

Future of Minerals in NSW

REPORT

Sb

Antimony

Cr

Chromium

Pt

Platinum

Cu

Copper

W

Tungsten

Fe

Iron

Au

Gold

Cd

Cadmium

Sn

Tin

Pd

Palladium

Nd

Neodymium

Mo

Molybdenum

Co

Cobalt

Ag

Silver

Zn

Zinc

Pb

Lead

Sc

Scandium

Ni

Nickel

Zr

Zirconium



Minister's Foreword

The minerals sector in New South Wales (NSW) is vibrant and robust, with world-class deposits, a highly skilled workforce and a well-earned reputation for safe, responsible and innovative mining practices. The sector generates many thousands of jobs, especially in regional NSW, which underpin social and economic wellbeing. The NSW Government strongly supports our minerals sector and the responsible development of our mineral resources. Our goal is to make NSW the number one state for new exploration and resources investment across the nation.

This report provides explorers, investors and industry stakeholders with a detailed overview of global trends expected to impact on the demand for minerals in the future, and the metallic mineral potential of NSW and how this can play a role in meeting future demand. It also highlights the work the NSW Government is doing to support new exploration and investment, provide responsible sources of supply, support the industry's social licence and provide certainty for the minerals sector in NSW.

Around the world, there is a growing demand for 'traditional' minerals like gold and copper, and emerging 'high-tech' metals such as rare earth elements, scandium, cobalt and platinum group elements. NSW has many of these metals, which are needed to build the infrastructure, transport, communication and renewable energy technologies for our current and future economy.

With our vast greenfield opportunities, NSW is well-placed to be a key player in the global minerals sector. New exploration and investment in NSW can provide a stable supply of critical metals and support environmentally and socially responsible supply chains to produce the raw materials the modern world needs.

The NSW Government is making it easier for explorers, project developers and potential investors to understand the geological potential of the state. We are also improving the way we authorise and monitor new projects and ensure best-practice regulation for mines that are up and running, which is important for maintaining public confidence in our mine operations.

We have offered \$6 million in grants to explorers through our New Frontiers Cooperative Drilling program, with a record number of applications from explorers received in the last funding round. Our 10-year, \$16 million commitment to the MinEx Cooperative Research Centre's National Drilling Initiative has also already seen us complete the largest aerial electromagnetic survey by area in NSW history.

This search for clues of new copper, gold and zinc deposits in the NSW Central West spanned more than 19,000 km² and may also uncover new sources of groundwater. The geological setting of the Central West is also rich in high-grade scandium oxide – a resource that is extremely rare worldwide.

Supported by world-class research and mapping, robust regulatory frameworks and a world-class mining equipment, technology and services sector, NSW has low sovereign risk and offers all of the conditions for success.

A handwritten signature in black ink, appearing to read 'John Barilaro'.

The Hon John Barilaro MP

Deputy Premier,
Minister for Regional NSW and
Minister Responsible for Resources

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Introduction

With its vast and underexplored metallic mineral deposits and its reputation for safe, socially and environmentally responsible mining practices, New South Wales (NSW) is well-placed to become a key player in the global supply of in-demand minerals into the future. The Future of Minerals in NSW Report is a key element in the NSW Minerals Strategy that aims to significantly grow investment in mineral exploration and mining in NSW.

From 'traditional' metals like gold, zinc and copper to high-tech metals such as cobalt, scandium and rare earth elements (REE), NSW is a minerals 'all-rounder' within Australia, a country renowned for its vibrant minerals sector.

New exploration and investment in the NSW minerals sector can help diversify global markets that provide responsible supply chains for emerging technologies aimed at decarbonising economies.

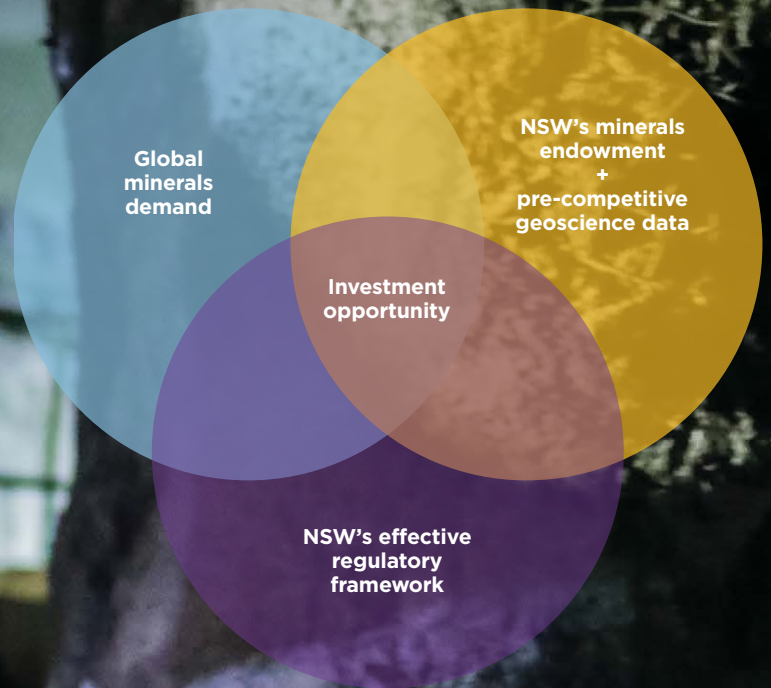
The NSW minerals sector is a major contributor to the state's economy, providing investment, regional development, job creation, royalties and export revenue. Mining provides economic stability that supports people in regional communities and supports a diversity of industries in regional NSW.

Although NSW mineral production is currently dominated by coal, the state has a long history of metal production from world-class deposits, such as the giant Broken Hill silver-lead-zinc and Cadia Valley copper-gold mines. With significant potential for further discovery, the state is well positioned to become a supplier of choice for the metals needed in the 21st Century.

Developed for the industry and investors, this report presents opportunities for investment in the NSW metallic minerals sector in the context of projected trends in global economic and technological development, and the implications these will likely have for global metallic mineral demand.

In response the Australian Government has committed to securing the future of rare earth and critical mineral projects, including those strategically important to defence end-use, with new financial options and a dedicated project facilitation office within the Department of Industry. Projects which boost the ability to extract and process critical minerals in Australia will be eligible for financial support through Export Finance Australia.

Figure 1: Alignment of factors to capitalise on NSW metallic minerals opportunities



NSW is well-placed to become a key player in the global supply of in-demand minerals into the future

1. NSW's strong minerals potential

NSW has significant investment potential for traditional metals that are already produced, such as copper, gold and base metals. These are likely to see increasing demand as the world continues to electrify and urbanise. NSW also has excellent potential for emerging metals such as cobalt, scandium, titanium and REEs. Demand for these metals is expected to grow strongly, but for some of these elements, consumption is currently constrained by a lack of reliable supply.

NSW is ideally placed to meet this demand, making the case for mineral exploration investment in NSW strong. Our substantial mineral endowment, world-class infrastructure, low sovereign risk, highly skilled workers, publicly available geoscientific data, and world-leading regulations, safety and environmental standards present opportunities to provide significantly better investment returns compared to some other resource-rich regions.

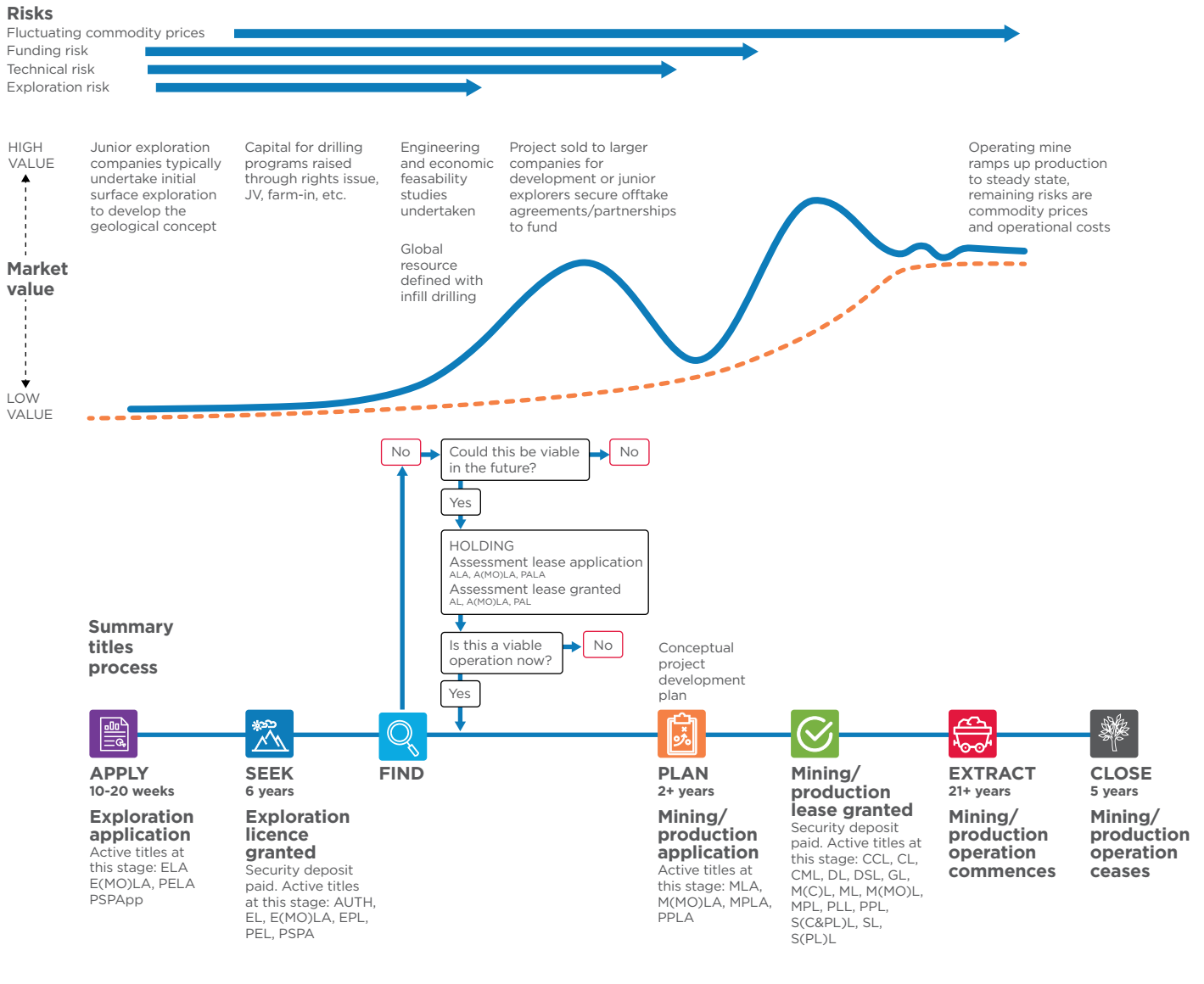
1.1 Robust frameworks to minimise industry risk

Metallic mineral exploration is intrinsically high-risk and complex. The cost to drill is high, the conversion rate of exploration projects into mines is low and, even when successful, the timeframe from initial discovery to production can be a decade or more. The high-risk nature of metal exploration means around 80 per cent of junior explorers record net losses in any given year. These losses must be offset by the possibility of large returns when a successful discovery is made.¹

In order to effectively balance social, environmental and economic considerations, and to provide certainty for potential investors, the NSW Government has established a robust planning and regulatory framework and an effective exploration and mining titles system.

Figure 2 shows the risks faced during a typical mine development, using the Lassonde curve to describe the change in project value during the lifecycle.² The diagram also shows a summary of the NSW resources titles process, which includes community consultation, landholder access negotiation and environmental assessment. The NSW Government is committed to ensuring efficient administration of the resources titles process, with clear rights and obligations for explorers and operators, as well as meaningful community and landholder engagement.

Figure 2: Mineral resource development lifecycles and the NSW resource titles process



Issues such as security of supply, community support and responsible environmental stewardship are key considerations for companies looking to responsibly source minerals. NSW is well respected for its commitment to robust regulation and best practice working conditions, and for ensuring a level of environmental and social responsibility that represents best practice and meets community expectations.

The NSW Government also recognises the value of freely available, readily accessible geoscientific information to the mineral exploration industry. The Geological Survey of NSW (GSNSW) is the custodian of the state's geoscientific data and maintains and delivers extensive statewide databases of geological and geophysical information, mineral occurrence locations, and surface and drillhole geochemistry, as well as a physical library of core samples that are freely available to explorers. Providing and maintaining these publicly available historic records of mineral occurrence information reduces future exploration costs and the time required to discover and develop a resource within NSW.

1.2. Uncovering the potential of NSW

There is a misconception that all NSW's large metallic mineral deposits have been discovered and that NSW is well explored.

In truth, like many other regions across the globe, the state's deep and undercover geology remains largely unexplored and NSW has significant mineral potential still to be discovered.

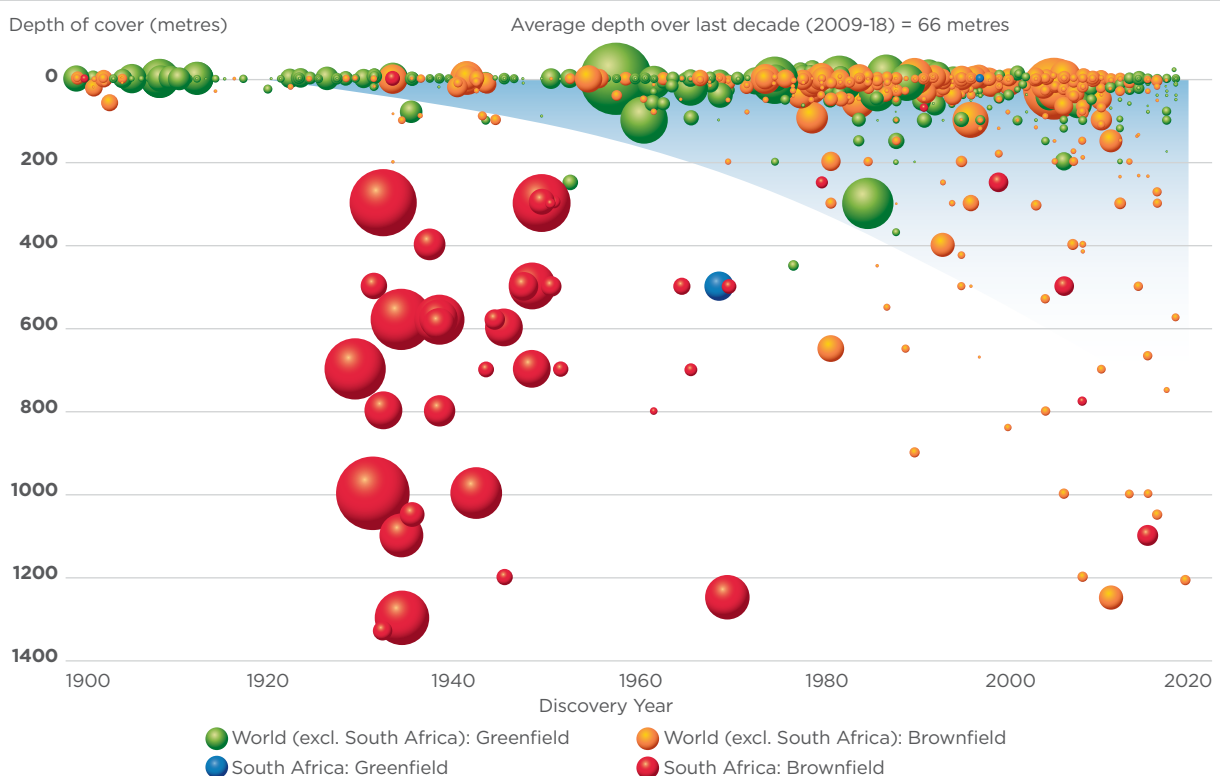
Mineral-bearing geology across NSW extends both at depth and under younger cover sequences. However, almost all historical exploration in the state is confined to areas where prospective geology is exposed at the surface and only eight per cent of the mineral drillholes across the state have been drilled deeper than 150m.³ This means very little of the mineral potential deeper underground and undercover has been realised.

There is no scientific reason why the NSW surface mineral endowment would not be replicated below the 150m depth.⁴ There is, for example, clear evidence that deep mineralisation occurs in NSW, such as at Ridgeway, in the Cadia Valley, where the copper-gold deposit starts at 500m below the surface.

Greater depth increases exploration and production costs and this has traditionally led to near-surface exploration. However, as demonstrated by Figure 3, the scale of deposits are not limited by depth, and the depth of deposits is not a barrier to mining operations. For example, the giant Cadia East porphyry copper-gold deposit in the NSW's Central West plans to mine beyond 2000m depth and the CSA mine at Cobar is currently mining at 1850m below the surface, with plans to go deeper.

Less than 10 per cent of Group 1 mineral exploration drillholes in NSW have been drilled to greater than 150m

Figure 3: Size and depth of global gold discoveries across years



Note: Primary gold deposit >0.1 Moz. Bubble size refers to Moz of pre-mined resource. Excludes satellite deposits within existing camps. Source: MinEx Consulting © October 2015.

Australian governments, geoscientists and industry recognise the importance of developing new concepts and technologies to expand the exploration search space at depth and in covered terranes. MinEx CRC is a \$220 million, 10-year program to address this key challenge at a national level. The NSW Government is a major participant in the MinEx CRC, committing \$16 million over 10 years. More information on the MinEx CRC initiative can be found in this report and at resourcesandgeoscience.nsw.gov.au/minexcrc



The state's deep and
undercover geology
remains largely unexplored and
has significant mineral potential

2. Future global demand for minerals

Over the next 40 years, global demand for metals and other key raw materials is expected to surge as a result of the following factors:

- a growing middle class – due to economic development, urbanisation and electrification across many regions of the world
- technological development – greater mineral intensity and variety of minerals required
- climate policy – the transition toward lower-carbon economies.

Table 1 shows metals that are expected to experience increased demand due to these drivers and for which NSW hosts mineral deposits bearing these metals.

Table 1: Summary of demand drivers for key metals/metal groups relevant to NSW

	Growing middle class	Technological development	Renewable energy
Traditional metals:			
Nickel	●		●
Aluminium	●	●	●
Copper		●	
Tin		●	
Lead	●		●
Silver		●	●
Zinc	●	●	●
Gold	●	●	
Platinum Group Elements		●	
Emerging metals:			
Cobalt		●	
Scandium		●	
Titanium		●	
Indium		●	●
Rare Earths Elements		●	●

2.1. The growing middle class

The United Nations forecasts that the world's population will reach 8.5 billion by 2030, 9.7 billion by 2050 and 11.2 billion by 2100.⁵ Over the same period, average living standards are expected to rise, creating a growing global middle class. This growing middle class is expected to drive demand for minerals through increased consumer spending and urban development.⁶

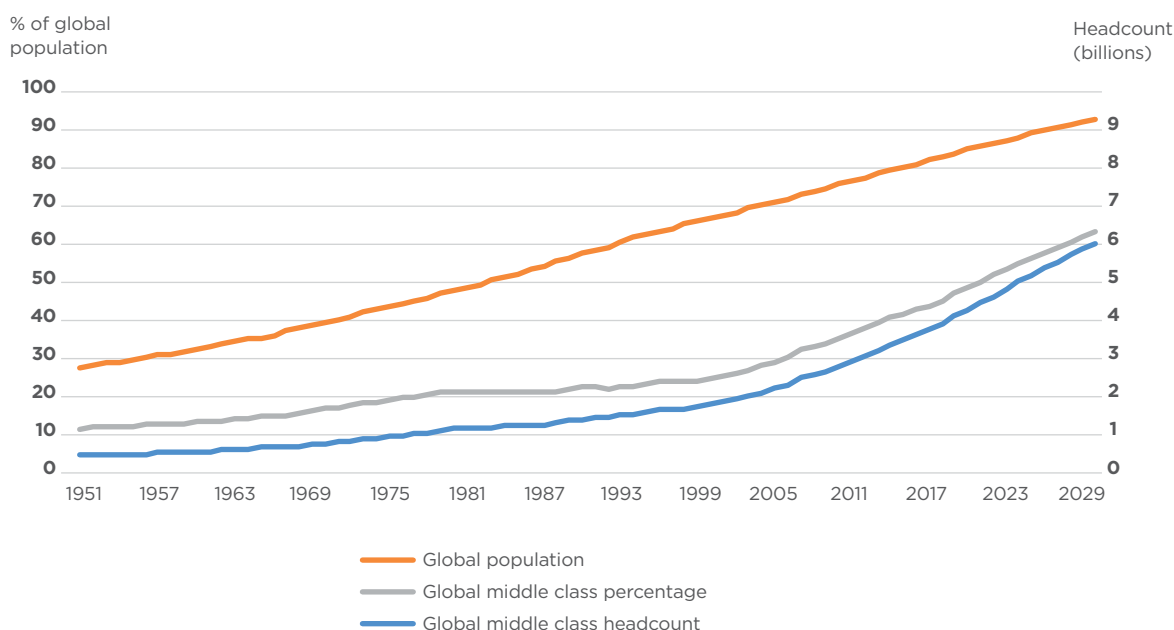
Investment initiatives targeted at economic development are accelerating the growth of the global middle class. Examples of such initiatives include China's Belt and Road, Asian Development Bank projects and the World Bank development partnerships.

The 'Trends Shaping Education 2019' report, published by the Organisation for Economic Cooperation and Development (OECD), shows that while the world population has tripled between 1961 and 2016, the global middle class increased by more than tenfold to reach 3.2 billion. Figure 4 below shows that a large proportion of the world's population will be middle class within 10 years, reaching 5 billion by 2028. The expectation is that the distribution of the middle class will also shift, with 90 per cent of growth expected to occur in China and India.

As populations and living standards increase, so will the consumption of goods. This can be seen by the changes in consumer spending in Africa as it has developed, where sales of refrigerators, televisions, mobile phones, motors and automobiles has surged. In Ghana, for example, the possession of cars and motorcycles has increased by 81 per cent since 2006.⁸

Figure 4: Historical and forecast of the world's middle class (OECD 2019)⁷

Estimates of the size of the global middle class, percentage of the world population (left axis) and headcount (right axis), 1950-2030



As Table 2 shows, by 2030 global middle class consumption is expected to shift towards China and India, and to be \$29 trillion more than it was in 2015.

Table 2: Forecast size and distribution of top 10 countries global middle-class consumption⁹

2015			2020			2030		
Country	\$ trillions (\$2011, PPP)*	Share (%)	Country	\$ trillions (\$2011, PPP)*	Share (%)	Country	\$ trillions (\$2011, PPP)*	Share (%)
U.S.	4.7	13	China	6.8	16	China	14.3	22
China	4.2	12	U.S.	4.7	11	India	10.7	17
Japan	2.1	6	India	3.7	9	U.S.	4.7	7
India	1.9	5	Japan	2.1	5	Indonesia	2.4	4
Russia	1.5	4	Russia	1.6	4	Japan	2.1	3
Germany	1.5	4	Germany	1.5	4	Russia	1.6	3
Brazil	1.2	3	Indonesia	1.3	3	Germany	1.5	2
U.K.	1.1	3	Brazil	1.2	3	Mexico	1.3	2
France	1.1	3	U.K.	1.2	3	Brazil	1.3	2
Italy	0.9	3	France	1.1	3	U.K.	1.2	2

* Purchasing Power Parity, constant 2011 US dollars

2.2 Developing technologies

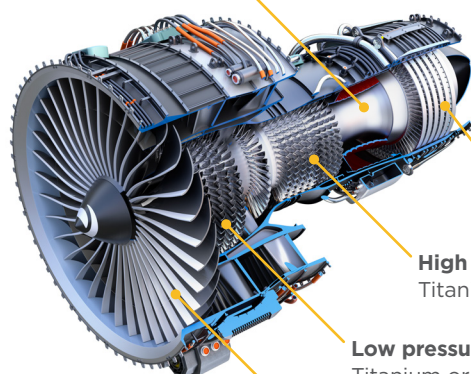
Minerals are essential to the manufacture of modern technologies. While some minerals have had well-established uses for some time, advances in material science research have led to the discovery of some previously unknown characteristics of these elements. This has enabled a broader range of commercial applications to produce materials with enhanced functionality and higher performance.¹⁰ A future trend, for example, will be the growing commercialisation of scandium in aluminium alloys used for industries such as aerospace, where strength and weight are key considerations. Even small quantities of scandium significantly improve the performance of aluminium alloys and scandium provides a higher increment of tensile strength per atomic per cent than any other alloying element. To date, there has not been a big commercial up-take of scandium as it not been mined in large quantities. This is likely to change as deposits with enough concentration to justify a dedicated mining operation are developed in NSW and elsewhere.

Much of the broader advancement in material science is due to combining multiple elements with unique properties into compound materials. This trend of using more minerals in technologies will continue as material science unlocks new applications.

Superalloys used in jet engines are a prime example of increasing metal variety within technologies. These superalloys are nickel-rich but also include metals such as titanium, aluminium, cobalt, molybdenum, tungsten and REEs. The addition of these metals has increased engine operating temperatures, improved engine efficiency and reduced greenhouse gas emissions.¹¹

Figure 5: Metals used in components a jet engine¹¹

Combustion chamber and high pressure turbine
Nickel based superalloys with a thermal barrier coating such as yttrium stabilised zirconia



Low pressure turbine
Nickel based superalloys

High pressure compressor
Titanium or nickel alloys

Low pressure compressor
Titanium or aluminium alloy

Fan
Titanium alloy

Silver, for instance, has unique properties that make it ideally suited to modern applications such as radio frequency identification device chips,¹² while platinum group elements have become indispensable for many industrial applications.

Advanced materials are providing significant efficiency benefits through technological improvement, but the broader range of elemental components have an impact on the reuse value cycle.

While recycling techniques have improved, recovery and reuse remain a small proportion of the supply of many minerals. Certain metals with enough market value and recognition such as copper, gold and platinum have significant levels of recycling. However, compound materials such as paints or photovoltaic panels are difficult to separate back into their mineral components, limiting the ability to recycle. Even as recycling becomes technically viable, the materials are locked up in products and must reach end of life before they are available for reuse. As a result, there remains a significant need to develop new mines to satisfy the growth in demand for minerals.¹³

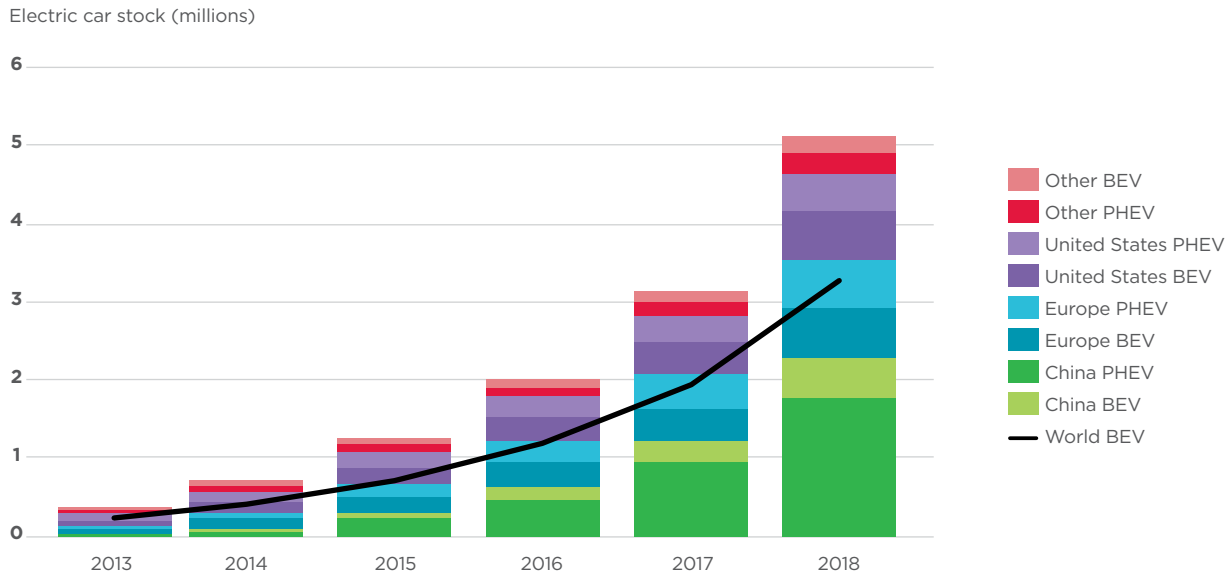
“Some metals that have become deployed for technology only in the last 10 or 20 years are available almost entirely as by-products”

*Thomas E. Graede,
Professor Emeritus of
Chemical Engineering, Yale*

2.2.1 Global uptake in electric vehicles

Growing social awareness of the environmental impact of carbon emissions, combined with government initiatives, has led to an increase in the global uptake of electric vehicles (EVs) as demonstrated in Figure 6. Currently, there are three general categories of EVs. These include battery electric vehicles (BEV), plug-in hybrid electric vehicles (PHEV) and fuel cell electric vehicles (FCEV). BEVs and PHEVs require similar materials to manufacture, while FCEVs have different material needs to convert hydrogen to electricity.

Figure 6: Electric car deployment in selected countries 2013-2018¹⁴



Future demand for materials that are required for the manufacture of EVs will depend on the speed of the transition to electric transport and on advances in battery technology and chemistry.

Growth in the EV market will drive demand for raw materials including:

- battery materials – the most common battery chemistries require lithium, nickel, cobalt and manganese aluminium, graphite and copper
- copper – a typical EV contains about five times more copper than an equivalent internal combustion engine car as it is present in the battery, electric motor and wiring.¹⁵ It will also be needed in large quantities for power grid upgrades and infrastructure extensions for electric vehicle charging
- lightweight superalloys – aluminium, nickel, titanium, scandium, vanadium and niobium are increasingly being used in conventional and electric vehicles to improve energy efficiency.

The expected increase in demand for EVs in the future is supported by recent private sector investments. For example, auto manufacturer Volkswagen has announced it will spend over \$US 30 billion on EV production capacity by 2023 to meet its target of EV sales, making up 40 per cent of its global sales by 2030. Chinese auto manufacturers such as BYD and Yutong have also been active in Europe and Latin America deploying electric buses, while European and North American manufacturers Scania, Solaris, VDL, Volvo, Proterra and New Flyer are also active in the electric bus market.¹⁶

2.3. Lower carbon economies

The growing renewable energy industry has the potential to reduce our dependence on, and mining of, fossil fuels. However, the manufacture of renewable technologies requires a significant amount of mined minerals. An example of the typical minerals required for a three-megawatt direct-drive wind turbine is shown in Figure 7.¹⁷

The transition towards lower carbon economies will accelerate the deployment of wind, solar and batteries, and this will have implications for commodities markets. It is expected aluminium, copper, silver, bauxite, iron, lead and other minerals will see growth in demand as the transition occurs.

Figure 7: Typical raw materials required for a 3MW direct drive wind turbine



2.3.1. Renewable technologies

The World Bank Group has calculated the mineral requirements associated with the deployment of renewable technologies that would be required to achieve three climate policy scenarios developed by the International Energy Agency (IEA). The IEA scenarios range from 2 degrees Celsius (°C) of warming (where the most investment in renewables occurs) through to 4°C and 6°C of warming.

The required investment in wind and solar electricity generation varies in each scenario and is shown in Table 3. Under the 2°C warming scenario, wind power generation is projected to increase to almost five times current capacity by 2050, with solar capacity increasing 13 times more than current levels. In the least ambitious 6°C warming scenario, there is a less dramatic growth in renewables, but with wind being still more than three times higher than current capacity and solar more than five times higher.

Table 3: Required growth in annual global renewable electricity production (terawatt-hours) forecast for various levels of global warming relative to 2018

Year	Wind electricity production			Solar PV Electricity Production		
	2°C warming	4°C warming	6°C warming	2°C warming	4°C warming	6°C warming
2018	1,500	1,250	1,200	360	360	360
2028	+153%	+114%	+86%	+257%	+162%	+108%
2038	+290%	+224%	+174%	+687%	+355%	+251%
2048	+390%	+340%	+256%	+1243%	+591%	+457%

Table 4 shows the metals required for the two dominant wind turbine technologies. In 2011, direct-drive turbines were 19.8 per cent of the wind generation market; by 2020, it is expected this share will increase to 29.6 per cent. This is expected to drive demand for neodymium that is used in the permanent magnets.¹⁸

Table 4: Metals required for wind turbine technologies

	Geared	Direct drive
Aluminium	●	●
Chromium	●	●
Copper	●	●
Iron	●	●
Lead		●
Manganese	●	●
Neodymium (REE)		●
Nickel	●	●
Zinc	●	●

For solar photovoltaics, different technologies have varying metal content. The current dominant technology is crystalline silicon cells with 85 per cent market share. It is heavily reliant on silver due to its good heat and electrical conductive properties.

Table 5: Metals required for solar photovoltaic technologies

	Crystalline silicon	Copper indium gallium selenide	Cadmium telluride	Amorphous silicon
Aluminium	●			
Copper		●	●	
Indium		●		
Iron	●			
Lead	●			
Nickel	●			
Silver	●			
Zinc			●	●

Due to different economies of scale and alternative technologies within the broader wind and solar applications, there is not a one-to-one relationship between growth in renewable generation capacity and mineral demand. However, the World Bank Group's study demonstrates the potential for all three of the climate change scenarios to dramatically drive demand for certain metals well beyond current production, with the 2°C warming scenario driving the greatest growth in demand. Table 6 shows the dramatic impact on neodymium demand the World Bank Group study expects as a result of growth in direct drive wind turbine investment, as well as the impact that growth in alternative photovoltaic technologies could have for silver and indium demand.

Table 6: Metals where projected renewables demand is likely to outstrip current production

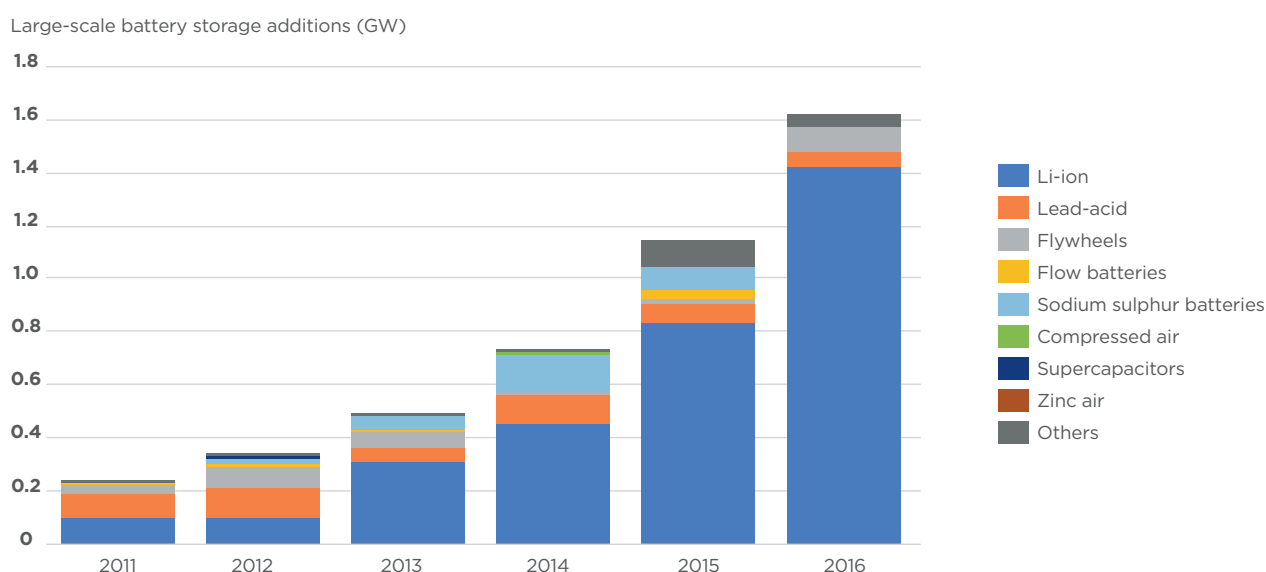
Assumption	Metal	Current total world production	Renewables demand by 2050		
			2°C warming	4°C warming	6°C warming
Proportion of direct drive wind turbines by 2050:					
25% onshore, 75% offshore	Neodymium	7,000 t	230,000 t	150,000 t	95,000 t
50% onshore, 75% offshore	Neodymium	7,000 t	395,000 t	275,000 t	185,000 t
Crystalline silicon solar PV retains high market share, currently 85%:					
83% by 2050	Silver	24,000 t	740,000 t	395,000 t	250,000 t
75% by 2050	Silver	24,000 t	475,000 t	265,000 t	175,000 t
Thin film solar PV gains market share, currently 7%:					
17% by 2050	Indium	670 t	50,000 t	30,000 t	15,000 t
25% by 2050	Indium	670 t	80,000 t	40,000 t	25,000 t

2.3.2. Energy storage

There is a real opportunity and demand for battery storage to support the use of renewable energy technologies. Currently, the average daily generation patterns for wind turbines and solar panels do not match times of higher household and industrial use. The misalignment of energy generation and use presents a challenge for renewable energy technologies, as supply from these sources cannot be easily adjusted. Energy storage provides a means to store the electricity generated by renewables for use in times of increased demand.

The Australian Energy Market Operator (AEMO) relies upon fossil fuel baseload generation to stabilise and meet demand when low carbon alternatives are insufficient. Batteries offer an opportunity to avoid future large investments in baseload generators to ensure generating capacity can accommodate the period of peak electricity use. As shown in Figure 8, lithium-ion or advanced variants are replacing traditional lead-acid batteries, resulting in greater demand for lithium (and integrated elements such as cobalt and nickel). Table 7 shows the range of metals required for the leading battery technologies and the expected growth for each metal under the 2°C warming scenario by 2050.

Figure 8: Global large-scale battery storage additions^{19,20}



19. IEA 2018, 20. Sandia Corporation 2018

Mobile household devices are also driving demand for lithium. Products such as vacuum cleaners, power tools and sound systems are transitioning towards lithium-ion battery-powered variants and their increasing uptake by the growing middle class will likely see demand for lithium-ion battery materials continue to grow.

Table 7: Metals required lead-acid and lithium-ion Batteries

	Lead-acid	Lithium-ion
Aluminium		●
Cobalt		●
Lead	●	
Antimony	●	
Lithium		●
Manganese		●
Nickel		●
Steel	●	●

3. World minerals supply

Due to the uneven distribution of mineral deposits, operating mines and metal refining infrastructure globally, no one nation can independently satisfy their mineral needs. Global mineral and metal supply chains operate across many countries. This makes mineral supply a complex function of accessibility, social constraints, politics, laws, environmental regulations, land restrictions, economics and infrastructure.

In more recent times, the security of supply of minerals has become a key concern for global markets. Governments have recognised the importance of particular minerals to their economies, with some developing lists of 'critical' minerals that have potential supply chain risks for their economy, due to their reliance on imports and the relative scarcity of these minerals in the market.

'Rarity' describes the abundance of the elements in the earth's crust, while 'scarcity' depends on the cost of acquiring an element in a usable form. Humans have no control over rarity, whereas scarcity is a function of the effort needed to liberate a mineral from known deposits and the prevailing market prices for the mineral. Market prices can potentially be manipulated by large producers who have excessive market control and have an incentive to hinder the development of competing supply.

REE are a prime example of the difference between rarity and scarcity, as while they are relatively common in the Earth's crust, they mostly occur in very low concentrations. The most critical aspects of their supply are their scarcity in the market and domination of supply by China, which is due to complex ore types, erratic price movements and historically low quantities being demanded by the industry.²¹

It is important to recognise that throughout history there have been instances where the future supply of finite minerals raised concern but then dissipated as advances in mineral exploration, extraction technologies and recycling have pushed the global minerals production beyond those previous production levels. Ongoing exploration has led to new resource discoveries, while higher prices and more cost-effective processing technologies have made previously unviable reserves viable. For example, the tailings of historical operations are sometimes reprocessed, as grades in the tailings are high enough for commercial development.²²

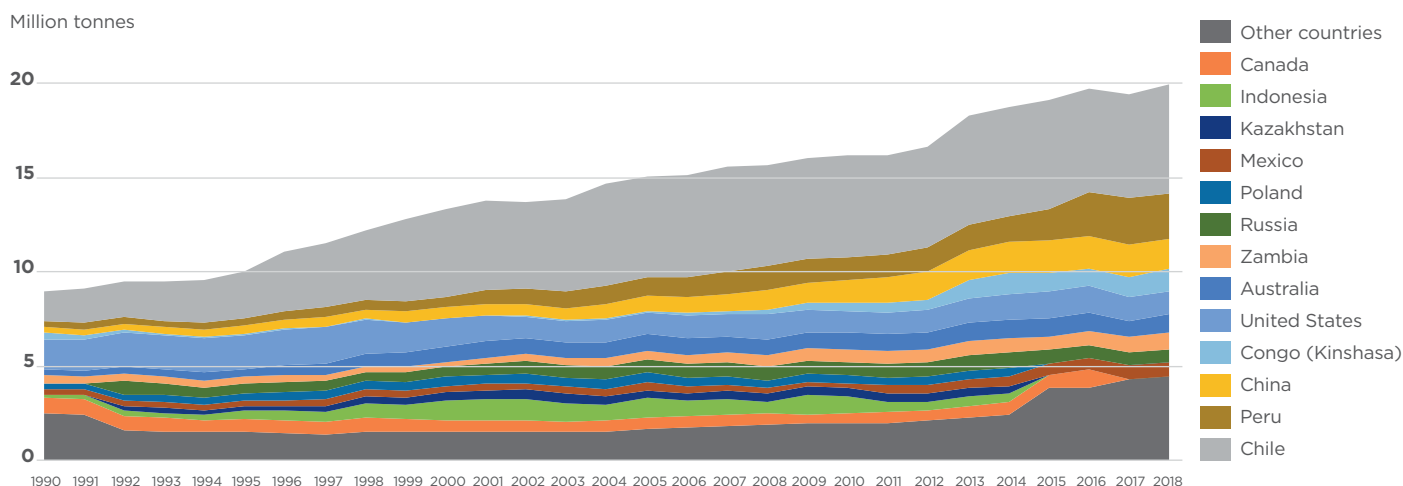
3.1 Global supply of traditional metals

Copper

Over the past decade, Chile has accounted for over 25% of global mine production of copper, with Peru and China both overtaking the USA as significant producers (Figure 9). Mined copper production is expected to reach its peak in 2026, at 23 million tonnes (Mt), and then decline to 17 Mt by 2035 as the reserves and grades of current operations decline. Chile, Peru and China will remain the three largest producers, all with new projects planned in the medium term.²³

In the medium to long term, a supply deficit is highly possible, due to a lack of new projects entering the market and declining output from current operations. Investment in new projects will be required, particularly from the late 2020s onwards.

Figure 9: Global mined copper production²⁴



See NSW endowment of copper, [Figure 16](#)

Gold

Gold has intrinsic characteristics that affect its value, with approximately 41 per cent held by investors or central banks. Gold investments can be broken down as 25 per cent held as gold coins and bars, 15 per cent held by central banks, and one per cent held for gold backed exchange traded funds. Non-investment uses account for 59 per cent of total demand. The non-investment uses include jewellery at 51 per cent, electrical circuitry at seven per cent, with other industrial and dental applications making up the difference. The share of these non-investment applications for gold are expected to remain relatively constant out to 2035.²⁵

Mined gold production passed its peak in 2018 at 3,101 tonnes and is expected to continue to decline due to falling average ore grades. Mine production is supplemented by a secondary market in recycled gold, which contributes about 1,300 tonnes annually. The scrap recycling market is not expected to rise significantly to cover production losses, as recycling rates for electronic scrap and jewellery are already very high.

Under these circumstances growth in gold demand would lead to higher prices that improve the viability of developing lower grade deposits. Despite hosting 18 per cent of known global reserves (Figure 11), Australia is currently the second largest gold producer after China, producing 9.7 per cent of the world's mined gold in 2018.

Figure 10: World gold production²⁶

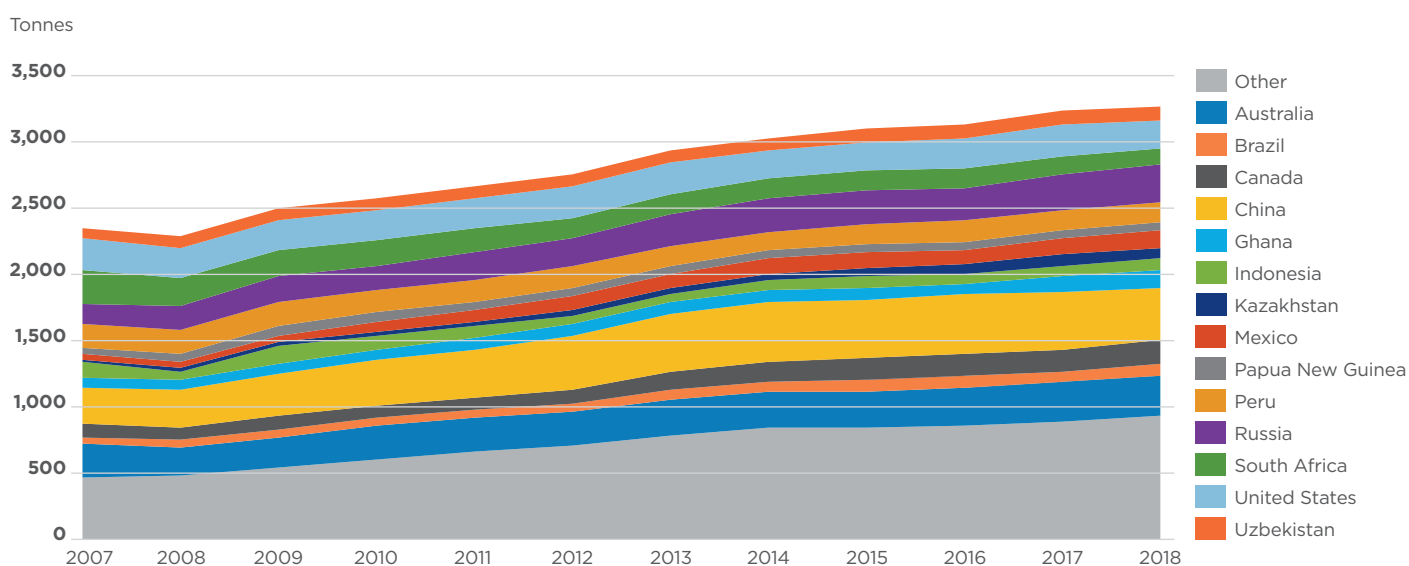
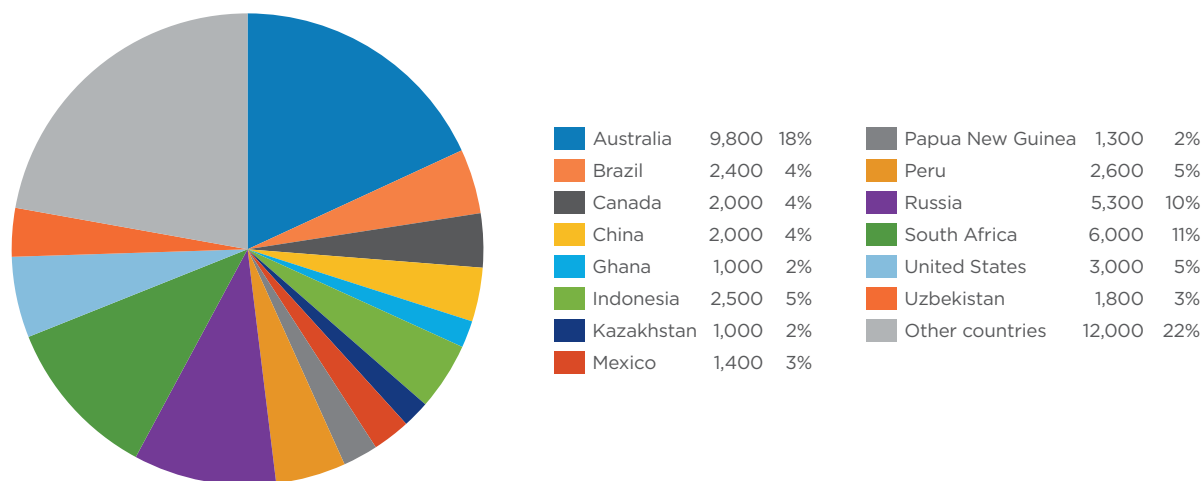


Figure 11: World gold reserves (tonnes)²⁶



* For Australia, Joint Ore Reserves Committee-compliant reserves were about 3,800 tonnes

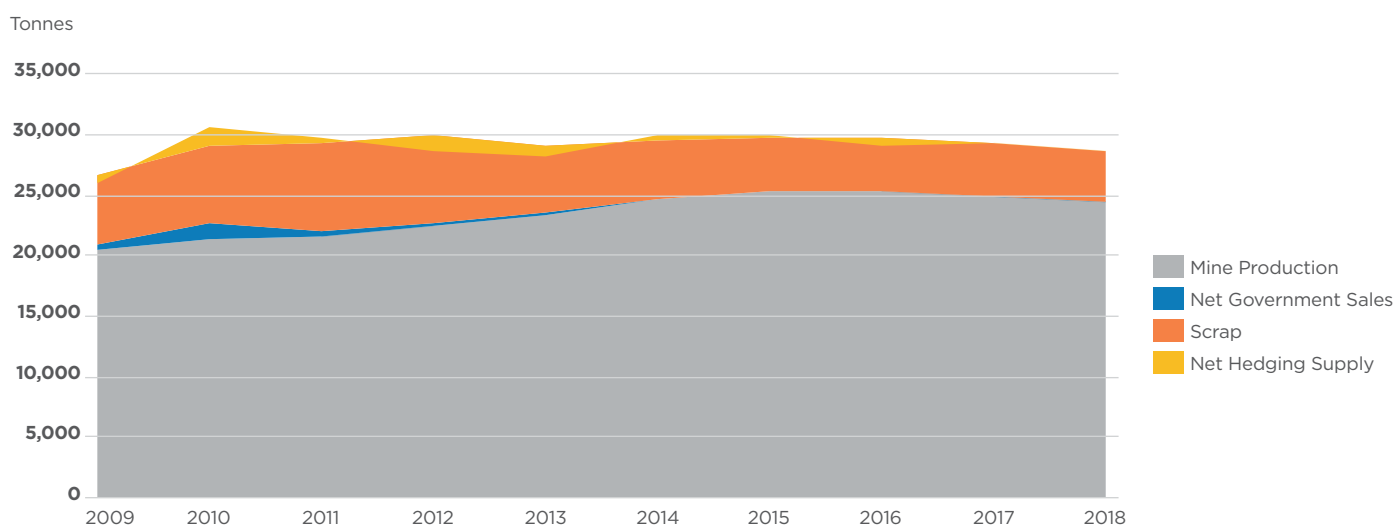
See NSW endowment of gold, [Figure 17](#)

Silver

Although silver is a principal product at several mines, it is primarily obtained as a by-product from lead-zinc mines, copper mines and gold mines. These polymetallic ore deposits from which silver is recovered account for more than two-thirds of the world's silver resources. Most recent silver discoveries have been associated with gold occurrences. However, copper and lead-zinc occurrences containing by-product silver will continue to account for a significant share of reserves and resources in the future.²⁷

As shown in Figure 12, silver output is in decline. This downward trend is expected to continue to 26,000 t in 2019, followed by an increase, expected to reach 29,000 t by 2023.²⁸ Australia's mined silver production is ranked 8th in the world, accounting for 4 per cent of world mine production in 2018.²⁹

Figure 12: World supply of silver²⁹



See NSW endowment of silver, [Figure 19](#)

Lead

Lead is commonly found with zinc and silver, as well as copper. Most of the mined lead production is from these polymetallic deposits.

Global refined lead production from smelting is forecast to increase from 11.8 million tonnes in 2018 to 15.3 million tonnes in 2035, with China accounting for 60 per cent of supply growth. In 2018, NSW produced 91,000 t of lead concentrates, NSW is also host to the world's ninth largest lead mine, located at Broken Hill.³¹

Recycling plays a major role in the lead market, accounting for around 60 per cent of total refined lead production. Secondary lead production is closely linked to demand as lead-acid batteries (LABs), which fail over time account for 85 per cent of global use and are easily recycled by smelters.³⁰ With an efficient recycling supply chain and plentiful mined supply, world lead supply is not expected to be limited.³¹

See NSW endowment of lead, [Figure 18](#)

Zinc

Zinc is used as an anti-corrosion agent, particularly in galvanised steel (60 per cent of demand) and brass or other alloys (29 per cent). The major sectors driving zinc demand are construction (45 per cent), transport (25 per cent) and consumer goods (23 per cent).³¹

China is a dominant refined zinc producer, supplying about 43 per cent of the global market. This dominance is expected to continue and rise slightly through to 45 per cent by 2035. Global refined zinc production is forecast to reach 16.5 million tonnes by 2035, up from 13.6 million tonnes in 2018. Australia is a significant zinc producer and hosts 27 per cent of global zinc reserves, with NSW accounting for about 3.6 per cent of world zinc reserves.³²

See NSW endowment of zinc, [Figure 18](#)

Aluminium

Bauxite is the world's main ore for aluminium and world resources of bauxite are estimated at between 55 billion to 75 billion tonnes; enough to meet demand well into the future. In 2018, Australia was the largest producer of bauxite and the second largest producer of alumina (pure aluminium oxide). Australia's aluminium smelters had a combined output that ranked 6th in the world, three per cent of total world output, while China was the world's largest producer, accounting for more than 50 per cent of world production.³²

Global demand is projected to rise over the five years through 2024-25 due to aluminium's continued use in the building and construction industry and increased use in motor vehicle chassis and EV batteries. However, supply growth is anticipated to match this trend over the period.³³ Annual aluminium production has grown significantly since the early 1950s when it was about 2 Mt and is now estimated at about 90 Mt per year. Production is from a combination of primary metal production and recycling, with recycling currently at 32 per cent of total output.³⁴

NSW has some identified bauxite deposits, but exploration to date has not found commercial resources. NSW is host to aluminium smelter production at the Tomago refinery and Weston Aluminium recycling in the Hunter region.

Nickel

Global demand for nickel is projected to increase over the next five years, driven by higher steel production. Approximately 71 per cent of the world's refined nickel output is used to manufacture stainless steel. Non-ferrous alloys are the next largest use at 10 per cent. In the form of nickel sulphate, battery demand currently accounts for 4 per cent of nickel demand. However, battery demand is expected to reach 34 per cent of total demand by 2035, driven by the expected growth in electric vehicles, energy storage and portable electronics.³⁵

Global production is expected to increase from 2.14 Mt in 2018 to 4.58 Mt in 2035. Asia will continue to lead nickel production, maintaining around a 60 per cent production share in the long term as China and Indonesia substantially increase nickel pig iron output for stainless steel. Australia's share of global nickel production is expected to remain relatively consistent, rising from 11 per cent to 13 per cent by 2035, however this represents a substantial growth in volume due to the market more than doubling over the same period.³⁶

Battery-grade nickel sulphate processing is not expected to be limited, as large capacity additions have already been announced by existing nickel producers. In addition, an increasing volume of sulphate is being produced by recyclers of batteries, spent plating solution, and other nickel-bearing wastes.

See NSW nickel endowment, [Figure 20](#)

Platinum Group Elements (PGE)

PGEs are among the rarest metals, with the Earth's upper crust containing only about 0.0005 part per million (ppm) of platinum. Almost all the reported production and identified resources are associated with ultramafic-hosted deposits. These include the Bushveld Complex in South Africa, the Great Dyke in Zimbabwe, and the Noril'sk-Talnakh area of Russia.³⁷

The most significant use of PGEs is in catalytic converters to reduce carbon monoxide, hydrocarbon and nitrous oxide emissions in automobile emissions. Other uses include glass manufacturing, fibreglass and flat-panel and liquid crystal displays. Consumer electronics uses include computer hard disks, hybridised integrated circuits and multilayer ceramic capacitors. The United States Geological Survey (USGS) estimates there are 100,000 tonnes of PGE resources remaining to be developed across world deposits, with most of these resources in South Africa.

See NSW platinum endowment, [Table 8](#)

Antimony

Antimony has a relatively low crustal abundance of 0.2 ppm. There are identified antimony resources as stibnite, the major ore mineral, but the bulk stibnite resources can be found in a few very large deposits unevenly distributed across the globe. The future mining of antimony is likely to be from deposits tied directly to precious metals, copper, lead, and/or zinc as a by-product or coproduct.³⁸

Australia has two known antimony resources that have been mined in conjunction with gold. These are Hillgrove, approximately 30km from Armidale in NSW and Costerfield, 50 km east of Bendigo in Victoria. Hillgrove was placed into care and maintenance in 2016 due to low prevailing antimony prices. The increase in gold price is expected to see the recommissioning of Hillgrove in 2020.

See NSW antimony endowment, [Table 8](#)

Molybdenum

The major end use for molybdenum is as an additive to steel, to provide strength and corrosion resistance. As a result, there are numerous sectors that indirectly drive demand for molybdenum through steel, including the oil and gas industry, automotive industry and mechanical engineering.³⁹

Molybdenum is supplied as both a primary product and as a by-product or co-product from other metal mining – predominantly copper. Historically, just under half of all supply comes from primary mines and these account for approximately 40 per cent of global reserves. Production at secondary mines is more flexible, as molybdenum is not the main product and can be processed when economically viable. However, it is also very dependent on the primary product being mined. As copper mines continue to mature and grades deplete, secondary molybdenum production will decrease.

China will remain the largest primary producer of molybdenum and will drive growth due to both governmental policy incentives and continued domestic demand growth. In the medium term, there will be enough primary and secondary supply coming from the mines and projects already identified to satisfy demand; however, in the 2030s, a supply gap will emerge and new supply (from plentiful global reserves) will be required.⁴⁰

See the molybdenum layer at minview.geoscience.nsw.gov.au

Tin

Almost without exception, tin is used in alloys. Although it is a metallic mineral, it is rarely used in the elemental form. The major uses of tin today are for cans and containers, construction materials, transportation materials, and solder. Tin recycling is relatively efficient, and the fraction of tin in discarded products that get recycled is greater than 50 per cent. The proportion of scrap used in tin production is between 10 and 25 per cent.⁴¹

About 80 per cent of the world's identified tin resources occur in unconsolidated secondary or placer deposits in riverbeds and valleys, or on the seafloor. The largest concentration of both onshore and offshore placers is in the extensive tin belt of Southeast Asia, which stretches from China in the north, through Thailand, Burma, and Malaysia, to the islands of Indonesia in the south. Although most tin is obtained from mining tin ores, cassiterite is also found in association with ores of tungsten, tantalum, and lead. Minor quantities of tin are recovered as by-products of the mining of these metals. Most tin deposits fall in a grade range of 0.1 to 1 per cent tin, have a resource tonnage range of from 1 to 100 Mt, and have between 10,000 and 100,000 tonnes of tin content.⁴¹

See NSW tin endowment, [Figure 21](#)

37 U.S. Geological Survey 2017, p447, 38. U.S. Geological Survey 2017, p65, 39. CRU Consulting 2019, 40. Ibid., 41. U.S. Geological Survey 2017, p715

3.2 Global supply of emerging metals

Cobalt

Cobalt has two end use forms, a metal-alloy and a high-grade chemical product. World demand reached approximately 117,700 t in 2018. Two thirds of current cobalt demand is for use as a chemical product: 15 per cent for EV batteries, 35 per cent for other lithium batteries and 16 per cent for other chemicals. Demand for cobalt in superalloys represents 16 per cent of demand, while other metal uses account for 18 per cent of current demand. It is expected that by 2035 there will be a four-fold increase in total demand, with the most significant growth being for EV batteries, which are expected to account for 67 per cent of future demand.⁴²

More than 98 per cent of cobalt is produced as a by-product (or co-product, depending on its value contribution) of copper mining in the Democratic Republic of the Congo (DRC) and Zambia, and copper and nickel mining elsewhere in the world. The DRC holds 50 per cent of global reserves of cobalt and accounted for 64 per cent of all mined cobalt in 2018.⁴³ In contrast, Australia hosts approximately 18 per cent of global cobalt reserves but accounts for less than 5 per cent of production.

As cobalt is a by-product metal in most operations, the economics of nickel and copper mining determine the economic viability of new cobalt supply. However, analysis has shown a strong correlation between the cobalt price and supply from several mines in the DRC, suggesting that supply into the cobalt market is highly elastic.⁴²

In the past, the DRC has been politically unstable, raising uncertainty concerning the security of future supply. However, the risk of an immediate shortage of cobalt chemicals is low. Mined supply from the DRC responded to market tightness in 2017/18 and there is ample production capacity.

See NSW endowment of cobalt, [Figure 22](#)

Scandium

Scandium is mainly used as an alloying ingredient with aluminium. Small amounts of scandium increase the strength of aluminium without compromising its workability. The push to improve transport energy efficiency by reducing weight could see greater adoption of aluminium-scandium alloys in aerospace, automotive and maritime applications. However, until greater adoption occurs the scandium market remains small, with only some speciality aerospace and sporting applications.⁴⁴

Scandium is more abundant globally than lead. However, like other Rare Earth Elements, scandium does not readily associate with common ore-forming minerals and so tends to be widely dispersed in low concentrations. Current scandium production is estimated at 15 tonnes per year, as a by-product primarily from Russia, China, Ukraine, and Kazakhstan.

Internationally, scandium projects in the pipeline include NioCorp's Elk Creek in Nebraska which has signed a sales agreement for 12 tpy of its planned production of 103 tpy scandium oxide with Traxys; and Coral Bay, a major nickel-cobalt producer in the Philippines, which introduced a 7.5 tpy capacity scandium circuit in 2018.⁴⁵

In Australia, there are several significant projects in the pipeline with scandium as the primary product. Profiles for the NSW-based projects Sunrise, the Nyngan Scandium Project and the Platina Scandium Project are provided in the online appendix at resourcesandgeoscience.nsw.gov.au/future-of-minerals

See NSW endowment of scandium, [Figure 22](#)

Rare Earth Elements (REEs)

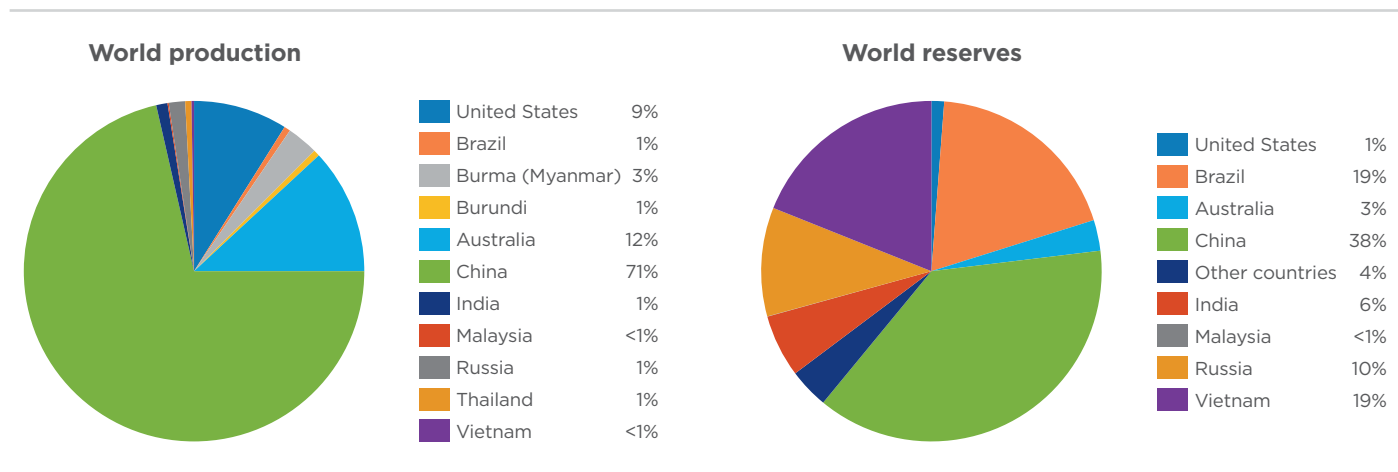
REEs are a group of 17 elements, 15 lanthanides plus yttrium and scandium, that are typically found together in complex orebodies. The group can be broken into light rare earths (La, Ce, Pr, Nd, Pm, Sm) and heavy rare earths (Y, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu). Scandium has been discussed separately as NSW has standalone scandium deposits.

Neodymium (Nd), praseodymium (Pr) and dysprosium (Dy) are important for producing permanent magnets, used in direct drive wind turbines and electric motors. Cerium (Ce) and lanthanum (La) are used in catalytic converters that reduce undesired exhaust gases to less harmful gases. Other applications for REEs include specialty glasses and military uses such as night vision goggles.⁴⁶

REEs are relatively common, but economically exploitable concentrations are rare. Overall, global reserves if developed can sustain long term demand if consumption rates remain consistent.

Global supply of rare earth oxides is forecast to increase from 151 thousand tonnes in 2018 to 223 thousand tonnes by 2035. As shown in Figure 13, REE production is dominated by China with 71 per cent of 2018 global output.⁴⁷ China is expected to drive supply growth in the long term, accounting for 69 per cent of total growth. With such dominance, any policy changes by China such as export restrictions will impact global markets and renew exploration and spur mine development in Australia and elsewhere.

Figure 13: World production in 2018 and reserves of rare earths⁴²



Despite an expected increase in China’s production volumes, new supply will be needed by the mid-2020s. New supply will be required even earlier for REEs used in the fast-growing magnets sector, such as neodymium, praseodymium and dysprosium. Globally there are several new projects in the pipeline, but many have struggled to fund development due to their complex metallurgy and the low prices that have prevailed since 2013. Currently, projects are focusing on the value of Nd, Pr and Dy in their orebodies, as these elements have the highest growth potential. Illegal mining of REEs is known to occur in several jurisdictions. The full extent of this is unknown, but it is likely to be 20-30 thousand tonnes, an additional 20 per cent on the reported 2018 output.⁴⁸

See NSW endowment of rare earth elements, [Figure 22](#)

Titanium

Titanium is the fourth most abundant metal in the Earth’s crust and can be found in nearly all rocks and sediments. However, only some titanium-bearing oxide minerals, particularly ilmenite and rutile, are economic ores. Rutile is the most economically valuable mineral for titanium, but global rutile sand deposits are limited, and a limited number of deposits of ilmenite sands are at economic grade. As a result, titanium resources are in relatively few countries. Australia has the largest rutile reserves at 47 per cent of the estimated world’s 62 Mt reserves in 2019, followed by Kenya at 21 per cent and South Africa at 13 per cent. For ilmenite, Australia also has significant reserves with 28 per cent of world’s 880 Mt. China’s reserves rank second at 26 per cent followed by India at 10 per cent.⁴⁹

Titanium ores are mined primarily for use as a pigment and to a lesser extent for use as a metal. In both applications, there is no real substitute due to the unique properties it has in each form. TiO₂ pigment is superior to alternatives as it is durable and environmentally safe. As a metal, titanium offers corrosion resistance, excellent weight-to-strength ratio and has a very high melting point. Due to the limited distribution of economic resources and the important uses for titanium, it is a significant metal for industrial economies. The critical supply issue is further compounded by the limited number of companies operating at either end of the titanium minerals supply chain.

See NSW endowment mineral sands, [Figure 24](#)

3.3 Strategic metals policies

Resource endowment is a result of mineral distribution in the earth's crust and no one region is able to mine all the minerals required for modern industry within its own borders. Therefore, countries depend on supply chains spanning the globe to source the raw materials, process them and refine them for use in manufacturing. Regions have different competitive advantages in cost production depending on their resource endowment, population, technical knowledge and policy positions. Efficiency gains in production can be achieved by exploiting these cost advantages within a global supply chain.⁵⁰

Within global markets, a concentration in the production of some minerals has emerged in some instances. For example, Chile is the world's leading copper producer, China dominates production of tin, tungsten and REEs and the Democratic Republic of Congo produces much of the world's cobalt.

In situations where a country or a company has dominant control over the supply of key minerals, there is potential for supply disruptions. These disruptions can cause price spikes, impact downstream industries and can have wide ranging economic impacts. Governments, companies and organisations are increasingly recognising the supply risk posed by being overly reliant on individual mineral producers with excessive market influence and are employing strategies to reduce the need for certain minerals or develop alternative supply chains. Military applications are another reason why governments wish to ensure security of supply for certain minerals. For example, Figure 14 shows a navy ship constructed with aluminium that could potentially include scandium to improve the strength of the hull.

Efforts to reduce dependence on dominant suppliers of key minerals by developing independent supply chains will adjust the least-cost model of global supply chains. These strategic policies reduce the importance of price as the dominant driver for investment, placing greater emphasis on the security of supply. NSW has the potential to provide this security of supply for several minerals due to its low sovereign risk and robust regulatory frameworks, which guarantee a high degree of social and environmental responsibility.



Figure 14: Austal is an Australian-based shipbuilder, a world leader in aluminium commercial and military vessels. Austal has signed a letter of intent with Scandium International, proponent of the Nyngan Scandium project in Outback NSW, to test scandium-aluminium alloys.

4. NSW metal resources and endowment

NSW hosts a variety of metal deposits across several key provinces. These are the Curnamona Province (Broken Hill), Lachlan Orogen (Cadia, Cobar, Cowal, Fifield-Nyngan) and the Murray Basin (mineral sands). The geology of NSW comprises a series of crystalline provinces and younger basins. Each of these provinces have separate geological histories that control known and potential mineral endowment, as shown in Figure 15.

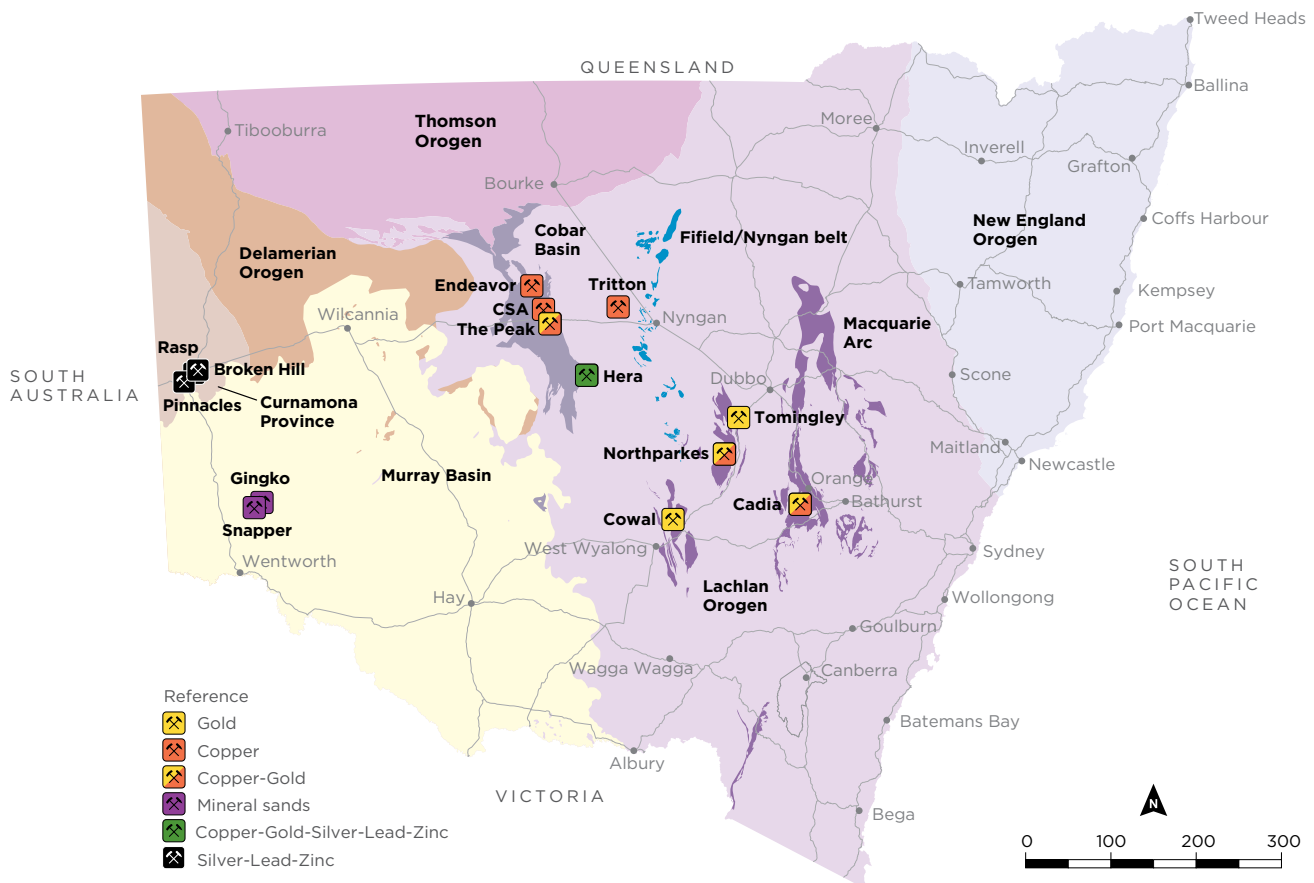
The geological endowment of NSW in conjunction with the growing demand for minerals presents opportunities to further grow the NSW minerals sector. Developing mineral deposits will contribute to stabilising global markets for critical minerals and facilitate greater adoption of emerging technologies by providing sustainable supply chains.

Major traditional metal resources in NSW are hosted in the Lachlan Orogen (gold, silver and base metals), the Curnamona Province (lead, silver and zinc) and the New England Orogen (gold and antimony). Most of the emerging mineral resources in NSW are hosted in the Lachlan Orogen, with some cobalt resources in the Curnamona Province and New England Orogen. The majority of NSW's heavy minerals sand resources are found in the Murray Basin.

Information on current operations and advanced projects in development can be found in the online appendix at resourcesandgeoscience.nsw.gov.au/future-of-minerals. The metal resource values expressed in this report are based on company reported resources, according to the Australasian Code for Reporting of Exploration Results, Minerals Resources and Ore Reserves 2012 (JORC code).

On a square kilometre basis, NSW has an estimated in-situ resource value of \$134,000/km²

Figure 15: Geological provinces and current major operating mines of NSW



4.1. Traditional metals

NSW currently produces gold, silver, copper, lead and zinc, and has previously produced antimony. There are 12 current mining operations and 10 advanced projects in the state.

- About 78 per cent of NSW traditional metal resources are held in the **Lachlan Orogen** and contained features such as the copper-gold porphyry deposits of the **Macquarie Arc**. The **Cobar Basin** also holds a large share of base metals in the form of volcanic associated massive sulfide (VMS).
- The **Curnamona Province** holds significant base metal resources (lead, silver and zinc).
- **New England Orogen** holds all the current antimony resource (63 thousand tonnes) and a portion of the gold resource.

Table 8: NSW traditional minerals resource endowment, thousand tonnes

	Curnamona Province		Delamerian Orogen		Lachlan Orogen		New England Orogen		NSW Total	
	Historical production	Remaining resource	Historical production	Remaining resource	Historical production	Remaining resource	Historical production	Remaining resource	Historical production	Remaining resource
Total	37,876	5,947		80	10,125	24,260	199	552	48,199	30,840
Antimony							19	63	19	63
Copper		14		60	4,176	14,709	11	197	4,187	14,981
Gold					1	2			1	2
Lead	19,236	2,625			1,861	2,694	15	65	21,113	5,384
Nickel						1,828		114		1,942
Platinum						0.011				0.011
Silver	10	5			5	16		3	15	23
Tin					43	175	146	33	189	208
Zinc	18,629	3,304		20	4,038	4,835	8	77	22,675	8,237

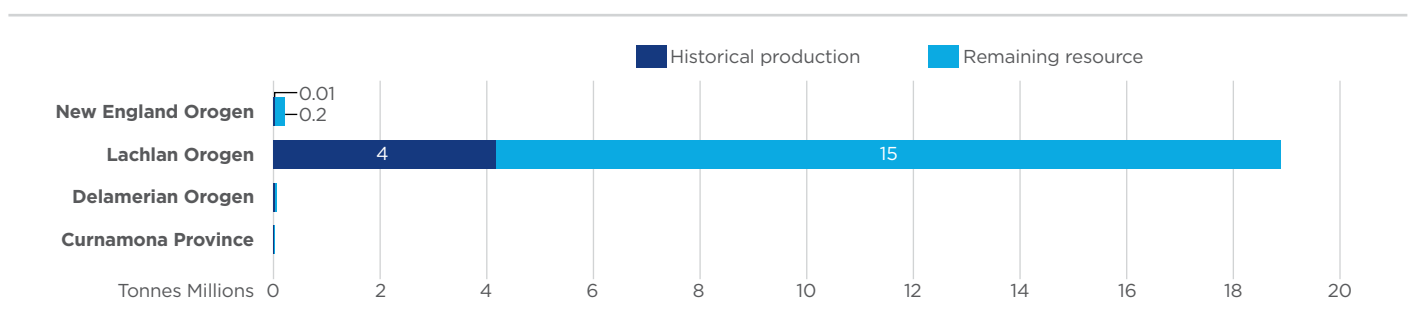
Numbers have been rounded

NSW copper

The total NSW copper resource is estimated at almost 15 Mt. As shown in Table 8, almost all of the known resource is within the Lachlan Orogen, split between the Cobar Basin at Tritton and porphyry copper-gold deposits of the **Macquarie Arc**.

Key Projects include Cadia East, Northparkes, CSA and Tritton. See the online appendix at resourcesandgeoscience.nsw.gov.au/future-of-minerals for more details of current copper operations.

Figure 16: NSW copper endowment

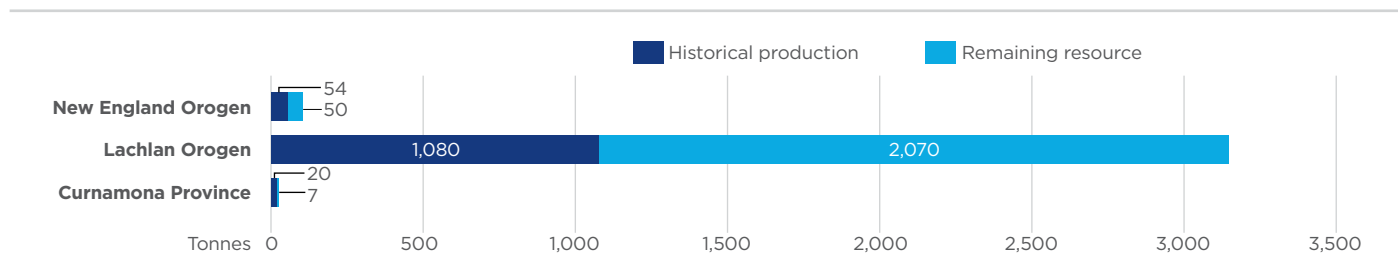


See the copper layer at minview.geoscience.nsw.gov.au

NSW gold

The total known remaining gold resource in NSW is estimated at 2,129 tonnes, predominantly within the Lachlan Orogen, which has also generated almost all the historical NSW gold production (Figure 17). Current production is dominated by the porphyry-epithermal copper gold deposits of the Macquarie Arc, which include the Cadia Valley, and Northparkes and Lake Cowal mines. Other significant gold producers in the Lachlan Orogen include the Tomingley gold mines and the polymetallic mines of the Cobar Basin.

Figure 17: NSW gold endowment



See the gold layer at minview.geoscience.nsw.gov.au

NSW lead, zinc and silver

The known remaining lead and zinc resource of NSW is estimated at 13.6 Mt. As shown in Figure 18, the historical lead and zinc production of NSW has largely occurred in the Curnamona Province (e.g. Broken Hill line of lode). The remaining resources are almost evenly split between the Curnamona Province and Lachlan Orogen, particularly in the Cobar Basin.

Figure 18: NSW lead & zinc endowment

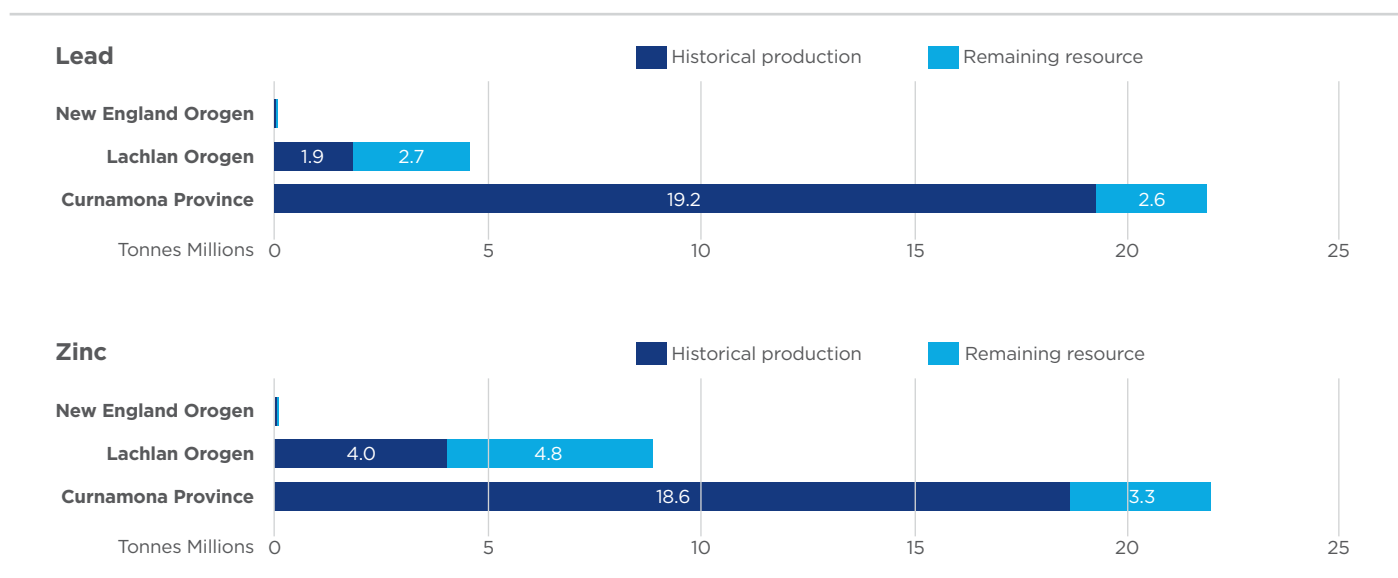
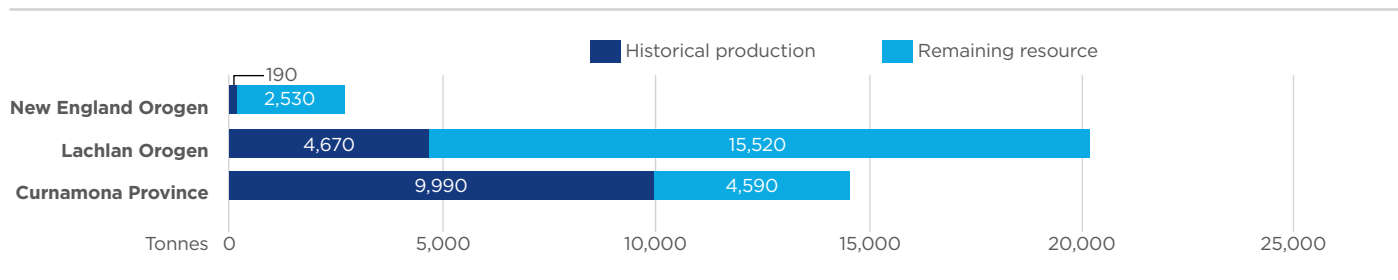


Figure 19 shows the endowment of silver across NSW. The historical production from the Curnamona Province is the most significant at over two thirds of NSW historical production owing to the rich lead-zinc-silver deposits of the Broken Hill line of lode. The other significant historical production of silver in NSW has been from the Lachlan Orogen. Historical production and remaining silver resources in the Lachlan Orogen come from a range of silver-rich deposit types: sediment hosted massive sulphides (Pb-Zn-Ag) in the Cobar Basin, volcanic-associated massive sulfides, and epithermal and orogenic base metal deposits. Silver deposits in the New England Orogen have been largely undeveloped. Exploration opportunities in the New England are discussed in the following section.

Figure 19: NSW silver endowment



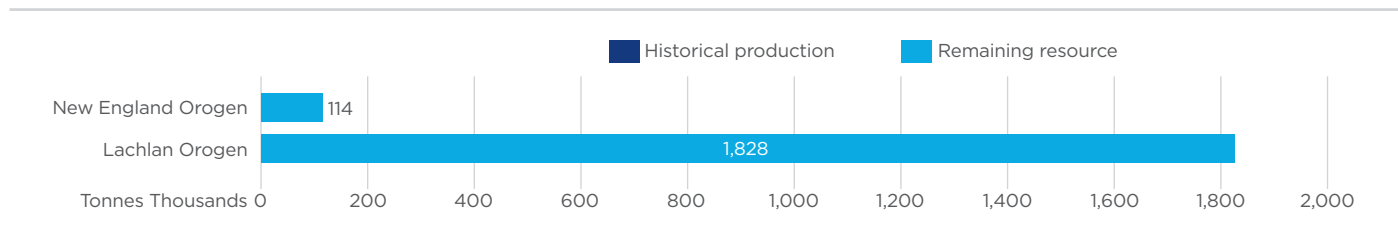
See the lead, zinc and silver layers at minview.geoscience.nsw.gov.au

NSW nickel

NSW has no historical nickel production. Figure 20 shows NSW nickel endowment, as remaining nickel resource, the bulk of which is within lateritic deposits of the Lachlan Orogen. The nickel laterite deposits of the Lachlan are associated with cobalt and scandium, and there are several projects in development to produce nickel as a co-product alongside cobalt and scandium. Further information on NSW nickel producing projects currently in development can be found in the online appendix at resourcesandgeoscience.nsw.gov.au/future-of-minerals

A small proportion of NSW’s nickel resource is hosted within the New England Orogen. There are no current projects in the pipeline to develop these resources.

Figure 20: NSW nickel endowment

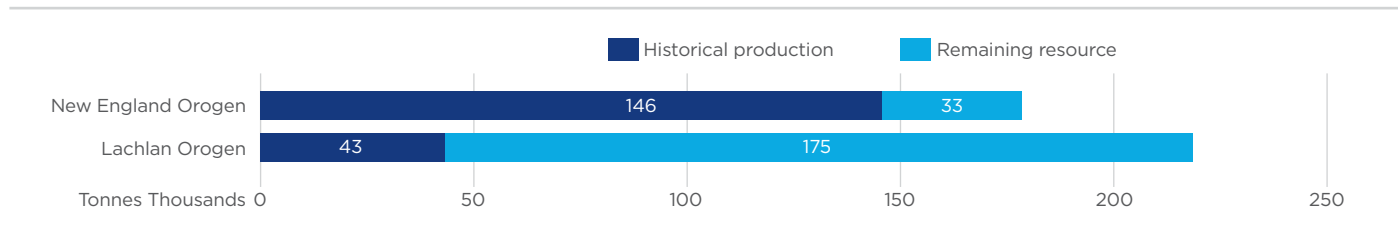


See the nickel layer at minview.geoscience.nsw.gov.au

NSW tin

Most of NSW’s historical tin production was from alluvial deposits in the New England Orogen, which hosted Australia’s largest in-situ tin resource at Taronga. The remaining resource is found in the Lachlan Orogen which has good potential for buried systems under cover. Figure 21 shows the historic production and remaining tin resource for each region.

Figure 21 : NSW tin endowment



See the tin layer at minview.geoscience.nsw.gov.au

4.2 Emerging metals

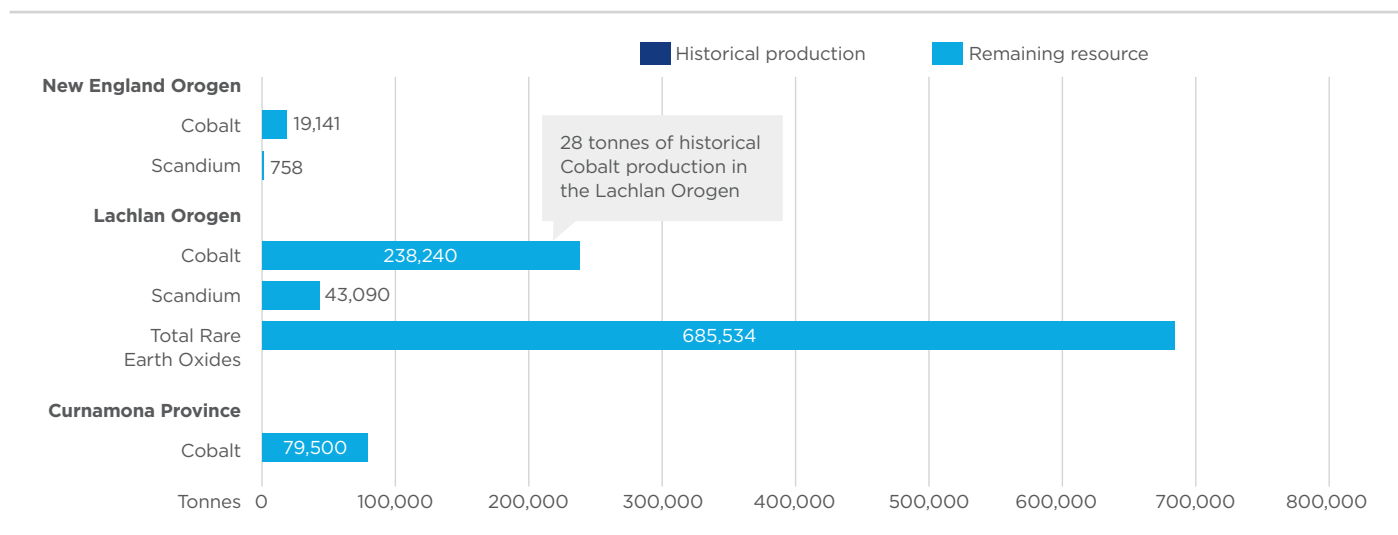
As shown in Table 9, although historical production is mostly small, NSW hosts a variety of emerging metals including significant reserves of cobalt, scandium and REEs. Projects relating to the resource estimates in Table 9 are outlined in the online appendix at resourcesandgeoscience.nsw.gov.au/future-of-minerals. The **Curnamona Province** hosts modest amounts of cobalt while the **Lachlan Orogen** has the bulk of NSW's resources in emerging minerals.

Table 9: NSW emerging minerals resources tonnes

	Curnamona Province		Lachlan Orogen		New England Orogen		NSW total	
	Historical production	Remaining resource	Historical production	Remaining resource	Historical production	Remaining resource	Historical production	Remaining resource
Total		79,500	23	966,864		19,899	23	1,066,262
Cobalt		79,500	23	238,240		19,141	23	336,881
Scandium				43,090		757.81		43,847
Rare Earth Elements				685,534				685,534

Numbers have been rounded

Figure 22: NSW emerging metal resources



NSW cobalt-scandium

In Central NSW, there are currently several advanced lateritic projects with nickel, cobalt, scandium and platinum potential proposed as either individual primary products or co-products. As shown in Table 9, the Curnamona Province (Broken Hill) is estimated to host modest amounts of cobalt in massive pyrite, with a cobalt resource of 79,500 tonnes.

The bulk of the estimated NSW cobalt resource is associated with polymetallic laterites of the Fifield-Nyngan Belt within the Lachlan Orogen. The laterites host 238,000 tonnes of cobalt and 43,000 tonnes of scandium. The reserves of cobalt and scandium for the advanced projects of the Lachlan Orogen are shown in Figure 22.

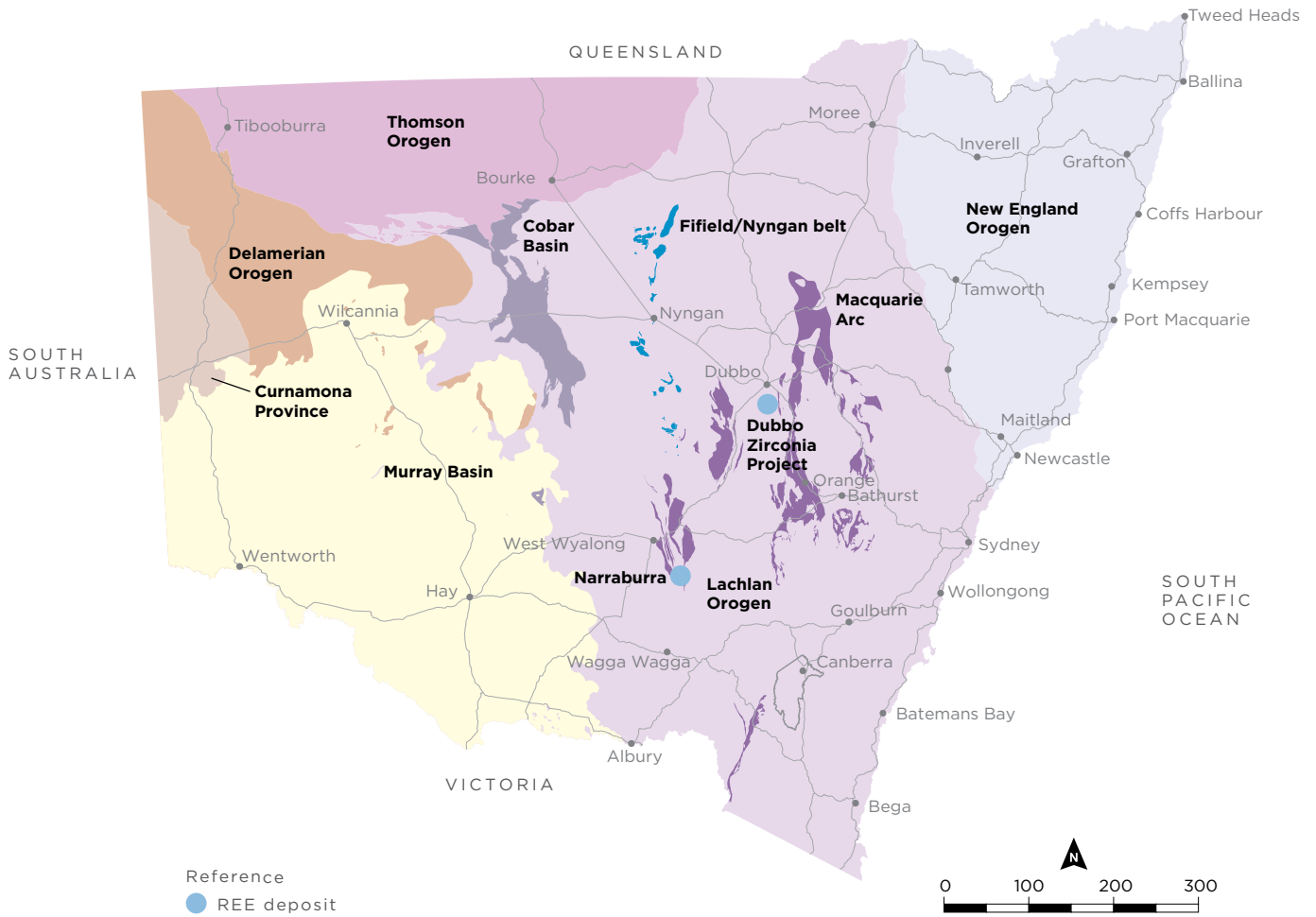
See the cobalt and scandium layers at minview.geoscience.nsw.gov.au

NSW rare earth elements

Within NSW, there are no current operations producing REE as a primary commodity or by-product. As shown in Figure 22 and Table 9, the NSW resource of 685,000 tonnes of REE is based on prospects in the Lachlan Orogen. The Dubbo Zirconia project, shown in Figure 23, is at an advanced stage of development, with all necessary government approvals in place and in the process of securing offtake agreements and finance to build a processing plant.

Figure 23 also shows the Narraburra REE project in the Lachlan Orogen where exploration is ongoing. Outside of these two known hard rock deposits of REE, the potential for REE in NSW is largely untested. An area warranting further exploration is the New England Orogen where REE-enriched granites are known, but only limited exploration has been undertaken.

Figure 23: Known rare earth element deposits of NSW



See the rare earth elements layer at minview.geoscience.nsw.gov.au

4.3 Heavy mineral sands

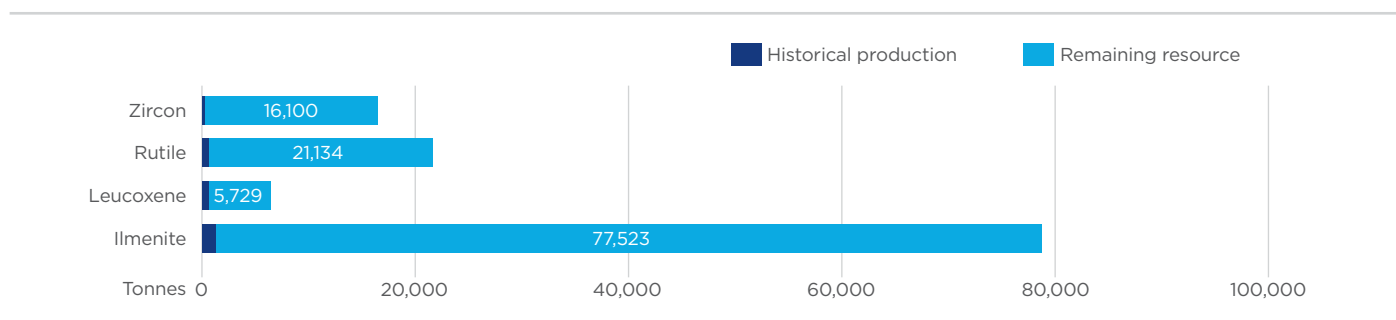
The remaining heavy mineral sand resources in NSW are estimated at over 120 million tonnes. While heavy mineral sand deposits have been identified in other areas of NSW, the heavy mineral sand resources currently being extracted and developed in NSW are hosted exclusively within the **Murray Basin**.

The Murray Basin is an intra-cratonic sedimentary basin that is highly prospective for further discovery. Estimated reserves of the component heavy mineral sands are shown in Table 10 and Figure 24. The Murray Basin deposits also have potential to produce REE and thorium from monazite [(Ce, La, Nd, Th) PO₄], although thorium mining is currently prohibited in the state. In part because of this, current operations do not process the contained monazite. Instead, it is returned to the tailings with site rehabilitation.

Table 10: NSW heavy mineral sands resource endowment, thousand tonnes

Murray Basin		
	Historical production	Contained resource
Heavy Mineral Sands	>2,766	120,486
Ilmenite		77,523
Leucoxene		5,730
Rutile		21,134
Zircon		16,100

Figure 24: Murray Basin heavy mineral sand resources



See the Group 10 (Mineral Sands) layer at minview.geoscience.nsw.gov.au





The state's deep and
undercover geology
remains largely
unexplored and
has significant
mineral potential

5. Exploration opportunities for NSW minerals

Its range of minerals and geological settings make NSW a minerals ‘all-rounder’ within Australia, a country that itself stands out on the world stage for having a vibrant minerals sector. The advantages of undertaking exploration in NSW are discussed in detail in **Section 6**, but for these to be realised, the prospective deposits and range of minerals need to be better known.

With global demand for many minerals increasing and likely price rises as a result of supply-demand shortfalls, it is expected many of the known occurrences have the potential to become increasingly prospective and economically feasible.

This section outlines the geological setting and exploration opportunities for metallic minerals within the geological provinces of NSW.

The state’s basement geological provinces (from oldest to youngest) are:

- Curnamona Province
- Delamerian Orogen
- Lachlan/Thomson orogens
- New England Orogen.

The Curnamona Province comprises Paleo- and Meso- Proterozoic rocks. The other orogens are part of the >1500 km-wide Tasmanides that developed along the Pacific margin of the Australian craton in the Palaeozoic.

Much of the prospective basement geology for metallic minerals is covered by younger sedimentary basins. These include the (mainly Devonian) Darling Basin, Permo-Triassic Sydney-Gunnedah-Bowen Basin, Mesozoic Eromanga Basin, the Cenozoic Murray Basin and the Permo-Mesozoic and Cenozoic igneous provinces.

The majority of the known 16,327 metallic mineral occurrences in NSW have been discovered in areas of exposed prospective geology or shallow cover (<150 m cover; Figure 25). As a result, NSW has been underexplored as the higher costs associated with exploration through areas of thicker cover sequences has deterred exploration activity.

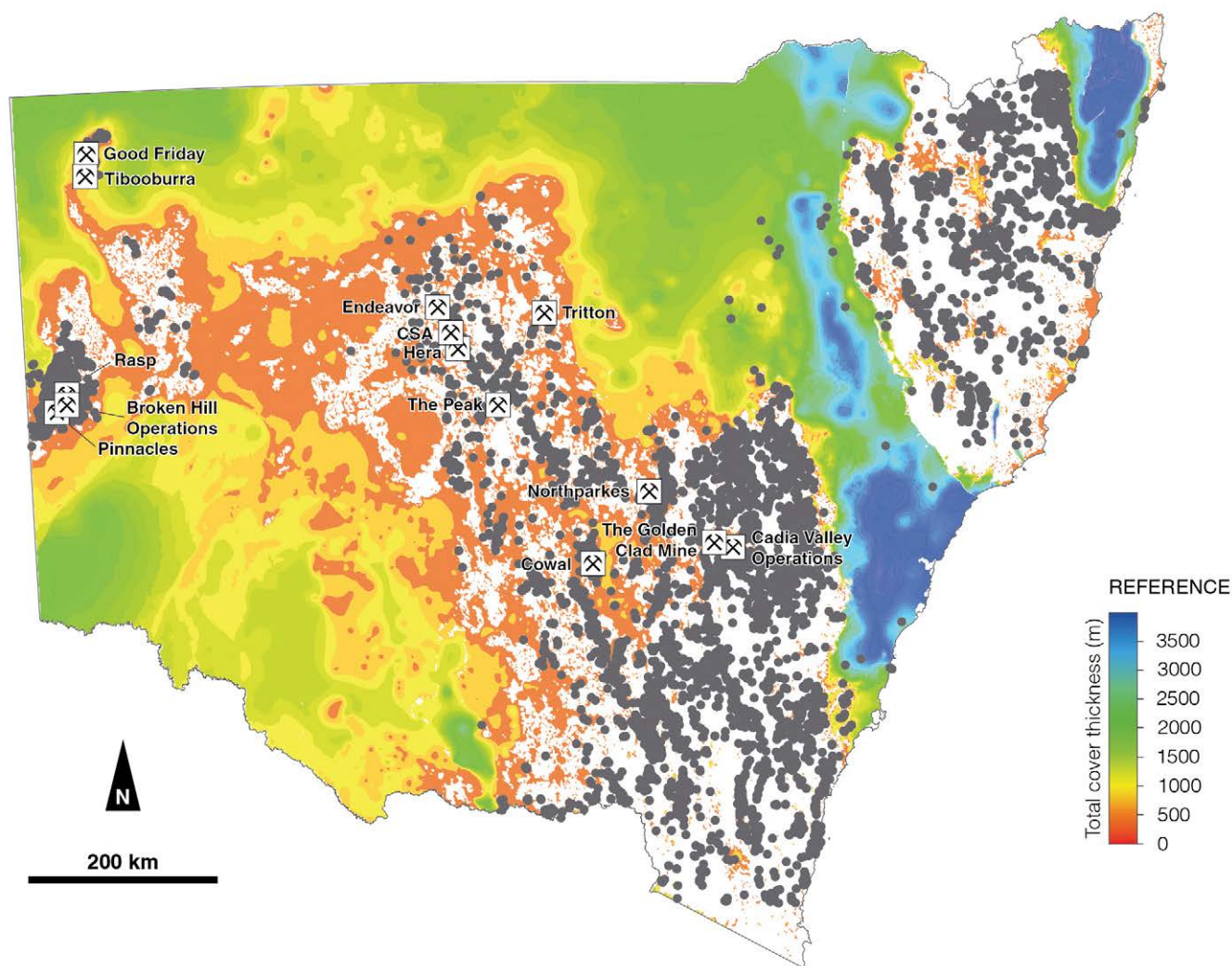
In addition to the metallic mineral occurrences, there are 195 heavy mineral sand occurrences located in the Murray Basin.

The geology of each of the provinces listed above is included in the Statewide Seamless Geology of NSW data package – including interpretation of basement geology under younger cover sequences. More information on this data package can be found at resourcesandgeoscience.nsw.gov.au/miners-and-explorers/geoscience-information/projects/nsw-seamless-geology-project

Mineral potential mapping has been completed across most of NSW by GSNSW in association with Kenex Pty Ltd, using a weight of evidence approach. The project included the generation of exploration models for a range of different mineral systems, a series of data layers pertinent to those mineral systems and maps of mineral potential.⁵¹

Information of the GSNSW mineral potential mapping project can be found at resourcesandgeoscience.nsw.gov.au/miners-and-explorers/geoscience-information/projects/mineral-potential-mapping

Figure 25: NSW known mineral occurrences and thickness of cover to crystalline basement. White areas represent exposed basement.⁵²

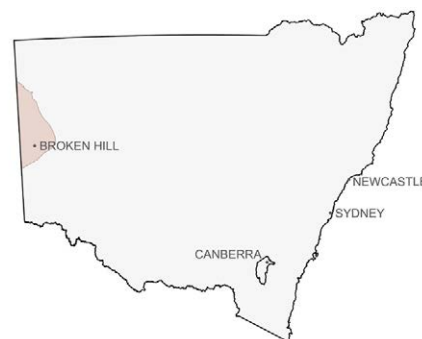


5.1 Curnamona Province

Geological setting

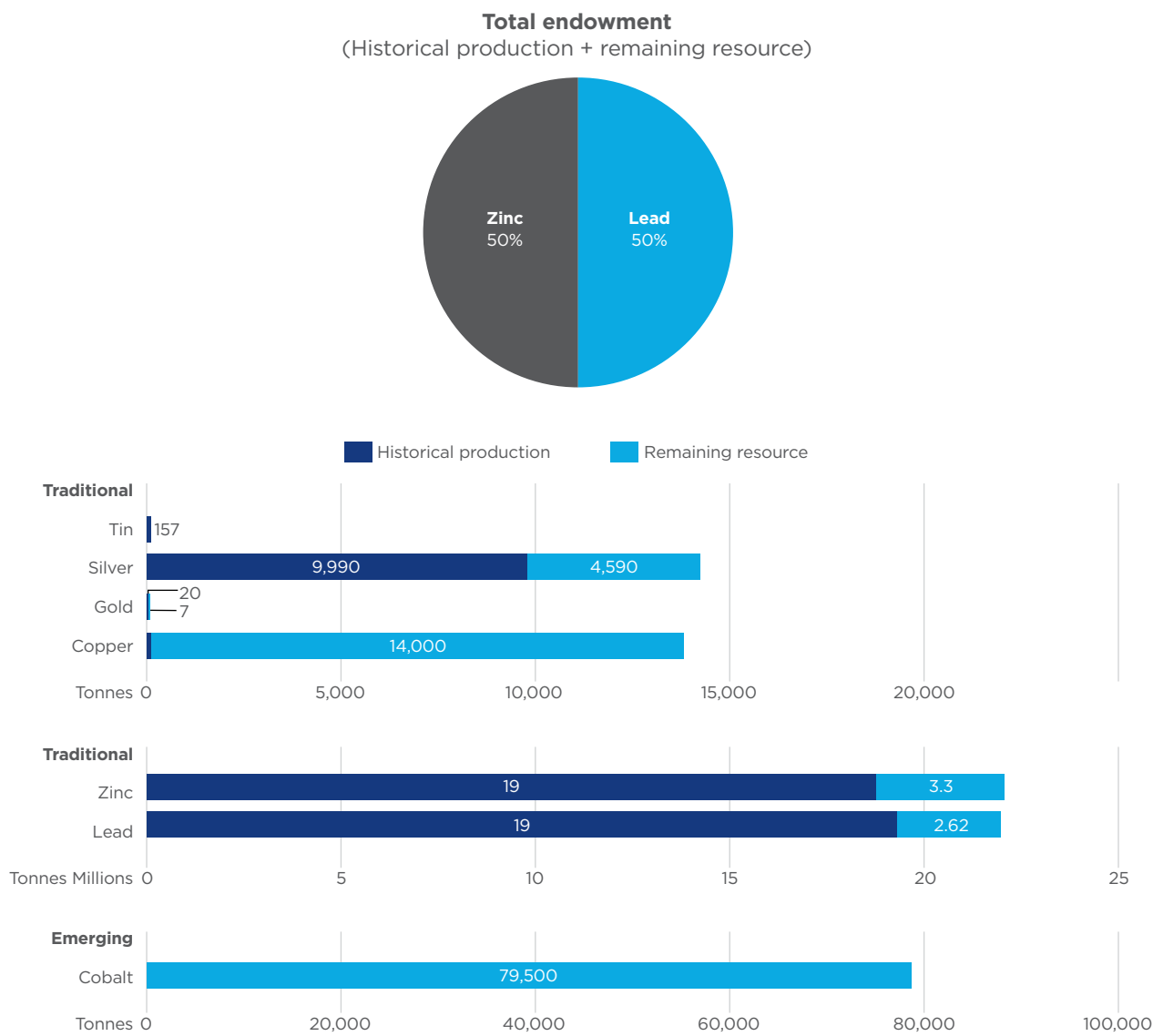
The Curnamona Province in NSW includes the Broken Hill and Euriowie blocks. They contain deformed metamorphosed sedimentary and igneous rocks of the Willyama Supergroup, which extends westwards into South Australia. These rocks were deposited in one or more rift basins about 1710–1640 million years ago and were strongly deformed approximately 1600 million years ago. The rocks now at the surface at Broken Hill were originally buried to 12–20 km depth and host the world-class Broken Hill silver-lead-zinc deposits, one of the largest base metal deposits ever discovered. Pb-Ag-Zn Broken Hill Type mineralisation along the Broken Hill line of lode accounts for most of the endowment. Cobalt mineralisation has been identified in the Thackaringa area (e.g. Pyrite Hill).

The mineral endowment estimates associated with the Curnamona Province are shown in Figure 26. There is a clear dominance of lead, silver and zinc in the historical production for the region.



52. GSNSW analysis (2019)

Figure 26: Mineral endowment of the Curnamona Province



Exploration opportunities

Due to the region’s rich and diverse range of rock types, recent focus has shifted to exploring for high-tech metals such as lithium, cobalt, REE and platinum group elements, with several new projects being developed in the area.

GSNSW, with Kenex Pty Ltd, completed mineral potential mapping using weights of evidence approach. The mapping included Broken Hill-style Pb-Zn-Ag and iron-oxide copper-gold within the Curnamona Province.

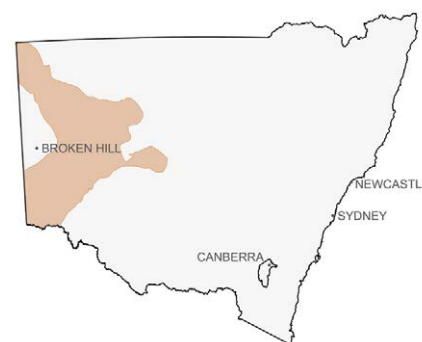
The results of the mineral potential analysis are available for download from DIGS at search.geoscience.nsw.gov.au/product/9233

5.2 Delamerian Orogen

Geological setting

The Delamerian Orogen is a curvilinear belt of rocks in Western NSW that wraps around the eastern margin of the Curnamona Province and continues into South Australia, Queensland and Victoria. The Delamerian Orogen records the break-up of the supercontinent Rodinia (~800 to 600 million years ago) with sedimentation and mafic volcanism, and the onset of west-dipping subduction and formation of Cambrian island arc volcanoes and associated rocks (~530 to 505 million years ago). The Delamerian Orogeny at ~505 to 495 million years ago terminated the orogenic cycle.

The Koonenberry Belt is the northwest trending part of the Delamerian Orogen from Wilcannia to Tibooburra, and the Loch Lilly-Kars Belt extends from near Menindee and southwest into South Australia. The Loch Lilly-Kars Belt is completely covered by younger sedimentary rocks.



Exploration opportunities

GSNSW, with Kenex Pty Ltd, completed mineral potential mapping using a weights of evidence approach. The mapping included volcanic massive sulfide mineralisation and orogenic gold.

The results of the mineral potential mapping for the Curnamona Province and Delamerian-Thomson Orogen, are available for download from DIGS at search.geoscience.nsw.gov.au/product/9233

Other mineral systems include magmatic nickel associated with the Mount Arrowsmith Volcanics, epithermal mineralisation associated with the Mount Daubeny Basin and porphyry mineralisation in the Loch Lilly-Kars Belt.

More information is available in the mineral systems chapter of the Koonenberry Belt explanatory notes at search.geoscience.nsw.gov.au/product/17

5.3 Lachlan Orogen

Geological setting

The Lachlan Orogen (otherwise known as the Lachlan Fold Belt) lies between the New England Orogen in the east and the Delamerian Orogen to the west. The boundaries between the different orogens are obscured by younger strata.

The Lachlan Orogen marks episodic extension and contraction from the Late Cambrian to the Early Carboniferous. The magmatic and sedimentary history has been complicated by multiple episodes of thrusting and strike-slip faulting during the Benambran, Tabberabberan and Kanimblan orogenies (in the early Silurian, mid-Devonian, and in the early Carboniferous respectively).

Elements of the Lachlan Orogen with high metallic mineral prospectivity include the:

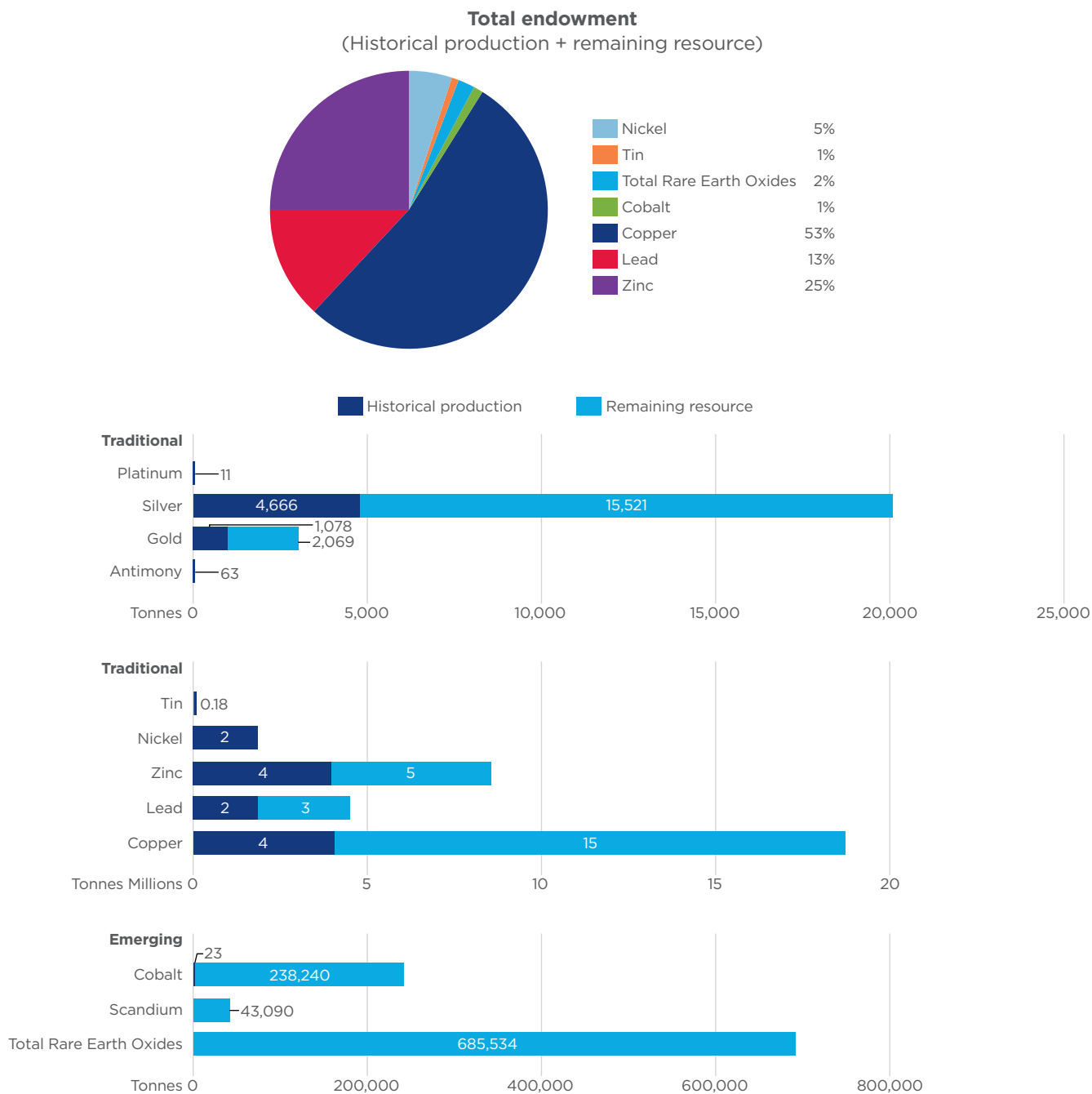
- Macquarie Arc
- Cobar Basin (and other Siluro-Devonian basins)
- Fifield-Nyngan Belt.

The Lachlan Orogen is one of the richest mineral regions in Australia. World-class copper-gold porphyry deposits can be found at Cadia and Northparkes. Lake Cowal and Tomingley are active gold producing mines. There is a long history of traditional metal mining in the Cobar region with production of copper, gold, zinc, silver and lead for the past 150 years. More recent developments targeting emerging minerals include the Dubbo Zirconia Project (zirconium and REE) and the world-class cobalt-nickel-scandium laterite deposits associated with the Fifield-Nyngan Belt. Overviews of current operations and advanced projects are provided in the online appendix at resourcesandgeoscience.nsw.gov.au/future-of-minerals

Figure 27 shows the dominance of copper, lead and zinc in remaining resource tonnage for the Lachlan Orogen.



Figure 27: Mineral endowment of the Lachlan Orogen



Exploration opportunities

GSNSW, with Kenex Pty Ltd, completed mineral potential mapping in the eastern Lachlan Orogen in 2019 for porphyry copper-gold, polymetallic skarn, orogenic Au (Kanimblan and Tabberabberan) and volcanic massive sulfide (VMS) mineralisation.

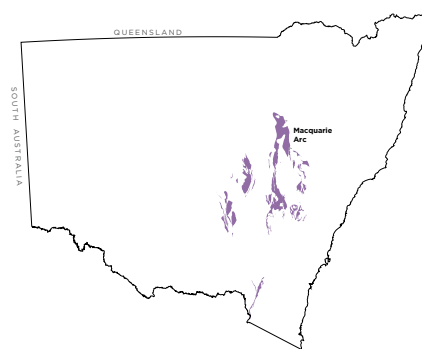
This information can be downloaded at search.geoscience.nsw.gov.au/product/9253

Mineral potential mapping in the western Lachlan Orogen (scheduled for completion in 2020) will focus on the Cobar-type deposits and intrusion-related tin-tungsten mineralisation in the eastern Riverina area. Further information on each region is provided in the following subsections below.

5.3.1. Macquarie Arc

The Macquarie Arc (also known as the Macquarie Igneous Province) is an Ordovician to early Silurian island arc located in the eastern Lachlan Orogen. The rocks of the Macquarie Arc include intrusive, volcanic and volcanoclastic rocks that host both porphyry copper and porphyry copper-gold deposits. The mineral endowment of the copper-gold porphyry deposits of the Macquarie Arc is estimated to hold 80 million ounces of gold and more than 13 Mt of copper.

The Macquarie Arc consists of three main belts, the Junee-Narromine Volcanic Belt, the Molong Volcanic Belt and the Rockley Gulgong Volcanic Belt. The latter two belts are interpreted to extend other young cover sequences to the north.



The Macquarie Arc host Australia's two major porphyry mines:

- Cadia Valley (including Cadia and Ridgeway)
- Northparkes.

Both the Cadia Valley and Northparkes operations cover multiple porphyry deposits as the deposits tend to occur in clusters. Further information on these operations can be found in the online appendix of current NSW mines and development projects at resourcesandgeoscience.nsw.gov.au/future-of-minerals

Exploration potential of the Macquarie Arc

Alkane Resources' discovery at the Boda prospect in 2019 has demonstrated the ongoing potential for very large porphyry discoveries within the Macquarie Arc. Major mining companies have recognised the potential for further discoveries and are actively exploring within the Macquarie Arc.

Two recent projects have studied the porphyry copper-gold potential of the Macquarie Arc.

In 2019, GSNSW with Kenex Pty Ltd completed mineral potential mapping using a weights of evidence approach. This work included an exploration model, a series of data layers and potential maps. This information can be downloaded from search.geoscience.nsw.gov.au/product/9253

A 2014 collaborative study between the United States Geological Survey, GSNSW and Geoscience Australia highlighted the strong exploration potential in the Macquarie Arc.⁵³ The study used available information to estimate the number of undiscovered porphyry copper deposits in eastern Australia. The available pre-competitive geological data for NSW was vital for the study.

It included:

- digital geological maps & geophysical databases
- known porphyry copper deposits and prospects
- grade-tonnage models which could be compared with the grades of known deposits.

The geologic maps and geophysical databases provided an estimate of known extents of the prospective rocks forming porphyry copper systems. The Macquarie Arc is a subset as a porphyry copper-gold system. The grade-tonnage measures from the Macquarie Arc were found not to be significantly different from the global model of grade-tonnage in porphyry copper-gold systems. The model could, therefore, be used in estimating the probability for the number of undiscovered deposits within the Macquarie Arc.

Key results from the study are shown in Table 11. The Macquarie Arc is estimated to have 6.9 undiscovered deposits in addition to the nine known deposits, indicating a very high deposit density of 39 deposits per 100,000 km². Compared to the other porphyry copper systems of eastern Australia, the results show the Macquarie Arc has an order of magnitude higher deposit density, making it a highly prospective area. It should be noted the estimated number of undiscovered deposits includes deposits that may never be discovered: the figures are a guide to the potential for discovery.

Table 11: Estimated number of undiscovered porphyry copper deposits within eastern Australia⁵⁴

Permissive tract (sub-tract)	Consensus undiscovered deposit estimates						Summary statistics					Tract area (km ²)	Deposit density (N _{total} /100,000 km ²)
	N ₉₀	N ₅₀	N ₁₀	N ₀₅	N ₀₁	N _{und}	s	C _v %	N _{known}	N _{total}			
Delamerian	0	2	5	7	7	2.5	2.2	91	0	2.5	50,747	4.9	
Macquarie	2	7	12	12	12	6.9	3.5	52	9	15.9	41,463	39	
Yeoval	1	1	2	3	3	1.3	0.75	57	1	2.3	53,157	4.3	
East Tasmanide (Central)	1	4	10	10	10	4.8	3.3	68	14	18.8	290,646	6.5	

N_{xx} = estimated number of deposits associated with the xxth percentile; N_{und} = expected number of undiscovered deposits; s = standard deviation; C_v% = coefficient of variance, N_{known} = number of known deposits in the tract that are included in the grade and tonnage model; N_{total} = total of expected number of deposits plus known deposits; Tract area, area of permissive tract in square kilometres (km²)

Further exploration could reveal the Macquarie Arc has a greater extent than currently known. If this is the case, the number of undiscovered deposits could be greater than what has been indicated in the study. It is possible the Macquarie Arc extends to the north-west of the known extent. Compared to the east Lachlan this area has been underexplored due to greater depth of cover.

5.3.2 Cobar Basin

The Early Devonian Cobar Basin is the most mineralised Palaeozoic sedimentary basin of the Lachlan Orogen, with significant resources of gold, silver, copper, lead and zinc. The basin includes a series of troughs (Cobar, Melrose, Mount Hope and Rast troughs) partitioned by shelf sequences (Walters Range, Winduck, Kopyje and Mourambra shelves). The geology is characterised by siliciclastic sedimentary rocks locally intruded with mostly felsic volcanic rocks with allochthonous and in-situ limestone horizons.

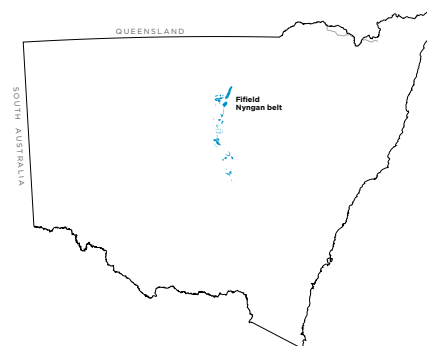
Mining operations in the Cobar Basin include CSA, Peak and Hera. Active exploration projects include Mallee Bull and Wagga Tank.

The Tritton copper mine is approximately 120 km east of Cobar, though the volcanic massive sulfide deposits are hosted by the Ordovician Girilambone Group rather than being within the Cobar Basin. These copper-rich deposits are an excellent exploration target with same-style Tottenham and Collerina projects discovered along strike to the south.



5.3.3 Fifield-Nyngan Belt

The late Ordovician – early Silurian Fifield-Nyngan Belt is a series of ultramafic-mafic rocks extending along approximately 600 km in central NSW. The ultramafic-mafic rocks contain nickel, scandium, cobalt, copper and platinum group elements. Weathering processes have concentrated these metals in surrounding soil, forming lateritic deposits of scandium, cobalt and nickel such as the Sunrise, Owendale and Nyngan deposits. The cobalt-rich Thuddungra deposit is located near Young.

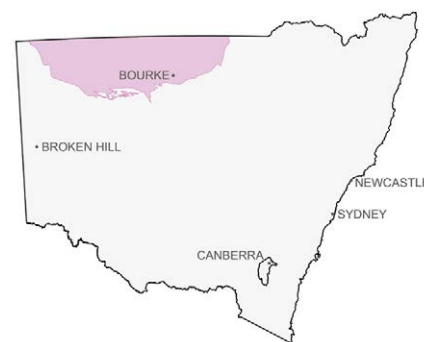


5.4 Thomson Orogen

Geological setting

The Thomson Orogen includes a broad area of basement rocks extending into four states, with the southern margin in north-western NSW known as the Southern Thomson Orogen. Despite being -15 per cent of NSW, only -1 per cent of the geology of the Thomson Orogen is exposed and is one of the last major greenfield terranes in NSW. The southern margin of the orogen is exposed in NSW near Bourke, White Cliffs, Hungerford and Tibooburra.

Recent collaborative projects involving GSNSW have identified Ordovician-Devonian sedimentary and igneous rocks.



Exploration opportunities

Compared to many other parts of Australia, little mineral exploration has been undertaken in the southern Thomson Orogen, due mainly to the extensive basin and regolith cover which conceals the basement geology.

The Thomson Orogen has potential for arc- and ocean-crust-related gold and base metal deposits, intrusion-related mineralisation (Au, Mo, W, Sn and base metals), orogenic gold and possibly polymetallic deposits similar to those found in the Cobar Basin to the south.

For more information see resourcesandgeoscience.nsw.gov.au/miners-and-explorers/geoscience-information/projects/southern-thomson-orogen-project

5.5 New England Orogen

Geological setting

The New England Orogen is an extensive fold belt extending along the eastern Australian coastline from Newcastle in the south to Townsville in the north. The portion within NSW is referred to as the Southern New England Orogen (SNEO).

The SNEO is internally divided by the major Peel-Manning Fault System into a western part that contains Silurian-Carboniferous arcs, a Devonian-Carboniferous forearc basin and an eastern part that contains Silurian-Carboniferous subduction complexes.

The province is prospective for orogenic gold-antimony, intrusion-related gold, intrusion-related tin-tungsten and epithermal gold. Exploration and development activities continue for a variety of commodities including gold, antimony, tin, molybdenum, tungsten and bismuth. The major commodities forming the estimated mineral endowment are shown in Figure 28.

Cobalt and scandium deposits have been identified near Port Macquarie and Emmaville. Granites around the Emmaville area have also been found to contain elevated concentrations of REE and lithium. Tin deposits in the New England are associated with highly evolved I-type granites in connection with polymetallic systems that include W, Mo, Ag, Pb, Zn and In.

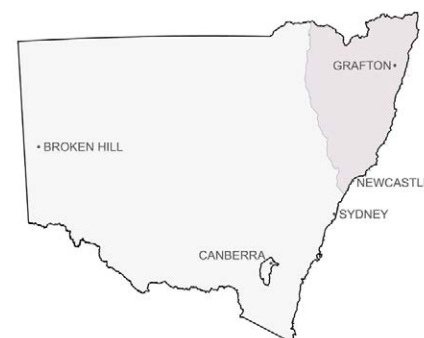
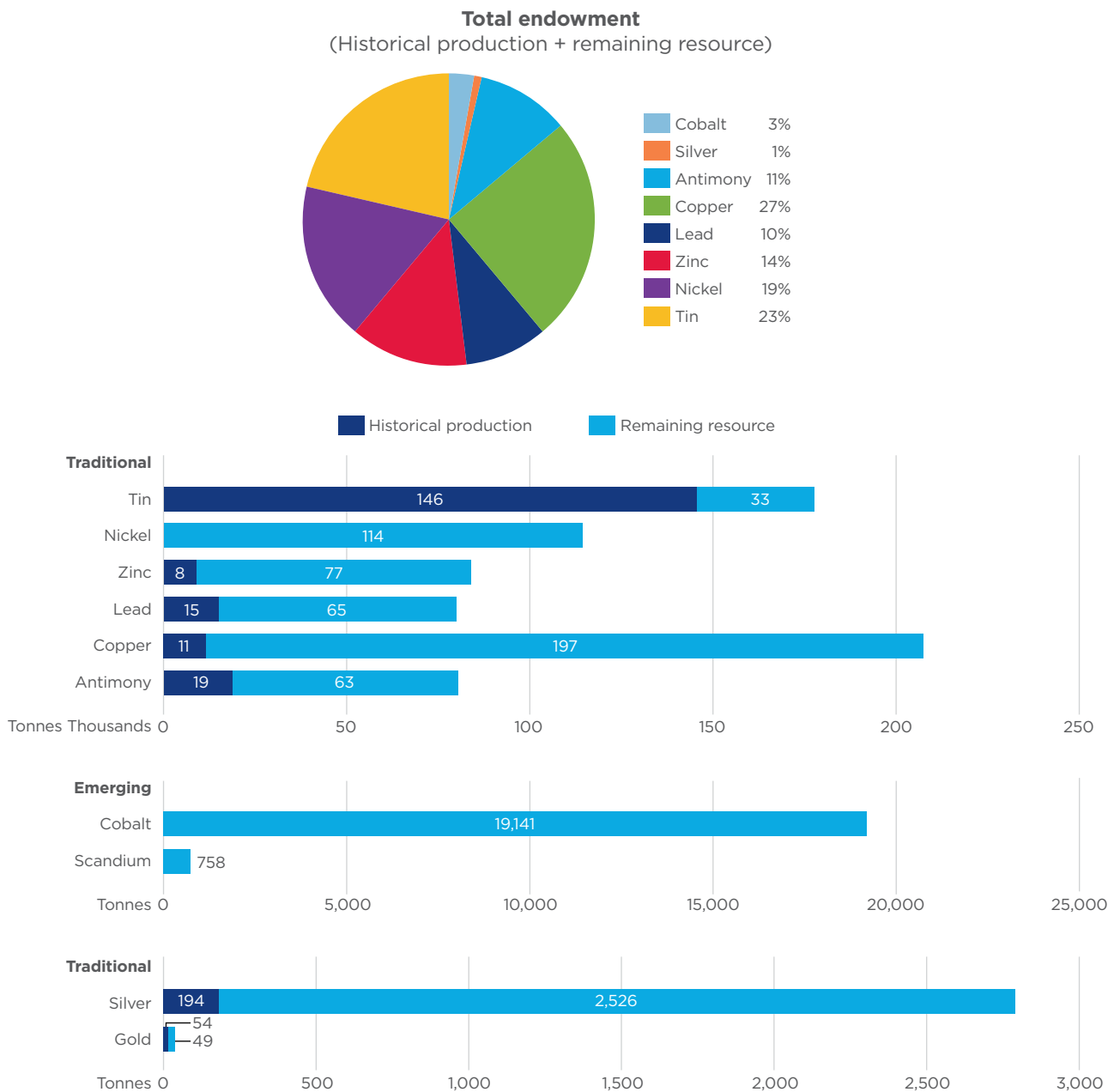


Figure 28: Mineral endowment of the New England Orogen



Exploration opportunities

The SNEO is known for its diversity of mineral deposits but has been underexplored by Australian standards. GSNSW has undertaken a study to understand its mineral potential⁵⁵. The study involved the creation of mineral potential maps, building on in-depth knowledge of deposit formation and statistical modelling with the extensive geological data the survey holds.

Analysis of the mineral potential in the Southern New England was done for three significant mineral systems:

- intrusion-related Au
- intrusion-related Sn-W
- orogenic Au-Sb.

The results of this analysis are map data packages for each of the mineral potential models. These are available for download from DIGS at search.geoscience.nsw.gov.au/product/9222

5.6 Murray Basin

Geological setting

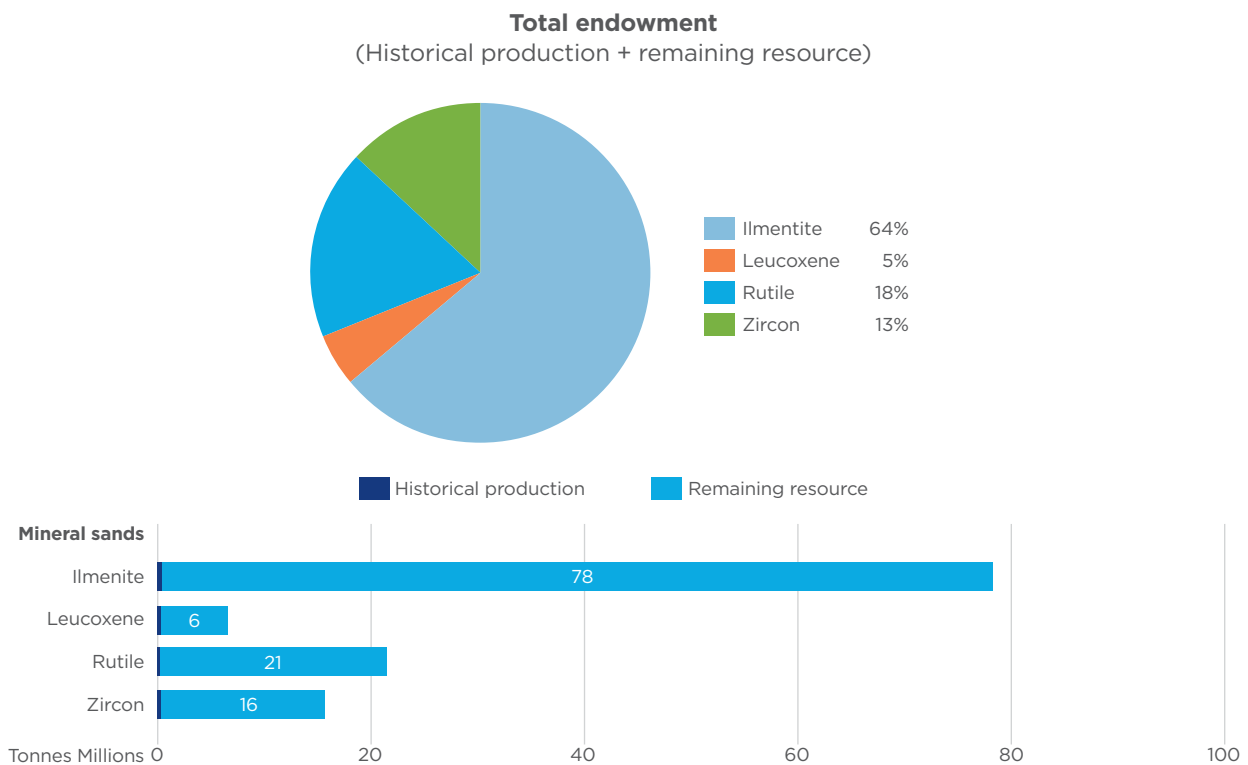
The Murray Basin of south-western NSW covers an extensive area extending into Victoria and South Australia. It consists of a widespread thin sequence of Cenozoic consolidated and unconsolidated sediments. However, the basin overlies several Palaeozoic and Mesozoic basement depressions that appear to be mainly deep grabens and half grabens, as well as shallower gentle basement downwarps.

The Murray Basin is over 300,000 km², containing extensive estuarine and marine sediments with significant concentrations of heavy mineral sand deposits amounting to 115 million tonnes total endowment (Figure 29). The heavy mineral sand deposits contain zircon, rutile, ilmenite, and monazite grains. The sands were eroded from granites on land and the heavy mineral-rich black sands were concentrated into strandlines along the seashore by waves and currents when the Southern Ocean was retreating from the region.

In NSW there are two major heavy mineral sand mines currently in operation (Gingko and Snapper), with several projects under development. See the online appendix at resourcesandgeoscience.nsw.gov.au/future-of-minerals for further information.



Figure 29 : Mineral endowment of the Murray Basin



Exploration Opportunities

The Murray Basin extends across NSW, Victoria and South Australia and has become one of the world's premier mineral sand provinces. There is outstanding potential for the development of known resources and for the discovery of new large heavy mineral sand deposits. The West Balranald deposit has an indicated resource totalling 29.5 million tonnes at 33.8 per cent heavy mineral sands (rutile, zircon and ilmenite). The nearby Nepean deposit has an inferred resource totalling 8.9 million tonnes at 26.5 per cent heavy mineral sands.



The NSW Government recently completed the largest ever airborne electromagnetic survey by area in the state's history searching for minerals as part of the MinEx CRC National Drilling Initiative



6. Benefits of exploration in NSW

NSW has a strong exploration and mining heritage built on its significant endowment of world-class metalliferous mineral systems and effective regulatory regime. There is a range of factors shared with other states and territories of Australia that have an impact on the state's international competitiveness. These include commodity prices, exchange rates, taxation, labour arrangements, sovereign risk and a robust legal framework at the national level.

In addition, the NSW minerals sector benefits from:

- well-established rail and road infrastructure to connect prospective mineral basins to large port facilities such as Newcastle, Sydney and Port Kembla
- an efficient mining titles process and ongoing improvements to planning and development frameworks
- pre-competitive geoscience data – the NSW Government makes significant amounts of geological data and records available at no cost, co-funds exploration and has introduced a sunset clause to release all available historical exploration data.

In February 2019, the NSW Government released the NSW Mineral Strategy to support the sector by creating the conditions needed for growth, encouraging innovation, attracting new investment, promoting marketing opportunities and delivering the infrastructure needed to bring new critical minerals projects into production. The NSW strategy is complemented by Australia's National Resources Statement⁵⁶ and Australia's Critical Minerals Strategy⁵⁷, both of which were released in the first quarter of 2019 by the Australian Government.

6.1 Efficient titles processing and frameworks

NSW has modern mining legislation incorporating responsible development standards. Approved projects in NSW can demonstrate the highest level of accountability.

This includes a fair and transparent land access arrangement including an arbitration system through the Mining Act 1992 and other legislation. Standardised legislative and title conditions across all minerals and areas of NSW assist companies to engage in clear and transparent negotiations with communities.

In December 2019, NSW launched the first phase of an online platform to streamline the management of exploration and mining licences and leases and improve transparency and accountability. More information about this system can be found at resourcesandgeoscience.nsw.gov.au/titles-management-system

6.2 Geoscience excellence

NSW has recognised the importance of the minerals sector throughout its history, with the Geological Survey of NSW (GSNSW) being created in 1875. Since its inception, the role of GSNSW has remained largely unchanged and continues today as part of the Division of Resources and Geoscience within the Department of Planning, Industry and Environment.

Under the mandate required by the NSW Government, GSNSW continues to:

- collect and manage geological, geophysical, geochemical and geospatial data specific to NSW
- collaborate with national and international governments and scientific bodies to share skills, data and promote information exchange
- inform stakeholders about the state's geology, and mineral, coal, petroleum and renewable energy resources
- facilitate the discovery, development and management of NSW mineral and energy resources for the benefit of all NSW citizens.

6.2.1 MinEx CRC

The NSW Government, through the GSNSW, is a major participant and has committed \$16 million to the MinEx Cooperative Research Centre (MinEx CRC). The program is a 10-year, \$220 million collaboration between the Australian and State Governments, CSIRO, leading Australian universities and the minerals sector.

MinEx CRC aims to enable mineral discovery in Australia's covered terranes by:

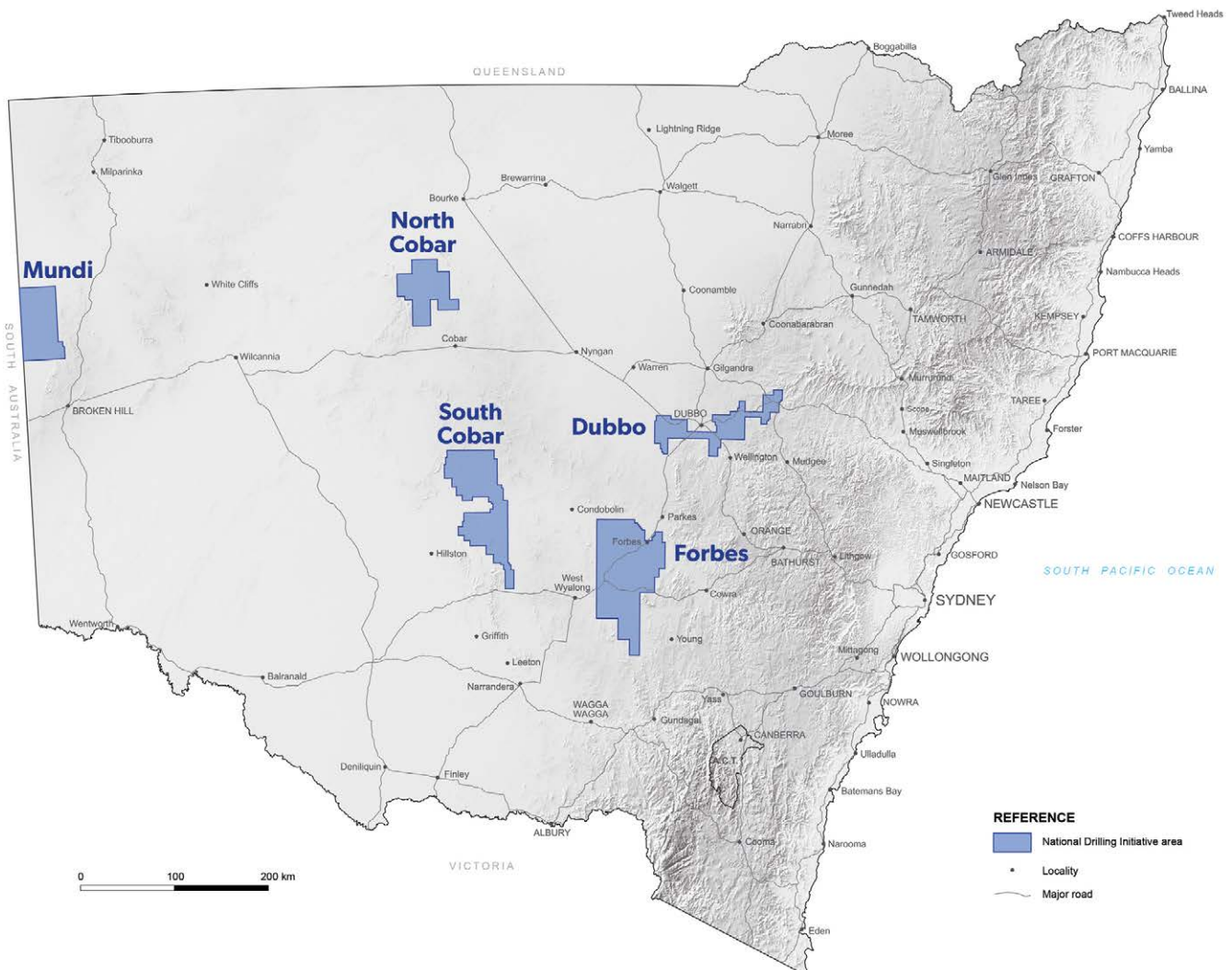
- developing more productive, safer and environmentally friendly drilling methods, including coiled tubing drilling technology, to discover and drill-out deposits
- developing new technologies for collecting data while drilling
- undertaking drilling to collect vital data in under-explored areas of potential mineral wealth in Australia through the National Drilling Initiative (NDI), a world-first collaboration of geological surveys, researchers and industry.

The NDI in NSW will focus on five New Frontier areas, shown in Figure 30. These areas are poorly characterised, underexplored and undercover extensions to known mineralised terranes. GSNSW will progressively undertake a review of legacy data and materials, and an extensive program of new geological mapping, airborne electromagnetic and other geophysical surveys, geochemistry (including hydrogeochemistry, biogeochemistry, geochronology and isotopic analysis), mineralogy (including HyLogging™) and drilling across the five NDI focus areas from 2019 to 2028.

For more information visit resourcesandgeoscience.nsw.gov.au/minexcrc

Data acquired through the NDI will feed into the NSW Government's ongoing program of developing a statewide geological framework, including the Statewide Seamless Geology of NSW data package and Mineral Potential Mapping projects.

Figure 30: MinEx CRC NDI focus areas in NSW



6.2.2 Co-operative drilling programs making funding available

From October to December 2019, the NSW Government accepted applications for a third round of its New Frontiers Cooperative Drilling program. The third funding round of the program will reimburse successful applicants for up to 50 per cent of their per metre drilling costs up to a maximum of \$200,000. The program includes \$2 million funding in the current round, which matches the \$4 million in funding allocated across two previous rounds of the program between 2015 and 2017.

For more information visit resourcesandgeoscience.nsw.gov.au/cooperative-drilling

6.2.3 World-class geological databases and tools

The NSW Government is working to expand geoscientific data available to explorers, and develop new exploration techniques.

Our resources include:

- high-tech metal resources of NSW map⁵⁸
- NSW Statewide Seamless Geology map – one of the most complex geodata sets ever compiled and released worldwide⁵⁹
- the state's drillcore libraries
- [MinView web viewer and data portal](#) – view and download all of NSW's geoscience data
- [DiGS publication archive](#) – fully searchable, with free download of over 140,000 maps, publications and reports.

Drillcore libraries making historic cores openly available

Under NSW legislation, all titleholders are required to preserve drillcore obtained during exploration or mining. Before a titleholder disposes of any drill core, cuttings or samples during or at the end of the life of an active title, they must offer the material to the NSW Government for archiving at one of its drillcore libraries. GSNSW determines which of the samples are significant enough to be stored for future resource exploration and research. The samples would otherwise be very expensive and in some cases impossible to re-acquire as the stored drillcore can contain materials that have been subsequently mined out or are otherwise unavailable.

The NSW Government currently stores 1.5 million metres of drillcore representing the most informative one per cent of all samples taken by industry and makes them freely available to inspect by appointment.

For details on the state's drillcore libraries visit resourcesandgeoscience.nsw.gov.au/miners-and-explorers/geoscience-information/services/drill-core-libraries

MinView

MinView is a web mapping tool providing free access to view, search and download a comprehensive range of geoscientific data for NSW. Over 50 unique map layers are available along with a range of technical information from the Geoscientific Data Warehouse. The available data includes supporting reference data, current and historic exploration and mining titles, areas available for exploration and cadastral information.

For more information visit minview.geoscience.nsw.gov.au

DIGS online report archive and the release of historical data

DIGS is a public, online archive that provides access to non-confidential reports and other important documentary material held by the NSW Government, including exploration reports on mineral and coal exploration titles, departmental reports, maps and publications. In total, there are over 140,000 reports, with approximately 3.5 million pages and 2 terabytes of digital data dating back to 1875.

The company reports available on DIGS contain prospecting activity and relevant geoscientific data which is required to be collected under the Mining Act 1992. However, a large majority of these records are currently confidential. Under an amendment referred to as the 'Sunset Clause', all confidential reports submitted prior to June 2016 will be made public from 2021. The data to be released has a replacement value conservatively estimated at over AUD\$1 billion, as shown in Table 12.

Table 12: Value of data to be released under the Sunset Clause amendment

Assay Sample	Sample count	Associated Cost (per Sample)	Total Value
Drill Hole Sample	3,655,673	\$100	\$365,567,300
Surface Sample	672,394	\$20	\$13,447,880
Drilling	Total (Metres)	Associated Cost (per metre)	Total Value
Drilled Metres	6,840,484	\$100	\$684,048,400
Grand Total			\$1,063,063,580

For more information visit digs.geoscience.nsw.gov.au

7. NSW: a leader in responsible mining practices

The NSW Government is committed to maintaining and enhancing our regulatory frameworks to ensure our minerals sector acts responsibly to minimise long-term negative impacts on the environment and local communities.

An environmentally responsible minerals sector allows mineral deposits to be discovered and extracted so that land and water resources can be returned to other productive uses once the mineral resources have been depleted.

Achieving the goal of responsible mining presents several challenges, which can only be overcome with innovative solutions from industry and research organisations, robust regulation and appropriate infrastructure partnerships between the private sector and government.

Water

Mines cannot operate without a consistent supply of water. Mining requires water for processing, transport and to manage environmental impacts (e.g. dust suppression). Although mines can be very water-efficient and operators take measures to recycle the water they use, there are always some losses from the system.

Water availability is a growing issue for mineral mining around the world. The industry in NSW has considerable experience dealing with water supply issues gained through periods of drought. Many operators have invested in water efficiency or infrastructure projects to increase their drought resilience, while other operators pause operations during these periods.

NSW mine operators take part in water sharing arrangements and work with local communities and government to improve water security. To make sure the operators' water use is transparent and accounted for, the NSW Government requires them to purchase and account for all water extracted or contributed to the water network.

The economic benefits created by mining make public and private investments in water infrastructure more viable, benefiting communities of regional NSW. Identifying more opportunities for commercially viable investments in water infrastructure reduces potential water conflicts with other users. To meet expectations of social and environmental responsibility, mining operations in NSW are supported by a strong governance framework ensuring water use is accounted for in a transparent manner, mitigating the risk of water use disputes.

Water sharing arrangements in NSW allow for water trading; recognising water is a precious resource and the best returns need to be achieved in an environmentally responsible manner.

Division of Resources and Geoscience

Vision

Our mineral and petroleum resources generate prosperity for the people of NSW

Mission

Foster the ecologically responsible development of the state's mineral and petroleum resources through excellence in geoscientific knowledge and efficient regulation

“Water is one of the greatest constraints to the new supply of mined products across the industry.”

*Anglo American CEO,
Mark Cutifani, 2017*

Energy

The amount of energy used to mine materials (energy intensity) varies depending on the mineral or metal being targeted and the mining method. For example, gold can have a high energy intensity as the cut-off grades are lower compared to other metals (e.g. copper), meaning greater volumes of material are processed per unit of gold recovered. In the long term, as mineral ore grades decline the energy intensity of extracting minerals will generally increase. This presents a challenge for mining globally, as the sources of this energy need to be cost effective and consistent with commitments to emissions reduction.

In 2017, most of the Australian mining sector sourced its energy from diesel (41 per cent) and natural gas (33 per cent), with grid electricity accounting for less than a quarter of energy supply (22 per cent). However, Australian miners are transitioning away from diesel and are moving towards natural gas and grid electricity to avoid volatility in oil markets. While fuel prices are at near-decade lows, increases in the diesel price in Australia between 2016–2017 increased production costs by \$0.64/tonne for bauxite, \$2.10/tonne for iron ore, \$3.99/tonne for copper ore and \$10.73/tonne for gold ore.⁶⁰

Over the past decade, advances in technology have enabled some mining processes to be electrified. This has reduced pollution by increasing the use of renewable energy from stand-alone systems or the grid. The NSW Government and Australian Government have also committed to actions supporting the NSW minerals sector through reduced wholesale electricity prices, improved supply reliability and consistent emissions reduction targets.

The NSW Electricity Strategy was released in 2019 as the NSW Government's plan for a reliable, affordable and sustainable electricity future to support a growing economy. The strategy encourages an estimated \$8 billion in new private investment over the next decade, \$5.6 billion of this in regional NSW. These investments will support a new affordable and reliable energy system.

Key components of the NSW Electricity Strategy that are particularly relevant to the NSW minerals sector are the proposed Renewable Energy Zones, support for new electricity generation projects, and the setting of an energy security target. Renewable Energy Zones (REZ) are areas with high wind or solar potential that are proposed for the New England, Central West and South West regions of NSW. The Central-West Renewable Energy Zone, shown in Figure 31, will be the first pilot REZ in response to strong investor interest, with an expected 4,500 megawatts of renewable generation already approved or in the planning system in the region. The development of new renewable energy generators in the Central West will bolster the electricity supply for existing and future mining operations in the Lachlan Orogen.

The Central West REZ will deliver:

- improved electricity reliability – unlocking up to 3,000 megawatts of new generation by mid-2020
- increased affordability by reducing wholesale electricity costs
- emissions reductions – using renewables to reduce the dependence on coal-fired generators.

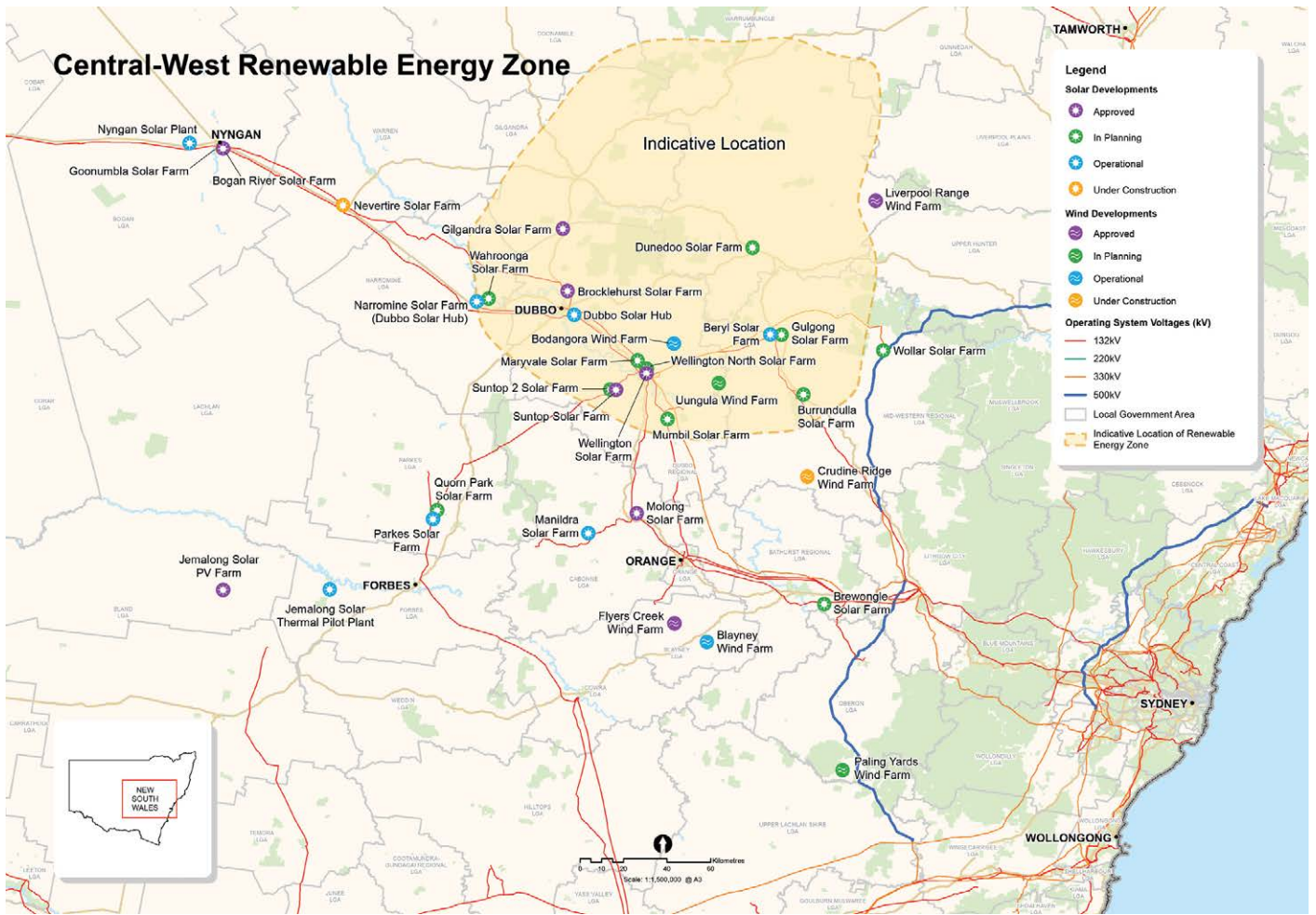
The Australian Government has also established the Underwriting New Generation Investments program to improve reliability and lower wholesale prices for commercial and industrial customers.

So far, the Commonwealth has shortlisted three projects for funding in NSW, including the:

- Australian Industrial Energy Gas project – Port Kembla, NSW
- UPC Renewables pumped hydro project – Armidale, NSW
- Delta coal upgrade project – Lake Macquarie, NSW.

The Commonwealth has also committed to developing the Snowy 2.0 scheme, a pumped hydro project in the Snowy Mountains near the NSW-Victorian border. Snowy 2.0 will deliver 2,000 megawatts of on-demand generation and up to 175 hours of storage capacity. It aims to put downward pressure on electricity prices and support greater generation from renewable sources. Snowy 2.0 is expected to be online in late 2024–25.

Figure 31: Indicative location for the pilot Central West Renewable Energy Zone



A global leader in mining skills and technology

Employment opportunities in the Australian and NSW minerals sectors have decreased compared to the peak of the mining investment boom. However, the cyclical nature of commodity markets and the mining industry will again create strong investment activity and increased demand for labour in the future.

The mining sector is increasingly at the frontier for advanced technologies and a transition from traditional engineering to that of data science and robotics requires – and presents – opportunities for a broader number of professionals.

NSW has a leading mining equipment, technology and services (METS) sector focused on researching and delivering solutions to address challenges faced by the mining industry. Many products and services used around the world today were developed in NSW.

Areas of innovation in the NSW mining industry include:

- dust suppression
- water recycling
- mine safety improvement.

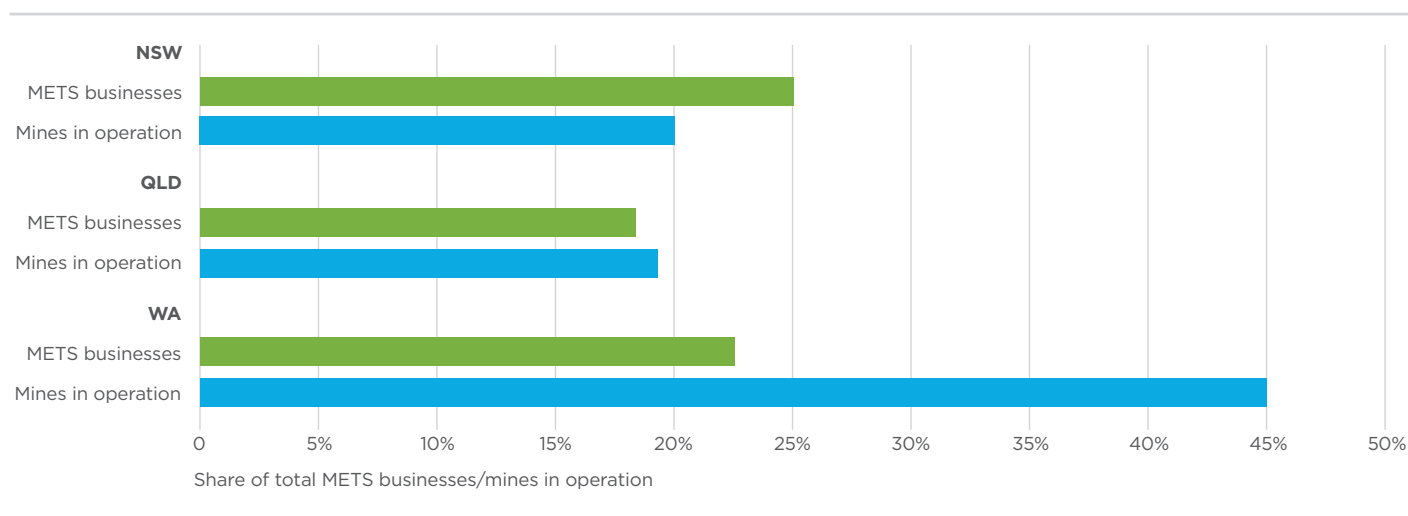
NSW mining research and development is also focused on improving environmental performance. A leading research group developing environmentally friendly mineral processing techniques is based at the University of Newcastle, the Australian Research Council (ARC) Centre of Excellence for Enabling Eco-efficient Beneficiation of Minerals.

The Centre aims to transform the industry through three focus research goals:

- double energy and water productivity in the mining sector by 2030, maintaining the drive towards the 'zero-emission mine'
- reduce the loss of high-value metals during mineral processing by 90 per cent, increasing the concentration of recovered products used in metals refining
- establish a new generation of scientists and research leaders in minerals beneficiation to support the innovation needed to sustain the Australian industry.

The expertise held in the NSW mining sector places it in a solid position to develop solutions to challenges and ensure mining can be carried out with minimal environmental impact. As shown in Figure 32, NSW has the largest percentage of METS business in Australia.

Figure 32: Share of mines in operation and METS businesses in selected states



Deloitte Access Economics estimates that, in the Hunter region of NSW, the mining and METS sector directly contributed \$8.5 billion in value added to the regional economy in 2015-16, supporting around 50,400 full time equivalent (FTE) jobs. The indirect economic contribution to the Hunter region is estimated to be \$6.7 billion, supporting approximately 43,100 FTE jobs. Overall, the total direct and indirect contribution of \$15.2 billion represented 34 per cent of all economic activity in the Hunter region in 2015-16.⁶¹

The NSW Government is exploring options to educate students and young adults in regional NSW on the broad range of careers available in the NSW mining industry. The technical innovation occurring in the industry requires a diverse skillset in regional areas. Developing pathways for young people to develop skills and experience is necessary for the ongoing development of responsible mining practices.

61. Deloitte Access Economics 2017

Land use conflict

Mining involves a range of activities requiring interaction with local communities, including exploration, project development and mining operations. Land use conflicts involving the minerals sector tend to occur if there is a lack of transparency and understanding of the decision-making processes governing the planning process.

Common Ground is a web-based tool of the NSW Government that provides local communities with clear explanations of the role of communities and the government in the decision process for any proposed exploration or mining activity. During the exploration phase, individuals or companies granted an exploration title may only enter land covered by the title once they have land access arrangements in place with relevant landholders.

Common Ground also addresses misinformation that may cause conflict between landholders and the mining industry. For example, while exploration titles can cover large areas, most mines have a much smaller footprint. For metals only a fraction of a percent of exploration projects proceed to mining and production. Globally, an average of US\$200 million is spent on exploration per deposit discovered.⁶² Many exploration licences will not lead to mine developments and those that do will only utilise a small portion of the original exploration title area for long term operations.

View Common Ground at commonground.nsw.gov.au

The need, benefit and added value of recycling

There is little need to convince the general public on the importance of, and need for, recycling. A survey conducted by HP Australia and Planet Ark found almost all Australian consumers are concerned about the environment and sustainability.⁶³

The NSW economy has traditionally been a mostly linear system ('take, make and dispose'). We extract raw materials, manufacture goods and use them. They are then either collected and recycled or disposed of in landfill.

In response, the NSW Government is developing a Circular Economy Strategy,⁶⁴ where the value of resources is maintained for as long as possible. The strategy will set a 20-year vision for reducing waste and driving sustainable recycling markets.

Replacing the demand for raw materials with recycled products will lower the demand for finite natural resources and minimise the environmental impacts associated with the extraction and processing of raw materials.

Some metals lend themselves to be more easily recycled. For example, the ability to repeatedly recycle copper without any loss in performance is a key driver for high recycling rates. It is estimated at least 65 per cent of all the copper mined is still in use, with around 50 per cent of Europe's copper demand met by recycled material. An advantage of recycling materials is that the energy required to recycle metals compared to extracting raw metals is significantly lower in many cases. For example, the energy used to recycle aluminium, copper and steel compared to extracting it is 92 per cent, 90 per cent and 56 per cent less respectively. This is often achieved by adding the recycled component into the raw material process to increase yield and in some cases improve the process.

The Commonwealth National Waste Policy incorporates five circular economy principles.⁶⁵ The NSW minerals sector can play a central role in two of these, namely 'improving resource recovery' and 'increasing the use of recycled materials', building demand and markets for recycled products. In effect, a responsible NSW mining sector will maintain living standards and quality of life for future generations.

8. Glossary

AEMO	Australian Energy Market Operator
BEV	Battery electric vehicle
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DIGS	GSNSW online report archive
DRC	The Democratic Republic of the Congo
EPA	NSW Environment Protection Authority
EV	Electric vehicle
FCEV	Fuel cell electric vehicle
GA	Geoscience Australia
GSNSW	Geological Survey of NSW
IEA	International Energy Agency
JORC code	Australasian Code for Reporting of Exploration Results
MAA	Mineral Allocation Area
METS	Mining equipment, technology and services
MinEx CRC	MinEx Cooperative Research Centre
MinView	GSNSW online data portal
OECD	Organisation for Economic Co-operation and Development
PGE	Platinum group elements
PHEV	Plugin hybrid electric vehicle
ppm	Parts per million
REE	Rare earth elements
REZ	Renewable Energy Zones
RFID	Radio frequency identification
SNEO	Southern New England Orogen
tpy	Tonnes per year
USGS	United States Geological Survey
VMS	Volcanic associated massive sulfide
Traditional metals	Metals that were widely used in 20th Century industry
Emerging metals	Metals that are emerging as key components of 21st Century communication, energy and medical technologies

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