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Unlocking Australia's resource potential

Innovation in the energy and mineral resources sector

A report by CSIRO Futures November 2015

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Foreword

Energy and mineral resources have been fundamental to Australia's economic growth and prosperity for many decades. However, these two sectors are currently facing significant shortterm and long-term challenges, driven by changing market conditions, greater social expectations, and deeper and more complex to access resources.

At the same time, a new generation of disruptive science and technology is creating rapid change that will likely lead to fundamental shifts and the emergence of new business models. This creates an enormous opportunity, not just for Australia's primary industries, but also for the services sector to harness these new technologies and develop solutions for the global resources market.

While there are many levers that can be considered to address these challenges and opportunities, it is our belief that innovation is the most important one in the long run. Historically, innovation has driven significant value creation in the resources sector. It has contributed to the discovery of new ore bodies and oil and gas reservoirs and unlocked previously unprofitable ones. Over the past century, innovation has led to massive increases in output and productivity – shifting the sector from being heavily labour-intensive to being increasingly mechanised and automated at a scale that would have been unimaginable in the past.

But Australia cannot afford to rely solely on past and present solutions for future growth and competitiveness. Successfully navigating the road ahead will require overcoming a number of barriers that are holding the resources sector back from recognising the full value of innovation. It will also require tackling Australia's innovation dilemma, the systemic challenge of translating innovation inputs to profitable outcomes for industry.

In fact, one of the most important findings of the report is that innovation success often hinges on collaboration across a strong and high-performing ecosystem of players. Major breakthroughs are typically underpinned by a series of developments - achieved over at least a decade - that require enduring partnerships and capabilities that effectively integrate a series of small and large ideas and technologies. This reinforces the importance of a long-term commitment from industry, leadership from the Government, technology capabilities within the services sector, and new knowledge creation through

the broader research community. It will also require the cross-fertilisation of ideas via new collaboration models that build and harness the full range of innovation capabilities across the nation.

As Australia's national science agency, CSIRO has a key role to play in addressing some of the structural issues that impede the effectiveness of the wider innovation ecosystem. This includes playing a stronger collaboration and integration role; and promoting increased mobility and exchange of people and know how across industry, government and research organisations.

While this report offers considerations to improve innovation performance at a company level, it ultimately stands as a call to arms. Maintaining Australia's place in the global resources sector requires bold innovation leadership and investment now. Together we have the potential to unlock a new wave of growth; one that builds on Australia's resources legacy, and one that creates a new benchmark for the sector of the future. Our future success will be determined by the decisions we make from here forward and the quality of the innovation conversation that underpins them. We look forward to playing our part in that conversation.

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Executive summary

According to the World Bank, innovation "is the main source of economic growth, it helps improve productivity, it is the foundation of competitiveness, and it improves welfare."⁽¹⁾ Companies that innovate grow faster⁽²⁾ and are more profitable⁽³⁾ than those that don't. Studies also show that innovation is the number one driver of productivity in the Australian oil and gas industry.⁽⁴⁾

Innovation has been instrumental in the development of energy and mineral resources, which are significant contributors to Australian economic growth and prosperity. Despite only accounting for around 10% of GDP, the resources sector (including minerals, oil and gas) contributed one-third of Australia's income growth between 2005 and 2011⁽⁵⁾ and is responsible for more than half of all Australian exports by value.⁽⁶⁾ Australia is the world's second largest producer of iron ore⁽⁷⁾ and second largest exporter of coal by tonnage.⁽⁸⁾

Going back further, innovation has played a key role in the growth of the resources sector and has often been a major factor in overcoming challenges and unlocking value. It can (literally) move mountains:



- Innovation can help discover new resources: Regolith and geochemistry advancements aided in the discovery of 14 Australian gold deposits, two of which were valued at over \$12 billion.⁽⁹⁾
- Innovation can unlock previously uneconomic resources: Horizontal drilling and hydraulic fracturing opened up shale gas production, doubling global estimates of remaining recoverable gas reserves.⁽¹⁰⁾
- Innovation can optimise operations: Longwall mining automation in the Australian coal industry delivered a 5–10% increase in productivity, adding \$1 billion in export value.⁽¹¹⁾
- Innovation can create completely new markets: The development of liquefied natural gas (LNG) created a new globally tradable energy source, which accounted for \$14.6 billion in Australian export revenue in 2013-14.⁽¹²⁾

Despite this innovative history, many resources companies struggle to realise full value from their innovation investments. For example a 2014 survey of senior decision makers found that 33% of mining companies rated new technology introductions into the business as not very successful or a general failure.⁽¹³⁾

For Australian resources companies, some of this is due to Australia's own innovation dilemma. Australia ranks 81st (out of 143 countries) in innovation efficiency,⁽¹⁴⁾ which measures how well innovation inputs are converted into outputs, and near the bottom of the OECD in the percentage of science and technology graduates and in innovation collaboration.⁽¹⁵⁾

However, there are also a number of sector-specific barriers that make innovation in the resources sector particularly challenging. This report attempts to provide insight into these barriers and to identify opportunities to improve innovation performance in the resources sector.

To accomplish this, interviews were conducted with 26 senior industry leaders, including Chief Executives, Board Members and General Managers of Research and Development, across Australia's largest minerals and energy companies. Synthesis these interviews suggested ten major innovation barriers across four broad categories:

- **Strategy** e.g. innovation strategy is often aligned with a short-term focus dictated by shareholders.
- Investment Timing e.g. innovation investment is often not maintained through the business cycle, leading to reduced spending during economic contractions.
- People and Culture e.g. the industry's conservative appetite for risk and the cost of potential failure make the risk-taking that is inherent in innovation more difficult.
- Collaboration e.g. there is often a disconnect between industry's needs and what research organisations are prioritising.

These interviews were supported by an extensive literature review and analysis of historic innovations in the resources sector, which identified a number of common traits behind past innovation success stories. In each case, collaboration played a large and important role, with suppliers, research institutions and government supporting industry efforts. Successful innovations required measured risktaking and perseverance through failures, setbacks and the short-term effects of the business cycle. And game-changing innovations often had a visionary leader who recognised the long-term opportunity early and inspired others to join the effort.

These successful traits were often directly at odds with the current barriers uncovered in the interview process, suggesting that they could give insight into overcoming these barriers. However, every company is different and innovation isn't a 'one size fits all' proposition. It needs to be tailored to the unique strategy and needs of and organisation. Therefore, rather than presenting a set of generic recommendations or a rigid framework, the report concludes with a set of questions that may be helpful for organisations seeking to critically review their current approach to innovation, such as:

- Has the company identified the areas where it will be an innovation leader or fast follower, versus areas where it will be a late adopter?
- Is there a historic track record of maintaining exploration and innovation investments through the business cycle?
- Are senior managers seen as champions for innovation? Who are the innovation champions at all levels who actively seek to improve the firm's capacity to innovate?

 Are novel collaboration approaches, such as corporate venturing and open innovation platforms, being used to discover emerging research and technologies?

Australia's resources sector can continue to be a major driver of economic growth, but to do so it will need to address the major opportunities and challenges it faces today. Innovation and early adoption of new technology will play a large role, supported by Australia's strength in minerals and energy research. By analysing the barriers that are holding this back and identifying ways to potentially overcome them, this report attempts to provide a useful framework for moving forward.





1 The value of innovation

Innovation is one of the most important factors in creating long-term economic growth and sustainability – at both a national level and within individual firms. It can be defined as *the implementation and maturation of a new idea that generates short and long-term business value*.

According to the World Bank, "innovation has always played a decisive role in the economic and social development of countries: it is the main source of economic growth, it helps improve productivity, it is the foundation of competitiveness, and it improves welfare."⁽¹⁾ At a national level, greater levels of research and development (R&D) investment have been found to correlate positively with global competitiveness.⁽¹⁶⁾

The link between innovation and growth has also been demonstrated within individual companies. In a multiyear study, PricewaterhouseCoopers found that the most innovative 20% of companies they analysed grew at a rate 16% higher than the least innovative.⁽²⁾ Furthermore, the 2014 Australian Innovation System report found that innovative Australian businesses are 31% more likely to increase income and 46% more likely to report increased profitability.⁽³⁾

Within the resources sector, a study by Ernst & Young of more than 80 firms in the Australian oil and gas industry found that innovation is the number one driver of productivity in the industry (out of more than 300 variables). The same report found that firms that innovate are 40 times more likely to have productivity increases than non-innovative firms.⁽⁴⁾

In light of this, it comes as no surprise that the industry's views on innovation are overwhelmingly positive. Every one of the Australian industry leaders interviewed for this report agreed on the importance and value of innovation, with many saying that it is a key factor in optimising value from assets, mitigating against external threats and ensuring the long-term survival of a business. However, it was noted that the sector's future innovation performance and success will need to take into account Australia's innovation efficiency challenges, as shown in Figure 1.



Note: Contains 33 OECD member nations. Innovation investment scale relates to gross domestic expenditure on research and development (GERD) as a percentage of GDP, using 2013 OECD average of 2.4%. Innovation efficiency relates to Global Innovation Index – Innovation Efficiency Ratio (Percentage Ranking).

Source: Cornell University, INSEAD, WIPO, 2014⁽¹⁴⁾; OECD, 2014⁽¹⁸⁾

Innovation is seen to be particularly important today, as the investment phase of the recent resources boom comes to an end and the industry shifts its focus from large capital investments to controlling costs and increasing productivity. It can and should play a key role in helping companies face many of their formidable challenges and open up new opportunities. For example:

Accessing deeper, more complex resources – In the minerals sector, as shallow resources are diminished and ore grades decline, companies are forced to dig deeper and develop new techniques to allow ore to be extracted and processed profitably. In energy, both deep offshore deposits and onshore unconventional gas deposits require

Increasing productivity and controlling

new technology and new processes.

costs – Multifactor productivity in the resources sector declined by 35% between 1994-95 and 2012-2013 (see Figure 2). This is partially due to investment in long-term capital assets that have yet to increase outputs.⁽¹⁵⁾ Unless this trend can be reversed, Australian companies risk losing future investment dollars to operations in lower-cost, more efficient countries.

Competing globally – China is now the world's largest producer of gold, iron ore and coal.^(7, 20) Investment in new production capacity in non-traditional mining countries is increasing; Chinese investment in Africa's mining sector totalled US\$15.6 billion in 2011, a tenfold increase from the previous year.⁽²¹⁾ Similarly, North American shale oil and gas production is reshaping global energy market dynamics.

Maintaining a 'social licence to operate' – Worker health and safety, and environmental sustainability will continue to be important challenges that resources companies will need to address in order to maintain a social licence to operate. Addressing substitutes – As potential substitutes such as renewable energy and recycled metals become cheaper and more viable, they could fundamentally alter markets and displace demand for traditional resources.

Harnessing transformational

technologies – A new generation of disruptive digital technologies have already made their mark by replacing traditional business models and creating opportunities for new entrants. While this trend started with information and services-based sectors, such technologies are already set to transform manufacturing (with 3D printing) and other heavy industries (through robotics).

To get a better sense of how innovation and early adoption of new technologies could help overcome these challenges, this report starts by analysing the role that innovation has played historically.

FIGURE 2 MULTIFACTOR PRODUCTIVITY IN MINING AND ENERGY VS OTHER SECTORS Source: ABS, 2014⁽¹⁹⁾



- Financial and insurance services
- Wholesale trade
- Construction
- Transport, postal and warehousing
- Professional, scientific and technical services
- Manufacturing
- Information, media and telecommunications
- Electricity, gas, water and waste services
- Mineral and energy resources

worked basis. Index equals 0 for base year 1994-95. Mining and energy resource data relates to multifactor productivity for ANZSIC Division B – Mining (e.g. extraction of coal, ores, petroleum and gases).

1.1 The historical perspective

Perhaps contrary to commonly held views, this report makes a case that throughout its history, the resources industry has continuously and successfully applied innovation to solve many of its largest challenges and to open up major opportunities. This has been true from the earliest use of sieves in the Ballarat gold fields and shovels in coal mines to the modern use of automation and digital technologies. To illustrate this point and to attempt to gain insights into how innovation works in the sector, a detailed analysis was conducted of four historical case studies. Each of these case studies highlights a different mechanism through which innovation created longterm value, as shown in Figure 3:



Regolith and geochemistry – Discovering new resources

Breakthrough innovations in exploration led to the discovery of new ore deposits and allowed increasingly accurate characterisation of these resources. Regolith and geochemistry, which is now widely used in Australia, has led to a range of discoveries, two of which were new gold deposits worth more than \$12 billion.⁽⁹⁾



Shale gas – Unlocking resources

Innovations in horizontal drilling and hydraulic fracturing opened up unconventional resources that were previously too difficult or expensive to extract. This created billions of dollars of value worldwide, opened up new sources of export revenue for Australia, and reduced the United States' dependence on foreign energy sources.



Longwall mining – Optimising operations

The innovations that led to a new method for mining coal (longwall) greatly improved resource recovery in Australia's coal mining industry and increased labour productivity. Further innovation in longwall automation, driven by a pre-competitive industry effort over the last decade, has led to even lower costs, improved worker safety and generated an estimated \$1 billion in Australian coal export value.(11)



Liquefied natural gas (LNG) – Creating new markets

Major disruptive innovations, such as the development and commercialisation of liquefied natural gas (LNG) in the mid–20th century, allowed natural gas to be easily stored and transported. This opened up new downstream markets and enabled new uses for a resource that had previously been limited to localised applications.

Additionally, each case study provides a number of unique lessons on what was needed for innovation to be successful. Further analysis of these lessons revealed a number of common and closely intertwined characteristics that underpin these innovation success stories:

Strong collaboration

Significant collaboration between companies and researchers often brought together previously disconnected technology or research. In some case studies, this was deliberately planned; in others, it happened on an ad-hoc basis.

Non-linear journey

The innovation journey, or lifecycle, often took many decades. A lack of understanding of this journey often falsely promotes the idea that innovation occurs in somewhat discrete and sudden events. However, in most case studies, value was captured through a series of small and large – and sometimes unrelated – innovations that when applied together, had a significant impact.

Perseverance

Nearly all innovative projects suffer major setbacks and failures, and outside criticism throughout their journey. Despite this, successful innovators maintained an unrelenting focus on succeeding.

Visionary leadership

Early foresight and a clear understanding of the opportunity allowed innovators to move early and inspire others to join them on the journey. These visionaries took a long-term view, often foregoing obvious short-term opportunities in favour of a bigger prize.

Measured risk-taking

Innovation is an inherently risky activity. Calculated short and long term risks were often the differentiating factor between those who succeeded and those who failed.

Government participation

Governments frequently play a role in innovation. They invest in opportunities that build the economy through export revenues and job creation, and that improve social well-being and environmental sustainability: two areas often improperly accounted for in economic valuations. In many cases, these goals complement industry's profit-seeking objectives, presenting opportunities for greater collaboration between government and industry.

These characteristics give some clues to harnessing innovation to address today's opportunities and challenges, and to overcoming the major barriers (see section 2).

The following pages present a high-level summary of each case study that outlines the enabling innovations, the impact they had on the industry, and the key insights that can be applied to future innovation efforts.

Regolith and geochemistry Discovering new resources

The prevalence of regolith (or deeply weathered bedrock, soil and sediments) across much of Australia (~80%) and other parts of the world presents a challenge when searching for new mineral deposits. However, increased understanding of regolith and geochemistry through a strategic and multi-disciplinary research effort has led to practical methods and refined models that have been adopted and applied by industry to facilitate the discovery of new mineral deposits. This research was greatly supported by parallel advances in technology which provided higher-resolution data (spatial and chemical).

Background

Regolith is formed by natural weathering, erosion, and the constant movement and deposition of soil and sediments. Regolith cover is complex, and can vary in thickness from a few centimetres to more than 100 metres deep.⁽²²⁾ This complexity has been perceived as a hindrance to exploration, adding expense and risk to the discovery process. As a result, vast areas of Australia and other parts of the world remain unexplored.

The importance of understanding the relationship between regolith–landscape formation and geochemical dispersion

processes (i.e. exploration geochemistry) was recognised in the 1950 and 1960.⁽²³⁾ However, the value of this understanding was not understood until Australia's 'nickel boom' (1969–1973) prompted a surge of interest in exploring the oldest areas of Western Australia.

The breakthrough

The basic principles used in regolith mapping integrate aerial photography and satellite imagery with data from airborne systems (e.g. radar and magnetic field data, and multispectral information). These principles were adapted from Australian land system

mapping techniques established in the early 1950s – techniques that were continually refined until the 1990s.

During the late 1980s to the 1990s, geochemical exploration techniques were refined, broadening the value of regolith mapping (both 2D and 3D) and characterisation.⁽²⁴⁻³¹⁾ These improvements led to more sophisticated data analysis and presentation techniques and helped researchers develop regolith–landform models and study geochemical dispersion processes.

The 1980s witnessed the publication of many company exploration case histories. Geochemical dispersion models were used to establish generalised predictive models. The first Australian models were published by Butt and Smith in 1980,⁽³²⁾ and subsequent models resulting from CSIRO–AMIRA research are accessible on open file and scientific journals.⁽³³⁻³⁹⁾ Together, these models provide valuable information that reduces risks and costs, and contributes to decisions about future exploration efforts.

Improvements in satellite imaging and geochemical analytical techniques and instruments have played a pivotal role in advancing regolith mapping. Continuous improvement of satellite imaging technology (Landsat 1 to 4), provided increasingly higher resolution data that can distinguish between vegetation, bedrock and regolith materials.

Independent of the advances in satellite imaging was the evolution of geochemical analytical techniques, in particular the mass spectrometry (inductively coupled plasma-mass spectrometry, ICP-MS) technique. The quality of data it reported – and its ability to provide excellent multielement data – improved geochemical analytical techniques. Before mass spectrometry, up to three separate techniques were needed to collect the same range of element analyses.

Lessons learned

Adopting a multidisciplinary approach

The combination of geological, geochemical and geophysical studies played a pivotal role in developing regolithlandscape understanding. However, at the time many were unfamiliar with the combination of disciplines that were employed to source the required information to create regolith maps.^(40, 41)

Industry involvement and support

The translation of research concepts into industry value required a long term collaborative approach. For example before laterite (a form of regolith) geochemistry could be commercially applied, a number of activities were required over a 15 year period. This included orientation studies and trial application programs, multi-sponsor AMIRA projects (involving 40 companies), as well as workshops, field trips and reports.^(42, 43)

Knowledge sharing and research networks

The vast amount of regolith–geochemical studies over the last few decades are easily accessible to explorers and the scientific community in general. This knowledge has continued to evolve and was supported through strong Australian and international research networks.

Enabling innovations

1953-2000s

Australian land system mapping techniques

1972–1999

Landsat satellite and Thematic Mapper (TM) technology

1980-today

Geochemical dispersion models for mineral exploration

1883-today

Geochemical analytical techniques – massspectrometry

impact

Regolith mapping and geochemistry has led to a range of Australian discoveries, two of which were new gold deposits worth

13 deposits in WA, 1 in NT

Lead-zinc-silver 2 deposits in QLD

Mineral resource discoveries (1983-1994) aided by regolith mapping studies

The Bronzewing deposit

Traditional ground-based surveys (i.e., magnetic, electromagnetic, induced polarisation, radiometric and gravity surveys) and airborne geophysical surveys could not identify the Bronzewing deposit in the Western Australia, because of the complex regolith cover. Specifically, there was a lack of susceptibility contrast between the ore and the host rock. Instead a geochemical approach to exploration led to the successful discovery of Bronzewing which holds approximately 4 million ounces of gold⁽⁴⁴⁾ in two separate ore systems.

Shale gas Unlocking resources

Shale gas has long been a potentially large source of energy; however, a number of significant technology hurdles have stood in the way of commercial production. The geology of shale gas reservoirs was poorly understood and accessing shale gas was more difficult than conventional sources because it was spread across large areas in low-permeability rock. As a result, shale gas remained largely unproven, uneconomical and ignored by major gas producers since its discovery. It would take an energy supply shock coupled with government investment and the determination of a single independent firm to finally commercialise shale gas production at scale, greatly increasing global proven gas reserves.

Background

The first commercial production of natural gas from shale in the United States occurred in Fredonia, New York in 1821. Although it was successful, production volumes were extremely limited and there were very few developments over the next hundred years.⁽⁴⁵⁾

A number of technical achievements in the first half of the 20th century played a key role in further developing shale gas. The first horizontal well was drilled in 1929 and hydraulic fracturing (or 'fracking') was first used in 1947.⁽⁴⁶⁾ But on their own, neither of these breakthroughs proved to be enough to unlock shale gas. The major producers remained sceptical, with only a few small independent players showing interest.

The breakthrough

The 1973 OPEC oil embargo led the United States to look at new policies to deal with the looming energy crisis. Between 1974 and 1979, US government spending on energy research doubled, including the creation of the Gas Research Institute (GRI), an industryled organisation formed in 1976.⁽⁴⁷⁾

Funding through the GRI, along with production tax credits, provided the necessary incentive for collaborative R&D that led to further breakthroughs in critical technologies like microseismic fracture mapping (which improved fracture designs and simultaneous fracturing) and gave small independent producers the support needed to drill their first wells.

One of these independents, Mitchell Energy, ended up being a critical player. Through the 1980s and 1990s, Mitchell drilled wells in the Texas Barnett shale deposit and experimented with different types of hydraulic fracturing with mixed results.⁽⁴⁸⁾ In 1996, an accident in mixing fracking fluids led to a fortuitous discovery in using water-based fracking fluid⁽⁴⁹⁾ that reduced costs by up to 50% and increased production rates ten-fold on existing wells.⁽⁴⁷⁾

This improvement in hydraulic fracturing combined with ongoing advances in horizontal drilling, 3D seismic imaging, fit-for-purpose completion designs and microseismic fracture mapping proved to be the final key to unlocking shale gas. Mitchell increased its production through the 1990s and 2000s and was ultimately acquired by Devon Energy in 2002, just as major oil and gas companies started making large investments in shale gas.⁽⁴⁷⁾ The number of horizontal wells in the Barnett region grew from around 400 in 2004 to over 10,000 in 2010.⁽⁵⁰⁾

Lessons learned

Innovation is often a non-linear journey

Ultimately there was no single "step change" innovation that unlocked shale gas. It was instead the knowledge gained through a slow progression of smaller innovations and accidental discoveries (and understanding how to combine them) that finally yielded results.

The importance of government participation

By investing in the Gas Research Institute, the government provided essential funding and incentive for collaboration on major technical challenges. This gave smaller producers access to R&D resources that wouldn't have been otherwise available.

Persistence and risk taking

George Mitchell's visionary leadership and willingness to take risks were key to Mitchell Energy's persistence in developing shale gas, even through multiple setbacks and failures. He was willing to take risks that the established major players were not.

Enabling innovations

1929 Horizontal drilling

1947 Hydraulic fracturing

1967 3D seismic imaging

1970s Microseismic fracture mapping

Years of production

The unlocking of Shale gas and other unconventional energy sources has doubled global estimates of the total remaining recoverable gas resources from around 120 years of production (at current rates), to estimates of approximately 250 years of production.⁽¹⁰⁾ Total proved U.S. natural gas reserves experienced a recent growth spike – from proven natural gas reserves declining between 1973 and 1998, to proven gas reserves almost doubling between 1998 and 2013.⁽⁵¹⁾

Source: U.S. Energy Information Administration, 2014⁽⁵¹⁾

Shale gas as a percentage of total US domestic gas production has increased from 1.6% in 2000⁽⁴⁷⁾ to 40% in 2012.⁽⁵²⁾ As a result, the US has created options for energy independence, altering global oil and gas markets, and spurring other countries such as Australia to consider further developing their own unconventional resources.

Longwall mining Optimising operations

Longwall mining revolutionised coal mining with its capacity for safe, cost effective and efficient large-scale extraction. Although it is now the dominant global coal mining method, early versions and applications of the technique faced significant barriers in safety challenges and technical limitations. Although the basic principles of longwall mining can be traced back to the 1650s,⁽⁵³⁾ the development of the process was largely achieved through successive innovations across an ecosystem of miners, equipment manufacturers, and research organisations.

Background

Up until the early 1900s, most coal mining in England was performed by the 'room-and-pillar method'.⁽⁵⁴⁾ This method required the establishment and maintenance of 'pillars' in order to support mined 'rooms' underground. The pillars were later on extracted to some extent in the depillaring process, leaving some portions of pillars as ground support, primarily for safety of operations at the working faces.

Unfortunately, these pillars were created from unmined resources (e.g. coal) reducing the recovery of operations. Longwall mining offered production advantages over the traditional method as it made use of the face's own weight for extraction, rather than manual cutting or drilling and blasting. While it removed the need for pillars the process was highly labour intensive.

The breakthrough

The adoption of longwall mining began to increase with the advent of undercutting machines in the early 1900s and the longwall face conveyor in 1924. This removed the need to use picks to undercut coal and eliminated

manual loading of coal into cars for transport out of the mine.⁽⁵⁴⁾

The technology developed further with the introduction of longwall mining machines which could efficiently cut out or break up large amounts of coal. Starting with the development of the plow, first installed in 1941,⁽⁵⁵⁾ longwall mining machines evolved further with the ranging arm drum shearer or 'shearer' first used in 1954 in England.⁽⁵³⁾

Self-advancing roof supports and 'chock' roof supports in the mid-1950s addressed safety and reduced labour requirements.⁽⁵⁶⁾ However, instabilities and directional structural weaknesses resulted in several operations in the US being abandoned due to roof support failures. While Australia experienced similar issues, several mines continued technology trials eventually leading to second generation high capacity modern longwall systems in 1979.⁽⁵⁷⁾

Digital technologies in the 1980s -2000s enabled advanced on-board process control and diagnostics. However, they were highly sensitive to vibration and dust creating reliability concerns in underground operations. In the early 2000s the vision of longwall automation and remote control made progress through a project launched by the Australian Coal Association Research Program (ACARP). The fundamental technical advance was the ability for the first time to measure the 3D position in space of all longwall equipment items using sensing methods which are sufficiently robust to operate reliably in the environment. This led to the development of automation systems that provide remotelycontrolled accurate positioning of roof support shields enabling more consistent longwall operation and better control of roof conditions.

Lessons learned

Accumulation of successive innovations

Longwall mining, like many other innovations was the result of the application of many technology advancements. However, the 100 year journey is far from over with recent advancements suggesting that completely autonomous longwall mining systems will be enabled in the near future.

Sharing of risk and reward

Through pre-competitive investment into longwall automation technology, ACARP – in collaboration with equipment representatives, CSIRO and CRC Mining – shared R&D risk and IP, accelerating technology development and diffusion.⁽⁵⁸⁻⁶⁰⁾

Perseverance and a strong risk/reward posture

Challenges such as early roof support failures or issues with digital technologies in harsh underground mines led to many abandoning longwall mining. However, those that understood long term risks and rewards persevered eventually leading to a far more efficient and safer mining method.

Enabling innovations

1953–2000s Undercutting machines (early 1900s)

1924 Longwall face conveyor

> **1954** Longwall ranging arm drum shearer

1954–1970s Advances in roof support and control

> **1990s to 2010** Automation and remote control

By 1993, longwall mines had 19% higher labour productivity than room-and-pillar mines⁽⁵⁴⁾ and in 1994 longwall mining surpassed roomand-pillar extraction tonnage in the United States, setting it up to being the dominant global coal mining method we know today.⁽⁶¹⁾

Longwall mining techniques has an increased recovery rate (75% recovery rate) over conventional roomand-pillar techniques (60% recovery rate).^{(8)*}

Longwall mining has dramatically improved safety due to changes in mining practice, reduced labour requirements, and the removal of workers from dangerous areas.

Estimate of longwall production trends in Australia

Source: Cram, 2006;⁽⁶²⁾ International Coal News, 2007/2011^(63, 64)

PANLINE AND AFC

Liquefied natural gas Creating new markets

The development of LNG created a new internationally tradable energy source that could be easily stored and transported. While natural gas was initially considered to be dangerous and uneconomical, scientific and engineering progress effectively solved these challenges. In particular, innovation helped to overcome a major disaster in 1940s which set the US industry back for approximately 20 years. Today the LNG market continues to grow, serving energy needs around the world. However, its beginning required the exploitation of new scientific knowledge, the right partnerships for execution and a long series of continuous improvements.

Background

In the 19th century, dramatic economic growth caused by the industrial revolution drove a need for new and abundant sources of energy around the world. While natural gas had previously been demonstrated as a potential source of energy for lighting and cooking, it was uneconomical to transport and store and therefore couldn't compete with manufactured gas (made from coal) that could be produced near the point of consumption.⁽⁶⁵⁾

The breakthrough

A key development in LNG was a patent in 1937 by Lee Twomey that linked the scientific research related to liquefaction of gases to the industrial energy challenges, recognising that larger volumes of natural gas could be stored in liquid form.⁽⁶⁶⁾

This development combined with extensive research into materials for handling LNG storage and transfer led to the first LNG pilot plant (1939), followed

by the first full-scale commercial LNG plant (1940). Just four years after the LNG plant became operational, one of the storage tanks exploded, destroying the plant and a neighbouring town, and claiming 130 lives.⁽⁶⁵⁾

Although the failure of the first full-scale commercial LNG plant had temporarily stalled the industry, natural gas still had potential as a form of energy. In 1951, a small power company (Chicago Stock Yards) kick-started a comeback for LNG with the idea of transporting LNG using river barges within the country.(67) As the concept developed, they identified the value of close partnerships with gas processing industry experts. Their initial partner, Continental Oil Company, helped them identify the more lucrative opportunity for international LNG trade, eventually leading to a joint venture in 1955 under the name of Constock International Methane Ltd.⁽⁶⁵⁾

Under a subsidiary, extensive research, development and engineering led to improvements in gas processing, liquefaction, materials and ship design, as well as several hundred international patents.⁽⁶⁷⁾ In 1959, the United Kingdom became the first country to import LNG from Louisiana on the Methane Pioneer, a converted World War ll ship,⁽⁶⁵⁾ an investment that was shared by Constock and the U.K Gas Council.⁽⁶⁷⁾ The demonstration of energy transport at scale restarted the LNG industry, and in 1964 the United Kingdom and Algeria became the world's first LNG importer and exporter respectively using the world's first purpose-built LNG carrier.(68)

Lessons learned

Taking advantage of new scientific understanding

Twomey's patent acted as the bridge between new scientific knowledge and the industrial energy challenge. Specifically, it allowed gas to be stored near the point of consumption – satisfying demand for gas without creating more pipelines or without operating existing pipelines at dangerously high pressures.⁽⁶⁵⁾

The right skills for execution

International transport of LNG required expertise from universities – specifically to translate research results into design criteria – and from four key engineering, design and construction firms. Together, these firms had expertise in gas processing, liquefaction, plant construction, wood and insulation, naval and marine engineering and storage and cargo handling methods.⁽⁶⁷⁾

Continuous improvement

Analysis by Foss (2007),⁽⁶⁸⁾ estimated that ongoing technology and productivity improvements between the 1980s and 2000s led to a 28% decline in LNG value chain cost structure. This included technologies that enabled large scale LNG liquefaction trains at a lower unit cost and greater competition among shipbuilders and builders of regasification plants that further reduced costs.

Enabling innovations

17th century–1908 Liquefaction of gases

> **1937–1972** Refrigeration and LNG treatment

~late 1930s-1980s Materials to store LNG

1951–1959 Transportation of LNG

It is estimated that natural gas accounts for one quarter of global energy consumption, with LNG the fastest growing gas supply accounting for 10% of global gas demand.⁽⁶⁹⁾

International trade of LNG has rapidly increased with 29 importing countries and 17 exporting countries in 2013.⁽⁶⁹⁾ LNG export revenues in Australia totalled \$14.6 billion in 2013-14,⁽¹²⁾ with the North West Shelf gas project contributing over \$5 billion in taxation and royalties.⁽⁷⁰⁾ In a 2040 scenario constructed by the International Energy Agency (IEA), Australia could become one of the world's leading exporters of LNG.⁽⁷¹⁾

Inter-regional LNG exports by source in the IEA New Policies Scenario

*Other includes OECD Europe and Other Developing Asia; anticipated exports from this region are less than 1% of the total in both 2012 and 2040 Source: IEA, 2014⁽⁷¹⁾

2 Innovation isn't easy

The four case studies outlined in the last section demonstrate some of the mechanisms by which the resources sector can create value through innovation. But the road to innovation success is long and can be difficult to navigate. In each case study, the major players had to overcome significant challenges and persist in the face of initial failures. The difficulty of innovation is further evidenced by the results the resources sector is getting from innovation today. While R&D expenditure figures* alone make it difficult to determine whether companies are spending 'enough' on innovation, there is evidence that suggests they are not gaining as much value from innovation as they could (and should) be, particularly in Australia:

A survey of 105 senior managers in industries related to the resources sector in Australia found that

of respondents believed the sector was not investing enough in cuttingedge technology.⁽⁷²⁾ A survey of senior leaders from over 100 mining and services companies found while majority (~60%) believed new technology introductions into the business were successful,

of mining companies rated their new technology introductions as not very successful or a general failure.⁽¹³⁾

Globally, less than half of oil and gas executives say they have a well-defined innovation strategy, compared to 79% of the top innovators across industries.⁽²⁾ Similarly,

of mining companies implemented new innovations in a completely ad hoc or not very structured manner.⁽¹³⁾ None of the companies in BRW's list of Australia's

50 most innovative companies

are in the energy or minerals sectors, despite Australia being a global leader in both.⁽⁷³⁾

Despite nearly universal agreement amongst senior leaders on the importance of innovation, the reality falls short of the potential.

These gaps in performance could be partially due to Australia's own innovation dilemma.

Australia is ranked at the 'bottom of the top' in global innovation, placing 17th in The Global Innovation Index 2014.⁽¹⁴⁾ However, it ranks far worse in other dimensions.

Australia doesn't do a good job of converting research into tangible outcomes that generate business value

Australia ranks 81st out of 143 countries in innovation efficiency – the ratio of innovation outputs to inputs.⁽¹⁴⁾

Australian companies are woefully short on skilled technical managers and labour

Australia ranks 73rd out of 104 countries in the percentage of tertiary students graduating in fields of science and engineering.⁽¹⁴⁾

*Definitions of innovation and R&D differ across companies, across countries and across different accounting standards, making the analysis of R&D expenditures difficult and often misleading.

Who we interviewed:

By position

- 5 Non-Executive Director
- 8 Chief Executive/Managing Director
- 7 SVP or GM of Innovation
- 6 Other Senior Managers

By sector

- 10 Minerals
 - 1 Energy
 - Services and suppliers

In addition to these national issues, there are a number of sector-specific factors preventing resources firms from optimising their use of innovation. Many of the 26 senior industry leaders interviewed for this report identified significant barriers that stand in the way of greater innovation impact, both in their firm and across the industry.

Through our analysis of the interviews and literature, we discovered ten commonly described barriers to the effective use of innovation across the sector (see Figure 4). Although the relevance of specific barriers to individual companies and commodities varies, these barriers can be loosely categorised into four high-level categories, as shown right, and are described in more detail on the following pages.

Many of these barriers stand in stark contrast to the successes stories and innovation characteristics presented in the case studies in the last section. Understanding these barriers – and their root causes – can provide opportunities to address them and improve innovation outcomes.

FIGURE 4: INNOVATION BARRIERS IN THE AUSTRALIAN RESOURCES SECTOR

It is difficult to focus on innovation due to:

Strategy

Short-term focus. Focus on maximising exiting assets. Regulatory considerations.

Investment timing

Difficult to maintain investment across the business cycle. Challenge of trialling technology in the field.

People & culture

Fear of failure. Lack of an innovation mindset. Difficulty attracting

innovative thinkers.

Collaboration

Industry needs and researcher priorities not aligned. Inefficient intellectual property arrangements.

2.1 Strategy

Short term focus

One commonly occurring theme from the interviews was that strategy was – at least in part – driven by investors, who tend to be short-term focused, expecting results and judging performance on a quarterly basis. The ASX 2012 *Australian Share Ownership Study* found that in 2012, 77% of shares traded were held for five years or less, with 17% held for one year or less.⁽⁷⁴⁾ This focus on short-term results often runs counter to the long incubation and payback period for major innovation projects.

One CEO highlighted that this short-term focus has become ingrained – to the point where CEO incentive plans focus more on short-term objectives than long-term outcomes. Another executive recalled how a one or two month delay on a 20-year project resulted in the company being severely penalised on the share market. This ultimately cements an attitude of risk avoidance due to the high cost of failure, which discourages long-term innovation.

CEOs are not paid to think 10 years out...they are now being selected for their ability to do the quick fixes to get the share price where it needs to be

Focus on maximising existing assets

Many interviewees stated that their focus was on continuous improvement to maximise return from their existing capital assets, many of which have an operating life that spans multiple decades. This frequently leads companies to have a strategy and innovation portfolio that tends to be imbalanced towards short-term incremental innovations, with limited consideration for the role that larger step-change innovation could play in completely reshaping operations.

A study found that in 2013, mining companies allocated 73% of their innovation budget to incremental operational improvements.⁽⁷⁵⁾ In oil and gas, between 47% and 78% of innovations are focused on incremental improvement, depending on the business area.⁽²⁾

3

The industry does incremental innovation reasonably well but there are a range of technologies that need more than a 3 year timeframe

Regulatory considerations

A number of interviews revealed that maintaining a long-term perspective is often difficult due to the potential for changes in regulation that shape market conditions. It is difficult to confidently make long-term decisions and raise capital for long-term projects in a fluctuating regulatory environment. This has even greater effects on innovationrelated projects, due to their perceived higher levels of associated risk.

> The government needs to make longer term choices and are afraid of doing so because they are not directly rewarded for them

2.2 Investment timing

Difficult to maintain investment across the business cycle

Cyclical market dynamics can influence cash flow and alter a company's appetite for innovation. During economic expansions, innovation investment tends to be directed towards bringing new operations online and increasing volumes as fast as possible, as well as towards new growth areas.

Conversely, during economic contractions, attention focuses on using innovation for cost reduction. Several interviewees suggested that this drives a large amount of incremental improvement efforts, often at the expense of innovation projects that could help to reduce the severity of the downturn or foster greater levels of growth once the cycle swings upward.

As market conditions go down, prices also go down and organisations focus on cost and may not have the spare cash for innovation

Challenges of trialling technology in the field

Emerging science and technology must ultimately move from prototypes and lab demonstrations to large-scale pilots in the field. This is a significant challenge due to the high cost associated with disrupting production. Several interviewees suggested that this creates a 'catch 22' situation: companies don't want to accept a new technology or innovation at a site until it is proven, but it can only be considered proven once a company is willing to trial it under real operating conditions. Furthermore, the potential value of the productivity gains from most technologies is relatively small when compared with the value of the ore itself. This often results in the avoidance of trailing a completely new or untested technology.

> The challenge is to figure out how to take up the innovation without impacting production

2.3 People and culture

Fear of failure

A number of interviewees suggested that innovation is hindered by the industry's habit of risk aversion, particularly for the mining sector. There is a pervasive attitude that projects must be 'derisked' to minimise the chance of failure, which is seen as an unacceptable outcome. Although the oil and gas industry ranks slightly higher than the global average for overall behavioural risk (5th out of 15 sectors), mining sits well below the global average, ranking 13th.⁽⁷⁶⁾ This culture of risk avoidance contradicts the very nature of innovation – which carries inherent risk – and can stifle innovative ideas from even the most capable employees.

One of the biggest issues is the lack of acceptance of failure – the industry DNA is wired to focus on mitigating risk to prevent failure

Lack of an innovation mindset

A common viewpoint raised during interviews was that in order to foster a culture of innovation that permeates the entire organisation, it is important to have people at the top with the right mindset. It was suggested that senior executives and board members need to have a balance of business acumen and technical understanding in order to understand and act on the value that innovation can deliver.

> Change must be led by the CEO, but brave CEOs are becoming rare commodities

Difficulty attracting innovative thinkers

Many of the industry leaders interviewed stressed the challenge of attracting and retaining creative thinkers and innovators – both from within and outside of the industry. A commonly held view is that the industry is full of individuals with fixed mindsets who are focused on continuing to do things the way they have been done before. The industry's risk averse culture presents another 'catch 22' situation: it needs an innovative culture to attract creative thinkers; but to build an innovative culture, it needs those creative thinkers in the first place.

> The industry is filled with people who are squares – with rigid thinking patterns. There are not enough circles

2.4 Collaboration

Industry needs and researcher priorities not aligned

The view of a number of industry leaders was that the research community often doesn't focus enough of its efforts on addressing the core needs of industry. Further stressing this challenge is a misalignment between delivery timeframes, with industry often expecting results in a shorter time horizon than research organisations can deliver in. Industry and researchers often have different incentives as well, with companies focused on profit-driven outcomes and researchers focused on publications.

It is important that researchers solve industry problems, not just science problems

Inefficient intellectual property arrangements

While exclusive IP rights may be appropriate in many circumstances, in other cases, broadening access to IP can facilitate greater benefits and deliver even greater long-term financial value to the organisation that originally developed the IP. The interviews suggested that there is a misplaced understanding of intellectual property and the competitive advantage it delivers across primary producers, services organisations and research institutions. This can lead to hoarding of valuable innovations or overzealous commercial arrangements. Furthermore, some innovations in energy and mining – although patented – may be weak or easy to 'invent around', given the pace of technological change. This misunderstanding of IP can foster a culture that stifles innovation by creating a community of isolated innovators, rather than a well functioning innovation ecosystem.

There is a need to share risk – both parties need to understand what IP they bring to the table and both parties need to be sensible

3 A tailored approach to innovation

As highlighted in the preceding sections, innovation can be complex and difficult. As a result, there is no 'one size fits all' approach to delivering better innovation outcomes. Instead, innovation needs to be tailored to the unique needs of an individual company, taking into account both its strategy and tactical needs.

Despite the bespoke nature of innovation, there are a number of common elements that can be taken into consideration. As with the barriers presented in the last section, these elements can be grouped into four key factors: strategy, investment timing, people & culture, and collaboration.

These factors have been examined through a series of questions for considerations (subdivided into a number of elements identified in Figure 5). Importantly, these factors and considerations aren't intended to form a rigid framework. In fact, executives and firms that were most successful in harnessing these factors were not following a simple playbook but embarked upon a process of constant learning and fine tuning, balancing short and long term needs to find even better innovation approaches. Even the most successful innovators benefit from regularly reflecting on their performance.

While the questions that follow are by no means exhaustive, they may help organisations critically review their current approach to innovation. To cover different innovation maturity levels the questions span from the relatively simplistic to those that are far more nuanced and complex depending on a firm's objectives. These considerations should be seen as a starting point with the goal of opening up a broader dialogue around how to improve innovation performance across an organisation and sector.

3.1 Strategy

The most successful innovators have a clear innovation strategy that supports their business strategy and prioritises innovation investments across a portfolio. Choosing to prioritise particular areas of innovation investment for competitive advantage involves making a decision to become a leader or a fast-follower in that space, rather than sitting and waiting for someone else to solve the challenge first.

Importantly, it requires finding the right balance of short and long term innovation investments (e.g. incremental, breakthrough and disruptive projects) based on a company's business objectives and needs. Interviews highlighted the use of a well-balanced innovation portfolio - a powerful tool to achieve corporate growth and profit objectives without exposing an organisation to undue risks.⁽⁷⁷⁾ While the mix within such a portfolio will be company specific, one cross sectoral analysis by Nagji and Tuff (2012) suggested a 70-20-10 innovation mix achieved superior performance – i.e. 70% of investment revolving around incremental projects, 20% focused on breakthrough projects, and 10% focused on disruptive projects.(78)

Another important factor identified through the interview process was how long term market trends (within and outside of the sector) can undermine the viability of an innovation project. For example a slight change in market conditions – such as the emergence of a new technology or a sudden change in the cost of a technology - can offset the viability of what would be considered a technically successful project.

One tool that can be used to explore the implications of external market conditions is scenario planning, a tool that emerged in the resources sector following the success it provided to

Shell in the 1970s.⁽⁷⁹⁾ Used correctly, scenarios can help to identify project opportunities or risks by understanding technology and market assumptions that underpin a given project. Furthermore, scenarios can be used to identify future innovation opportunities.

Regardless of the tool used, understanding the implication of long-term trends should draw upon a diverse set of individuals both within and outside of the organisation. This ensures that trend analysis is both challenging and grounded and avoids under prediction or over prediction of future opportunities and challenges.⁽⁸⁰⁾

Future scenarios* (2015–2040)

*Illustrative scenarios

Questions for consideration

Considerations

Strategy: elements

Alignment

How well is the organisation's innovation strategy aligned and integrated with its business strategy?

Innovation priorities

What innovations is the firm leading and why?

Investment mechanism

Does the organisation have a mechanism to direct innovation investments?

Horizon scanning

How does the organisation assess long-term opportunities and challenges and how do these shape innovation priorities?

- Does the organisation have an explicit innovation strategy?
- Does the innovation strategy support the objectives and business model set out in the business strategy?
- Is the innovation strategy owned and supported by the leadership team and board and clearly communicated across the organisation?
- Is there visibility of planned innovation investments over time?

- Has the firm distinguished between the areas where it will lead / fast follow versus those areas where it will be a late adopter?
- For each area in the innovation portfolio is there a clear business case that evaluates objectives, risks and rewards?
- Is there an understanding of the innovations required to secure competitive advantage (offensive) versus innovations that are required in order to survive (defensive)?
- Is there a clearly articulated mechanism for making innovation investments (i.e. funding mechanisms) that is as robust as the mechanisms used for any other major capital project?
- Is there an agreed upon investment mix between incremental, breakthrough and disruptive innovations?
- Does this investment mix align with the business strategy?
- Does the company have methods for measuring ROI that can appropriately account for the uncertainty of breakthrough and disruptive innovation types?

- Does the organisation have a mechanism to regularly identify and assess the impact of external market parameters and long-term trends?
- What internal and/ or external sources are used to identify potential market disruptions?
- For each major innovation project is there a clear understanding of assumptions or critical factors (external market and internal performance) that underpin project success?

3.2 Investment timing

Innovations in the resources sector can have long incubation periods. Engaging early, particularly for breakthrough and disruptive innovation projects, often requires an investment commitment of more than a decade. This can prove challenging due to the cyclical nature of the industry which often results in fluctuations in innovation investments (see Figure 7).

The ability to maintain investment is further complicated by the journey each innovation must go through before it is commercially and technically viable. One mechanism often used in understanding the implications of different investment timings is the technology readiness level (TRL) methodology. TRLs map different stages of a technology's lifecycle across 9 levels from the observation of basic principles to the innovation or technology being proven successful under a full range of operating conditions.⁽⁸¹⁾

Generally speaking, companies will seek to make innovation investments at

technology readiness levels that aligns with their strategy. Key considerations are often: appetite for risk, IP stance, investment horizon and the competitive landscape (see Figure 8).

The uniqueness of the challenge or opportunity may determine whether there is anyone else in the innovation ecosystem who is likely to initiate the innovation process. If a firm identifies a particular innovation need in an area where no one else is willing to invest, they will likely need to make investments in technologies at a low readiness level, but this could also present opportunities to develop IP that can be used for competitive advantage. For example, one executive highlighted how early investment presented opportunities to gain and protect proprietary implementation lessons that created barriers to adoption, particularly as their lessons were tacit in nature and associated with new skills that were not readily available in the market.

*Illustrative

FIGURE 8 TECHNOLOGY READINESS LEVELS

Questions for consideration

Elements

Considerations

Risk reward posture

What is the firm's appetite for risk and expectations for returns?

IP strategy

Does the firm have an interest in acquiring ownership of IP?

Through the cycle mindset

Is the organisation willing to maintain investment for a sustained period?

Competitor analysis

Will anyone else in the innovation ecosystem initiate the innovation process?

- For each area of innovation, has the organisation explicitly articulated the risks it is prepared to take and the rewards it expects to receive?
- How well does the firm understand the full costs of innovation and benefits based on different investment timings?
- Does the firm have a mechanism for deciding at what development stage to invest?
- For each project in the innovation portfolio is there an explicit understanding of the value of owning IP versus acquiring IP through sharing or licensing?
- What has been the historic track record of maintaining investments 'through the cycle', i.e. exploration and innovation expenditure?
- Is there an understanding of the key milestones and time required to move a project through the development stages - invention, concept validation, pilot, commercial?
- Does the existing project funding model account for any short term market shocks or unforeseen problems through the business cycle?

- Is the firm looking to address a unique challenge or opportunity?
- Does the organisation have a clear understanding of key players in the market and their innovation priorities?

3.3 People and culture

Our interviews and case study analysis showed that both people (capabilities) and culture are vital to successful innovation.

Developing and delivering an innovation project requires a range of capabilities - from project management and specific scientific or technical expertise through to more general creative and innovation skills, including the ability to translate business objectives into appropriate research and development project questions (see Figure 9).

Deciding whether to source or develop these different capabilities in-house or through an external partner depends on a range of factors. For

example, the decision will be driven by a comparison of internal strengths against the strengths of potential partners in the innovation ecosystem. As with any project, sourcing the strongest possible capabilities will be preferred. However, this will also need to be balanced with a second consideration regarding whether there is a long-term advantage to the firm of developing the skills and capabilities internally to build or improve core competency in a new or existing area.

A failure to address the cultural aspects of innovation can result in projects being stifled early in their journey, or worse yet, not even being initiated. Innovation

starts with the 'tone at the top', where senior executives actively seek to improve the firm's capacity to innovate and champion key strategic innovations.

Governance and incentives play an important role as well; innovation achievements should be celebrated internally and externally with appropriate recognition and reward provided at both an individual and team level. Open discussion about past successes and failures can help an organisation learn and adjust accordingly. A mature attitude to risk awareness and management ensures that new ideas are constantly developed and explored.

FIGURE 9 PEOPLE AND CULTURE INPUTS

Leadership, creativity, business acumen, technical prowess, collaboration, learning.

Attitude to risk, rewared and recognition, governance, empowerment, partnerships.

Questions for consideration

* Many of these considerations are based on select findings from CSIRO's Innovation Roadmap which provides a research-based framework that enables organisations to identify their current capacity for innovation, their desired future state and key areas for improvement.

3.4 Collaboration

Collaboration plays an important role in sharing risk across stakeholders, gaining access to all requisite capabilities, crossing conventional technology boundaries, and improving outcomes.

In the area of R&D and innovation, collaborative approaches have been shown to deliver superior results. The GE Global Innovation Barometer 2014 found that 64% of companies collaborating with external partners on innovation activities report larger annual revenues and that 77% of executives believe that the risks associated with innovation collaboration are worth taking.⁽⁸²⁾ Similarly, the Australian Innovation System report 2013 shows that in 2010-11, 32.7% of Australian businesses that used innovation in the absence of collaboration reported a year on year increase in productivity, while this figure jumped to 62.9% for innovation active businesses that also collaborated (including public research organisations).⁽⁸³⁾

Despite the wealth of evidence that demonstrates the value of innovation collaboration, there are indications that the Australian innovation ecosystem is not leveraging collaboration as well as it could, as Australia continues to rank near the bottom of the OECD for all types of innovation collaboration.⁽³⁾

One of the challenges is to design fit-for-purpose collaborative models to match with each type of innovation project and each type of industry player across the global and local innovation ecosystem (see Figure 10).⁽⁸⁴⁾

The most effective collaborations are likely to involve parties from multiple

stakeholder groups working together to achieve an integrated innovation outcome. However, it is important to consider the differences in R&D drivers and objectives and attitudes relating to IP discussed below (see Figure 11).

FIGURE 10 KEY STAKEHOLDERS IN THE RESOURCES SECTOR

	Revenue model	Drivers	Technology	IP stance		
Primary producers	Discovery and production sales	Driven by ore bodies and reservoirs	Technology consumer	Generally protect IP for access not revenue		
Suppliers and service providers	Service and equipment sales	Driven by cost and relevance of opportunity	Technology producer and consumer	IP may protect competitive position		
R&D providers	R&D delivery and IP licensing	Driven by research and discovery	Technology producer	IP may protect ability to operate		
SMEs and startups	Service and equipment sales	Driven by cost and relevance of opportunity and ability to deliver	Technology producer	IP may protect competitive position		
Government	n/a	Driven by long term national economic and social performance	Technology facilitator	Little interest in IP unless it may provide national advantage		

FIGURE 11 KEY CHARACTERISTICS OF DIFFERENT STAKEHOLDERS

Questions for consideration

Key elements

Partner selection

Does the firm have a strategy for engaging with the different stakeholder groups in the ecosystem?

Collaboration models

How does the firm select appropriate collaborative models in order to achieve innovation outcomes for each specific project?

Considerations

- Does the organisation have an explicit framework that helps to determine which collaborators to use?
- Are factors such as R&D objectives and attitudes relating to IP assessed when selecting innovation partners?
- Are novel approaches being used to meet innovation objectives, e.g. incubators, corporate VCs, open innovation platforms?
- Is there an opportunity to leverage government support to solve industry wide challenges?

- Are there regular reviews of tactical collaborations to determine if a more strategic model would deliver greater value?
- Are there areas where there could be greater sharing of funding, resources and risk?
- How well does the organisation maximise on-going investment in unproven research areas to stay ahead of technology change?

4 Effective collaboration tactics

Given the importance of collaboration, this section contains a more detailed examination of the topic by providing a framework that can be used to help select appropriate collaboration models.

This framework is adapted from work by Markus Perkmann and Ammon Salter published in the MIT Sloan Management Review.⁽⁸⁵⁾ Their work provides a valuable framework for thinking about different collaboration modes based on the time horizon of the collaboration and the degree of disclosure of the research results. Their study was designed specifically to investigate collaboration between industry and universities and covered a broad range of industries. It identified four modes for collaboration: open and short-term; open and longterm; protected and short-term; and protected and long-term.

The findings of Perkmann and Salter's study can be adapted to develop a collaboration framework for the Australian resources sector that uses the time horizon of the collaboration and the degree of openness regarding Intellectual Property (IP) as the two main dimensions (see Figure 12).

Each collaboration mode has its own advantages and disadvantages. Longterm projects allow for the development of strong, trusted relationships where greater accumulation and sharing of knowledge over a longer period of time can improve outcomes. Short-term projects, on the other hand, allow for a quick response to near-term challenges.

Typically, in the resources sector, a 'short-term' innovation project would be defined as one that lasts 5 years or less, while a 'long-term' innovation project can last upwards of 10-15 years. However, there will always be exceptions. From the firm's perspective, the IP approach employed can range from completely open, where the firm cannot claim any rights on the results of an innovation project, through to completely closed, where the firm maintains full and exclusive rights of all IP that a project creates.

In protected IP collaborations, the innovating firm must take on the investment burden and risks and must select the right partners to include in the project. However, this allows the innovating firm to control the terms of intellectually property use. Alternatively, more open IP collaboration modes can help identify new opportunities from a broader range of partners and can reduce wasted investment through duplication of effort and an unnecessarily high risk burden. However, the process can go off-track and become complicated if tensions and differing opinions arise between collaborating parties.

Furthermore, a single innovation project (particularly breakthrough and disruptive ones) can apply multiple types of collaboration modes depending on the different science and technology elements required to deliver a project's vision.

The remainder of this section explores each of the quadrants of the framework in more detail and provides a few specific considerations for applying them.

4.1 Open, short-term: exploratory development

It is not always known where great innovations will come from. As such, providing an avenue for new ideas and concepts to be continually developed and tested in an open environment can lead to significant breakthroughs. This approach to collaboration can be slightly less applied in the sense that it is not always clear exactly what benefits will be derived from the technology or research findings.

Exploratory development can provide a low-risk and low-cost option (due to co-investment) for continually testing new ideas in unproven areas, and offers a mechanism to test out relationships with new innovation partners.

A large number of examples of this approach can be seen through short term projects managed by industry innovation intermediaries. For example AMIRA International, an independent association of minerals companies, acts as broker and facilitator of short and long term collaborative research projects. Exploratory development examples span from projects in specific fields (such the one year UNCOVER Stage 1 project, a geosciences effort with 34 sponsoring organisations),⁽⁸⁶⁾ to multi-disciplinary projects (such as the two year Transportable Moisture Limit for Iron Ore project with 8 sponsoring organisations and 4 research partners).⁽⁸⁷⁾

It is important to acknowledge the role that start-ups can play in this mode of collaboration due to their speed, flexibility, appetite for risk and unique perspective. This group however requires fostering which can be achieved through corporate venturing, incubators and accelerators.

Stakeholder perspectives:

Key Application:

Attract and test new partners, and ideas in unproven areas

Key Advantages:

- Low-risk, low cost
- Can be an effective means to attract and test new collaboration partners, before making more substantial commitments
- Allows for ongoing testing of new ideas in unproven areas with the potential to lead to future, larger-scale breakthroughs and opportunities

Key Challenges:

- Project benefit (i.e. return on investment) is not always clear upfront
- Relatively high failure rate

Primary producers

- Funding may be difficult as business case isn't always obvious
- At the same time, however, funding doesn't need to be substantial
- Maintaining engagement may be difficult if project milestones don't show potential for direct industry application of ideas
- Inability to control IP may further limit engagement levels

R&D providers

- Attractive to R&D providers due to the prospect of frequently publishing research results – may be more willing to co-invest
- Can be at risk of straying too far away from industry needs
- Likely to be most effective if part of a larger collaboration effort

- Suppliers and service providers can use this model to test new ideas where IP is not a concern
- Can act as a bridge between researchers and industry to help new concepts get off the ground
- More likely to be involved if activities form part of a larger collaboration effort

4.2 Protected, short-term: tactical investment

This is the area where the resources sector is currently most proficient – working with partners to solve specific challenges and develop proprietary solutions through tactical technology or research. This type of incremental innovation is generally focused on optimisation of existing assets (i.e. continuous improvement), rather than developing new breakthroughs.

For example, Xstrata Technology has been working in partnership with CSIRO for approximately three years to develop the acoustic emissions analyser allowing for real-time monitoring of Xstrata's grinding mill. Using the technology Xstrata will be able to reduce downtime and maximise process efficiency. In addition to addressing near-term productivity goals, it is estimated that even a 5% increase in the grinding process as a result of the technology would lead to substantial savings.⁽⁸⁸⁾ Outside of the traditional continuous improvement projects, a number of firms in oil and gas, such as Chevron, BP, Shell and ConocoPhillips, have corporate venturing arms that invest in small start-ups. As a result, these firms can gain access to new technologies that could significantly enhance operations without needing to commit extensive internal resources.⁽²⁾ In most of these initiatives the firms maintain significant control over IP related decisions, differentiating them from the role of start-ups in the Exploratory Development mode of collaboration. For example, Shell's GameChanger program combines elements of open innovation, incubators and corporate venturing and has so far worked with over 1,500 entrepreneurs and converted more than 100 ideas into reality.⁽⁸⁹⁾ Ideas submitted through Shell's GameChanger program may be deemed proprietary and incorporated into Shell's internal R&D funnel for direct use by the firm.⁽⁹⁰⁾

Stakeholder perspectives:

Key Application:

Address immediate operational challenges

Key Advantages:

- Proven mode of collaboration
- Benefits are clear easy to build a business case for innovation investment

Key Challenges:

- Narrow focus may overlook larger opportunities and challenges that could deliver greater benefits over the long-term
- Similarly, partners may focus on the specific issue being addressed without developing a wider understanding of the business needs

Primary producers

- Easier to fund due to lower risk (but also relatively low reward)
- Often take part out of necessity to solve specific problems, rather than because of opportunity identification
- Can use it as an opportunity to test partners for longer term projects in the future

R&D providers

- Can offer depth of research knowledge not found elsewhere but may find it difficult to align research timeframes with businesses timeframes
- Lack of opportunities to publish – may need to develop alternative incentives (e.g. follow-on projects)

- Opportunity to apply indepth understanding of industry challenges
- Many have high chances of project success due to strong project management skills
- Often provide as 'feefor-service' consulting

4.3 Open, long-term: collective action

This type of collaboration involves cross-industry collaborative groups working together to solve large, pre-competitive problems where risks are too large for a single organisation to bear or where solutions provide shared benefit to the industry. This type of collaboration is more focused on helping to improve and/or sustain the future of the entire industry rather than providing an advantage to any single company. It is therefore suited to challenges in areas such as environmental impact, social licence to operate or improved worker safety.

An international example of industry members joining forces to address mutual challenges is the Canada Oil Sands Innovation Alliance (COSIA). COSIA was formed in 2012 as thirteen companies came together to commit to sharing experience and IP in order to accelerate improvement in environmental performance through collaborative action and innovation. COSIA member companies have so far shared 777 distinct technologies and innovations that cost over \$950 million to develop.⁽⁹¹⁾

However, the Collective Action approach to collaboration doesn't always need to involve an alliance of multiple industry players. Sometimes it can involve one industry player collaborating with one or more research providers. This is the case with the four-year, \$20 million Great Australian Bight research program aimed at improving our understanding of the environmental, economic and social value of the region. It is a collaboration between BP, CSIRO, the South Australian Research and Development Institute, University of Adelaide and Flinders University. The research results will be openly published in science journals, literature and published reports. The study is intended to provide the science to decision makers (e.g. Commonwealth and State regulators and governments) to support sustainable development in the Great Australian Bight and to allow for the monitoring of possible future impacts.⁽⁹²⁻⁹⁴⁾

Stakeholder perspectives:

Key Application:

Tackle large-scale shared and/ or pre-competitive challenges

Key Advantages:

- Allows for costs and/ or risks to be shared
- Provides industry-wide benefit – increasing overall competitiveness and sustainability
- Avoids unnecessary duplication of effort across collective industry challenges

Key Challenges:

- Can be difficult to determine which challenges are best suited to collective action (firms will want to avoid giving up potential for competitive advantage)
- Projects involving multiple industry players can be difficult to manage due to competing priorities

Primary producers

- Can benefit from sharing risk – makes it easier to justify investment
- Needs strong coordination and collective leadership when multiple industry players are involved, which can be challenging amongst a group of competing companies

R&D providers

- Government funded R&D providers are more likely to invest due to public interest benefits or as a way to overcome market failure in areas where industry incorrectly values externalities
- Attractive to R&D providers due to significant opportunities to publish findings

- Can play a central role in connecting the needs of industry with research findings to develop new technologies that can make a significant impact on the industry
- Can often bring technically savvy execution resources that are able to cope in a dynamic environment

4.4 Protected, long-term: strategic advantage

There are some large problems for which a company is willing to bear a significant portion of the risk due to the potential for the innovation outcomes to deliver competitive advantage for the firm. Under such circumstances an industry player will form long-term partnerships with one or more technology or research providers but will negotiate exclusive rights.

There is a significant opportunity for firms to foster deeper relationships with partners that can be part of a longerterm journey towards increasing their overall competitiveness. In this mode partners are involved at every stage of the planning and implementation process, from the development of the innovation strategy through to optimisation following implementation. This approach can deliver significant benefits through the accumulation of shared knowledge of both industry and technical challenges and opportunities, rather than having to regularly wait for new partners to climb the steep learning curve. This accumulation of knowledge can lead to a greater ability to link science and research capabilities and solutions to industry needs. It is also more likely to foster greater trust between partners.

Rio Tinto's long-term relationships formed as part of their Mine of the Future[™] programme provides a clear example of this mode of collaboration, particularly the ongoing partnership with Komatsu working to develop advanced truck technology. In 2000-O1 Rio Tinto extended Komatsu's autonomous dump truck prototype and assessed its performance and impact on current mining practices.⁽⁹⁵⁾ A decade later (and through on-going investment during the global financial crisis), this relationship saw Komatsu sign a memorandum of understanding for the deployment of 150 autonomous trucks, with the first automated trucks deployed in 2012.⁽⁹⁶⁾ As a result, in 2011 Komatsu received a supplier recognition award from Rio Tinto.(97)

Key Application:

Address fundamental challenges that can deliver competitive advantage at a firm level

Key Advantages:

- Can deliver significant financial return through providing a sustainable competitive advantage for the firm
- Collaboration partners provide input at every stage of the project
- Partners develop intimate understanding of the business and industry

Key Challenges:

- Requires ongoing investment
- The ongoing management of long-term relationships can prove challenging

Primary producers

- Research projects align closely with business strategy and innovation needs – clear case for investment
- However, this approach requires significant, ongoing investment that can conflict with boom/bust cycles and/ or management tenure
- Can build more trusted relationships with partners

 share and draw on proprietary knowledge

R&D providers

 Allows R&D providers to build a strong understanding of business needs and challenges

Stakeholder perspectives:

- Allows for the accumulation of knowledge over time that can be central to developing solutions
- May be attracted by the potential to work on large, long-term challenges if allowed to publish noncompetitive findings

- Can apply in-depth knowledge of industry needs to develop very strong, long-term partnerships
- Can play a central role in transitioning ideas through to implementation, including project management discipline

4.5 Applying the framework

Similar to having a portfolio of innovation projects, collaboration efforts can be evaluated as a portfolio using the framework. This allows innovation projects / programs to be regularly reviewed to determine the most appropriate collaboration mode(s) and identify opportunities to move a project between different modes depending on objectives and progress.

Are there regular reviews of tactical collaborations to determine if a more strategic model would deliver greater value?

Tactical Investment is a mode favoured by many in the industry due to its ability to provide near-term benefits and control over intellectual property. However, firms should regularly review tactical investments to determine whether a deeper relationship may be more appropriate. Tactical Investment projects will help to overcome shortterm challenges and can sometimes provide a certain level of competitive advantage. However, longer and deeper relationships are more likely to deliver a competitive advantage that can be sustained over a longer period of time.

Are there areas where there could be greater sharing of funding, resources and risk?

Firms should review whether the challenges they are looking to address are shared by others in the industry and, if so, explore the potential for a Collective Action approach to collaboration. Sharing industry-wide challenges amongst multiple parties can be an effective way to share cost and risk when a project is deemed too risky for a single company to invest.

Although the discussion of collaboration modes in this section focuses on collaboration across the identified stakeholder groups, the framework can also be applied to collaboration within stakeholder groups, such collaboration between primary producers from oil and gas and mining. For example funding, resources and talent in oil and gas and mining could be shared to areas such as water and energy efficiency, exploration, and how to better utilise big data, to name a few. The challenges faced in these areas are not unique to either mineral resources or energy and therefore warrant consideration of a joint approach to developing potential solutions.

How well does the organisation maximise on-going investment in unproven research areas to stay ahead of technology change?

Exploratory Development should not be overlooked as an important part of the collaboration mix as it allows firms to identify and participate in early stage technologies with unclear benefits.

It can act as a gate way to all of the other collaboration modes, allowing firms to stay ahead of the rapid pace of technological change and avoid overlooking the new opportunities and threats this change creates. This includes testing the value and feasibility of applying innovations in adjacent sectors areas such as innovations from manufacturing, aerospace, communications, healthcare, etc.

5 Conclusion

Given the pace of change, it is likely that in the next few decades the resources sector will fundamentally reshape the way it operates. As market and operating conditions change, the sector will continue to look to innovation to create value, as it always has. A new generation of science, technology and innovation developed both within the sector and outside of it will help address a broad range of opportunities and challenges.

For example, at an operational level, the confluence of rapidly evolving digital technologies such as sensors and the internet of things, robotics and automation and big data and new IT service models (cloud computing) could completely transform operations - increasing productivity, improving worker safety, and in some cases creating new ways to extract resources (such as mining in-situ). Harnessing these technologies will drive even greater levels of competition for already scarce science and engineering talent.

A number of new technologies also have the potential to drive greater demand for some commodities while disrupting the usage of others. For example, the direct injection carbon engine (a Novel High Efficiency Low Emissions fossil fuel technology) could create a new export market for black and brown coal, stimulating demand at the expense of other sources of energy. Similarly, while renewable and energy storage technologies create major opportunities to cut operational costs in mining, they may dramatically alter oil, gas and coal usage - not too dissimilar from how radical changes in recycling could create threats to some commodities.

At a national level, advanced geosciences knowledge, capability and technology through projects like UNCOVER offer opportunities to identify and unlock valuable mineral and energy resources, creating a new pipeline for resource development and maintaining Australia's position as a leading resources nation. However, this will require coordination across industry, suppliers, research organisations and government.

Technology and innovation will also play an important role as the industry is forced to look at completely new methods of extraction such as extremely deep water oil and gas operations, floating LNG operations and sea bed mining.

While it is unclear exactly how the resources sector will change over the coming decades, it is clear that it will change and that innovation will play a central role. Firms will therefore benefit from expanding their understanding of the innovation process – a process that is by its nature extremely complex, poorly understood and difficult to master. While case studies and anecdotal experiences help to unpick the journey, they often provide only a glimpse of the true path that was undertaken to transition an idea (with very little certainty) to one that delivers value at scale (in a repeatable fashion).

Primary producers, suppliers and research organisations will all have an important role to play in helping to facilitate growth through innovation. Government action can also play a role by helping to establish the right environment that nurtures innovation, develops capability and encourages risk taking. Given the different stakeholder groups with a vested interest in the sector's future, collaboration will be vital in ensuring innovation success, alongside strategic considerations concerning innovation strategy, investment timing, capability and culture.

The complexity of the challenges ahead will require a tailored approach. As such, this report aims to open up a broader dialogue around how innovation can be better leveraged to ensure that Australia's resources sector prospers well into the future.

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