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Hidden Gems – a Patent Analytics Study on Innovation in the Australian Mining Sector

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SUMMARY

Australia is an attractive investment destination in the global mineral resources sector. With the world's largest identified resources of nine major mineral commodities, Australia's robust mining industry is a world leader. Australia is in the top five world locations as a producer of twenty important commodities, including gold, bauxite, iron ore, rare earths, mineral sands, zinc, lead and coal.

These rich resources are a mainstay of the Australian economy. Mining accounted for 7.4 per cent of Australia's gross domestic product in the 2016–17 financial year; in 2016, mineral resources made up 45 per cent of all Australian exports, with a value of \$151 billion. Innovation in the mining and mining equipment technology services (METS) sector is driven by strong global competition.

Here we use patent data to analyse innovation trends from 1997–2015 in the Australian mining and METS sector, with an emphasis on both Australian-led global innovation and filings for patent protection in the Australian market.

We identified 2997 Australian mining and METS sector inventions filed from 1997–2015. The number of patents filed by Australians peaked in 2010–12, but dropped back to 1998 levels in 2015. The top three Australian innovators, Rio Tinto, BHP Billiton and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) filed 15 per cent of total Australian patent filings in the mining and METS sector. About 58 per cent of patent filings by the top three Australian innovators are in ore refining technologies. Further technology analysis showed that the mining operations sector was the most active, with 36 per cent of total Australian patent filings.

Australian mining and METS sector inventions are primarily targeted to the Australian market. Patent filings in Australia by Australian applicants are 77 per cent greater than those filed in the second largest target market, the United States. In addition, the relative number of filings into Australia has increased compared with our previous analysis in 2015.

Analysis of Australian collaboration in patenting showed that publicly funded entities collaborate more than twice as often (12 per cent) as companies (5 per cent). Publicly funded entities collaborate more than the companies, but are also slightly more likely to collaborate internationally.

We analysed patenting activity in the light of company participation in Australia's R&D Tax Incentive. Patenting activity and R&D Tax Incentive expenditure broadly followed similar trends over time, peaking in the years around 2010 and declining thereafter. Research and development expenditure under the R&D Tax Incentive in the mining sector has grown six-fold from 2000–01, peaking in 2008–09 with an expenditure of \$3.74 billion, with large firms having an expenditure six times that of small and medium enterprises (SMEs). This was followed by a 67 per cent decline to 2015–16, which represented a ten-year low for large firms.

Patent filings in Australia peaked in 2012, and have declined slightly thereafter, although to a somewhat lesser extent than patents filed by Australians. This indicates that global activity in the Australian market is relatively stronger than Australian innovation in the mining and METS sector. Innovation in this sector leads market strength; ongoing stimulation and support of Australian innovation will help to ensure Australia's future prosperity as a global leader in the mining and METS sectors.





INTRODUCTION

Australia is a world leader in mineral resources, with the world's largest reserves of iron ore and gold, second largest reserves of bauxite and copper, and fifth largest reserves of black coal. Australia is a top-five global producer of twenty important commodities, including gold, bauxite, iron ore, rare earths, mineral sands, zinc, lead and coal. In particular, it is second largest producer of gold and alumina, third largest producer of uranium and zinc, and fifth largest producer of nickel in the world. Australia is also the largest exporter of iron ore, metallurgical coal and bauxite (Britt et al, 2017).

These and other resources are a mainstay of the Australian economy. The Australian mining industry was valued at \$138.2 billion in 2017–18 (Australian Bureau of Statistics, 2018a), with growth of 2.9 per cent (\$3.9 billion), in line with the overall growth of the economy (Australian Bureau of Statistics, 2018b). Mining accounted for around 8 per cent of Australia's gross domestic product (GDP) in the 2017–18 financial year. With around a quarter of a million people employed in the sector, and 72 per cent of Australia's exports of goods in 2017–18, Australia's resource and energy exports are likely to hit a new record high of \$252 billion in 2018–19 (Australian Government Department of Industry, Innovation and Science, 2018b).

"Because Australia is a small open economy, its comparative advantage in minerals and energy exports makes the mining and mining equipment technology services (METS) sector an important driver of broader economic growth.

We estimate that in 2015–16, the mining sector's total economic [i.e. direct and indirect] contribution to Australia was \$236.8 billion, representing around 15% of the Australian economy. This economic activity supported a total of 1 139 768 FTE jobs across Australia, which represents around 10% of total FTE employment." (Deloitte Access Economics, 2017)

This report builds on our previous patent analytics study of the Australia mining sector by Francis, 2015, which focused on determining who filed patents and in what technology areas. Francis analysed mining inventions filed in Australia from 1994–2011, during the development of the Australian 'mining boom', finding that the METS sector accounted for the bulk of the mining patents.¹ Most patent filings in Australia originated from Japan or Germany, and the primary market for Australian patent applicants was the United States. With the passing of the Australian mining boom, however, the overall picture of patent activity in the Australian mining industry has altered. Most patent filings in the mining sector in Australia are now originating from the United States, and the primary market for Australian patent applicants is now domestic.

This report uses patent data to analyse innovation in the Australian mining sector over the past two decades,² with an emphasis on both Australian-led innovation and filings for patent protection in Australia. The patent data analysed in this report is leveraged from the technology search on mining completed by Daly et al. (2019). Finally, the report also discusses how government-supported expenditure in research and development (R&D) is linked to inventions in the mining industry and their commercialisation.

¹ The study by Francis, 2015 identified mining entities using data supplied by Resource Information Unit, mining equipment technology services (METS) sector firms by the Australian Government Department of Industry and Science, publicly-funded entities manually selected from a list of universities and Cooperative Research Centres (CRCs) in mining-rich states as well as the Commonwealth Scientific and Industrial Research Organisation (CSIRO), or using Australian and New Zealand Standard Industrial Classification (ANZIC) divisions in the IP Government Open Data (IPGOD) database.

² Patent data for 2016–17 is incomplete due to the lag between earliest priority of a patent application and its publication, and was included where available.

AUSTRALIAN MINERS

This section of the report focuses on Australian innovation in the mining sector by identifying patents that originate from Australia.³ This analysis highlights the role of Australian innovation in the global mining industry.

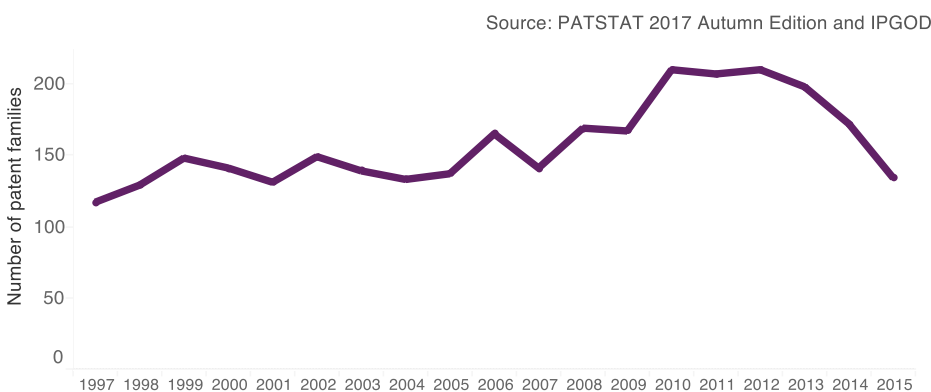
Patenting by Australian innovators over time

Analysing patent filings over time (Figure 1) can help to identify innovation trends. Such trend analysis is useful for informing R&D investment decisions and related activities such as collaboration and commercialization. The following section of this report, using data from the Australian Government’s R&D Tax Incentive program, investigates R&D investment in the mining industry and compares this to patent filings to give a broader picture of Australian innovation in this sector.

As a basis for this study, we used the dataset of Daly et al. (2019), derived using a modular hierarchical search strategy of International Patent Classification (IPC) and Cooperative Patent Classification (CPC) classification symbols and keywords. The data used in this report includes 2997 unique INPADOC patent families derived from PATSTAT 2017 Autumn Edition and IPGOD 2017 data, with earliest priority dates from 1 January 1997 onwards.⁴

The number of patents filed annually rose from 117 in 1997 to 169 in 2008, an increase of 44 per cent. A further 24 per cent increase from the level of 2008 was observed during 2010–12, averaging around 210 annual filings. This is in line with increased investment in the mining sector during the latest Australian ‘mining boom’ period. Since the mining boom’s peak, patenting activity has sharply declined from 2013, to 134 filings in 2015, comparable to the 1997–2004 period average.

Figure 1: Patent families of Australian origin, by priority year, 1997–2015



³ ‘Australian’ status or country of origin of an invention was attributed as follows.
 The applicant/inventor address was used from PATSTAT where available (www.epo.org/searching-for-patents/business/patstat.html)
 If the applicant/inventor address was available in IPGOD but not in PATSTAT then IPGOD was used (www.ipaustralia.gov.au/about-us/data-and-research/ip-government-open-data)
 If the applicant/inventor address was not available in either PATSTAT nor IPGOD, then country of origin was determined using the methods of Daly et al., 2019.

⁴ Post-2015 data is incomplete due to the lag in patent publication, and therefore excluded in the analysis over time. The remnant sections report on all the available data from 1 January 1997.



Australia's mining boom

In a Reserve Bank of Australia research paper published in 2014, Downes et al. used historical time series data to review and model Australia's 'mining boom', in which the world price of Australia's mining exports more than tripled over the 10 years to 2012, and investment spending in the mining sector increased from 2 per cent of GDP to 8 per cent during this period. Iron ore prices rose from about \$20 a tonne in 2002 to peak at about \$170 a tonne in 2011.

This mining boom had three phases: price rise, investment boom and production boom. The investment boom began as world commodity prices rose, driven largely by a Chinese demand to fuel its infrastructure investment. The boom in mining production lagged a few years until the capacity created by the surge in mining investment became available. While export prices have fallen from their peak in 2012, the volume of Australian mining production has remained high, thus maintaining strong export revenues, although the picture varies by commodity (Australian Government Department of Industry, Innovation and Science, 2018a).

Downes et al. (2014) portrayed the mining boom as a confluence of events that boosted world minerals prices and mining investment, and in turn the volume of Australian mining output.

For example, the development of horizontal drilling and seam fracturing or fracking technology allowed the exploitation of coal seam and shale gas reserves that previously were difficult or impossible to tap. Together with the development of new technological capabilities and resources, a combination of factors in Asian energy markets, particularly concerns over energy security, pollution and greenhouse gas emissions, led to a demand for long-term contracts that allowed commitments to build large-scale projects. The boom can also be explained by less complex factors, such as growth in Chinese steel demands.

Top Australian innovators

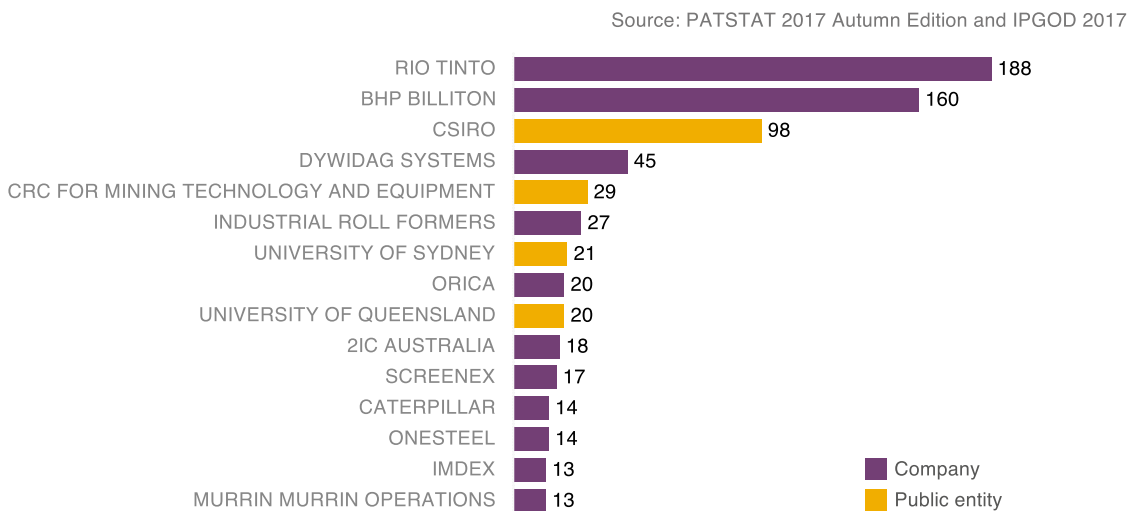
In Australia, a patent provides the owner of an invention an exclusive right for 20 years to commercialize the invention. Inventors file patents to protect their products and processes from imitation without compensation, and so the number of patent families filed by an applicant in a particular technology can be indicative of their interest, strength and market presence, or their desire to build and maintain a market share.

Figure 2 identifies the top innovators originating from Australia.⁵ The top three patent filers contributed 15 per cent of total patent filings in the mining sector; about 59 per cent of these were related to metal refining technology.

⁵ This study identifies applicants that have each filed at least 11 patent families. Applicants and inventors are classified as Australian based on PATSTAT address data. Australian-based subsidiaries of multinational companies are included as Australian applicants.



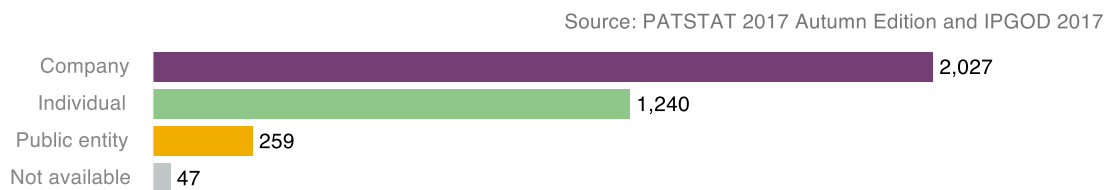
Figure 2: Top Australian patent filers



While the multinationals Rio Tinto and BHP Billiton dominate Australian patent filing through their Australian subsidiaries, Australia’s publicly-funded Commonwealth Scientific and Industrial Research Organisation (CSIRO) is the third largest Australian filer.⁶

The relatively large number of patent filings by CSIRO demonstrates the importance of the mining sector in Australian publicly-funded research. However, overall patent filings in the mining sector are driven by corporate entities and individuals. Figure 3 shows that 67 per cent of patent filings are directly attributable to companies, in a total of 2997 patent families filed by Australian innovators.⁷

Figure 3: Australian entities who file patents, by entity type⁸



⁶ CSIRO is an independent Australian Government agency responsible for scientific research. One of its main purposes is to improve the economic and social performance of industry for the benefit of the community. CSIRO Mineral Resources works closely with industry partners to deliver innovation to grow Australia’s resource base, increase productivity and drive environmental performance. Their goal is to deliver science and technology options for the discovery and efficient development of Australia’s mineral resource endowment that enable flow-on benefits to the wider national economy, with a focus on three key impact areas for industry and the nation: growing Australia’s resource base, increasing productivity and driving social and environmental performance. www.csiro.au/en/Research/MRF/Areas/Our-impact-strategy

⁷ ‘Individuals’ and ‘Not available’ are grouped together into the category ‘Other’ in the subsequent sections referring to sector information.

⁸ Note: Data on entity type is not available for 47 Australian patent filers



Case study: Australian autonomous vehicle systems

Patent application [WO0107976](#) (CMTE Development Limited) tells a remarkable and enduring story of Australian research excellence, collaboration and commercial translation that solves real world problems and is used across the globe. First filed on 23 June 1999, the patent describes a major technological advance in reactive vehicle navigation that remains the system of choice for autonomous mining vehicles.

Mining vehicles operate in dangerous and unstable environments. Because of this, mining operations have taken a leading role in autonomous vehicle research and development. Filed in 1999, this patent describes a system of autonomous vehicle navigation that is particularly suitable for mines, and which can also be used in any other environment.

Traditional vehicle navigation systems rely on precise maps to determine absolute locations. These absolute navigation systems are effectively blind to the operational environment, making the vehicle vulnerable to risks of imprecise data localisation and of changes to the operating environment.

This story begins in 1996, when CSIRO researchers teamed up with the Australian Centre for Field Robotics (ACFR)⁹ on a strategic project to automate mine load haul dump (LHD) vehicles, managed by the Cooperative Research Centre (CRC) for Mining Technology and Equipment (CMTE), to investigate underground navigation at Mount Isa Mines (MIM) in Queensland.

The scientists set out to develop systems for autonomous vehicle navigation that did not require precise, relative localisation. To achieve this, the researchers applied algorithmic techniques using nodal networks coordinated with on-board sensors to control the vehicle by analysing free space in front of the vehicle. This system is particularly suited to the closed conditions of underground mines where it reacts to the environment and tunnel walls and decides how to best respond, with no fixed path. The advantage of this system is that it can tolerate errors in position and overcome lack of traction. The research project trialled an auto-guidance system that fused data from two separate sets of laser sensors, combining natural feature recognition, nodal maps and inertial navigation technique (Roberts et al, 1998).

⁹ One of the largest robotics institutes in the world, the ACFR at The University of Sydney focus on the research, development and application of autonomous and intelligent robots, and systems for use in outdoor environments. <https://sydney.edu.au/engineering/our-research/robotics-and-intelligent-systems/australian-centre-for-field-robotics.html>

In response to great initial results from the feasibility study, the Australian Mineral Industries Research Association (AMIRA) set up a consortium in 1998 to build a research prototype that only required existing mine infrastructure and could be retrofitted to any commercial underground haulage vehicle. The consortium included partners in research (CSIRO, CMTE and ACFR), mining (MIM, Normandy Mining, Western Mining Corporation (WMC) and North Limited) and OEM equipment manufacturers (Caterpillar Elphinstone Pty Ltd (CEPL)¹⁰ and Automotive Industrial and Mining Supplies Ltd (AIS), now Remote Control Technologies Pty Ltd (RCT))¹¹.

Next, the patent story began. In 1999 the provisional patent was filed by CMTE, and licensed to CEPL. After demonstrations of the consortium's research prototype, completed after only 12 months, a contract was negotiated between CMTE, AMIRA, AIS and CEPL. Technology transfer assistance was provided in 2000 by Dynamic Automation Systems (DAS), a joint venture between CEPL and Lateral Dynamics, a small business funded by WMC. In 2001, CMTE withdrew and CSIRO took ownership of the patent. Then, in 2003, Caterpillar took full control of CEPL and the patent license was renegotiated with CSIRO.

The technology was commercially released by Caterpillar as MINEGEM™ and later rebranded to Cat®MineStar™ Command for Underground, and remains in commercial use to date (CAT 2019). The system has been sold around the world, and is now in everyday use moving millions of tonnes of broken ore while operators sit safely in control rooms. Mines using the system have reported 40-60 per cent productivity increases over manual operation, in addition to savings in machine wear and tear that are achieved because the machine is driven to the manufacturer's specifications (CSIRO Data61 Robotics and Autonomous Systems Group, 2016).

This technology is a great success story that spans two decades and shows a major global impact directly attributable to a small team of Australian publicly-funded researchers. This story also reveals the reality of research commercialisation in Australia, with our most commercially successful research becoming 'hidden gems' in patent portfolios of multinationals.

¹⁰ CEPL is an Australian success story. The LHD manufacturer Elphinstone modified Caterpillar surface equipment to operate underground, growing into a 50:50 joint venture with Caterpillar to design and manufacture underground LHD and articulated dump and ejector trucks. <https://www.aumanufacturing.com.au/profile-of-success-elphinstone-and-caterpillar>

¹¹ RCT is also an Australian success story. Started in 1972 by a young electrician, Bob Muirhead, who developed world first remote mining equipment, RCT is now a global leader, and the Australasian market leader, in smart guidance, teleremote and remote control automation solutions for the mining industry. <https://rct-global.com/company/#profile>



Technology specialization by Australian innovators

So far, we have observed the volume of patents and patent filers over the past two decades. This section explores the different patenting technology areas with a view to understanding areas of strength and competitive advantage for Australian innovators. Patents are assigned a technology category based on the inventions they describe. This allows us to compare activity levels for different categories or sub-categories in the technology.

Based on the IPC and/or CPC symbols, Figure 4 illustrates the total number of patent families by each broad technology category, while Figure 5 shows their movements over time. These broad groups are further subdivided in Table 1 and Table 2.¹²

Patents within the mining operations category make up 36 per cent of total patent filings, with twice as many filings as the metal production category, which is the second largest category overall. Filings over time in the metal production category do not reflect the overall pattern of the whole sector observed in Figure 1, of growth to 2010–12 followed by a sharp drop in 2015.

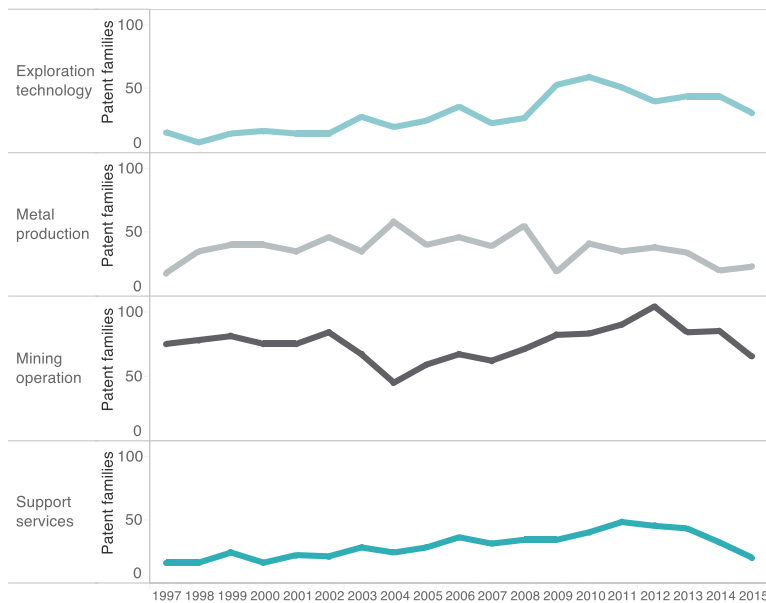
Figure 4: Patent filings by Australians, by mining technology⁵

Source: PATSTAT 2017 Autumn Edition and IPGOD

Mining operation	Mining	1,195
	Processing	202
	Blasting	76
Metal production	Refining	690
	Metallurgy	10
Exploration technology	Exploration	570
Support services	Environmental	394
	Transport	172
	Automation	2

Figure 5: Patent filings by Australians, by mining technology, by priority year, 1997–2015⁵

Source: PATSTAT 2017 Autumn Edition and IPGOD



¹² For the purpose of this analysis, definitions of technology sectors are as explained in Daly et al. (2019). Within the mining supply chain, environmental, transport and automation technologies are considered as support services for mining. Mining operation (blasting, mining, processing), metal production (refining, metallurgy) and exploration technology (exploration) are considered as the primary technologies.

Table 1 (mining operation, production and exploration) and Table 2 (mining support services) show the number of patent families filed within technology sub-categories by entity type. Corporate entities filed the highest number of patent families in most areas. This was closely matched by numbers of patent families filed by entity type 'other', which may be individuals or entities not identified as companies or public entities.

Table 1: Mining patent filings by Australians, by technology and entity type⁵

			Company	Other	Public entity
Exploration technology	Exploration	Assays	15	20	9
		Core extraction	39	32	1
		Drilling	114	101	3
		Drilling tools	49	54	
		Exploration	83	74	25
		Methods or apparatus for drilling	96	91	8
		Surveying and testing	91	80	9
		Surveying and testing - automatic control	16	15	7
Metal production	Metallurgy	Casting/powder metallurgy	2	2	
		Coating		1	1
		Electrometallurgy	3	3	
		Metallurgy	2	3	1
	Refining	Ferrous	162	156	10
	Inorganic chemistry	19	14	3	
	Non-ferrous	425	278	77	
Mining operation	Blasting	Blasting	66	59	5
		Fuses	4	3	
	Mining	Excavation	232	242	32
		Ground control support	267	220	8
		Other mining categories	266	234	47
		Safety/rescue	47	56	8
		Shafts	14	11	
		Subsea	30	27	
		Tunnels	47	48	4
		Ventilation	30	32	
	Processing	Bio-processing	1	1	
		Crushing/grinding	14	10	
		Crushing/grinding mineral	18	13	2
		Flotation	48	48	10
Processing		7	4	1	
Separation		94	82	6	

Source: PATSTAT 2017 Autumn Edition and IPGOD 2017

Table 2: Mining support service patent filings by Australians, by technology and entity type⁵

			Company	Other	Public entity
Support services	Automation	Automation	2	1	
	Environmental	Biological treatment of soil	5	7	2
		Environmental	188	148	25
		Reclamation of mining areas	3	4	
		Technologies related to metal processing	31	32	5
		Technologies related to mineral processing	36	43	7
		Treatment of waste water	7	9	2
		Treatment of waste water - metallurgical processes	45	38	1
		Waste disposal	10	12	1
	Transport	Containers	13	18	1
		Control	10	11	4
		Conveying	20	30	2
		Hauling	16	14	
		Hoisting	28	29	
		Infrastructure	11	12	4
		Rail	15	16	2
		Shipping	5	5	
Vehicles		15	17		

Source: PATSTAT 2017 Autumn Edition and IPGOD 2017

Where do Australians seek patent protection?

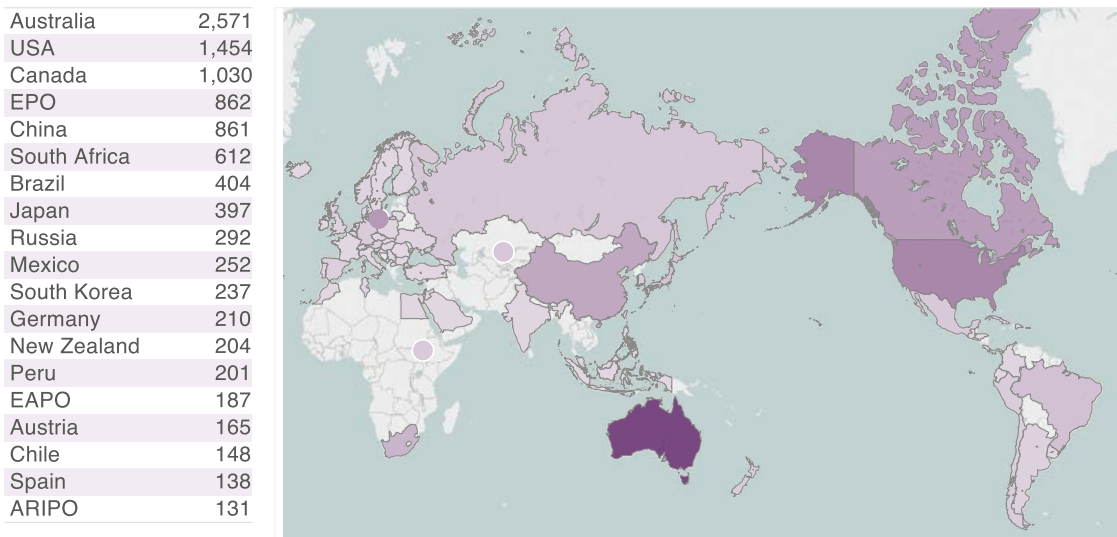
Applicants must file patent applications in each country or patent jurisdiction where they wish to have patent protection. This means that possible target markets for inventions in any technology can be indicated by the jurisdictions in which patent applications are filed.

Figure 6 shows the countries where Australian innovators file patent applications in the mining sector. Australian patents are primarily filed in

Australia, with 2571 patents filed since 1997. This represents 77 per cent more patent filings than those filed by Australians in the second largest target market, the United States, which highlights the importance of the domestic market for Australian-origin mining innovation. The relative number of filings into Australia by Australians has increased from the analysis of Francis (2015). The United States and Canada represent the second and third largest target markets for Australian innovators, respectively.

Figure 6: Jurisdictions in which Australian innovators seek patent protection^{13, 14}

Source: PATSTAT 2017 Autumn Edition and IPGOT



¹³ The number of patent filings in the top nineteen target jurisdictions are listed in figure 6, all target jurisdictions are shown on the map.

¹⁴ Note: European Patent Office (EPO) Eurasian Patent Organisation (EAPO) and African Regional Industrial Property Organization (ARIPO) patents are enforceable in designated contracting states at the date of filing of the application. They are, therefore, included in the target market analysis, and are represented here by non-proportional dots over central Europe, central Asia and central Africa, for indicative purposes only. Patent applications can also be filed directly in individual European, Eurasian or African countries.

Research collaboration in the mining sector

One advantage of analysing patent data is the ability to identify research partners collaborating on patent applications. The presence of multiple applicants on a patent application may be used as a proxy indicator for collaboration.

Figure 7 shows the proportion of patents filed collaboratively by Australians by entity type. Overall, Australians have low levels of collaboration in the mining sector. Publicly-funded entities are more likely to collaborate than companies. The proportion of applications filed collaboratively by publicly-funded entities (12 per cent) is more than double those filed by companies (5 per cent).

Collaboration between Australians and non-Australians was also analysed (data not shown); domestic and overseas collaboration was roughly equal. Public entities were somewhat more likely to collaborate internationally than companies. The proportion of collaboration of the publicly-funded entities with overseas entities (53 per cent) was slightly more than that of companies (42 per cent).

Figure 8 shows the top collaborating Australian applicants for patent filings in the mining sector. Most of the top collaborators are companies, which reflects the dominance of companies in overall patent filings by Australians. In the public sector, Rio Tinto has filed four patents in collaboration with the University of Sydney and one with the University of Manchester, and two patent filings are three-way collaboration between CSIRO, BHP Billiton and the University of Queensland.

Figure 7: Australian patent filing collaboration by entity type

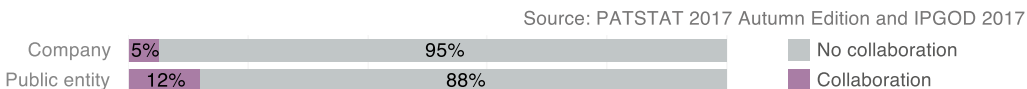
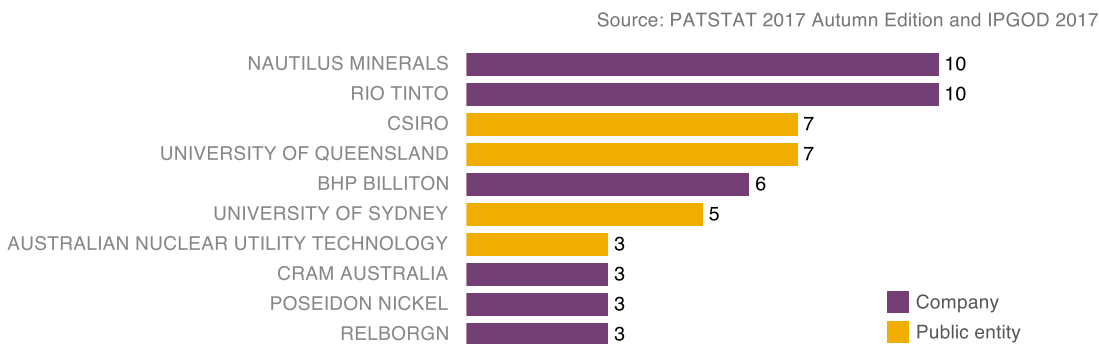


Figure 8: Top Australian collaborators in patent filings





Case study: Cooperative Research Centres

The Australian Government’s Cooperative Research Centre (CRC) Program supports industry-led research collaborations between industry, researchers and the community. This is a proven model for connecting researchers with industry for the purpose of commercial R&D. The CRC Program is a competitive, merit-based grants program that supports industry-driven, multi-year research collaborations. Since its inception in 1991, the Australian Government has supported over 210 CRCs and committed over \$4 billion in program funding (Australian Government Department of Industry, Innovation and Science, 2016).

Figure 9 shows patents filed by CRCs in the mining sector. Identifying CRCs is a complex task as they normally have a short lifecycle (up to ten years) and can have multiple iterations where the collaborating entities may differ in some cases (Encyclopedia of Australian Science, 2010; Mining3, 2018a; Lever, P., 2014). As a result, the data below may not capture all involvement of CRCs in the mining sector.

The CRC for Mining Technology and Equipment (CMTE), the Deep Exploration Technologies CRC (DET CRC) and the CRC for Greenhouse Gas Technologies (CO2CRC) have each filed more than one patent family.

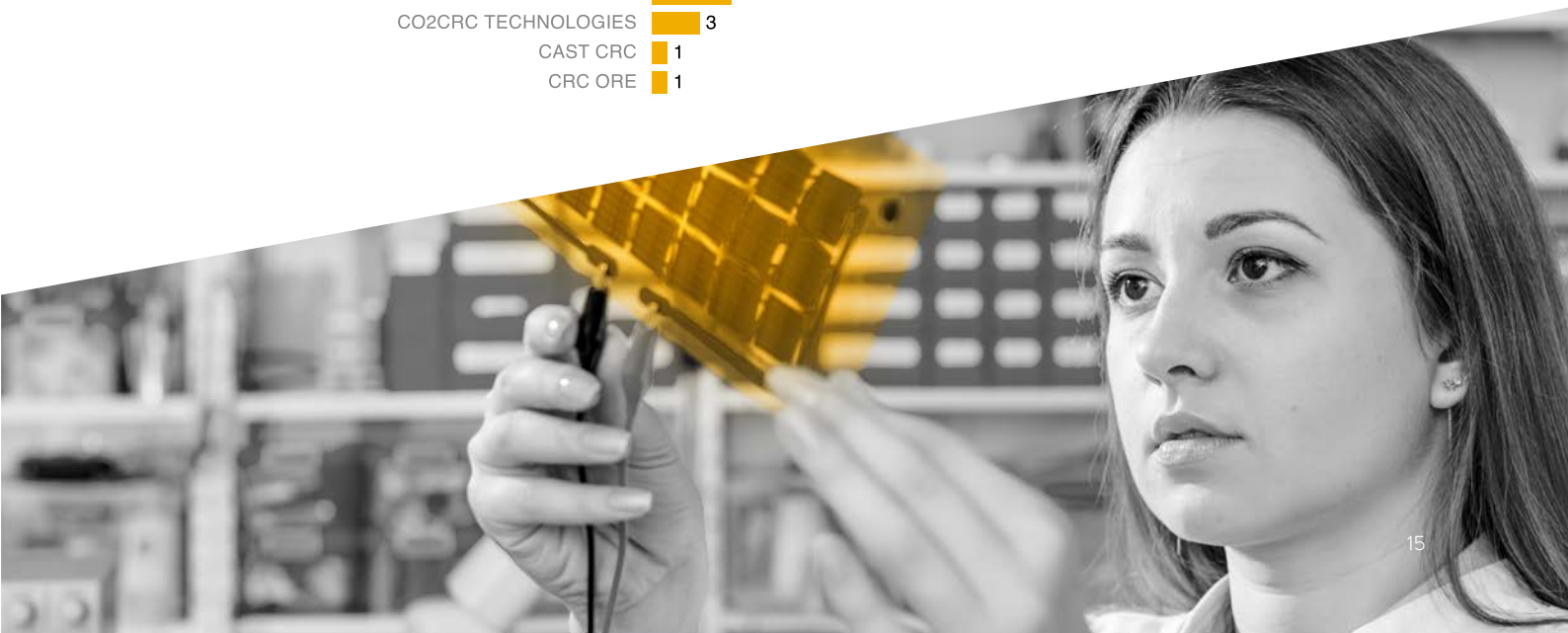
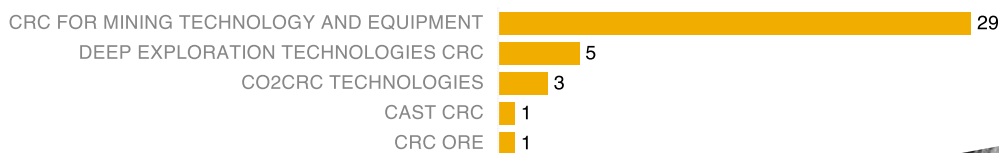
Established in 1991, CMTE was one of the first CRCs formed. This CRC had successful funding renewals in 1997 (CMTE 2), in 2003 (CRC Mining 1) and 2009 (CRC Mining 2). Its most current iteration, Mining3, is a partnership between CMTE and the CSIRO Mineral Resources group formed in July 2016. Their research includes areas such as fracture and damage mechanics, rock and coal characterization, and fragmentation and instrumentation. CMTE has filed 29 patent families, which is three times more than the combined number of filings by all other mining CRCs. Most of its patent filings are in technologies related to excavation, drilling, exploration and safety (Mining3, 2018b).

DET CRC was established in 2010 to address the challenge of decreasing mineral resource availability due to high production rates and low mineral exploration success. This CRC has filed five patent families broadly covering aspects of drilling, data logging, and sensing and targeting of mineral deposits (Deep Exploration Technologies CRC, 2018). DET CRC was wound up in September 2018 at the end of its Commonwealth funding period. DET CRC licensed a number of its products and services to its company sponsors; these licences are now being managed by MinEx CRC.

The CO2CRC was established with the aim of researching and demonstrating carbon capture and storage as a major industrial emissions reduction technology. All three patent families filed by the CO2CRC are associated with carbon capture technologies (CO2CRC, 2019).

Figure 9: Australian patent filings by CRCs

Source: PATSTAT 2017 Autumn Edition and IPGOD 2017



RoXplorer®

RoXplorer® is an innovative success story developed by DET CRC. One of the major challenges in mineral exploration is to find evidence of mineralization. This is generally a painstaking drilling process. In practice, this means drilling more holes in the right places to give a higher chance of making a discovery. A conventional drill string is made up of individual steel rods that must be connected and disconnected as the drill hole deepens. The requirement for manual rod handling restricts drill rate and poses a risk to operator safety (Soe, 2017).

RoXplorer® is a technology developed by DET CRC to overcome this challenge. It is a coiled tubing drilling rig with a continuous malleable steel coil in the drill string. A motor within the drill string near the base of the hole drives the drill bit. This eliminates the need to add individual drill rods, making drilling quicker, cheaper and safer. RoXplorer® has a much lower estimated operational cost than diamond drilling or reverse circulation drilling (Deep Exploration Technologies CRC, 2018). DET CRC aims to lower the cost of drilling to about \$50 per metre by advancing their RoXplorer® technology. Patents [WO2018132861](#) (Mobile coiled tubing drilling apparatus) and [WO2018132862](#) (Rotary drill head for coiled tubing drilling apparatus) are recent mining innovations filed by DET CRC.¹⁵

¹⁵ Due to the publishing lag, these patents are not captured in the current data set analysed.



AUSTRALIA’S R&D TAX INCENTIVE

Australia’s R&D Tax Incentive is the Australian Government’s primary means of supporting business investment in R&D, targeting areas likely to benefit the wider Australian economy. The R&D Tax Incentive, which replaced the former R&D Tax Concession in 2011, provides a company tax benefit to help offset costs of eligible R&D activities in companies registered with the scheme. For the 2016–17 income period, the program reported a \$13.7 billion of R&D expenditure by 15,177 R&D performing entities across all industry sectors (Australian Government Department of Industry, Innovation and Science, 2018c).

Ongoing reform helps to ensure the effectiveness, integrity and financial viability of the program. There were 13,346 registrations across all technology areas in 2016–17, including 3,021 new registrants representing an annual increase of 21 per cent. The R&D Tax Incentive was reviewed by Ferris, et al., 2016, with recommendations to improve the effectiveness, integrity and additionality of the program. These recommendations have been reflected in reforms to the R&D Tax Incentive in the Australian Government Budget 2018–19 (Australian Government, 2018).

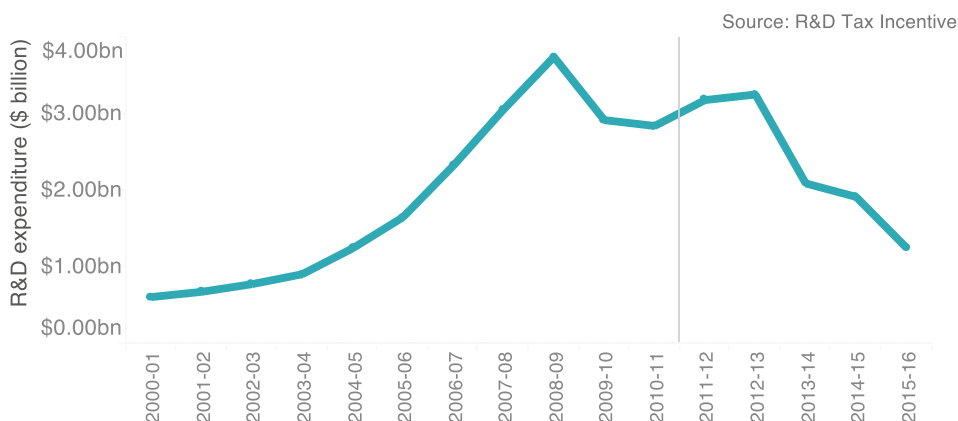
The R&D Tax Incentive and the Australian mining sector

To assess the impact of the R&D Tax Incentive on the mining sector, we analysed data on mining companies registered with the program.¹⁶

Figure 10 shows R&D expenditure of registered mining entities using data from the R&D Tax Concession (2000–01 to 2010–11) and the R&D Tax Incentive (2011–12 to 2015–16) programs.

Under these programs, R&D expenditure in the mining sector has grown six-fold from 2000–01. At its peak in 2008–09, the expenditure of \$3.74 billion was nearly 21 per cent of the total R&D expenditure of the entire program that year. After a decline from 2008–09 to 2010–11, there was a small recovery in expenditure to 2012–13, following a pattern across the whole program (Australian Government Department of Industry, Innovation and Science, 2018c). This was followed by further decline, with a total decline of 67 per cent by 2015–16 relative to its peak in 2008–09. This decline reflects the overall picture of investment over time in the mining sector following the mining boom, as discussed in the following sections of this report.

Figure 10: Mining sector expenditure in the R&D Tax Incentive, 2000–01 to 2015–16¹⁷



¹⁶ The R&D Tax Incentive data was provided by the Department of Industry, Innovation and Science. Mining sector companies were identified by Australian and New Zealand Standard Industrial Classification (ANZSIC) codes related to coal and mineral ore mining and exploration and other mining services. To align as closely as possible with our patent dataset, industries relating to oil and gas extraction and non-metallic mineral mining and quarrying are omitted from this analysis.

¹⁷ There is a break in the data in the 2011–12 income period, in moving to the R&D Tax Incentive from its predecessor, the R&D Tax Concession; this transition is denoted by the grey line

Company size

An analysis of company size can provide insight into the differential impact of the program on different business classes. The annual turnover threshold of \$20 million is used to separate small-to-medium-sized enterprises (SMEs) from larger ones. The data on mining companies registered with the R&D Tax Incentive was analysed by company size (Figure 11). R&D expenditure of both SMEs and large firms followed the overall expenditure trend from 2000–01 to 2015–16 shown in Figure 10. The R&D expenditure of large firms grew from 2003–04 to 2008–09, with a peak expenditure six times greater than that of SMEs. Since 2008–09, R&D expenditure by large firms has dropped to a ten-year low in 2015–16.

Mining by industry subdivision

We analysed the data on mining companies registered with the R&D Tax Incentive by Australian and New Zealand Standard Industrial Classification (ANZSIC) code (Trewin and Pink, 2006) for two subdivisions: mining and exploration and other support services (Figure 12). While R&D expenditure of the registered companies in the mining subdivision drove the overall trend shown in Figure 10, companies in the exploration and support services industry subdivision did not conform to this trend, with a lower uptake of the program. Figure 4 above also shows more patenting activity in the mining area compared with exploration and support services, although not such a marked difference as seen here.

Figure 11: Mining sector companies by entity size, 2000–01 to 2015–16¹⁷

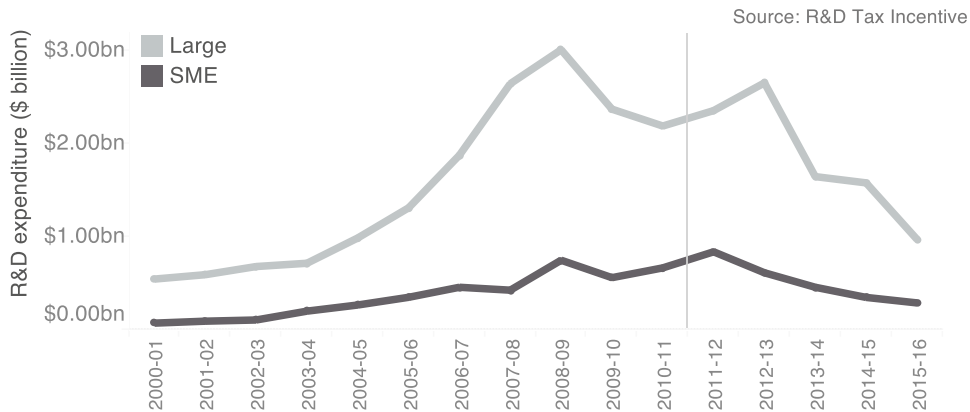
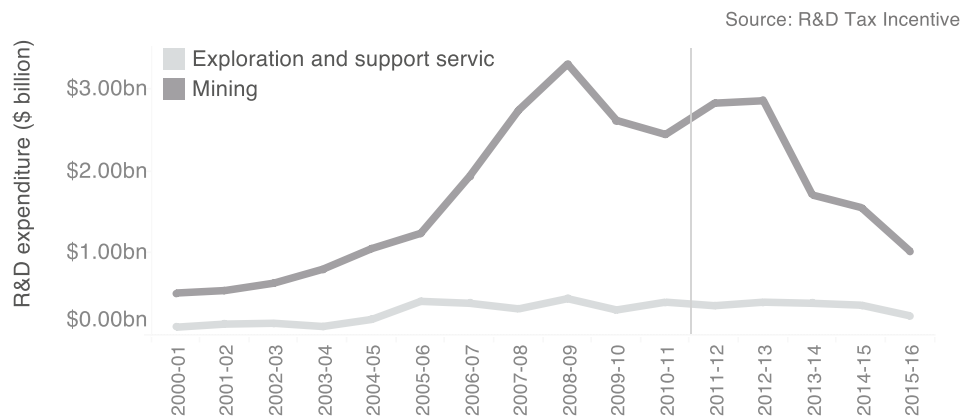
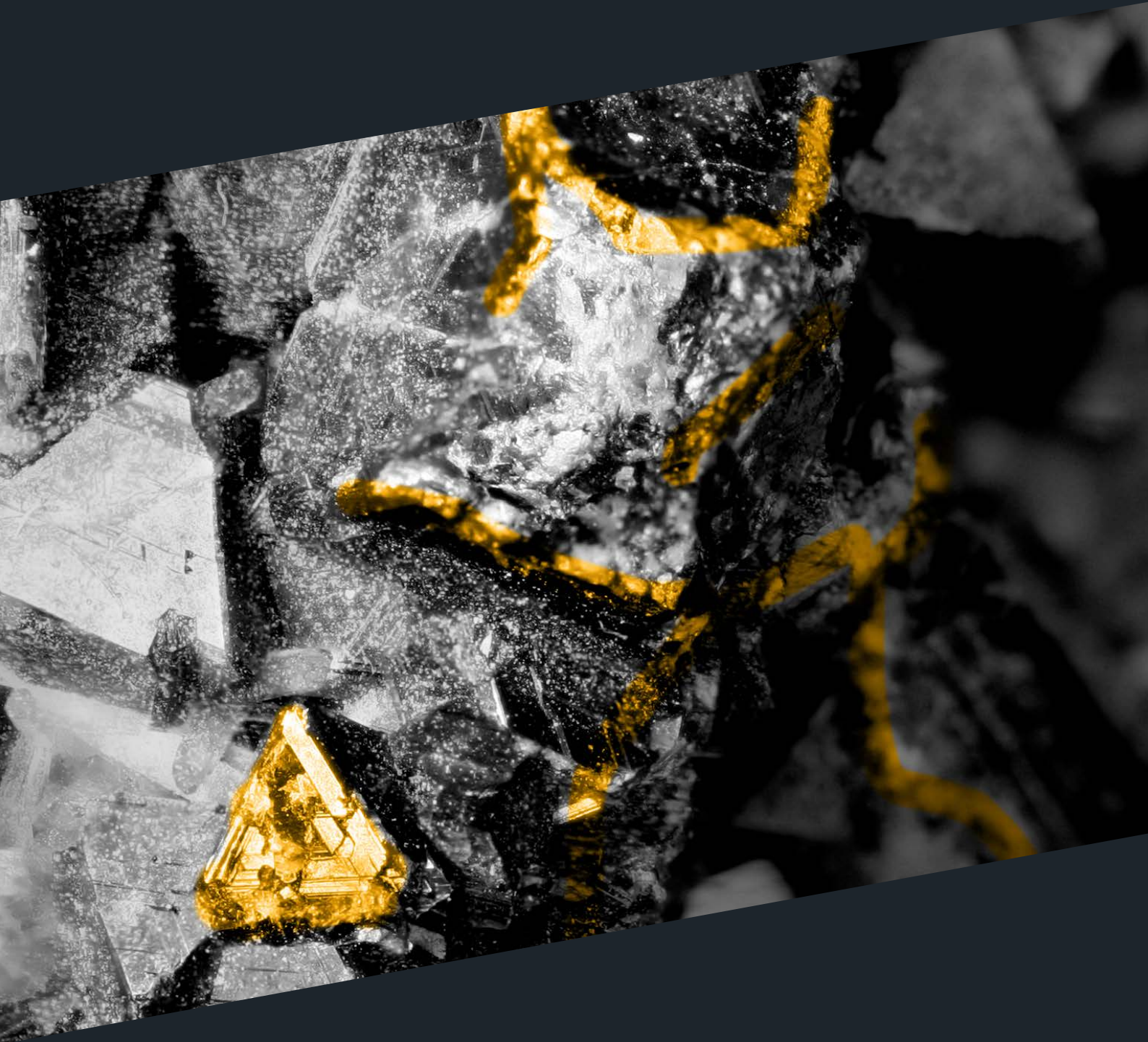


Figure 12: Comparison of mining sector industry subdivision trends under the R&D Tax Incentive by industry subdivision, 2000–01 to 2015–16¹⁷



¹⁷ There is a break in the data in the 2011–12 income period, in moving to the R&D Tax Incentive from its predecessor, the R&D Tax Concession; this transition is denoted by the grey line



Patenting activity and the R&D Tax Incentive

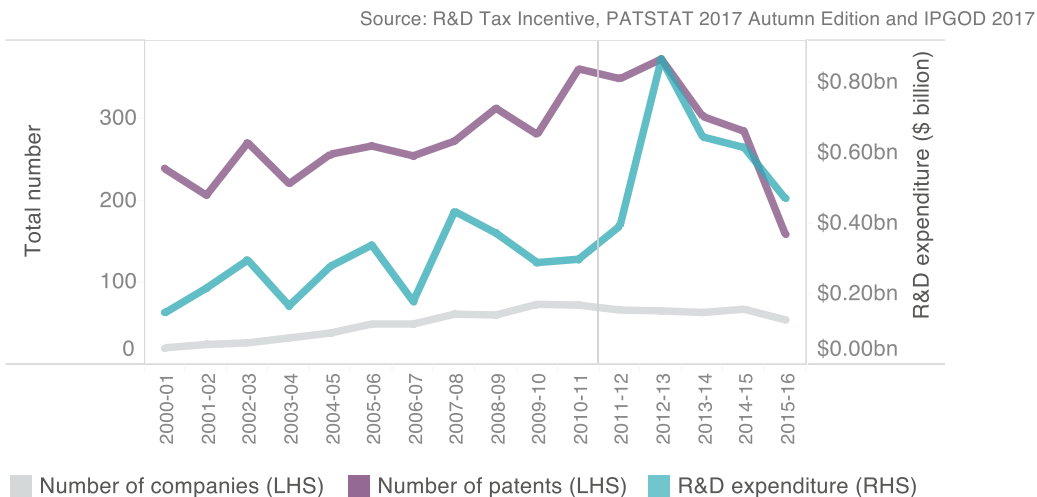
To explore potential correlations between R&D expenditure and patenting activity in the mining industry, we analysed patent family filings and R&D expenditure of R&D Tax Incentive-registered entities (Figure 13).^{18,19}

R&D expenditure and patenting show similar patterns over time, with an overall increase from 2000–01 to 2009–10. Both the number of patents filed and R&D expenditure increased from 2009–10, with a peak in 2012–13.

R&D expenditure grew three-fold from 2009–10 to 2012–13, representing a stronger increase than the corresponding growth in the number of patent filings. This indicates the expenditure was not associated with innovation in products and processes requiring commercial protection to hold or build market share.

Both R&D expenditure and patenting activity declined steeply since 2012–13, which follows the overall decline after the peak of the Australian mining boom in 2012.

Figure 13: Mining sector R&D expenditure and patent filings for R&D Tax Incentive companies, 2000–01 to 2015–16¹⁷



¹⁸ This analysis is limited to registered entities that have filed patents in the mining sector. The R&D Tax Incentive data fully matches 62 per cent of the patent data reported in this section. This is not an exact comparison between entities identified in the patent data and those in the R&D Tax Incentive data due to data confidentiality. The patent data is limited to business entities identified as Australian innovators in this report.

¹⁹ Due to the lag in publication of patent applications, the number of patents for 2015–16, with a priority date after 1 January 2016, is incomplete.

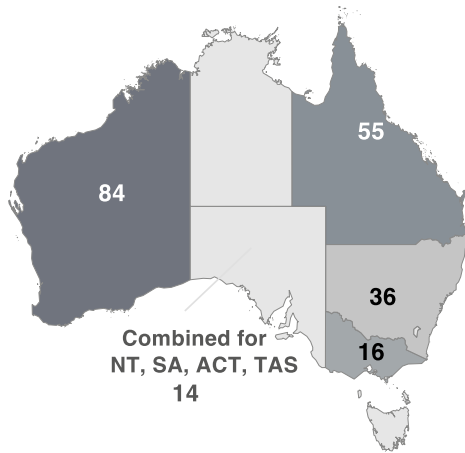
R&D expenditure and patent filing by Australian State and Territory

Mining investment and activity varies considerably across Australia. To provide insight into the impact of the R&D Tax Incentive on the mining industry in different Australian States or Territories, we have compared R&D expenditure, patenting activity and the number of R&D Tax Incentive-registered entities in the mining sector by State or Territory (Figure 14).²⁰

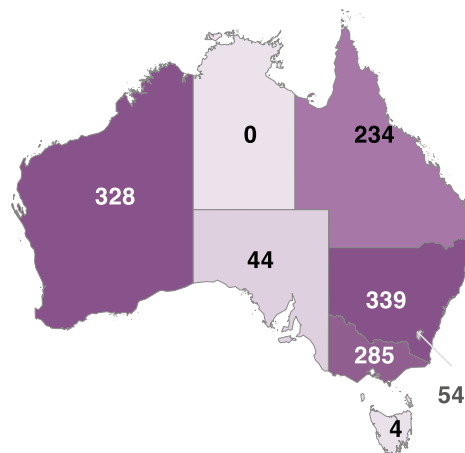
Figure 14: Mining sector performance under the R&D Tax Incentive by State, 2000–01 to 2015–16

Source: R&D Tax Incentive, PATSTAT 2017 Autumn Edition and IPGOD 2017

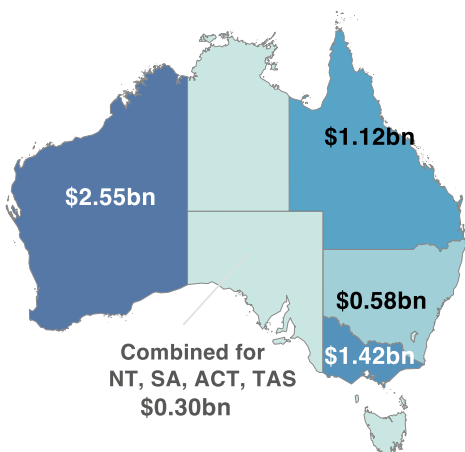
Number of companies



Number of patents



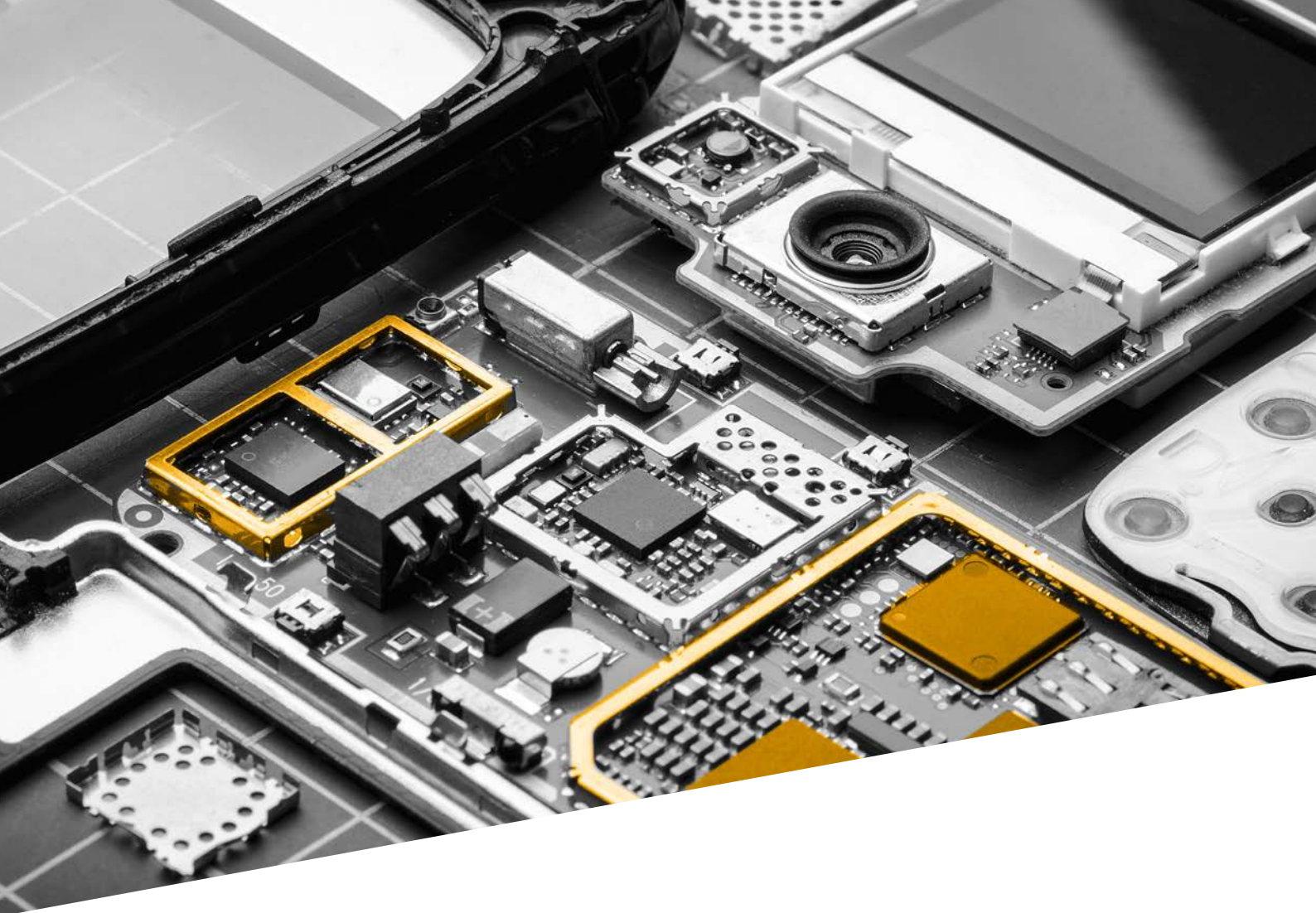
R&D expenditure (\$ billion)



Australian States and Territories



²⁰ State-level aggregated R&D Tax Incentive data for the period 2000–01 to 2015–16 includes combined data for South Australia (SA), the Australian Capital Territory (ACT), the Northern Territory (NT) and Tasmania (TAS) due to low or negligible mining activity in these regions. In contrast, the patent data is not aggregated, and is plotted against each individual state or territory.



This geographical analysis demonstrates considerable differences between the number of companies registered for the R&D Tax Incentive, R&D expenditure, and the number of patents originating from each state and territory.

Western Australia (WA) has the highest R&D expenditure under the R&D Tax Incentive (\$2.55 billion) and the highest number (84) of R&D Tax Incentive-registered entities in the mining sector. WA also has the second highest number of patents (328) filed by matched companies. This may be attributable to the richness of the iron ore and gold resources of this region: the majority of Australia's gold exploration activity and iron ore deposits with operating mines are located in WA. This makes WA's mineral resources particularly valuable to the global market since Australia is the largest iron ore exporter in the world, holding 29 per cent of global iron ore reserves, and is the second largest producer of gold in the world, after China (Australian Government Department of Industry, Innovation and Science, 2018a).

Victoria (VIC) has the second highest mining R&D expenditure (\$1.42 billion) and the third highest number of patents (285) filed by matched companies. However, only 16 R&D Tax Incentive-registered

entities are located in Victoria. Queensland (QLD) has the second highest number (55) of R&D Tax Incentive-registered entities, third highest R&D expenditure (\$1.12 billion) and is fourth in terms of the number of patents filed.

The overall disparity in the number of patent filings by state and the R&D Tax Incentive data could be a consequence of corporate headquarters filing both patents and R&D Tax Incentive claims. These corporate offices are usually located in metropolitan cities, with Sydney being a very popular choice. This might account for New South Wales (NSW) having the highest number of patent filings recorded in Australia, but much lower R&D expenditure than Victoria, Queensland and Western Australia.

This indicates that, while there is useful information to be derived from comparing matched R&D Tax Incentive data with patent data in the mining sector, geographical data does not appear to be directly comparable, likely due to differences in defining entity locations.

PATENTING IN AUSTRALIA

While the focus of this report is to explore Australian innovation in the mining sector, we have also included an analysis of patent filings into Australia as part of a broader overview of the Australian mining industry. Patents are filed to seek patent protection in specific jurisdictions. As such, patent filings in a country can give an indication of how valuable a technology is considered to be in a particular market. The analysis of patent filings in Australia can therefore be used to infer the relative importance of Australia in the global mining landscape.²¹

Patent filing in Australia over time

Over the past two decades, a total of 16 374 patent families were filed in Australia in the mining sector. Figure 15 shows the annual number of patent families filed from 1997 through 2015.

Patenting activity tripled between 2005 and 2012, with a decline since then. While this may be partly due to incomplete data for 2015,²² the severity of the decline indicates that there may be further underlying factors.

To understand the fall in mining sector patenting activity in Australia since 2013, we have investigated other proximate factors such as commodity prices as well as mining profits and investment. First, Figure 16 shows movements in commodity prices (Reserve Bank of Australia, 2018). Second, Figure 17 shows Australian mining sector profits as a share of GDP (Australian Bureau of Statistics, 2018c). Third, Figure 18 shows mining sector investment proportional to GDP (Australian Bureau of Statistics, 2018d). In all three Figures 16 to 18, we observe a sharp drop from a peak around 2012–13, which coincides with the fall in patenting activity in Australia.

Figure 15: Patent filings into Australia, by priority year, 1997–2015

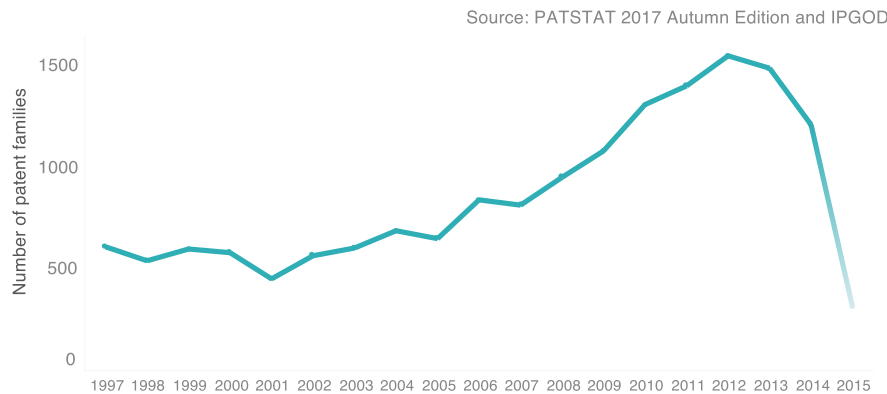
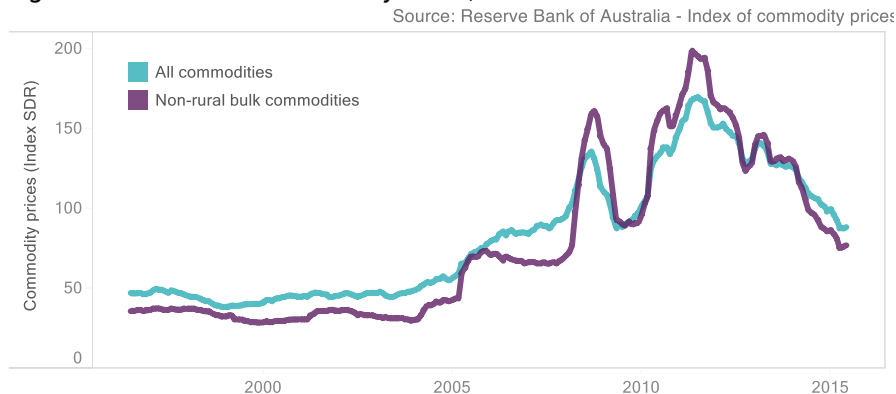


Figure 16: RBA Index of Commodity Prices, 1997–2015²³



²¹ In this analysis, applicants were defined in accordance with the IPGOD database

²² Incomplete data in 2015 results from the Patent Cooperation Treaty (PCT) filing route, which allows for up to 30 months between PCT priority filing and national phase entry. This means there is incomplete data available from 2015 onwards (2016 and 2017 data is not shown in figure 15). Data for the Autumn edition of PATSTAT is usually compiled with publications up until July of that year and release around October, so the full year of 2015 patent applications through the PCT route is not captured in this edition.

²³ Commodity price is SDR; 2016/17 average = 100



While the decline in patent filings and R&D expenditure by Australian companies (Figure 13) coincides with the fall in commodity prices as well as mining profits and investment after 2012–13, they do not reflect the severity of the drop in patent filings into Australia from 2013–15. This suggests a number of other factors, including global issues, may have contributed to the decline in patent filings into Australia since 2012–13 (Kent, C., 2016).

While acknowledging that the patent filing data is incomplete for 2015 onwards, as discussed above, it seems likely that a complex combination of factors has contributed to the dramatic drop in patent filings into Australia from 2013–15.

This drop — to a 20-year low and with half the number of patent filings of 1997 — which is particularly noticeable given the mining industry was much bigger in 2015 than in 1997. The drop in R&D expenditure by Australian companies may be attributable to the overall drop in mining investment, which is in turn attributable to the drop in commodity prices and in corporation profits, none of these downturns are as severe as that in patent filings into Australia. Revealing its underlying causes therefore warrants further research.

Figure 17: Mining sector profits as a share of nominal GDP, 1997–2015²⁴

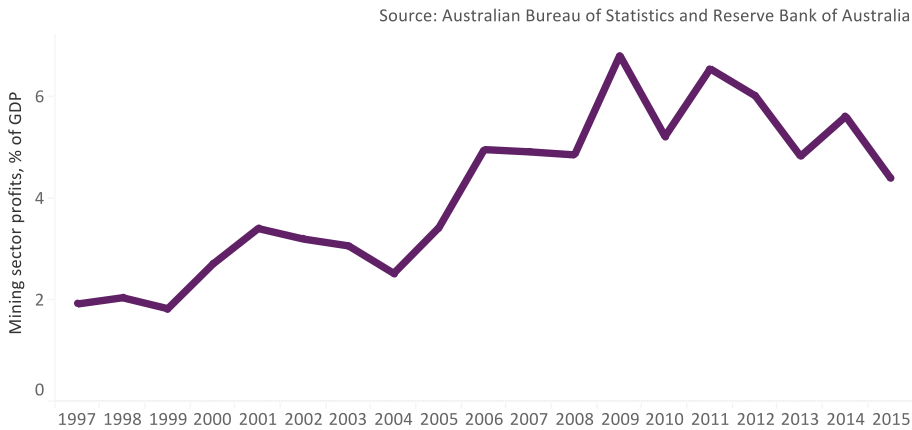
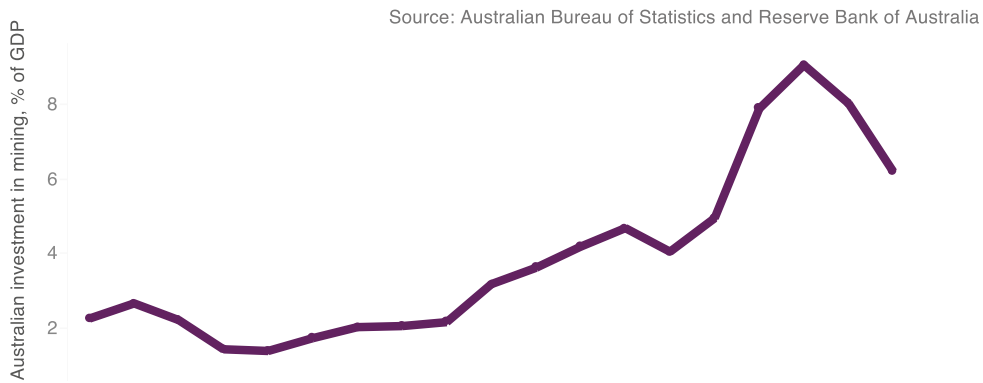


Figure 18: Australian investment in mining as a per centage of GDP, 1997–2015



²⁴ Gross operating profits, inventory valuation adjusted

Technology specialisation in Australia

An analysis of patenting in different technology areas provides an overall picture of innovation in the sector. In this vein, Figure 19 shows the number of patent families filed into Australia in different mining technology areas.

The top three technology categories for patent filings into Australia are exploration, mining and refining. This differs from global patent filings originating from Australian applicants, in which the top three technology areas are mining, refining and exploration, respectively (Figure 4). This reflects the differences between foreign and domestic patent applicants in terms of what they invent and want to protect in Australia.

Who is filing patents in Australia?

Patent filing data can be used as a proxy indicator of innovation performance of a nation; therefore, the analysis of patent applicant origin may reflect how innovative a country is. Figure 20 shows the total number of patent families filed in Australia in the mining sector by various source countries from 1997 onwards. Australia ranks second,

with 1968 domestic patent filings filed by Australian applicants. A total of 6477 patent filings originate from applicants in the United States, by far the most from any country, and about three times more filings than the second-placed Australian applicants. The most prominent Australian companies filing into Australia are the Australian subsidiaries of Rio Tinto (139 patent filings) and BHP Billiton (103 patent filings).

Top innovators filing patents in Australia

The number of patent families filed by an applicant in a specific technology can be indicative of its strength, interest and market presence or desire to build and maintain a market share. Figure 21 shows the top applicants for inventions that were filed into Australia in the mining sector.

The core business for a number of these applicants, such as the top applicant, Halliburton, appears to centre on providing products and services predominantly to the oil and gas sectors, which are specifically excluded from the definition of mining technologies in this analysis.

Figure 19: Patent filings into Australia by mining technology²⁵

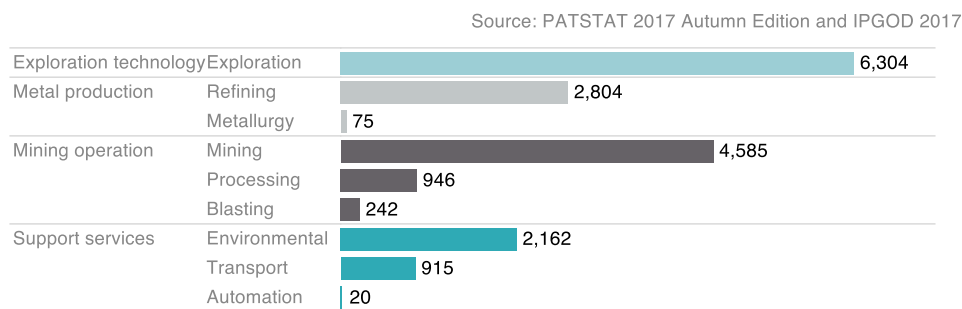
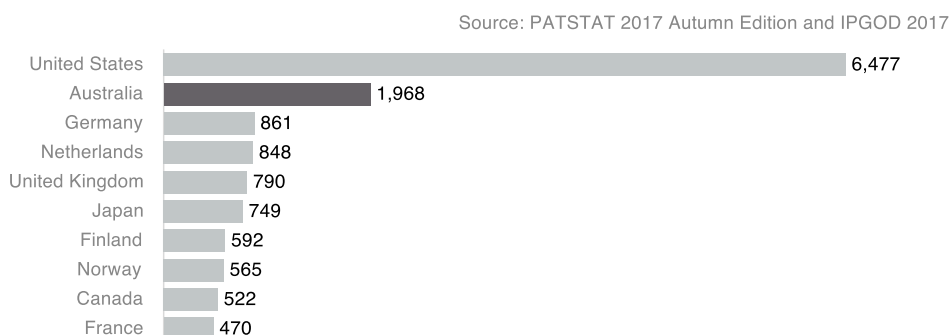


Figure 20: Patent filings into Australia by applicant origin



²⁵ Patent data analysed by INPADOC patent families derived from PATSTAT 2017 Autumn Edition and IPGOD 2017 data, with earliest priority dates from 1 January 1997. Post-2015 data is incomplete due to the lag in patent publication, all available data is included in our analysis, except for trend analysis over time where post 2015 data is excluded.

The fact that these companies are key players for patents in the mining technologies covered by this report indicates an overlap of technologies used by both the mining and the oil and gas sectors.

Haliburton

Halliburton, founded in 1919 and with its headquarters in the United States, is one of the world’s largest providers of products and services to the global energy industry and in particular to oil and gas companies. Its services include locating resources, managing geological data, drilling, construction and supporting production throughout the life of a project (Haliburton, 2019; Bloomberg, 2019a). Halliburton also owns Landmark, a technology solutions provider of data and analytics, science, software and services for the exploration and production industry (Halliburton Landmark, 2019b). Patent filings by Landmark (194 families or 11 per cent) are a significant contribution to overall filings in Australia by Halliburton in the mining sector.

Halliburton has been a consistent patent filer in Australia to 2008, after which its filings increased strongly, particularly in 2012 and 2013. Halliburton’s filings have predominantly been in the exploration area (89 per cent).

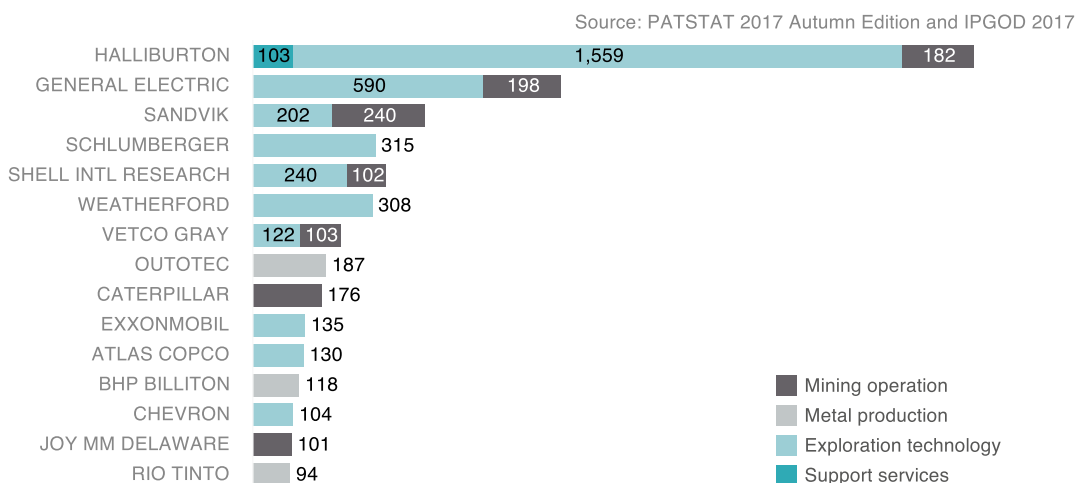
General Electric

Based in the United States, General Electric is a global company operating in diverse fields including power, renewable energy, oil and gas, aviation, healthcare, transportation and lighting (GE Australia, 2019; Bloomberg 2019b). The General Electric group includes Baker Hughes, a global company with operations in over 120 countries.

Baker Hughes is a provider of integrated oil-field products, services and digital solutions (Baker Hughes, 2019). Like Halliburton, the core Baker Hughes business appears to centre on providing products and services predominantly to the oil and gas sectors.

Patent filings in Australia by General Electric in the mining area have been mostly through the Baker Hughes company (650 families or 81 percent). Like Halliburton, General Electric (Baker Hughes) was a consistent patent filer in Australia up to 2008, after which their filings increased dramatically, particularly during 2009–2011. Its filings have also been predominantly in the exploration area (74 per cent).

Figure 21: Top applicants filing patents into Australia in the mining sector²⁶



²⁶ This figure compares collaborations between applicants in the same country (internal collaborations) and between applicants of different countries (external collaborations).

Sandvik AB

Sandvik AB, with headquarters in Stockholm, Sweden, is a global high technology engineering group. It provides equipment and tools, service and technical solutions for the mining industry (Sandvik, 2019; Bloomberg, 2019c). Sandvik AB has consistently filed for patents in Australia with increased activity here between 2003 and 2011, and in 2013. Its filings have predominantly been a mixture of the exploration and mining operations areas.

Schlumberger

Schlumberger, operating in over 85 countries, is a global provider of products and services for exploration and production of the oil and gas industry (Schlumberger, 2019). It has principal offices in Paris, Houston, London, and The Hague. Schlumberger has consistently filed for patents in Australia with a sharp increase from 2008. Its filings have mainly been in the exploration area.

Collaboration in patent filings in Australia

The presence of multiple applicants on an application is indicative of collaboration. Figure 22 shows the top countries of origin for collaborative mining sector patents filed in Australia.²⁷ The United States

is the most collaborative country filing patents in Australia, with Australia ranking second. All the top collaborative countries have a mixture of domestic and international collaborations.

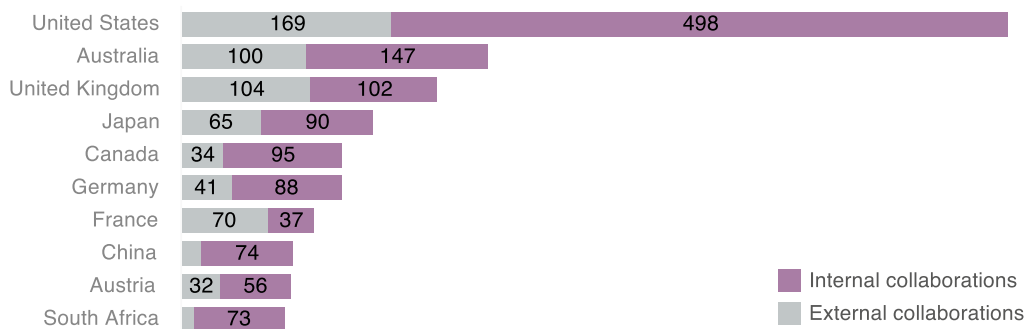
Figure 23 shows the top mining technology areas for collaborative patents; the top three areas are mining operations, exploration and refining technologies. Differences in collaboration in different technologies by country of origin are shown in Figure 24, which highlights patterns of specialization and indicates the resultant competitive advantage of countries.

In summary, interest in the Australian mining market has been through a period of turbulence from 1997–2015, including strong collaboration and strong investment by domestic innovators. The market has a focus driven by United States firms on exploration, mining and refining technology development.

There has been a steep drop in patent filings into Australia during 2013–15, which does not appear to be purely cyclical. It is possible that factors not identified in the data used for this report have affected the perceived value and strength of this sector in Australia.

Figure 22: International collaboration on patent filings into Australia in the mining sector²³

Source: PATSTAT 2017 Autumn Edition and IPGOD 2017



²⁷ This figure compares collaborations between applicants in the same country (internal collaborations) and between applicants of different countries (external collaborations).

Figure 23: Collaboration on patent filings into Australia in the mining sector by technology²³

Source: PATSTAT 2017 Autumn Edition and IPGOD 2017

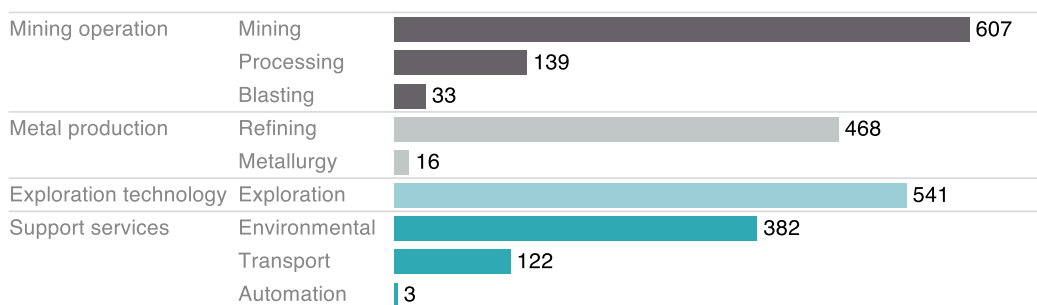
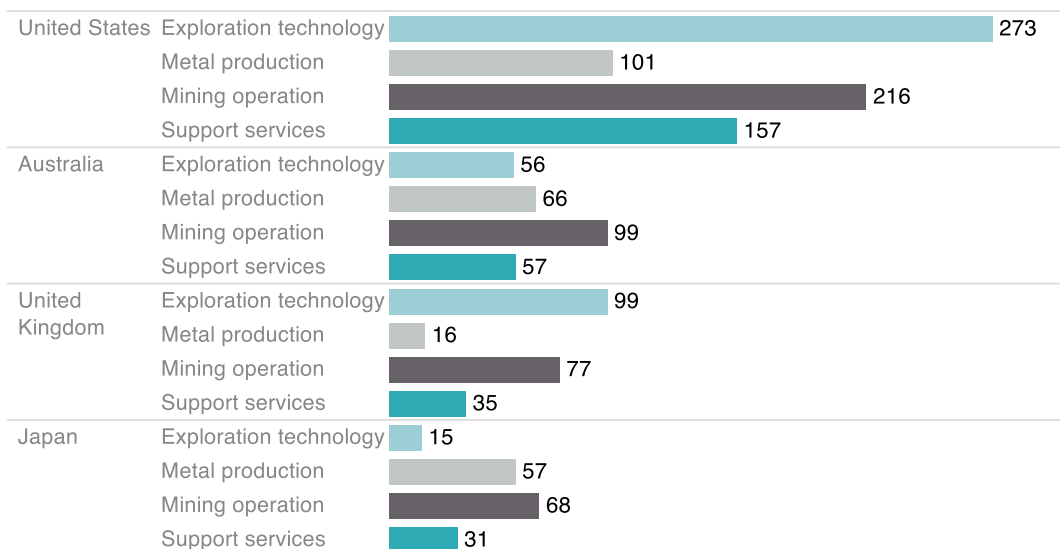


Figure 24: Collaboration on patent filings into Australia by technology by country^{23, 28}

Source: PATSTAT 2017 Autumn Edition and IPGOD 2017



²⁸ Collaboration by the top four collaborating countries



CONCLUSION

Australia is a global leader in the mining sector, both due to its rich resources and to its technological innovation and investment in this sector.

We have analysed innovation in the Australian mining sector using patent data from 1997–2015,²⁹ finding a total of 2997 Australian mining sector patents filed during this period. Patenting activity by Australian entities increased from the early 2000s to peak during 2010–12. This was followed by a decline, returning to the 1998 level in 2015. The rise and fall in patenting activity coincides with similar movements in commodity prices, as well as mining profits and investment.

We analysed patenting activity in the light of company participation in the Australian Government's R&D Tax Incentive program. Patenting activity and business R&D expenditure broadly followed similar patterns over time, peaking in the years around 2010 and then declining. R&D expenditure by entities registered for the R&D Tax Incentive grew six-fold from 2000–01, peaking in 2008–09 with an expenditure of \$3.74 billion. By 2015–16, this declined by two thirds.

A similar picture is observed in patent filings into Australia. These peaked in 2012, and declined strongly thereafter. This indicates a decline in patent protection in the Australian market from both domestic and international applicants, which could reflect the perceived value and strength of this sector.

Overall, patenting activity and R&D expenditure followed the rise and fall of the Australian mining boom, peaking in 2012 and declining thereafter to 2015. However, the Australian mining industry is well-positioned to fuel a growing demand for electric vehicles. Australia has the world's largest reserves of nickel, and is the world's largest producer of lithium. Australia is the fourth largest global producer of manganese ore and cobalt, and the fifth largest producer of nickel and copper (Britt et al., 2017). These are essential inputs for the production of electric vehicle batteries. The demand for these metals is forecast to rise steeply by 2030 in the lithium-ion battery supply chain for electric vehicles (Bloomberg New Energy Finance, 2018).

To realise the opportunities, Australia will need enough targeted investment in R&D in different mining technologies. This will not only support efficient use of resources but also build investor confidence in the Australian market.

²⁹ Patent data analysed by INPADOC patent families derived from PATSTAT 2017 Autumn Edition and IPGOD 2017 data, with earliest priority dates from 1 January 1997 onwards. Post-2015 data is incomplete due to the lag in patent publication, all available data is included in our analysis, except for trend analysis over time where post 2015 data is excluded.

REFERENCES

Australian Bureau of Statistics, 2018a, 5204.0 – Australian System of National Accounts, 2017-18, Table 51, Gross Fixed Capital Formation by Type of Asset

www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/5204.02017-18?OpenDocument

Australian Bureau of Statistics, 2018b, 5204.0 – Australian System of National Accounts, 2017-18

www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/5204.02017-18?OpenDocument

Australian Bureau of Statistics, 2018c, 5676.0 – Business Indicators, Australia, Sep 2018, Tables 11-12, Company Gross operating profits

www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/5676.0Sep%202018?OpenDocument

Australian Bureau of Statistics, 2018d, 5204.0 - Australian System of National Accounts, 2017-18, Table 5, Gross Value Added by Industry

www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/5204.02017-18?OpenDocument

Australian Government Department of Industry, Innovation and Science, 2018a, Resources and Energy Quarterly, June 2018, Office of the Chief Economist, Australian Government Department of Industry, Innovation and Science, Canberra

publications.industry.gov.au/publications/resourcesandenergyquarterlyjune2018/documents/Resources-and-Energy-Quarterly-June-2018.pdf

Australian Government Department of Industry, Innovation and Science, 2018b, Resources and Energy Quarterly, September 2018. Office of the Chief Economist, Australian Government Department of Industry, Innovation and Science, Canberra

publications.industry.gov.au/publications/resourcesandenergyquarterlyseptember2018/index.html

Australian Government Department of Industry, Innovation and Science, 2018c, Innovation and Science Australia Annual Report 2017–18, Australian Government Department of Industry, Innovation and Science, Canberra

www.industry.gov.au/sites/default/files/2018-11/innovation-and-science-australia-annual-report-2017-18.pdf

Australian Government Department of Industry, Innovation and Science, 2016, Innovation Australia Annual Report 2015/16, Australian Government Department of Industry, Innovation and Science, Canberra

www.industry.gov.au/sites/g/files/net3906/f/July%202018/document/pdf/innovation-australia-annual-report-2015-16.pdf

Australian Government, 2018, Budget 2018-19 Fact Sheet: Reforming the R&D Tax Incentive

www.budget.gov.au/2018-19/content/factsheets/6-tax-integrity.html

Baker Hughes, 2019, “Our Company”

www.bhge.com/our-company

Bloomberg 2019c, Company Overview of Sandvik AB

www.bloomberg.com/research/stocks/private/snapshot.asp?privcapId=621806

Bloomberg New Energy Finance , 2018, Electric Vehicles Outlook: 2018

bnef.turtl.co/story/evo2018?teaser=true

Bloomberg, 2019a, Company Overview of Halliburton Company

www.bloomberg.com/research/stocks/private/snapshot.asp?privcapId=177698

Bloomberg, 2019b, Company Overview of General Electric Company

www.bloomberg.com/research/stocks/private/snapshot.asp?privcapId=177031

Britt, A., et al., 2017, “Geoscience Australia 2017. Australia’s Identified Mineral Resources 2017”.

Geoscience Australia, Canberra.

dx.doi.org/10.11636/1327-1466.2017

CAT, 2019, “Take command of your mine”

https://www.cat.com/en_US/by-industry/mining/underground-mining/underground-technology/command.html

CO2CRC, 2019, “Our History”

www.co2crc.com.au/our-history/

CSIRO Data61 Robotics and Autonomous Systems Group, 2016, “Load Haul Dump (LHD) Automation”

<https://research.csiro.au/robotics/load-haul-dump-lhd-automation/>

Daly A., Valacchi G. and Raffo J., 2019, “Mining patent data: measuring innovation in the mining industry with patents”, Economic Research Working Paper No. 56, May 2019, World Intellectual Property Organization (WIPO), Geneva

https://www.wipo.int/edocs/pubdocs/en/wipo_pub_econstat_wp_56.pdf

Deep Exploration Technologies CRC, 2018, detcrc.com.au/

Deep Exploration Technologies CRC, “Uncovering the Future”

detcrc.com.au/wp-content/uploads/downloads/2018/07/DET_187-DET-CRC-Legacy-Book_190x240mm_FINAL_LR.pdf

Deloitte Access Economics, 2017, “Mining and METS: engines of economic growth and prosperity for Australians”, Report prepared for the Minerals Council of Australia, 2017

www.minerals.org.au/sites/default/files/Mining%20and%20METS%20engines%20of%20economic%20growth%20and%20prosperity%20for%20Australians.pdf

Downes, P., Hanslow, K. and Tulip, P., 2014, “The effect of the mining boom on the Australian economy”.

Research Discussion Paper RDP 2014-08, Reserve Bank of Australia

rba.gov.au/publications/rdp/2014/pdf/rdp2014-08.pdf

Encyclopedia of Australian Science, 2010, CRC for Mining Technology and Equipment (1991-2003)

www.eoas.info/biogs/A001916b.htm

Ferris, B., Finkel, A., and Fraser, J., 2016. Review of the R&D Tax Incentive,

www.industry.gov.au/sites/g/files/net3906/f/May%202018/document/pdf/research-and-development-tax-incentive-review-report.pdf

Francis, E., 2015, “The Australian Mining Industry: More Than Just Shovels and Being the Lucky Country”, IP Australia, Canberra

www.ipaustralia.gov.au/sites/g/files/net856/f/the_australian_mining_industry_more_than_just_shovels_and_being_the_lucky_country.pdf

GE Australia, 2019

www.ge.com/au/

Halliburton Landmark, 2019 “About Landmark”

www.landmark.solutions/About

Halliburton, 2019, “About Halliburton”

www.halliburton.com/en-US/about-us/default.page?node-id=hgbr8q6o

Kent, C., 2016, “After the Boom”, Speech at Bloomberg Breakfast, Sydney 13 September 2016

www.rba.gov.au/speeches/2016/sp-ag-2016-09-13.html

Lever, P., 2014, “Transforming mining”,

crca.asn.au/wp-content/uploads/2014/06/05-CRCMining-CRCA-Conf-Lever-May-2014.pdf

Mining3, 2018a, “Who we are”

www.mining3.com/about-us/who-we-are/

Mining3, 2018b, “What we do”

www.mining3.com/about-us/what-we-do/

Reserve Bank of Australia, 2018, Index of Commodity Prices, November 2018

www.rba.gov.au/statistics/frequency/commodity-prices/2018/icp-1118.html

Roberts, J.M., Corke, P.I., Cummingsham, J. and Durrant-Whyte, H., 1998, “Automation of underground LHD and truck haulage”, Annual Conference of the Australasian Institute of Mining and Metallurgy on the Mining Cycle (AusIMM 98), 19-23 April, 1998, Mount Isa, Australia. Australasian Institute of Mining and Metallurgy Publication Series, vol. 98 (2), pages 241-245

<http://apps.webofknowledge.com/InboundService>.

Sandvik, 2019, "About Us"

www.home.sandvik/en/about-us/

Schlumberger, 2019, "About Us"

www.slb.com/about.aspx

Soe, S., 2017, "The coiled tubing drilling rig for mineral exploration: the Roxplorer®", Australian Institute of Geoscientists Bulletin No.64, Conference Proceedings, Drilling for Geology II, 26-28 July 2017, Brisbane, Australia, Extended Abstracts, pages 25-26, 2017

www.csaglobal.com/wp-content/uploads/2017/08/D4G2_Extended-Abstracts-Volume.pdf

Trewin, D. and Pink, B., 2006, Australian and New Zealand Standard Industrial Classification 2006, ABS Catalogue No.. 1292.0, Australian Bureau of Statistics, Canberra

www.ausstats.abs.gov.au/ausstats/subscriber



