METS SECTOR SOLUTIONS

Australia's long history of mining activity has left many lower grade, stranded, remote and otherwise marginal materials in the ground. Development and commercialisation of advanced extraction technologies may lead to a step change in extraction economics that may result in a large increase in the exploitable reserves for Australia. METS companies will continue to play key roles in developing advanced drilling, processing and monitoring technologies; and providing consulting and other services to help operators adopt new methods and technologies.

In the long term, these technologies will increasingly be standardised, integrated and designed to be modular and transportable.

The following provides example METS solutions that can be taken to market and is supported by Figure 20 which explores how these solutions may evolve in the short, medium and long term. The short, medium and long-term horizons are based on a mixture of maturity and capability requirements. However, the timeframes should be viewed as a guide as different mining and METS maturity levels may allow opportunities to be brought forward or set back.

EXAMPLE METS SECTOR SOLUTIONS

MODULAR AND MOBILE EQUIPMENT AND INFRASTRUCTURE

While advanced extraction technologies expected over the short term will largely be used by early adopters, the underlying drilling, sensing, sorting and processing technologies will have a high degree of overlap with other opportunities ***discussed*** in this report. In the long term, these technologies will increasingly be standardised, integrated and designed to be modular and transportable. Technological convergence will require product miniaturisation and consolidation to simplify maintenance, integration and durability of processing technologies for below surface environments.

MINE PLANNING AND PROCESS RE-ENGINEERING

Adoption of advanced extraction technologies such as ILR, IMR and ISR will result in changes to current mining processes and practices. For METS businesses, there is an opportunity to assist in this process by providing consulting and change management services, and by developing assessment, modelling and planning services and tools that help operators adopt advanced technologies. These offerings will challenge current functional silos by increasing and ensuring collaboration between geologists, mining and process engineers, so that mineralisation with different geological and metallurgical characteristics can be efficiently processed.

FIGURE 20: METS SECTOR SOLUTIONS

SHORT TERM (0 – 3 YEARS)	MEDIUM TERM (3 – 10 YEARS)	LONG TERM (10+ YEARS)
MODULAR AND MOBILE EQUIPMENT AND INFRASTRUCTURE		
From discrete products and equipment to support early adopters...		**...to integrated, modular and mobile equipment for selective mining**
• Ore sorting and pre-concentration offerings that use geological, geochemical and geophysical data to cost-effectively process valuable minerals from waste. • Precision cutting, fragmentation and hard rock drilling technologies to minimise maintenance, speed and directional control and in-hole sensing. • Sensors, fragmentation analysis, advanced resource characterisation and modelling technologies to manage ore transport along the value chain. • Hydrology control technologies to isolate the mining from the external environment.	• Advanced and remote contaminant monitoring, management and mitigation sensors, tools and services. • Visualisation and robotics offerings to improve remote and autonomous control of rock breakage and in-seam drilling. •	• Miniaturisation and modularisation of below surface mineral processing and beneficiation equipment to improve mobility and reduce installation requirements. • Embedded end-to-end management tools and technologies that help manage contaminant monitoring and mitigation processes. • Remote monitoring and automated maintenance of advanced extraction equipment.
MINE PLANNING AND PROCESS RE-ENGINEERING		
From education and mine planning for advanced extraction...		**...to redesign and optimisation of the mining value chain**
• Change management services to help miners, METS and research organisations reorient processes to adopt advanced extraction technologies. • Services to improve community and government engagement to better understand new selective mining methods. • Assessment and planning tools to help align geological and ore characteristics with advanced extraction methods to optimise mine-to-mill flowsheet.[101]	• Capital project planning services including world-class risk assessment tools that consider geological, environmental and social implications. • Design and decision support services that improve collaboration between exploration, capital project, mine planning and operational teams. • End-to-end management tools and technologies that identify subsurface water resources and risks.	• Modelling and optimisation offerings that integrate variable geological and metallurgical characteristics and processing rates with market changes (e.g. commodity prices). • Process improvement offerings to support surface based sorting that can direct parcels of material to different processing activities or streams.

101 Murphy, B., van Zyl, J., Domingo, G. (2012). *Underground preconcentration by ore sorting and coarse gravity separation*. In Narrow Vein Mining Conference (pp. 26-27).

ENABLING BUSINESS CHANGES

In order to unlock this opportunity METS companies will need to invest in business transformation – taking action internally and externally.

BUSINESS PRIORITIES: CREATING ADVANTAGE THROUGH CAPABILITY AND LEADERSHIP

People and skills

- Invest in developing staff with skills in installing, operating, and manufacturing advanced extraction technologies and the necessary underlying drilling, sensing, sorting and processing technologies.
- Develop staff with financial capabilities to demonstrate the long-term value proposition of advanced extraction technologies through assessment of the characteristics and mineralisation of rocks. For example, in ISR, critical parameters include hydrogeological conditions, permeability, leachability, location of mineralisation and chemical composition.[102]
- Draw on non-mining industry innovations and approaches to improve internal technology and engineering approaches towards standardisation, miniaturisation, modularity, repeatability and integration. This may involve setting up a shared architecture and roadmap for a pathway to an ideal future state of a smart and automated mine.

Process and standards

- Work with operators, industry associations and research organisations to define solutions required for the interoperability of advanced extractive technologies, including appropriate hardware and software, extraction and processing standards and standard development governance.
- Work with industry and government stakeholders to define and develop regulatory frameworks for advanced extraction technologies.

Culture and collaboration

- Collaborate with mining operators to develop a concise value proposition for advanced extraction technologies, addressing sunk costs and required rates of return.
- Improve alignment of key performance drivers and foster interdisciplinary collaborations across mining, metallurgical and geological personnel.[103]
- Develop new approaches that improve community attitudes related to advanced extractive technologies. For example, demonstrating and gaining acceptance of ILR, IMR and ISR as environmentally friendly and sustainable processes.

BUSINESS MODEL CONSIDERATIONS – PERFORMANCE BASED SERVICES AND LEASING

There is an opportunity for Australian METS to explore new after-sales services (such as monitoring and maintenance) and performance-based leasing models for advanced extraction technologies – particularly for smaller mining companies who may find the financial structure appealing. As highlighted in CSIRO's Advanced Manufacturing Roadmap, developing complementary service offerings is a key opportunity for growth for Australian manufacturers. For example, aircraft engine manufacturers have been offering performance-based service and logistics agreements to customers for decades. These services involve a fixed warranty and operational fee for the hours engines are running, meaning that in addition to making the product, the manufacturer takes care of installation, after-sales maintenance, repair, overhaul and overall service and parts management.

102 Seredkin, M., Zabolotsky, A., & Jeffress, G. (2016*). In situ recovery, an alternative to conventional methods of mining: Exploration, resource estimation, environmental issues, project evaluation and economics,* Ore Geology Reviews, 79, 500-514

103 Murphy, B., van Zyl, J., Domingo, G. (2012). *Underground preconcentration by ore sorting and coarse gravity separation.* In Narrow Vein Mining Conference (pp. 26-27).

ENABLING SCIENCE AND TECHNOLOGY

Scientific and technological developments both within and outside of the mining industry will be key to unlocking this and many other opportunities. To stay ahead, METS businesses need to invest in developing the right capabilities and gain practical experiences in emerging areas to successfully convert leading scientific and technological breakthroughs into repeatable and operationally ready solutions.

RESEARCH PRIORITIES: CREATING ADVANTAGE THROUGH RESEARCH*

Advanced drilling and cutting technologies

- Technologies for controlled fracturing to access resource deposits, create and maintain a connected surface area ('porosity').
- Development of tools for generating permeability; and an ability to quantify the impact of fractures on rock porosity and permeability.[104]
- Precision rock cutting and smart blasting knowledge and technologies combined with improved resource characterisation and block model resolution and interaction.
- Advanced and intelligent materials that increase the strength and performance of drilling equipment, reduce weight and minimise maintenance requirements.
- Rock mechanics better linked to equipment design (including customisation to local / current conditions).

Sensors and ore sorting

- Real-time (or near real-time) sensors and methods for exploiting variations in extracted material grade and physical rock properties for early waste rejection.
- Systems and sensors (including down-hole) for more comprehensive mineral system characterisation, deposit mapping and advanced monitoring; and modelling of fractures and the processes of pre-conditioning and leaching.
- Multi-resolution and attribute representations to facilitate continuous refinement of orebody block models and mine plans.

Integrated beneficiation technologies

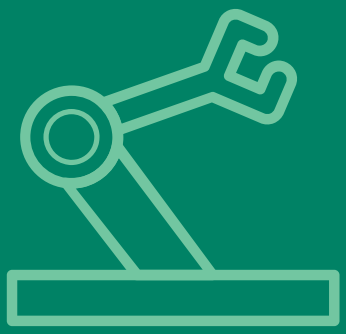
- Modular, standard and interchangeable solutions for provision of mobile or incremental processing and materials handling capacity.
- Processing plant technologies that automatically adapt to feed conditions.
- High intensity (low footprint) processing flowsheets which focus on product / intermediate production, reagent recycling and waste minimisation.
- More environmentally benign and selective chemical and biological lixiviant technologies and leaching systems that reach the minerals of interest, extract the target metal(s) and are captured / returned to the surface in a safe, responsible and low impact manner.
- Improved hydrogeological investigations and treatment technologies, including better understanding and modelling of hydrogeology, fluid flows and control; and improved barrier and remediation technologies and tools.

**Draws on research areas identified during METS Ignited IKP development*

104 Kuhar L., et al (2015). *In-situ recovery – current status and proposal for future research program development,* Unpublished paper, CSIRO Mineral Resources Flagship. – Check with Dave R.

Mining automation and robotics

Recent technology cost and performance breakthroughs in robotics, automation, artificial intelligence, data communications and vision systems are enabling safer and more efficient operations.



KEY DRIVING MEGATRENDS

- The innovation imperative
- Plugged in and switched on

QUICK STATISTICS

- Rio Tinto's innovation program is demonstrating a 14% higher utilisation of autonomous haul trucks than manned trucks and a 15% increase in availability of automated drills over manned drills.[105]
- Longwall mining automation in the Australian coal industry delivered a 5-10% increase in productivity, adding $1 billion in export value.[106]
- Automation is predicted to be the most important driver of innovation over the next 15 years based on a survey of senior leaders from over 100 mining and services companies.[107]

105 Matysek, A., & Fisher, B. (2016). *Productivity and Innovation in the Mining Industry*, BAEconomics.
106 CSIRO Futures (2015). *Unlocking Australia's resource potential: Innovation in the energy and mineral resources sector,* CSIRO.
107 VCI (2014). *Innovation State of Play 2014 Report*.

4.5 Mining automation and robotics

FUTURE STATE OF THE MINING CUSTOMER

The future of mining automation and robotics are systems and machines that are more agile, can learn and adapt to changes in their environment and can carry out necessary actions without intervention. Advanced automation is suited to large-volume production tasks, whereas robotics is better suited to lower volume, customised activities. While these technologies will eventually be applied across the mining lifecycle, this opportunity is focused on mineral extraction to:

- **Improve safety** – removing the need for humans to be in dangerous environments.
- **Increase productivity** – improving throughput, consistency, continuity and predictability while reducing human error.
- **Enhance sustainability** – reducing waste and optimising consumables and energy inputs for extraction and processing.
- **Improve recovery** – applying small-scale robotics to assist in the recovery of previously inaccessible resources.

The mining industry has been taking advantage of automation for decades, with a number of world-leading mining automation projects based in Australia. However, deployments have been limited due to the large, complex and hazardous operating environments and the technology barriers that exist (e.g. interoperability). As the technology matures and barriers are removed, there is potential for completely autonomous future mining environments – both leveraging large and small-scale robotics fleets. However, it is important to note that automation may not suit all sites due to operational complexity, international regulatory changes and differences in labour and technology requirements. In such regions, partial automation in the form of operator assist will find increasing application.

Case study

Applied Mining Technologies

Applied Mining Technologies (AMT), founded in Brisbane in 1998, specialises in the development of high accuracy navigation systems, automated mining methods and advanced sensing technologies for the international coal mining industry. With a long history in the development and application of automated navigation technologies for underground mining, AMT was instrumental in establishing the wide spread use of inertial guidance within the highwall mining sector.

Precision and accuracy is of critical importance for safe and productive highwall mining; AMT's autonomous navigation systems help to reduce the risk of collapse and improve mining efficiency and productivity. Since AMT supplied the first commercial highwall mining guidance package in the 1990s it has further developed the technology to incorporate the latest generation inertial navigation sensors, data processing and intelligent sensing technologies.

AMT's automation technology has been used by UGM Addcar, an Australian company that leads the global design, manufacture and operation of highwall mining systems, as an essential part of the company's highwall mining package. The technology significantly reduces the risk of highwall collapse and equipment entrapment, and has allowed UGM Addcar systems to confidently increase mining penetration depths, enabling significant increases in recoverable coal.

AMT is now established as a world leader in this advanced mining guidance technology for underground coal and potash mining applications.

METS SECTOR SOLUTIONS

Leveraging Australia's research strengths in mining robotics and automation, opportunities exist for Australian METS to develop integrated equipment and componentry, such as advanced sensors and control systems for use within automation and robotic systems. METS companies will also have the opportunity to provide change management and other ongoing services to help mining operators adopt these technologies.

The following provides example METS solutions that can be taken to market and is supported by Figure 21 which explores how these solutions may evolve in the short, medium and long term. The short, medium and long-term horizons are based on a mixture of maturity and capability requirements. However, the timeframes should be viewed as a guide as different mining and METS maturity levels may allow opportunities to be brought forward or set back.

EXAMPLE METS SECTOR SOLTUIONS

ADAPTABLE AND OPTIMISED EQUIPMENT AND INSTRUMENTATION

As large-scale automation and small-scale robotics equipment and instrumentation become commoditised, Australian METS differentiation will be achieved through superior design and value-adding. For example, redesigning equipment so that it is lighter, smaller and cheaper, or contains superior attributes such as energy harvesting. Further differentiation can be achieved by applying design-led thinking to improve communication interfaces between equipment, parts, sensors, and open / closed software platforms to achieve greater situational awareness, higher adaptability and continuous robotic learning.

RAPID DEPLOYMENT AND LOW RISK INTEGRATION

The high complexity, safety and production risks associated with technology adoption in mining has led to highly customised deployments with long development lead times. While there is some shared learnings through OEMs and the movement of staff, many miners have developed proprietary processes and very few are able to rapidly exploit global advancements in automated and robotic equipment. The Australian METS sector has the opportunity to develop skills, processes, technologies and services that help to commoditise deployment and integration, increasing repeatability and standardisation, while lowering risk and shortening lead times. Current and future offerings will need to create opportunities for automation and robotics to complement existing workers, while applying change management practices to improve staff acceptance and community engagement.

FIGURE 21: METS SECTOR SOLUTIONS

SHORT TERM (0 – 3 YEARS)	MEDIUM TERM (3 – 10 YEARS)	LONG TERM (10+ YEARS)
ADAPTABLE AND OPTIMISED EQUIPMENT AND INSTRUMENTATION		
From products that service current operator and OEM needs...		**...to products that define future needs**
• Automated and semi-automated equipment and systems for discrete processes – such as continuous drilling, excavation and dragline. • Durable sensors, actuators and computing hardware to increase autonomous equipment up-time and simplify retrofitting of existing mobile equipment. • Advanced communications and positioning systems for autonomous surface and underground equipment – such as high accuracy, strong signal, coverage over large distances and penetration of earth. • Collision avoidance and orchestration software and algorithms. • Small-scale robotic fleets that target deep and narrow deposits. • Drones and small-scale autonomous equipment for mapping and environmental monitoring. • Site based condition monitoring, diagnostics and predictive maintenance. • Operator-assist, remote supervision and diagnostics services.		• Dexterous, high-precision and small-scale robots that can support on-site staff and remove workers from dangerous environments. • Energy harvesting and battery technologies / systems to extend operational uptime of autonomous equipment. • Adaptable and mobile autonomous systems and robotics that can react, learn and be easily trained to operate with changing geological conditions. • Redesign and consolidation of parts to reduce repair complexity or embed self-healing materials.
RAPID DEPLOYMENT AND LOW RISK INTEGRATION		
From high risk, long and custom deployments...		**...to low risk, short and standardised deployments**
• Change management, process integration and safety solutions to improve uptake and acceptance, and ensure value is realised. • Services to help optimise deployment on existing sites with legacy software, systems and technologies. • Operator training, and community and workforce engagement services that transition workers to complementary, supervisory or higher order activities. • Training and change management services to improve forward planning maintenance optimisation.	• Capital planning processes and tools that improve pre-feasibility and feasibility assessments. • Tools, services and strategies that introduce greater predictability and best practices in automation deployments. • Collaborative OEM and operator maintenance offerings and agreements that are performance based, share real-time equipment data and leverage global experts. • Virtual / Augmented reality offerings to provide remote and collaborative support.	• 'Digital twinning' offerings that use virtual environments to test deployment and integration plans and identify risks and issues. • Flexible sensing technologies that allow customers to tailor or fine-tune sensing needs with minimal impact to operations, particularly during teething phases of deployments. • Process redesign to integrate autonomous and robotics systems with new mining methods (e.g. selective mining). • Multi-site orchestration and control of equipment and vehicles.

Case study

RCT

Headquartered in Perth, RCT is a global leader in smart guidance, teleremote and remote control automation solutions for the mining industry. With a history spanning 45 years, RCT has pioneered many remote control and teleremote solutions for dozers, excavators, loaders and most types of mobile equipment. Today, the company manufacture, install, commission, service and support all products, with clients in more than 64 countries.

RCT's vast range of technologies includes the ControlMaster suite of smart automation and control products, which encompasses line-of-sight remote controls, Guidance systems, portable teleremote systems and components. These technologies and solutions enable clients to remotely operate equipment from a safe location on either the surface or underground.

Recently, RCT was able to help Aeris Resources achieve record productivity at its Tritton underground copper mines in central west New South Wales. These mines operate using the conventional open stoping method of mining, which requires miners to come to surface before blasting. Travel time to the surface, at a distance of around 1000m, and back again, resulted in significant lost time and poor productivity. Installation of RCT's ControlMaster Surface Control system improved the miners working environment as well as enabled them to operate the fleet of loaders from an operator control station located at the surface of the mine, allowing production to continue right through to firing time, resuming immediately after. This provides an additional hour or more each day of productive loading time and has helped the site reach record productivity.[108]

BUSINESS MODEL CONSIDERATIONS – COLLABORATIVE SUPERVISION AND MAINTENANCE

As predictive maintenance and remote operation centres mature, Australian METS companies could partner to develop an internationally competitive, multi-site and collaborative supervision and maintenance support offering. In this model, innovative SMEs could integrate their offerings across the value chain, developing specialised expertise that offers higher levels of solution and support. Together these organisations can build a reputation in differentiated and niche areas, using partnerships to reach international markets and operations.

108 RCT (2016). Aeris Resources – Tritton Mine Site, NSW, Australia, Case Study, [Online] Available from: http://rct-global.com/media/aeris-resources-tritton-mine-site-nsw-australia/ Accessed 23/02/2017

ENABLING BUSINESS CHANGES

In order to unlock this opportunity METS companies will need to invest in business transformation – taking action internally and externally.

BUSINESS PRIORITIES: CREATING ADVANTAGE THROUGH CAPABILITY AND LEADERSHIP

People and skills

- Identify workforce skills gaps in the application, operation and maintenance of autonomous equipment and technologies. This could include: understanding specialist and IT skills required for future site technicians and developing approaches for future remote operators that do not have first-hand experience in a physical mine environment.[109]
- Improve digital literacy skills to help manage and optimise autonomous and robotic fleets and equipment.
- Develop human-machine interface design skills to improve equipment adoption.
- Build on mechanical engineering, electrical engineering and computer science technical expertise to include material sciences and nanotechnology.

Process and standards

- Address interoperability and integration issues, supporting and leveraging existing initiatives such as the EMESRT Vehicle Interaction project for mining equipment, the AMIRA International P1025 project and several GMSG projects.[110]

Culture and collaboration

- Challenge the role of automation and robotics in mining, redefining extraction and processing methodologies beyond mechanisation and legacy human and 'shovel and truck' requirements.
- Use change management to address cultural and organisational acceptance of technologies.
- Collaborate with Australian manufacturers outside the mining sector to gain experience with low cost robotics and automation technologies.
- Address the divide between IT and OT staff and systems within METS and Mining. For example, supporting mining companies to develop appropriate governance models for automation and increase knowledge sharing between operational and IT staff to ensure appropriate skills are developed and that change is not resisted.[111]

109 Farrelly, C T (2016). *Are we ready for the brave new world in mining?* Indago Partners. [Online] Available from: http://indagopartners.blogspot.com.au/2016/03/are-we-ready-for-brave-new-world.html Accessed 28/02/2017

110 Farrelly, C T., Ballantyne R J. (2016). Achieving Interoperability across the Minerals Value Chain, Phase 1 – Surface Mining Equipment, P1025 Summary Report, AMIRA International, Australia

111 Seixas, C (2016). *Mining: Laying the foundation for IT-OT governance.* Accenture natural resources blog. Accenture. [Online] Available from: https://www.accenture.com/us-en/blogs/blogs-mining-laying-foundation-it-ot-governance Accessed 03/03/2017

ENABLING SCIENCE AND TECHNOLOGY

Scientific and technological developments both within and outside of the mining industry will be key to unlocking this and many other opportunities. To stay ahead, METS businesses need to invest in developing the right capabilities and gain practical experiences in emerging areas to successfully convert leading scientific and technological breakthroughs into repeatable and operationally ready solutions.

RESEARCH PRIORITIES: CREATING ADVANTAGE THROUGH RESEARCH*

Machine vision, materials and robotics

- Machine vision and sensor developments / miniaturisation to allow robots to develop perception and situational awareness to safely interact with humans and their environments, particularly in underground environments.
- Advanced materials and additive manufacturing (3D printing) developments focusing on light weighting, energy harvesting, strength and functionality.
- Increased energy density and miniaturisation of batteries for autonomous robots and software to optimise the use of on-board power.[112]
- Advanced, more dexterous end-of-arm tooling such as intelligent grippers, servo grippers, vacuum grippers, jamming grippers, sizing software for grippers and other application specific grippers.[113]

Control systems and algorithms

- Improved computational ability with the integration of machine learning algorithms, sensors, machine vision, big data, cloud technologies and the internet of things to allow robots to autonomously move, repair, self-calibrate and change behaviour based on complex and highly variable mining environment (surface and underground), geological conditions and changing goals.
- Improved machine-to-machine communication, interoperability, positioning and signal processing for heterogeneous autonomous robots and fleets.
- Intelligent / smart sensors able to process system and resource data on board, allowing real-time highly accurate decisions and corrective action.
- Improvements in operations and maintenance control architectures to allow distributed control at site instrument level.[114]

Virtual and augmented reality

- Advanced software and sensors for virtual and augmented reality such as depth sensors for 3D impact and Natural User Interface (NUI) sensors, permitting remote teams and on-site staff to interact with autonomous vehicles and diagnose problems in more natural ways through sensory tracking, speech, touch, vision and gestures.[115]
- Improved solutions for haptics (integration of touch) and audio integration, such as dismissing standard keyboard and mouse for voice and gesture commands.
- Alignment of different spatial orientations in the same reality to allow educators and pupils to perform joint-training / tasks in the same virtual reality space.

**Draws on research areas identified during METS Ignited IKP development*

112 Frost & Sullivan (2016). *Power Technologies for Drones and Autonomous Robots (TechVision)*, Mountain View.
113 Frost & Sullivan (2016). *Evolution of Robotics—Growth Opportunities in the Age of Industrie 4.0*, Mountain View.
114 Frost & Sullivan (2016). *2016 Outlook of the Global Automation Industry,* Mountain View.
115 Frost & Sullivan (2016). *Global Sensor Outlook 2016,* Mountain View.

Conclusion

5 Conclusion

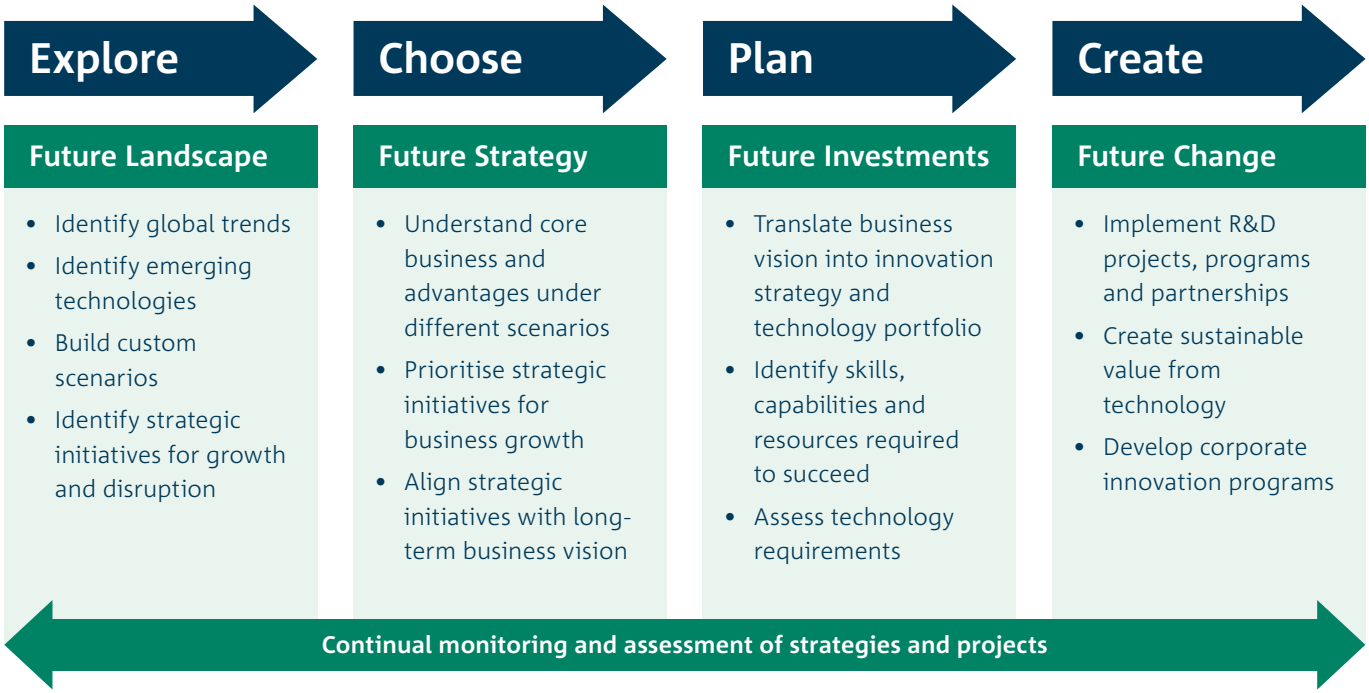
The mining industry's increasing dependence on specialist technologies, combined with a changing global landscape is creating new opportunities and threats for Australia's METS sector. While Australian METS have comparative advantages, these alone do not position companies to capture the opportunities discussed.

Navigating long-term change requires METS businesses to re-evaluate and re-position themselves – ensuring that scarce resources, such as labour and capital are appropriately allocated, that business decisions are underpinned with strong underlying market and technology assumptions, and that innovation is proactively applied.

The narrative presented in this Roadmap can be continuously applied at a company level to inform the strategic decision making process. For example, global mining megatrends, opportunities for growth, and enabling science, technology and business changes can all be tailored and revisited as the market evolves.

Given the cyclical nature of the mining industry, METS business may gain value in conducting scenario planning. This strategic technique allows businesses to look beyond conventional wisdom and account for uncertainty about the future. Given the scale of change, business could use this technique to consider expanding their target mining markets across commodities, regions and parts of the value chain. This may help develop solutions and pathways that provide more resilience by taking advantage of the respective boom / bust cycles of each of these dimensions. Figure 22 provides a framework for applying scenarios at a company level – additional information can be found in CSIRO's *Australia 2030* report.

FIGURE 22: CSIRO FUTURES STRATEGIC PLANNING FRAMEWORK



5.1 Considerations for businesses

The five opportunities explored in Chapter 4 provide examples of differentiated and specialised areas of investment. However, unlocking those opportunities requires METS businesses to consider the following actions:

- developing the right skills, culture and processes to sustainably manage growth domestically and internationally; and
- gaining practical experiences in emerging research areas to successfully convert leading scientific and technological breakthroughs into differentiated, repeatable and operationally ready solutions.

FIGURE 23: SUMMARY OF CHANGES PER GROWTH OPPORTUNITY

	BUSINESS ENABLERS			ENABLING SCIENCE AND TECHNOLOGY
	PEOPLE AND SKILLS	CULTURE AND COLLABORATION	PROCESS AND STANDARDS	
Data driven mining decisions	Foster skills to improve interpretation, modelling and decision making using big and small datasets.	Improve how the business uses and responds to data, moving from reactive to proactive.	Address interoperability and integration issues, working with industry and research to implement appropriate data standards.	• Sensors and the Internet of Things • Analytics and optimisation • Visualisation • Cyber security
Social and environmental sustainability	Establish cross-disciplinary skills – engineering, financial, social, environmental and economic – to better demonstrate the long-term value proposition of triple bottom line solutions.	Connect miner, government, social and environmental groups to support and improve technical and regulatory decision making processes.	Assess operational and regulatory barriers that may limit social and environmental monitoring and reporting, and the associated liabilities.	• Monitoring and sensing • Decision support and stakeholder engagement • Site and equipment design
Exploration under cover	Develop geophysical and geochemical knowledge, data analysis, modelling and geographic information system (GIS) skills.	Increase multidisciplinary collaboration and support activities that improve decision making and resource governance.	Identify and promote best practice in data acquisition, processing, sharing and integration to improve data quality and reduce issues with integrating large exploration datasets.	• Next generation drilling technologies • Expanding exploration knowledge and processes
Advanced extraction	Develop skills in installing, operating and manufacturing advanced extraction technologies as well as drilling, sensing, sorting and processing technologies.	Improve alignment of performance drivers and foster interdisciplinary collaboration across mining, metallurgical and geological personnel.	Support development of regulatory frameworks for advanced extraction technologies, including standards for interoperability of technologies.	• Advanced drilling and cutting technologies • Sensors and ore sorting • Integrated beneficiation technologies
Mining automation and robotics	Foster skills in the operation and maintenance of autonomous and robotic equipment; develop technical expertise in material sciences and nanotechnology.	Challenge the role of automation and robotics in mining, and use change management to address cultural acceptance of technologies.	Support sector wide actions to address interoperability issues, leveraging existing initiatives e.g. AMIRA (P1025), EMESRT and GMSG projects.	• Machine vision, materials and robotics • Control systems and algorithms • Virtual and augmented reality

5.2 Positioning the sector for future success

While the report has largely focused on opportunities from an individual business perspective, the long-term success of the METS sector will require the development of new business, scientific and technological knowledge and capabilities, and effective collaboration across the sector.

A key vehicle for achieving this is the METS 10 Year Sector Competitiveness Plan and the key programs of work and six industry knowledge priorities (IKPs) that have been identified. Through participation in the national METS workshops and close collaboration with METS Ignited, this Roadmap and the growth opportunities identified aim to build on and support the IKPs.

The first three IKPs relate to world-class capability and leadership and have been broadly explored through the enabling business changes within each opportunity discussion (Chapter 4).

The importance of collaboration in achieving the long-term vision for Australia's METS sector cannot be understated.

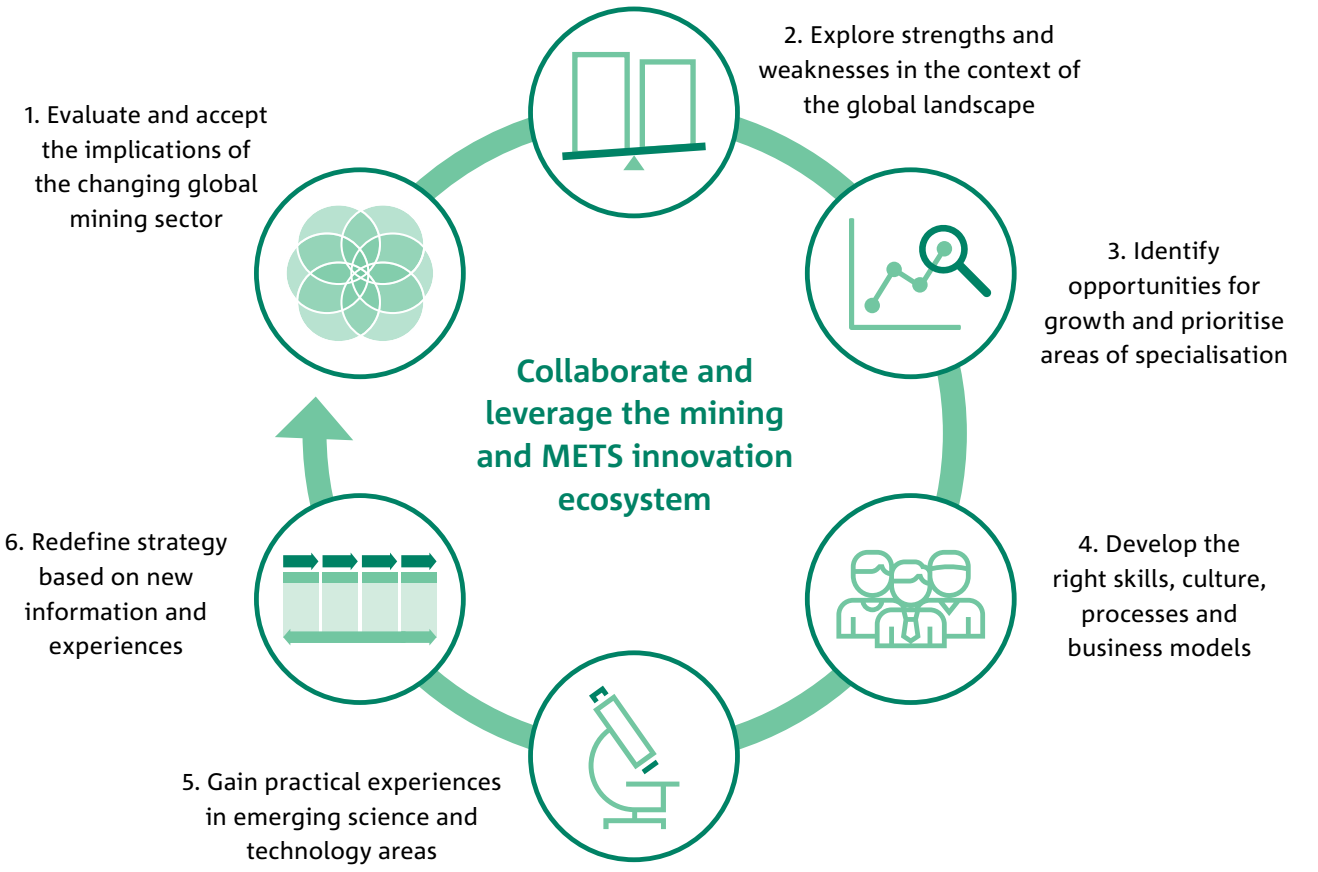
All players across the ecosystem will need to take practical steps to develop connections and overcome existing collaboration barriers.

From a science and technology perspective, the research community will need to ensure projects are well aligned to industry needs and that technologies are developed for market pull rather than technology push. This includes streamlining and improving the approach to industry partnership, ensuring the research engagement process is efficient and not overly complicated or onerous on industry.

CALL TO ACTION

Working together, the Australian METS sector is well placed to succeed. METS businesses will need to take calculated risks and invest in the future, and can use this Roadmap and the SCP as a tool for sustained competitive advantage.

FIGURE 24: USING THE METS ROADMAP



Appendix

Appendix

A.1 Comparative advantages and related disadvantages for Australian METS

AUSTRALIA'S MINING INDUSTRY

Australia's mining industry, the primary buyer of METS products and services, is a source of significant comparative advantage for the sector.

- Australia's mining industry operates nearly 400 mines and produces Australia's largest exports.[116] For example, in FY2016, iron ore was Australia's largest export, accounting for $47.8 billion and over 15% of Australia's total exports.[117]
- Australia has a rich and diverse mineral endowment including the world's largest resources of gold, iron ore, lead, nickel, rutile, uranium, zinc and zircon. Australia produces all major metals.
- Australia's mining industry is the world's leading producer of bauxite, ilmenite, iron ore, rutile and zircon.
- A need for increased productivity is compelling the mining industry to focus on innovation, which can be supported by the METS industry.[118]
- METS companies can operate in allied sectors during the cyclic downturn of the mining industry.

Related disadvantages – hard times

- The cyclical or 'boom / bust' characteristics of mining industry directly impact the METS sector, both in Australia and globally. Austmine's 2015 National Survey (n=432) highlights the impact of the cyclical mining industry, with 79% of METS reporting a decrease in revenue and 61% reporting a decrease in profitability due to the recent downturn.[119]
- Decline in commodity prices has forced mining companies to wind back or abandon new projects that would have engaged the METS sector.
- Australian mining companies currently have a low appetite for risk which undermines the sector's ability to innovate.[120]
- Barriers restraining mining innovation include long project lead times and lack of national regulatory harmonisation.
- Isolation from other geographic markets has reduced the need in the past for many Australian METS businesses to aggressively position themselves on the international stage.

EXPERIENCED WORKFORCE

Australia's strong history in mining together with its high quality education and training system supports the following advantages:

- World-class mining and engineering tertiary education courses produce skilled graduates for the METS industry. Australia is home to 8 of the world's top 50 universities in mineral and mining engineering.[121]
- Strong and innovative METS capabilities and technologies applicable across a diverse range of commodities.
- Highly skilled and experienced METS workforce that is well positioned to capture opportunities created by increasing stability in global mining jurisdictions.
- Specialised knowledge and expertise on state-of-the-art locally developed technologies.
- Regional clusters of expertise, such as Australia's recognised strength in drilling and related services.

116 Geoscience Australia (2016). *Minerals Basics,* [Online] Available from: http://www.ga.gov.au/scientific-topics/minerals/basics Accessed 19/12/2016.

117 Thirlwell, M., (2017), *Australia's export performance in 2015-16,* Australian Trade and Investment Commission, [Online] Available from: https://www.austrade.gov.au/news/economic-analysis/australias-export-performance-in-2015-16

118 Matysek, A., & Fisher, B., (2016). *Productivity and Innovation in the Mining Industry*, BAEconomics.

119 Austmine (2015). *New Realities, Bigger Horizons - Australian Mining Equipment, Technology and Services (METS) National Survey.*

120 METS Ignited (2016). *Mining Equipment, Technology and Services - 10 Year Sector Competitiveness Plan (SCP).*

121 QS (2016). *QS World University Rankings by Subject 2016.* Quacquarelli Symonds Limited. [Online] Available from: http://www.topuniversities.com/university-rankings/university-subject-rankings/2016/engineering-mining Accessed 19/12/2016.

Related disadvantages – low levels of collaboration and 'traditional thinking'

Despite having a skilled and experience workforce – collaboration within and between the METS, mining and research sectors could be improved, particularly to ensure that appropriate levels of skills are available as the mining cycle changes:

- While Australia has strong education institutions, alignment of courses with METS businesses combined with low enrolments (cyclical in nature)[122] requires greater attention and collaboration between mining, METS and universities.
- Less than half of Australian METS companies report collaborating with mining companies, universities and other organisations on R&D.[123]
- Comparatively low levels of collaboration in the sector result in METS companies extrapolating the needs of their customers based on general trends, often leading to solutions developed in isolation and a technology-push approach.
- The METS sector has a high proportion of SMEs and relatively few networking forums to discuss strategic issues within the industry, resulting in comparatively low business-to-business collaboration which impacts the sector's ability to evolve and innovate.[124]
- Relationships within the sector between METS, mining and research sectors are often characterised as transactional rather than strategic, discouraging innovation and forcing price minimisation.
- Strong competition for skilled staff from other sectors.
- The 'traditional thinking' of some METS businesses is being challenged by a range of new entrants within and outside of the traditional METS sector.

INNOVATIVE RESEARCH SECTOR

Australia's world-leading research organisations, together with its technologically sophisticated domestic mining and METS companies have helped to:

- Foster a truly global reputation for Australian excellence and leadership in mining research, with a unique blend of institutional technology and R&D capability, including publically funded research organisations, government agencies and university based specialist centres.
- Develop a uniquely Australian capability to research the entire mining process and value chain, enabling impact through integrated systems innovation.[125]
- Attract world-leading development in transformative technologies such as in the areas of automation, remote operations, materials handling and machine learning.
- Develop and nurture high quality informational mining assets – such as Australia's high quality geosciences information.

Related disadvantages – poor translational outcomes

Despite having some of the strongest mining related research institutions in the world, the sector has:

- Weak translation of mining research into commercial outcomes and innovation, with a poor track record for commercialisation and innovation. Mining companies are often reluctant to be first to trial new technologies due to the additional risk that failure may impact cash flow or social licence. Because of this, many mining companies aim to be second to adopt innovations, being 'fast followers'.[126]
- Long innovation cycles particularly for the development of new equipment
- Capability and planning risks resulting from the cyclical nature of the industry and the resulting changes in priority by mining companies.
- High cost of failure and a lack of risk sharing mechanisms, for example as exists in the petroleum industry.
- High rates of digital and technological change which no longer creates a barrier or unique advantage for Australia. Ideas can now be applied quickly and come from anyone, located anywhere in the world.[127]

122 Minerals Council of Australia (2016). Submission to the Australian Government discussion paper: Driving innovation,fairness and excellence in Australian higher education. [Online] Available from: https://submissions.education.gov.au/Forms/Archive/AHE/Documents/8.%20Minerals%20Council%20of%20Australia.pdf

123 Austmine (2015). *New Realities, Bigger Horizons - Australian Mining Equipment, Technology and Services (METS) National Survey.*

124 METS Ignited (2016). *Mining Equipment, Technology and Services - 10 Year Sector Competitiveness Plan (SCP).*

125 Australian Trade and Investment Commission (2014). *Resources research and development*. Australian Government.

126 Monitor Deloitte (2016). *Innovation in mining Australia 2016*.

127 Edmands, P (2015). Advantage Australia: harnessing our comparative advantage in resources and the METS sector – Austmine 2015, Brisbane. Rio Tinto. [Online] Available from: http://www.riotinto.com/documents/150519_Speech_Austmine2015_Phil_Edmands.pdf Accessed 23/02/2017

FAVOURABLE ENVIRONMENT

Australia's social-economic stability and resilience, demonstrated by 25 years of uninterrupted annual growth,[128] has supported:

- Advanced environmental and social sustainability awareness and policies which have generated low impact technologies and practices that Australian companies can exploit internationally.
- Secure development of IP through low risk and well-regulated business conditions for METS companies, with low corruption, low crime and relative government stability compared to other mining regions.
- Public awareness about mining and its role as a significant contributor to Australia's economy and standard of living, and its importance to the country's future prosperity, as demonstrated in a 2014 'Australian attitudes toward mining' survey (n = 5,121).[129]
- National and State government policies, strategies and investments to develop competitive METS-focused organisations, such as the Australian Government's Industry Growth Centres initiative,[130] building on existing mining industry investments. For example, there many national and state-based funding schemes available to Australian SMEs and start-ups that support innovation and commercialisation (see Appendix A.2)
- Significant footprint of high quality mining assets being developed by Australian mining companies and international mining companies with an Australian heritage.

Related disadvantages – industry characterised by small, dispersed companies and evolving competitors

Australia's METS sector is comparatively young, with 73% of businesses established in the last 30 years,[131] leading to:

- Less resilience due to company maturity, the cyclical nature of the industry and national challenges. For example, Austmine's 2015 National Survey highlights that the cost of doing business in Australia is a key challenge for nearly half of Australia's METS businesses.[132]
- A larger proportion of SMEs, compared to the global METS sector, which is dominated by established and large international companies. Australian SMEs find it difficult to break into local and global supply chains.
- SMEs that develop strong growth are sometimes acquired early by international companies who do not necessarily continue to develop their products and services locally.
- A large proportion of METS companies that are yet to maximise value, due to typically long innovation cycles.[133]

128 Australian Trade and Investment Commission (n.d.). *Invest in Australia - Why Australia.* [Online] Available from: http://www.austrade.gov.au/International/Invest/Why-Australia/Growth Accessed 19/12/2016

129 Moffat, K., Zhang, A., & Boughen, N. (2014). *Australian attitudes toward mining: Citizen survey–2014 results,* CSIRO.

130 Australian Government, Department of Industry, Innovation and Science website, *Industry Growth Centres,* [Online] Available from: https://www.industry.gov.au/industry/Industry-Growth-Centres/Pages/default.aspx

131 Austmine (2013). *Australian METS Sector – Economic Powerhouse and Australian Owned.* [Online] Available from: http://www.austmine.com.au/News/articleType/ArticleView/articleId/1660/Australian-METS-Sector-Economic-Powerhouse-and-Australian-Owned Accessed 19/12/2016

132 Austmine (2015). *New Realities, Bigger Horizons - Australian Mining Equipment, Technology and Services (METS) National Survey.*

133 Australian Trade and Investment Commission (n.d.). *Invest in Australia - Why Australia*. [Online] Available from: http://www.austrade.gov.au/International/Invest/Why-Australia/Growth Accessed 19/12/2016

A.2 Co-contributing funding schemes for Australian SMEs and start-ups

Many of the activities recommended in this report require investment in R&D. In addition to the R&D tax incentives available, the figure below lists national and state-based funding schemes available to Australian SMEs and start-ups that support innovation and commercialisation.[134]

FIGURE 25: NATIONAL AND STATE-BASED FUNDING SCHEMES

PROGRAM			PROJECT	
NAME	STATE	VALUE	SME CONTRIBUTION	ELIGIBILITY / NOTES
Innovation Connections	All	< $50k	1:1 cash	• $1.5m - $100m turnover, 3+ years in business. • Grants available for researcher, business researcher and graduate placements.
CSIRO SIEF STEM+ Business	All	< $105k p.a.	1:1 cash	• $1m - $100m turnover. • Projects delivered by early-career researchers.
Accelerating Commercialisation	All	< $1 mil	1:1	• < $20m turnover. • Funds commercialisation, not research and development.
ICon Proof of Technology grant	ACT	$5k-30k	1:1 cash and/or in-kind	• < $2m turnover.
ICon Accelerating Innovation grant	ACT	$5k-10k	1:1 cash and/or in-kind	• < $2m turnover.
TechVouchers	NSW	< $15k	1:1 cash	• < $30m turnover, < 20 employees, 1+ years in business. • Preference for companies not previously engaged in research.
BISI Innovation Voucher	NT	< $25k	40%	• < 100 employees.
Knowledge Transfer Partnerships	QLD	< $50k	1/3 cash	• < 200 employees, 2+ years in business. • Research performed by KTP eligible graduates.
Innovation Voucher program	SA	$10k -$50k	1:2 or 1:1	• < $200m turnover, 1+ years in business. • Contribution 1:2 for SMEs below $5m.
Business Transformation Voucher	SA	< $50k	1:1 cash	• 1+ years in business. • Can include developing new business models or R&D.
BioSA Industry Development program	SA	$50k-250k repayable		• Early-stage/start-ups. • Bioscience and related industry sectors.
SBDF Start-up business grant	SA	< $20k	1:1 cash	• To contribute to starting a new business or buying a business.
SBDF Business Expansion grant	SA	$10k-100k	1:1 cash	• < 20 employees, 1+ years in business.
Innovation Vouchers	WA	< $20k	At least 20%	• < $500k turnover, < 200 employees.

134 For more information on the funding schemes available to Australian SMEs and start-ups see CSIRO's SME Connect Program http://www.csiro.au/SMEConnect

A.3 Further reading

The following reports provide deeper insights into some of the specific trends and concepts covered in this Roadmap:

1. METS Ignited, 2016. *Sector Competitiveness Plan*.
2. Austmine (2015). *New Realities, Bigger Horizons - Australian Mining Equipment, Technology and Services (METS) National Survey*.
3. Francis, E. (2015). *The Australian Mining Industry: More than Just Shovels and Being the Lucky Country. IP Australia*.
4. McKinsey Global Institute, 2012. *Beyond the boom: Australia's productivity imperative,* McKinsey & Company.
5. Durrant-Whyte, H., et al, 2015. *How digital innovation can improve mining productivity,* McKinsey & Company.
6. Franks, D.M., et al, 2013. *Designing Mining Technology for Social Outcomes: Final Report of the Technology Futures Project*.
7. Australian Academy of Science, 2012. *Searching the deep earth A vision for exploration geoscience in Australia*.
8. Farrelly, C T., Ballantyne R J. (2016). *Achieving Interoperability across the Minerals Value Chain, Phase 1 – Surface Mining Equipment, P1025 Summary Report*, AMIRA International, Australia.
9. Davis, R., Franks, DM (2014). *Costs of Company-Community Conflict in the Extractive Sector.* Corporate Social Responsibility Initiative Report No. 66. Cambridge, MA: Harvard Kennedy School.

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This Roadmap is the third of a series of roadmaps that are being developed by CSIRO.

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- Medical Technologies and Pharmaceuticals – A Roadmap for unlocking future growth opportunities for Australia.
- Food and Agribusiness – A Roadmap for unlocking value-adding growth opportunities for Australia. (*in development*)
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