Australian Government
Geoscience Australia

AUSTRALIA'S
IDENTIFIED MINERAL RESOURCES
2017

Australian Government
Geoscience Australia

AUSTRALIA'S
IDENTIFIED MINERAL RESOURCES
2017

Contact Details
mineral.promotions@ga.gov.au

Department of Industry, Innovation and Science
Minister for Resources and Northern Australia: Senator the Hon Matthew Canavan
Secretary: Dr Heather Smith PSM

Geoscience Australia
Chief Executive Officer: Dr James Johnson
This document is published with the permission of the CEO, Geoscience Australia

ISSN 1327-1466
eCat ID: 116001
GA PP-1368

Bibliographical Reference
Britt, A., Summerfield, D., Senior, A., Kay, P., Huston, D., Hitchman, A., Hughes, A., Champion, D., Simpson, R., Sexton, M. and Schofield, A. Geoscience Australia 2017. Australia's Identified Mineral Resources 2017. Geoscience Australia, Canberra. http://dx.doi.org/10.11636/1327-1466.2017

Cover Image
Gold mining in the Havana Pit at Tropicana, Western Australia. Photograph courtesy of AngloGold Ashanti Australia Ltd.

Minister's Foreword

By almost any measure, Australia is a world leader in mineral resources. We hold the largest identified resources and are the major producer of many commodities essential to our everyday lives. We also lead the way internationally in mining innovation and are exporting more mining services around the globe than ever before.

The importance of mineral resources and the mining industry sector to our economy, and to regional Australia in particular, cannot be overstated. In 2016–17, mineral resources made up around 37 per cent of Australia's exports. Overall, the mining industry sector currently accounts for 7.4 per cent of our gross domestic product. It directly employs approximately 230,000 people in high-value jobs and indirectly supports the employment of many more.

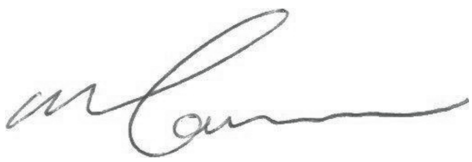
Compiled by Geoscience Australia and its predecessors since 1975, Australia's Identified Mineral Resources (AIMR) reaffirms Australia's reputation as a world leading destination for investment in mineral resources. The 2017 edition includes: assessments of reserves and resources at operating mines and other deposits; evaluations of long-term trends for major commodities; and comparative world rankings for mineral resources.

Figures included in AIMR 2017 show that Australia has the world's largest identified resources of nine commodities, including extremely valuable mineral resources such as gold. We are also the world's largest producer of five commodities—including lithium, a mineral resource with potential that is just beginning to be unlocked through new and emerging technologies.

Collected directly from the mining industry sector, the statistics in AIMR 2017 provide a strong evidence base for the development of policy, investment by the Australian Government, and the continued optimal management of our nation's valuable mineral resources.

Although AIMR 2017 tells us Australia has the potential to continue supplying the world with mineral resources for decades to come, the type of world-class mineral deposits that have helped build our nation are not discovered overnight. From the first gold rushes of the 1850s to the 2000s commodities boom, much of our economic prosperity has been underpinned by the discovery of world-class mineral deposits. While mineral exploration activity continually unearths new deposits, it has been more than a decade since a new tier-one discovery in Australia.

To remain internationally competitive as an investment destination for resource companies, we must continue to explore. Only the highest quality deposits with low operating costs will attract the investment needed for development and insure our future economic prosperity. Through programs such as Exploring for the Future, led by the Geoscience Australia, the Australian Government remains committed to ensuring we have world-class mineral deposits for decades—in fact, for generations—to come.



Senator the Hon Matt Canavan
Minister for Resources and Northern Australia

Contents

Gold mining at Tropicana, Western Australia. Photograph courtesy of AngloGold Ashanti Australia Ltd.

1. Introduction

Australia has a robust and world-leading mining industry evidenced by a top five position as a producer for some 19 commodities including gold, aluminium, iron ore, rare earths, mineral sands, zinc, lead and coal. In 2016, Australia's mineral exports (excluding petroleum products) amounted to more than $151 billion which was almost 58% of all export merchandise and 46% of all exported goods and services. In the 2016–17 financial year, mining accounted for 7.4% of gross domestic product[1]. In addition, the mining industry employed more than 230 000 people in 2016, with many more employed by related industries[2].

Given the importance of mineral resources to the Australian economy, Geoscience Australia publishes an annual assessment of the nation's mineral reserves (Table 1 and Table 2) and resource estimates (Table 3) for all major, and some minor, commodities. This assessment provides useful long-term indicators of potential resource life and future supply capability. Its broad outlook should assist with government policy decisions as well as programs and planning associated with the minerals sector and the sustainable development of Australia's mineral resources.

This publication also provides useful comparisons of reserves and resources at operating mines as proportions of the national inventory (Table 4, Table 5) and insights into the distribution of Australia's mineral wealth (Table 6). It is also of interest to note Australia's position as a global source of minerals as many countries are dependent on reliable supply from Australia for their own economies (Table 7).

Australia's Identified Mineral Resources 2017 presents estimates of Australia's mineral reserves and resources as at 31 December 2016. The data in the national minerals inventory is mainly sourced from published company reports, but includes some confidential and historical data. The highest category in the national inventory is Economic Demonstrated Resources (EDR) which, in essence, combines the Joint Ore Reserves Committee (JORC) Code categories of Proved and Probable Ore Reserves and most of Measured and Indicated Mineral Resources.

Mine production data are based on figures from the Office of the Chief Economist at the Department of Industry, Innovation and Science. World rankings of Australia's mineral resources have been calculated mainly using information published by the United States Geological Survey (USGS).

Geoscience Australia and its predecessors have prepared the annual assessment of Australia's mineral resources since 1975. Thus, this publication is able to draw on 40 years of data to reveal trends in reserve estimates, resource estimates and mine production over both short and long periods of time.

As at 31 December 2016:

- Australia's EDR increased for black coal, cobalt, gold, ilmenite, lithium, molybdenum, potash, rutile, tantalum, tin, vanadium and zircon. The strongest gains in EDR were mineral sands (11%), lithium (70%), potash (73%), cobalt (13%), tantalum (9%) and tin (12%) as improved markets for these commodities, particularly for those associated with battery technology, has stimulated exploration and resource delineation.
- EDR for brown coal, chromium, copper, fluorine, lead, magnesite, nickel, niobium, oil shale, PGEs, phosphate, rare earths, thorium and zinc remained at levels similar to those previously reported.
- Australia's EDR decreased for antimony, bauxite, diamond, iron ore, manganese ore, tungsten and uranium. The most significant fall in EDR was diamond (-45%) as the Argyle mine in Western Australia winds down.
- Australia's EDR of gold, iron ore, lead, nickel, rutile, tantalum, uranium, zinc and zircon are the world's largest.
- Australia's EDR of antimony, bauxite, black coal, brown coal, cobalt, copper, diamond, ilmenite, lithium, magnesite, manganese ore, niobium, silver, thorium, tin, tungsten and vanadium all rank in the top five worldwide.
- Australia is also the top global producer for bauxite, iron ore, rutile and zircon.
- Australia is the second largest producer of gold, lead, rare earths and diamonds, the third largest producer of ilmenite, uranium and zinc, the fourth largest producer of antimony, black coal and manganese ore and fifth for brown coal, cobalt, copper, nickel and silver.
- Australia had a large number of mines producing gold (130), black coal (93), copper (34), iron ore (29) and silver (22).
- Australia had few operating mines producing nickel (13), zinc (13), lead (13), zircon (8), ilmenite (7), rutile (7), bauxite (6), uranium (3), manganese ore (1) and diamond (1).
- Using 2016 rates of production at operating mines, Australia's Measured and Indicated Resources of bauxite, black coal, copper, lead, manganese ore, silver, uranium and zinc could potentially last more than 40 years.
- Using 2016 rates of production at operating mines, Australia's Measured and Indicated Resources could have a life of 18 to 33 years for mineral sands, 32 years for nickel, 22 years for gold, 19 years for iron ore, but only 8 years for diamond.
- At 2016 rates of production, operating gold mines have enough Measured and Indicated Resources to last an average of 22 years. However, operating lode-gold deposits, which provide most of the gold production, have an average resource life of 8 years.
- The main mineral export earners in 2016 were iron ore (36% of $151 billion), black coal (26%), gold (12%), copper (5%), alumina (4%), aluminium (2%), nickel and zinc (both 1.5%). These same minerals were the main income earners in 2015 but only iron ore and gold earned greater income in 2016 than in 2015. Iron ore export income improved by 10% and gold by 28%.
- The price of most commodities has generally decreased since peak prices in 2011. The exception is gold which, in Australian dollars, has remained high resulting in strong production and export income.
- Lower iron ore prices have been offset by increased production, resulting in increased export income in 2016 and reversing the decline of recent years.

[1] Office of the Chief Economist (Resources and Energy Quarterly, December 2017).
[2] Australian Bureau of Statistics. Labour Force, Australia, Detailed, Quarterly.

JORC CODE

The following terminology and definitions are used by the Joint Ore Reserves Committee (JORC) Code for reporting of Mineral Resources and Ore Reserves (2012 Edition). A full copy of the JORC Code can be found at *www.jorc.org.*

Mineral Resource: A 'Mineral Resource' is a concentration or occurrence of solid material of economic interest in or on the Earth's crust in such form, grade (or quality), and quantity that there are reasonable prospects for eventual economic extraction. The location, quantity, grade (or quality), continuity and other geological characteristics of a Mineral Resource are known, estimated or interpreted from specific geological evidence and knowledge, including sampling. Mineral Resources are sub-divided, in order of increasing geological confidence, into Inferred, Indicated and Measured categories.

Inferred Mineral Resource: An 'Inferred Mineral Resource' is that part of a Mineral Resource for which quantity and grade (or quality) are estimated on the basis of limited geological evidence and sampling. Geological evidence is sufficient to imply but not verify geological and grade (or quality) continuity. It is based on exploration, sampling and testing information gathered through appropriate techniques from locations such as outcrops, trenches, pits, workings and drill holes. An Inferred Mineral Resource has a lower level of confidence than that applying to an Indicated Mineral Resource and must not be converted to an Ore Reserve. It is reasonably expected that the majority of Inferred Mineral Resources could be upgraded to Indicated Mineral Resources with continued exploration.

Indicated Mineral Resource: An 'Indicated Mineral Resource' is that part of a Mineral Resource for which quantity, grade (or quality), densities, shape and physical characteristics are estimated with sufficient confidence to allow the application of Modifying Factors in sufficient detail to support mine planning and evaluation of the economic viability of the deposit. Geological evidence is derived from adequately detailed and reliable exploration, sampling and testing gathered through appropriate techniques from locations such as outcrops, trenches, pits, workings and drill holes, and is sufficient to assume geological and grade (or quality) continuity between points of observation where data and samples are gathered. An Indicated Mineral Resource has a lower level of confidence than that applying to a Measured Mineral Resource and may only be converted to a Probable Ore Reserve.

Measured Resource: A 'Measured Mineral Resource' is that part of a Mineral Resource for which quantity, grade (or quality), densities, shape, and physical characteristics are estimated with confidence sufficient to allow the application of Modifying Factors to support detailed mine planning and final evaluation of the economic viability of the deposit. Geological evidence is derived from detailed and reliable exploration, sampling and testing gathered through appropriate techniques from locations such as outcrops, trenches, pits, workings and drill holes, and is sufficient to confirm geological and grade (or quality) continuity between points of observation where data and samples are gathered. A Measured Mineral Resource has a higher level of confidence than that applying to either an Indicated Mineral Resource or an Inferred Mineral Resource. It may be converted to a Proved Ore Reserve or under certain circumstances to a Probable Ore Reserve.

Modifying Factors: 'Modifying Factors' are considerations used to convert Mineral Resources to Ore Reserves. These include, but are not restricted to, mining, processing, metallurgical, infrastructure, economic, marketing, legal, environmental, social and governmental factors.

Ore Reserve: An 'Ore Reserve' is the economically mineable part of a Measured and/or Indicated Mineral Resource. It includes diluting materials and allowances for losses, which may occur when the material is mined or extracted and is defined by studies at Pre-Feasibility or Feasibility level as appropriate that include application of Modifying Factors. Such studies demonstrate that, at the time of reporting, extraction could reasonably be justified.

Probable Ore Reserve: A 'Probable Ore Reserve' is the economically mineable part of an Indicated, and in some circumstances, a Measured Mineral Resource. The confidence in the Modifying Factors applying to a Probable Ore Reserve is lower than that applying to a Proved Ore Reserve.

Proved Ore Reserve: A 'Proved Ore Reserve' is the economically mineable part of a Measured Mineral Resource. A Proved Ore Reserve implies a high degree of confidence in the Modifying Factors.

2. Australia's Estimated Ore Reserves

Over 2200 companies and securities are listed on the Australian Securities Exchange (ASX) of which nearly 900 (40%) are categorised as belonging to the materials and energy sectors. Recognising that confidence in such a large part of the Australian economy is paramount, the Joint Ore Reserves Committee (JORC) of The Australasian Institute of Mining and Metallurgy, the Australian Institute of Geoscientists and the Minerals Council of Australia has developed a world-class code, the JORC Code, for reporting Exploration Results and estimates of Mineral Resources and Ore Reserves to the public. The JORC Code has been adopted by the ASX as part of its listing rules and is mandatory for all mining companies listed on the ASX and New Zealand Stock Exchange. Variations of the JORC Code have been adopted in many other parts of the world and the code is compatible with the international United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources.

As part of the Australian Government's regular annual assessment of the national minerals inventory, Geoscience Australia compiles all known estimates of Ore Reserves and Mineral Resources reported publicly by mining companies. In addition, some private companies and some foreign companies operating in Australia also use the JORC Code, or equivalent codes, for reserve and resource estimation and this information is also included in the annual compilation wherever possible.

Determining how much of a particular mineral commodity is in the ground and how much is extractable is not an exact science, hence Ore Reserves and Mineral Resources are always referred to as estimates, never calculations. Mineral Resources and Ore Reserves are categorised by confidence in both the geology of the deposit and the economic viability of production. Of all the different categories (see description of JORC Code on page 2), an Ore Reserve is the category of highest confidence and, from a commercial point of view, is the most applicable to the current state of Australia's minerals industry and the near future (say, the next five years).

Reserve Life of Major Commodities

It is useful to look at the number of operating mines and their associated Ore Reserves and Mineral Resources (Table 1) as these are the deposits that produced all of Australia's minerals in 2016. Some of these mines have since closed or been placed on care and maintenance but most will continue mining for the foreseeable future, subject to favourable economic, environmental and regulatory conditions. An impression of future viability can be gained by determining the ratio of current reserves and resources to the latest production figures (Table 1). The resulting reserve and resource "life" must be treated with caution as production rates vary from year to year and mining companies typically upgrade resources to replace ore depletion. Nonetheless, this ratio provides a snapshot of the current situation and a glimpse of one potential future (in which exploration and resource upgrades have ceased and mining activity has remained static).

Gold has by far the largest number of mines (Table 1), although many companies have multi-mine operations so a single company failing could potentially affect the exploitation of a greater number of individual deposits. In addition, gold reserves and resources are dominated by large multi-element deposits such as Olympic Dam (Cu-Au-U) in South Australia and Cadia (Cu-Au) in New South Wales, whereas production is dominated by lode-gold deposits such as those of the Kalgoorlie goldfields of Western Australia. In 2016, out of the 288 t of gold produced, 182 t came from lode-gold deposits, which accounted for 830 t of the Ore Reserves and 1464 t of the Measured and Indicated Resources. At this continued rate of production, operating lode-gold deposits have an average reserve life of less than 5 years and a resource life of 8 years compared to 10 years and 22 years, respectively, for all gold-producing mines (Table 1).

Australia also has a large number of operating black coal mines (Table 1), nearly all of which occur in New South Wales and Queensland. Black coal Reserves at operating mines could last 22 years at 2016 rates of production and, when all Reserves are considered (Table 2), this figure extends to 35 years.

There were 29 operating iron ore mines in 2016 producing 38% of the global supply (Table 7). At 2016 rates of production, these mines have enough Ore Reserves for another seven years but longer (22 years) when the Mineral Resources of these mines are included. When non-operating mines are included, the 2016 ratio of Ore Reserves to production is 27 years.

Of the other bulk commodities—bauxite, manganese ore and minerals sands—manganese ore has the longest reserve (24 years) and resource life (44 years) largely because there is now only one operating mine in Australia (Table 1). The mine at Groote Eylandt in the Northern Territory produced 3.2 Mt of ore in 2016, positioning Australia as the fourth largest producer of manganese ore in the world (Table 7). Mine closures at Woodie Woodie and Nicholas Downs in Western Australia and at Bootu Creek in the Northern Territory have resulted in Australia's ranking slipping in recent years.

Bauxite mining remains strong in Australia with Australia ranking number one as a bauxite producer (Table 7). Of the six operating mines (Table 1), the four large mines of Gove (Northern Territory), Weipa (Queensland), Worsley and Huntly (both Western Australia) account for almost all production. At 2016 rates of production, Ore Reserves at these mines could last an average of 10 years and when developing mines (e.g. the large Amrun project south of Weipa) are considered, reserve life could potentially be 28 years.

Seven mines produced ilmenite, rutile and zircon in 2016, with an eighth (Keysbrook, Western Australia) recording just zircon and leucoxene production. In 2016, Australia produced the largest amount of rutile and zircon in the world and third largest amount of ilmenite (Table 7). At 2016 rates of production, Ore Reserves at these operating mines could last 11 years for ilmenite, 7 years for rutile and 8 years for zircon. The reserve life of all deposits using 2016 rates of production is much greater at 40 years for ilmenite, 22 years for rutile and 33 years for zircon.

The nonferrous metals of copper, lead, zinc and nickel all have potential reserve lives of 20 years or greater at 2016 rates of production (Table 1). Copper, of course, is dominated by the huge Olympic Dam deposit which produced nearly 20% of Australia's copper output in 2016. If Olympic Dam were removed from the calculations, and assuming the lost production was made up elsewhere, then Australia's copper Reserve at the remaining 33 operating mines would drop by more than 10 Mt and the reserve life would be just 12 years. The resource life of operating copper mines is 73 years, again skewed strongly by Olympic Dam.

Lead and zinc resources at operating mines could potentially last around 60 years at 2016 rates of production (Table 1). Lead-zinc(-silver) deposits are widely dispersed in Australia

with lead and zinc produced in Queensland (Cannington, Dry River, Mount Garnet, George Fisher, Mount Isa), New South Wales (Broken Hill, Rasp, Endeavour, Hera), the Northern Territory (McArthur River), Tasmania (Rosebery) and Western Australia (Gossan Hill). The Dry River mine was, however, placed on care and maintenance during 2016. In addition, the Bentley mine (Western Australia) produced zinc and the Peak mines (New South Wales) produced lead.

Nickel is mined at 13 deposits (Table 1), all in Western Australia, from either sulphide or lateritic ores. The reserve life of operating mines at 2016 rates of production is potentially 20 years (Table 1) but almost 50% greater at 29 years when all deposits are included in the calculation. This is because low nickel prices in recent years have led to some nickel mines being placed on care and maintenance and delayed the development of others. Consequently there is a relatively large Ore Reserve of nickel that is not currently being exploited but is still published as current by the owners.

Silver was produced at 22 mines in 2016 and these mines have a potential reserve life of 14 years and a possible resource life of 46 years, at 2016 rates of production (Table 1). Reserve life of all deposits is 18 years. Australia is richly endowed in silver, ranking second globally (Table 7). Much of it is associated with lead- zinc deposits, but silver is also commonly found with gold and other deposit types. It is widely dispersed in Australia, with all states having Ore Reserves (Figure 2), dominated by Queensland (45%), the Northern Territory (20%), South Australia (14%) and New South Wales (12%). Despite this dispersion, just six deposits—the McArthur River (Northern Territory), George Fisher and Cannington (Queensland), Olympic Dam and Carrapateena (South Australia) and Cadia (New South Wales) —hold 75% of Australia's silver deposits between them.

Australia has a large uranium Ore Reserve (329 kt; Table 2) of which more than 80% is associated with three mines (Table 1). These mines are located in South Australia (Olympic Dam and Four Mile) and the Northern Territory (Ranger). In 2016, mining took place at the South Australian properties with Ranger producing from stockpiles. At 2016 rates of production, these mines have an average reserve life of 43 years and a potential resource life of 152 years (Table 1), strongly skewed by Olympic Dam which is the world's largest uranium deposit. In 2016, Olympic Dam alone produced more than 50% of Australia's uranium with reserves that could last about 80 years.

Australia has very few diamond deposits with only Argyle in the Kimberley region of Western Australia and Merlin in the Northern Territory having current Ore Reserves. In 2016, only Argyle was fully operational (Table 1). After pilot production in 2013, diamond mining at Merlin restarted at the end of 2016 but without significant production (hence it is not included in Table 1). The Argyle diamond mine (Rio Tinto Ltd) is a leading global supplier and the largest supplier of naturally coloured diamonds. It is particularly famous for its pink stones, producing more than 90% of all pink diamonds in the world. Argyle is expected to close in 2021.

Trends in Reserve Life

Figure 1 shows that many commodities experience long periods of time with little variation in each year's reserves to production ratio. Gold is a particularly good example with a reserve life that has varied little (from 12 to 16 years) since 2002. It reflects ongoing industry practice of steadily replenishing depleted Ore Reserves by upgrading a similar quantity from Measured and Indicated Resources. In turn, Inferred Resources are upgraded to Measured and Indicated and new resources are added through exploration.

Odd variations to the reserve to production ratio occur from year to year for some commodities (e.g. lead and zinc; Figure 1) mostly explained by mine closures (sometimes temporary) with accompanying loss of production; companies upgrading or downgrading Ore Reserves as individual projects succeed or fail; or companies reducing or ramping up production in response to price fluctuations. Lead and zinc have both seen an uptick in reserve life in 2016 reflecting reduced production at Mount Isa and McArthur River but are expected to return to trend as Dugald River comes online.

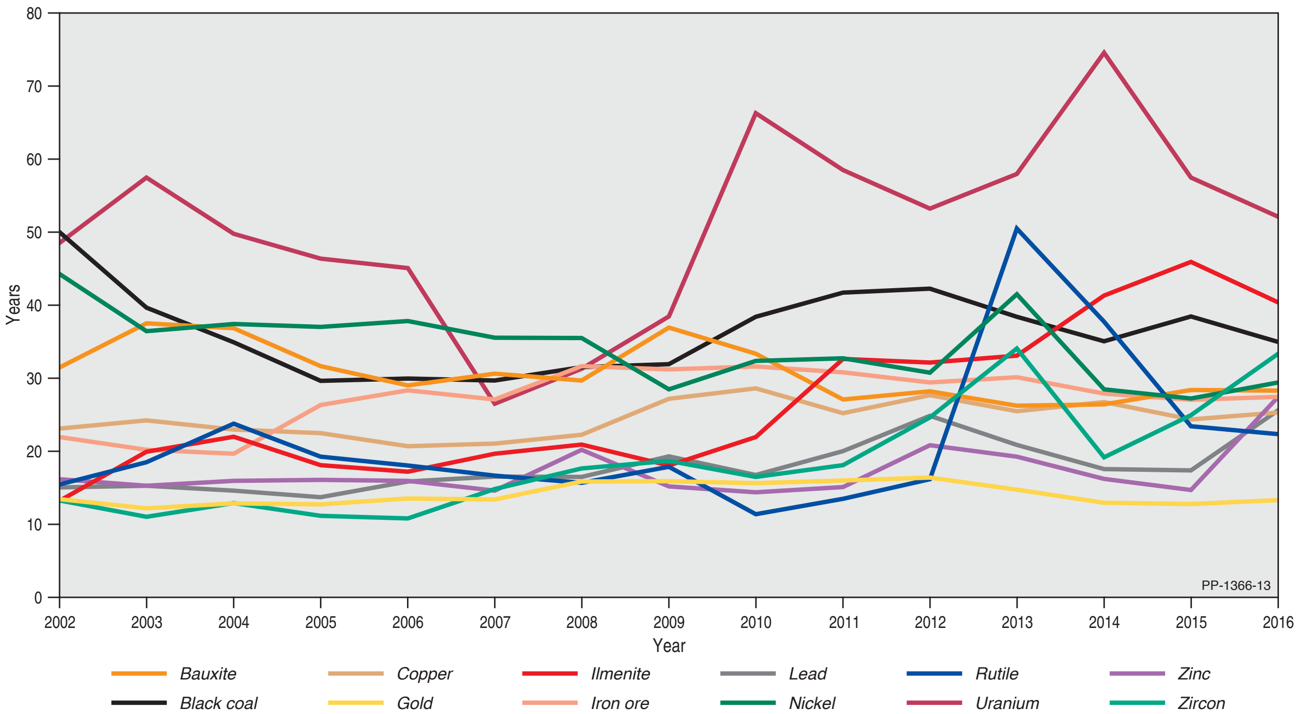


Figure 1 Trends in reserve life for major commodities from 2002 to 2016.

Larger trend changes are seen for nickel, uranium and mineral sands (Figure 1). Nickel reserve life decreased from 2002 to 2009 as production was not matched by new reserve delineation. Production subsequently fell as some mines became uneconomic at lower nickel prices post the global financial crisis of 2007–08 which, along with lagging reserve increases, resulted in greater reserve life. Uranium reserve life, while always large, has been volatile over the last 15 years (Figure 1). With so few existing mines and the difficulty of developing new mines, any reassessment of reserves or change in production can result in a large variation in reserve life from year to year.

For about ten years from 2002, the reserve life of mineral sands ranged from 13 to 22 years for ilmenite and 15 to 24 years for rutile with zircon generally trending up (Figure 1). From 2011 to 2013, reserve life increased strongly for each commodity. For ilmenite and rutile this was mainly a result of falling production outpacing new Ore Reserve estimates. Production fell in response to lower prices for these commodities after the global financial crisis. Zircon production did not fall, rather it has generally increased since 2011, but reserve estimates have risen faster resulting in an increased reserve life overall.

Table 1 Australia's Ore Reserves and Mineral Resources of Major Commodities at Operating Mines in 2016.

Commodity	Unit	No. of Operating Mines[1]	Ore Reserves[2] at Operating Mines	Measured and Indicated Mineral Resources[3] at Operating Mines	Mine Production 2016[4]	Average Reserve Life (years)	Average Resource Life (years)
Bauxite	Mt	6	806.5	3399	82.152	10	41
Black Coal	Mt	93	12 243	33 774[5]	566.3[6]	22	60
Copper	Mt Cu	34	19.37	69.15	0.948	20	73
Diamond	Mc	1	66.7	114.7	13.958	5	8
Gold	t Au	130	2750	6221	288	10	22
Iron Ore	Mt	29	6368	16 224	858	7	19
Lead	Mt Pb	13	10.06	29.84	0.45	22	66
Manganese Ore	Mt	1	79.6	144.4	3.2[7]	24	44
Mineral Sands							
Ilmenite	Mt	7	14.70	45.03	1.4	11	32
Rutile	Mt	7	2.10	5.03	0.3	7	18
Zircon	Mt	8	4.78	11.8	0.6	8	21
Nickel	Mt Ni	13	4.18	6.47	0.204	20	32
Silver	kt Ag	22	19.22	65.37	1.418	14	46
Uranium	kt U	3	269.79	960.93	6.314	43	152
Zinc	Mt Zn	13	18.53	51.48	0.884	21	58

Abbreviations
t=tonne; kt=kilotonnes (1000 t); Mt=million tonnes (1 000 000 t); Mc=million carats (1 000 000 carats).

Where an element symbol follows the unit it refers to contained metal content.

Notes

1. The number of operating mines counts individual mines that operated during 2016 and thus contributed to production. Some of these mines may belong to larger, multi-mine operations and some may have closed during or since 2016.
2. The majority of Australian Ore Reserves and Mineral Resources are reported in compliance with the JORC Code, however there are a number of companies that report to foreign stock exchanges using other reporting codes, which are largely equivalent. In addition, Geoscience Australia may hold confidential information for some commodities. Ore Reserves are as at 31 December 2016.
3. Mineral Resources are inclusive of the Ore Reserves. Mineral Resources are as at 31 December 2016.
4. Source: Resources and Energy Quarterly, June 2017 published by the Office of the Chief Economist, Department of Industry, Innovation and Science unless otherwise stated.
5. Measured and Indicated Resources for black coal are presented on a recoverable basis (these are Geoscience Australia estimates unless provided by the company).
6. Mine production refers to raw coal.
7. Production figures from South32 Ltd (Annual Report 2016).

Table 2 Australia's Estimated Ore Reserves as at December 2016.

Commodity	Unit	Ore Reserve[1]	Mine Production 2016[2]
Antimony	kt Sb	65	5.5*
Bauxite	Mt	2319	82.152
Black Coal	Mt	19 800	566.3*
Brown Coal	Mt	n.a.	63.3*
Chromium	kt Cr	0	0
Cobalt	kt Co	386	*
Copper	Mt Cu	24.0	0.948
Diamond	Mc	67.31	13.958
Fluorine	kt F	0	0
Gold	t Au	3826	288
Iron			
Iron ore	Mt	23 532	858
Contained iron	Mt Fe	10 470	531
Lead	Mt Pb	11.52	0.45
Lithium	kt Li	1361	14*
Magnesite	Mt $MgCO_3$	37.5	*
Manganese Ore	Mt	110.2	3.2*
Mineral Sands			
Ilmenite	Mt	56.5	1.4
Rutile	Mt	6.7	0.3
Zircon	Mt	20.0	0.6
Molybdenum	kt Mo	3.6	0
Nickel	Mt Ni	6.0	0.204
Niobium	kt Nb	116	0
Oil Shale	GL	0	0
PGE (Pt, Pd, Os, Ir, Ru, Rh)	t metal	0	*
Phosphate			
Phosphate rock*	Mt	289	*
Contained P_2O_5	Mt P_2O_5	51	
Potash	Mt K_2O	0	0
Rare Earths (REO & Y_2O_3)	Mt	2.1	0.014*
Silver	kt Ag	25.74	1.418
Tantalum	kt Ta	36.7	*
Thorium	kt Th	0	0
Tin	kt Sn	258	6.635
Tungsten	kt W	215.8	0.11*
Uranium	kt U	329	6.314
Vanadium	kt V	1341	0
Zinc	Mt Zn	24.26	0.884

Abbreviations

t=tonne; kt=kilotonnes (1000 t); Mt=million tonnes (1 000 000 t); Mc=million carats (1 000 000 carats); GL=gigalitre (1 000 000 000 L); n.a.=not available.

Where an element symbol follows the unit it refers to contained metal content.

Notes

1. Ore Reserves predominantly comprise Proved and Probable Ore Reserves that have been publicly reported in compliance with the JORC Code to the ASX. Some Ore Reserves have been reported using other reporting codes to foreign stock exchanges but are included when regarded as equivalent to the JORC Code. In addition, Geoscience Australia may hold confidential data for some commodities.
2. Source: Resources and Energy Quarterly, June 2017 published by the Office of the Chief Economist, Department of Industry, Innovation and Science unless otherwise stated.

*

Antimony: Mine production (Costerfield operation) reported by Mandalay Resources Corp to Toronto Stock Exchange 23 February 2017.

Black Coal: Mine production refers to raw coal.

Brown Coal: Mine production is a Geoscience Australia estimation.

Cobalt: The Western Australian Department of Mines and Petroleum (Statistics Digest 2015–16) reported 5.47 kt of production in 2015–16.

Lithium: Mine production is not reported for the Greenbushes Mine. Production figures are based on reported production of concentrates for Greenbushes (Lithium: investment opportunities, Western Australia. Commodity Summary, Geological Survey of Western Australia, 2016), and ASX reported tonnages of concentrates for Mount Marion and Mount Cattlin. Concentrates are assumed to contain 6% Li2O.

Magnesite: The Department of State Development, South Australia (Report Book 2017/00014) reported magnesite production of 6554 t in 2016. The Queensland Department of Natural Resources and Mines (Annual mineral and metal statistics) reported magnesite production of 462 901 t in 2015–16.

Manganese: Production figures from South32 Ltd (Annual Report 2016).

Platinum Group Elements: The Western Australia Department of Mines and Petroleum (Statistics Digest 2015–16) reported 687 kg of platinum and palladium
by-product was produced during 2015–16.

Phosphate: Phosphate rock is reported as being economic at grades ranging from 8.7% to 30.2% P2O5. Christmas Island mined 508 201 t in 2016. The Queensland Department of Natural Resources and Mines (Annual mineral and metal statistics) reported phosphate production of 1 034 957 t in 2015–16.
Minor production (1972 t) was recorded in South Australia (Report Book 2017/00014).

Rare Earths: Mount Weld in Western Australia supplies rare earth mineral concentrates to the Lynas Advanced Materials Plant (LAMP) in Malaysia. Lynas Corporation Ltd (Quarterly Reports to the ASX) reported that LAMP produced 13 872 t of ready-for-sale rare earth oxides.

Tantalum: The Western Australian Department of Mines and Petroleum (Statistics Digest 2015–16) reported tantalite production of 183 t in 2015–16.

Tungsten: Mine production estimated at approximately 108 t, based on figures released by Tasmania Mines Ltd for the Kara operation (Quarterly Reports to the ASX) and by the Department of Natural Resources and Mines, Queensland for 2015–16 (Annual mineral and metal statistics).

NATIONAL CLASSIFICATION SYSTEM

The following terminology and definitions are used in Australia's National Classification System for Identified Mineral Resources.

Resource: A concentration of naturally occurring solid, liquid, or gaseous materials in or on the Earth's crust and in such form that its economic extraction is presently or potentially (within a 20–25 year timeframe) feasible.

Identified Resource: A specific body of mineral-bearing material whose location, quantity and quality are known from specific measurements or estimates from geological evidence for which economic extraction is presently or potentially (within a 20–25 year timeframe) feasible.

To reflect degrees of geological assurance, Identified Resources can be divided into Measured Resources, Indicated Resources and Inferred Resources where Measured Resources have the most geological confidence and Inferred Resources the least. The National Classification System's definitions for Measured, Indicated and Inferred Resources are consistent with those of the JORC Code.

Under the JORC Code, with the application of Modifying Factors and mine planning, Measured Resources can be converted into Proved Ore Reserves or Probable Ore Reserves and Identified Resources can be converted into Probable Ore Reserves.

Demonstrated Resource: A collective term for the sum of Measured and Indicated Resources, including Proved and Probable Ore Reserves.

Economic: This term implies that, at the time of determination, profitable extraction or production under defined investment assumptions has been established, analytically demonstrated, or assumed with reasonable certainty.

Economic Demonstrated Resource (EDR): A Demonstrated Resource that is regarded as economic under the definition above. The EDR category provides a long-term view of what is likely to be available for mining (potential supply). It does not include Inferred Resources which do not have enough geological confidence to support mine planning. For shorter term, commercial viewpoints of the economic category see Table 1 (Ore Reserves and Mineral Resources at Operating Mines) and Table 2 (Australia's Ore Reserves).

Subeconomic: This term refers to those resources that are geologically demonstrated but which do not meet the criteria of economic at the time of determination. Subeconomic Resources include paramarginal and submarginal categories:

- **Paramarginal:** That part of Subeconomic Resources which, at the time of determination, could be produced given postulated limited increases in commodity prices or cost-reducing advances in technology. The main characteristics of this category are economic uncertainty and/or failure (albeit just) to meet the criteria of economic.
- **Submarginal:** That part of Subeconomic Resources that would require a substantially higher commodity price or major cost-reducing advance in technology to render them economic.

Accessible Economic Demonstrated Resource (AEDR): Some resources have enough geological confidence to be considered a demonstrated resource and, in normal circumstances, would also be regarded as economic but they are not currently available for development because of legal and/or land-use restrictions. They are included in EDR but not in AEDR.

3. Australia's Identified Mineral Resources

The National Classification System for Identified Mineral Resources has been used by the Australian Government since 1975 for classifying mineral resources for regional and national assessments. It provides a long-term view on what is likely to be available for mining.

The National Classification System uses two general criteria for classifying Australia's national inventory of mineral resources:

1. the geological certainty of the existence of the mineral resource, and
2. the economic feasibility of its extraction over the long term.

The National Classification System uses reports on mineral resources published by companies using the JORC Code (or equivalent foreign codes) and, to a lesser extent, confidential information, to compile national total resources for the classification categories set out in Table 3 (see page 8 for terminology and definitions). Both the National Classification System and the JORC Code are based on the McKelvey resource classification system used by the United States Geological Survey (USGS). Thus Australia's national system is compatible with the JORC Code and remains comparable to the USGS system as published in the annual USGS Mineral Commodity Summaries.

Economic Demonstrated Resources (EDR) is the category used for the national totals of economic resources and provides a basis for meaningful comparisons of Australia's economic resources with those of other nations. For major commodities, Section 5 presents long-term trends in EDR as well as trends in Ore Reserves, total resources and production, and also comparisons to cumulative production, with accompanying notes on significant changes.

Estimating the total amount of each commodity likely to be available for mining is not a precise science. For mineral commodities, the long-term perspective takes account of the following:

- Ore Reserves reported in compliance with the JORC Code (or equivalent foreign codes) will all be mined, but they only provide a short-term view on what is likely to be available for mining.
- Most current Measured and Indicated Resources reported in compliance with the JORC Code are also likely to be mined.
- Some current Inferred Resources will be transferred to Measured and Indicated Resources and Ore Reserves.
- New discoveries will add to the resource inventory.

All of Australia's EDR for gold, silver, tin, zinc, lead, iron and any number of commodities will be mined. At first glance, this statement might seem somewhat astonishing because, obviously, not every deposit with an EDR will have all of that EDR brought into production. Indeed, some deposits currently contributing to EDR will never produce an ounce of metal. However, the National Classification System is not meant for individual mine assessments but as a way of estimating regional and national totals. So, from an agglomerated point of view, it is a reasonable proposition that over time people will mine all of current EDR and more. This is seen in the data presented in the figures for each of the major commodities in Section 5 (e.g. Figure 13).

Australia is yet to run out of EDR because, to use JORC Code terminology, as individual Ore Reserves are depleted, Measured and Indicated Resources are reassessed into Proved and Probable Categories, Inferred Resources are worked on to bring them to Measured and Indicated status and new drilling at existing mines as well as new greenfield discoveries add to the resource inventory. In addition, extractive technologies improve over time and if a commodity becomes rare then the laws of supply and demand result in previously subeconomic deposits becoming profitable. Thus EDR fundamentally differs from Ore Reserves under the JORC Code because it is not meant to provide a picture of what is currently commercial to mine but rather an outlook on what is likely to be available for mining over the long term, i.e. of opportunity for supply.

Table 3 Australia's Identified Mineral Resources as at December 2016.

Commodity	Unit	Australia						World	
		Demonstrated Resources			Inferred Resources[2]	Accessible EDR[3]	Mine Production 2016[4]	Economic Resources 2016[5]	Mine Production 2016[6]
		Economic (EDR)[1]	Subeconomic						
			Paramarginal	Submarginal					
Antimony	kt Sb	138.9	8.8	0	190.6	138.9	5.5*	1500	130
Bauxite	Mt	6005	144	1429	1942	6005	82.152	28 000	271.5*
Black Coal									
In situ	Mt	85 753	1370	4421	104 151				
Recoverable	Mt	70 927	1018	3815	81 864	64 045	566.3*	712 000*	7795*
Brown Coal									
In situ	Mt	92 887	44 069	234 987	124 326				
Recoverable	Mt	76 508	41 112	215 449	103 579	66 439	63.3*	317 000*	783.3*
Chromium	kt Cr	0	302	0	6786	0	0	500 000*	30 400*
Cobalt	kt Co	1164	426	25	1238	1164	*	7000	123
Copper	Mt Cu	87.78	1.27	1.09	48.15	87.78	0.948	720	19.4
Diamond	Mc	115.84	0	0	20.93	115.84	13.958	750*	127
Fluorine	kt F	343	505	6	2301	343	0	126 000	3100*
Gold	t Au	9830	213	67	4389	9800	288	57 000	3255*
Iron									
Iron ore	Mt	49 588	10 939	1433	90 123	49 588	858	173 769	2230
Contained Iron	Mt Fe	23 771	3672	480	40 342	23 771	531	82 986	1360
Lead	Mt Pb	35.09	3.00	0.14	31.92	24.09	0.45	88	4.82
Lithum	kt Li	2730	0	0	966	2730	14*	15 130	34.7*
Magnesite	Mt $MgCO_3$	320.48	21.90	35.00	849.74	320.48	*	8500	27.7*
Manganese Ore	Mt	219	2.8	190.2	379.7	219	3.2*	1790	44
Mineral Sands									
Ilmenite	Mt	276.9	26.2	0.03	235.1	247.0	1.4	1523.2	11.6
Rutile	Mt	33.0	0.3	0.06	34.1	29.1	0.3	64.6	0.7
Zircon	Mt	78.6	1.1	0.07	61.3	72.1	0.6	118.2	2.4
Molybdenum	kt Mo	210	1220	0.5	614	210	0	15 133	227
Nickel	Mt Ni	18.5	4.1	0.1	23.3	18.5	0.204	78	2.25
Niobium	kt Nb	286	15	0	418	286	0	>4500	64
Oil Shale	GL	0	213	2074	1472	0	0	760 934*	n.a.
PGE (Pt, Pd, Os, Ir, Ru, Rh)	t metal	5.3	140.4	1.4	168.6	2.6	*	67 000	380
Phosphate									
Phosphate rock*	Mt	1072	312	0	2461	1072	*	68 000	261
Contained P_2O_5	Mt P_2O_5	180	61	0	403	188			
Potash	Mt K_2O	56	7	0	91	56	0	4300	39
Rare Earths (REO & Y_2O_3)	Mt	3.43	0.35	29.22	25.81	3.43	0.014*	120	0.126
Silver	kt Ag	89.29	1.79	0.49	52.00	89.29	1.418	570	27.0
Tantalum	kt Ta	75.7	7.4	0.2	32.9	75.7	*	>100	1.1
Thorium	kt Th	0	129.9	0	644.2	0	0	n.a.	n.a.
Tin	kt Sn	486	65	31	319	486	6.635	4657	278
Tungsten	kt W	391.0	0.4	4.5	240.0	391.0	0.11*	3484	86.5
Uranium	kt U	1270	13	19	915	1212	6.314	3472*	62.0*
Vanadium	kt V	2111	14 677	1376	17 002	2111	0	19 000	76
Zinc	Mt Zn	63.5	0.59	0.75	38.44	63.5	0.884	220	11.9

Abbreviations

t=tonne; kt=kilotonnes (1000 t); Mt=million tonnes (1 000 000 t); Mc=million carats (1 000 000 carats); GL=gigalitre (1 000 000 000 L); n.a.=not available. Where an element symbol follows the unit it refers to contained metal content.

Notes

1. Economic Demonstrated Resources (EDR) predominantly comprises Ore Reserves and most Measured and Indicated Mineral Resources that have been reported in compliance with the JORC Code to the ASX. In addition, some reserves and resources have been reported using other reporting codes to foreign stock exchanges and Geoscience Australia may hold confidential data for some commodities.
2. Total Inferred Resources in economic, subeconomic and undifferentiated categories.
3. Accessible Economic Demonstrated Resources (AEDR) is the portion of total EDR that is accessible for mining. AEDR does not include resources that are inaccessible for mining because of environmental restrictions, government policies or military lands.
4. Source: Resources and Energy Quarterly, June 2017 published by the Office of the Chief Economist, Department of Industry, Innovation and Science unless otherwise stated.
5. Source: Mineral Commodity Summaries 2017 published by the United States Geological Survey (USGS) and adjusted with Geoscience Australia data, unless otherwise stated.
6. Source: Mineral Commodity Summaries 2017 (USGS) unless otherwise stated.

*

Antimony: Mine production (Costerfield operation) reported by Mandalay Resources Corp to Toronto Stock Exchange 23 February 2017.

Bauxite: World bauxite production sourced from the Office of the Chief Economist (Resources and Energy Quarterly, June 2017).

Black Coal: Australian mine production refers to raw coal. World economic resources dated 2015, sourced from the Federal Institute for Geosciences and Natural Resources, Germany (Energy Study 2016). World mine production sourced from the Office of the Chief Economist (Resources and Energy Quarterly, June 2017).

Brown Coal: Australian mine production is a Geoscience Australia estimation. World mine production sourced from International Energy Agency (Coal Information 2017 Overview). World economic resources dated 2015, sourced from the Federal Institute for Geosciences and Natural Resources, Germany (Energy Study 2016).

Chromium: World resources and mine production presented as chromite ore.

Cobalt: The Western Australian Department of Mines and Petroleum (Statistics Digest 201516) reported 5.47 kt of production in 2015–16.

Diamond: World resource figures are for industrial diamonds only, no data provided for resources of gem diamonds.

Fluorine: World mine production excludes the USA.

Gold: World mine production sourced from the Office of the Chief Economist (Resources and Energy Quarterly, June 2017).

Lithium: Australian mine production is not reported for the Greenbushes Mine. Production figures are based on reported production of concentrates for Greenbushes (Lithium: investment opportunities, Western Australia. Commodity Summary, Geological Survey of Western Australia, 2016), and ASX reported tonnages of concentrates for Mount Marion and Mount Cattlin. Concentrates are assumed to contain 6% Li_2O. World mine production excludes the USA.

Magnesite: The Department of State Development, South Australia (Report Book 2017/00014) reported magnesite production of 6554 t in 2016. The Queensland Department of Natural Resources and Mines (Annual mineral and metal statistics) reported magnesite production of 462 901 t in 2015–16. World mine production excludes the USA.

Manganese: Production figures from South32 Ltd (Annual Report 2016).

Oil Shale: World resources from World Energy Council (Survey of Energy Resources 2013).

PGE: The Western Australia Department of Mines and Petroleum (Statistics Digest 2015–16) reported 687 kg of platinum and palladium by-product was produced during 2015–16.

Phosphate: Phosphate rock is reported as being economic at grades ranging from 8.7% to 30.2% P_2O_5. Christmas Island mined 508 201 t in 2016. The Queensland Department of Natural Resources and Mines (Annual mineral and metal statistics) reported phosphate production of 1 034 957 t in 2015–16.
Minor production (1972 t) was recorded in South Australia (Report Book 2017/00014).

Rare Earths: Mount Weld in Western Australia supplies rare earth mineral concentrates to the Lynas Advanced Materials Plant (LAMP) in Malaysia. Lynas Corporation Ltd (Quarterly Reports to the ASX) reported that LAMP produced 13 872 t of ready-for-sale rare earth oxides.

Tantalum: The Western Australian Department of Mines and Petroleum (Statistics Digest 2015–16) reported tantalite production of 183 t in 2015–16.

Tungsten: Mine production estimated at approximately 108 t, based on figures released by Tasmania Mines Ltd for the Kara operation (Quarterly Reports to the ASX) and by the Department of Natural Resources and Mines, Queensland for 2015–16 (Annual mineral and metal statistics).

Uranium: World economic resources sourced from the International Atomic Energy Agency estimate for Reasonable Assured Resources (RAR) recoverable at costs of less than US$130/kg U and Geoscience Australia. World production sourced from the Office of the Chief Economist (Resources and Energy Quarterly, June 2017).

Trends in EDR

Australia's EDR of the following 12 mineral commodities increased during 2016: black coal, cobalt, gold, ilmenite, lithium, molybdenum, potash, rutile, tantalum, tin, vanadium and zircon. EDR for brown coal, chromium, copper, fluorine, lead, magnesite, nickel, niobium, oil shale, PGEs, phosphate, rare earths, thorium and zinc remained at levels similar to those previously reported. The EDR of seven commodities decreased in 2016: antimony, bauxite, diamond, iron ore, manganese ore, tungsten and uranium.

The trends in EDR for Australia's major mineral commodities have undergone significant and sometimes dramatic changes over the period 1975 to 2016 (see Section 5). Changes for each commodity can be attributed to one, or a combination, of the following factors:

- Increases in resources resulting from discoveries of new deposits and delineation of extensions of known deposits.
- Depletion of resources as a result of mine production.
- Advances in mining and metallurgical technologies, e.g. carbon-based processing technologies for gold have enabled economic extraction from low-grade deposits that were previously uneconomic.
- Adoption of the JORC Code for resource classification and reporting by the Australian minerals industry and the subsequent impacts on re-estimation of Ore Reserves and Mineral Resources to comply with the requirements of the JORC Code. The impacts of the JORC Code on EDR occurred at differing times for each of the major commodities.
- Significant changes in the prices of mineral commodities driven largely by both escalating and cooling demand from China over the past decade.

In 2016, there were significant increases of EDR for mineral sands (11%), lithium (70%), potash (73%), cobalt (13%), tantalum (9%) and tin (12%) as improved markets for these commodities in recent years, particularly for those associated with battery technology, has stimulated exploration and resource delineation. Significant falls were seen for diamond (-45%) as the Argyle mine in Western Australia winds down and antimony (-13%) as the Costerfield project in Victoria was reassessed.

Mine Inventories as a Proportion of EDR

While the national inventory is an agglomeration of individual resources, it is a useful exercise to compare the national total with the EDR attributable to currently operating mines (Measured and Indicated Resources in Table 1) as, in most cases, operating mines dominate the minerals inventory (Table 4). With the exception of mineral sands, black coal, iron ore and nickel, operating mines of all other major commodities make up more than 50% of EDR (Table 4). And when all mines are considered (adding those on care and maintenance and under development), these mines (still excepting mineral sands, black coal, iron ore and nickel) make up more than 60% of EDR and, in some cases, 90–100% of EDR (Table 4).

This dominance of operating mines as a proportion of EDR leads to a number of potential susceptibilities in the minerals sector. Many commodities, such as manganese ore, bauxite, uranium and mineral sands have relatively large EDR but few mines (Table 1). Price shocks or other circumstances leading to the permanent closure of one or more of these mines would dramatically impact EDR, i.e., Australia's potential to supply of these minerals over the long term. If there is no foreseeable possibility of a mine reopening, then the deposit is removed from EDR. For some operations, the mine simply runs out of ore but EDR will only be replaced from new deposits if mining and exploration companies can attract the capital necessary for exploration, drilling and development.

Other commodities with large EDR, such as gold, black coal and iron ore, have many mines. Thus, Australia's EDR of these commodities do not appear to be particularly vulnerable to the fortunes of individual mines. Certainly, black coal has one of the lowest proportions of EDR at operating mines as a proportion of total EDR (48%; Table 4). In 2016, there were 290 coal deposits with EDR and 93 operating mines (Table 4); if even a sizeable proportion of coal mines were inaccessible in the future, a large resource could potentially still be exploited.

This is not necessarily the case for gold. Australia has the largest EDR of gold in the world (Table 7) but most of it is associated with large, low-grade, multi-commodity deposits such as Olympic Dam and Cadia. The majority of production, however, comes from lode-gold deposits which produced 63% of Australia's gold in 2016. At this rate of production, all lode-gold deposits have a potential resource life of 22 years based on EDR, but the operations mining lode gold only have a resource life of 8 years (based on Measured and Indicated Resources). With depletion of these high-grade mines, it is unlikely that production at the other types of deposit could make up the shortfall in the same time period, thus Australia's gold production, and export income, would inevitably decline.

This circumstance is, of course, based on the very unlikely scenario that future rates of production will be unchanged from those of 2016 and that companies will not replace depleted gold resources. The gold EDR from these lode-gold deposits will most likely be replaced by successful mineral exploration. (Advances in extractive technologies or substantial price rises could also contribute to future EDR.) Some of this exploration will occur in and around existing mines (brownfield exploration) but the most important contributions to Australia's future EDR of gold, and other commodities, is more likely to come from successful exploration in new and under explored areas of the continent (greenfield exploration). It is through the discovery of large, globally significant mineral deposits such as Broken Hill, Mount Isa, Olympic Dam and the Kalgoorlie goldfields, that Australia has become a mining "superpower". If Australia wishes to remain globally competitive then new discoveries are essential as only the very best deposits will attract the investment necessary for development in an internationally competitive investment environment.

Table 4 Comparisons of EDR of major commodities at Australian mines to total EDR as at December 2016.

Commodity	Total EDR	Number of Deposits with EDR	Operating Mines			All Mines		
			Number of Mines	EDR	% of Total EDR	Number of Mines	EDR	% of Total EDR
Bauxite	6005 Mt	20	6	3399 Mt	57	9	5303 Mt	88
Black Coal (recoverable)	70 927 Mt	290	93	33 774 Mt	48	117	41 008 Mt	58
Copper	87.78 Mt	169	34	69.15 Mt	79	46	71.35 Mt	81
Diamond	115.84 Mc	3	1	114.7 Mc	99	3	115.84 Mc	100
Gold	9830 t	690	130	6221 t	63	164	6539 Mt	67
Iron Ore	49 588 Mt	91	29	16 224 Mt	33	42	17 480 Mt	35
Lead	35.09 Mt	66	13	29.84 Mt	85	16	32.45 Mt	92
Manganese Ore	219 Mt	5	1	144.4 Mt	66	4	215.0 Mt	98
Mineral Sands								
Ilmenite	235.1 Mt	80	8	44.9 Mt	19	9	44.9 Mt	19
Rutile	29.1 Mt	58	7	5.03 Mt	17	8	5.05 Mt	17
Zircon	72.1 Mt	81	8	11.80 Mt	16	9	11.82 Mt	16
Nickel	18.5 Mt	67	13	6.47 Mt	35	18	7.88 Mt	43
Silver	89.29 kt	121	22	65.37 kt	73	28	70.18 kt	79
Uranium	1270 kt	38	3	961 kt	76	6	995 kt	78
Zinc	63.5 Mt	75	13	51.5 Mt	81	15	57.2 Mt	90

Abbreviations: Mt=million tonnes, kt=kilotonnes, t=tonnes, Mc=million carats.
Note: 'All mines' refers to mines that are currently operating, placed on care and maintenance or under development

Ore Reserves as a Proportion of EDR

The National Classification System's category of EDR captures those Demonstrated Resources that are considered to be economic under current conditions or those of the foreseeable future. EDR indicates potential supply. However, just because a deposit could be exploited profitably does not mean that it will be. Mining companies must apply modifying factors (such as metallurgical, engineering, processing, infrastructure, environmental, social and regulatory considerations) to determine an Ore Reserve and mine plan. These factors also include a company's costs and an internal rate of return, but EDR does not capture such commercial considerations. Table 5 shows the proportion of EDR and AEDR for major commodities that mining companies have stated to be currently commercial, and subject to a mine plan, by publication as an Ore Reserve.

Table 5 Comparisons of Ore Reserves of major commodities to total EDR and AEDR as at December 2016.

Commodity	Ore Reserves	EDR	AEDR	Ore Reserves as a % of EDR	Ore Reserves as a % of AEDR
Bauxite	2319 Mt	6005 Mt	6005 Mt	39	39
Black Coal (recoverable)	19 800 Mt	70 927 Mt	64 045 Mt	28	31
Copper	24.00 Mt	87.78 Mt	87.78 Mt	27	27
Diamond	67.31 Mc	115.84 Mc	115.84 Mc	58	58
Gold	3826 t	9830 t	9800 t	39	39
Iron Ore	23 532 Mt	49 588 Mt	49 588 Mt	47	47
Lead	11.52 Mt	35.09 Mt	35.09 Mt	33	33
Manganese Ore	110.2 Mt	219 Mt	219 Mt	50	50
Mineral Sands					
Ilmenite	56.5 Mt	276.9 Mt	235.1 Mt	20	24
Rutile	6.7 Mt	33.0 Mt	29.1 Mt	20	23
Zircon	20.0 Mt	78.6 Mt	72.1 Mt	25	28
Nickel	6.0 Mt	18.5 Mt	18.5 Mt	32	32
Silver	25.74 kt	89.29 kt	89.29 kt	29	29
Uranium	329 kt	1270 kt	1212 kt	26	27
Zinc	24.26 Mt	63.5 Mt	63.5 Mt	38	38

Abbreviations: Mt=million tonnes, kt=kilotonnes, t=tonnes, Mc=million carats.

Distribution of EDR

Most of Australia's EDR of major commodities is skewed heavily toward a small number of relatively large deposits. Table 5 shows that more than 80% of all EDR lies in the top 20 deposits for most commodities. The exceptions are gold and black coal, both of which have the largest number of deposits with EDR. Even so, the top 20 deposits of gold (3% of 690 deposits with an EDR) account for 64% of all gold EDR. For black coal, the top 20 deposits (7% of 290 deposits with an EDR) account for 38% of EDR.

Figure 2 shows that most bauxite EDR is attributable to the giant deposits in Cape York, Queensland, and the Darling Range of Western Australia. Similarly, Australia's enormous iron ore EDR is geographically concentrated in the Pilbara region of Western Australia. Western Australia also holds almost all diamond EDR and nickel EDR. Manganese ore EDR is found in Western Australia and the Northern Territory.

On the other side of the country, almost all black coal EDR is located in Queensland and New South Wales. Silver, lead, zinc, copper, uranium and mineral sands are more dispersed across the country (Figure 2), but the top ten deposits for each of these minerals dominate EDR (70–93%; Table 6). Thus, because EDR is a long-term indicator of potential mineral supply, Australia's ongoing ability to produce these commodities is potentially vulnerable to geographic disruption or to reduced access to the endowment of major deposits (e.g. a mine may become uncommercial or a deposit may become inaccessible). The latter effect can be seen with the decline of the manganese ore industry (there is currently only one operating mine), the diamond industry (Argyle is scheduled to close in 2021) and the significant loss of lead-zinc production in 2016 when just two large operations were curtailed.

Table 6 Distribution of EDR of major commodities as at December 2016.

Commodity	Total Number of Deposits	Number of Deposits with EDR	Total EDR	% of Deposits with EDR	10 Largest Deposits		20 Largest Deposits	
					EDR	% of Total EDR	EDR	% of Total EDR
Bauxite	38	20	6005 Mt	53	5930 Mt	99	6005 Mt	100
Black Coal (recoverable)	403	290	70 927 Mt	72	18 278 Mt	26	26 938 Mt	38
Copper	379	169	87.78 Mt	45	72.96 Mt	83	78.67 Mt	90
Diamond	12	3	115.84 Mc	25	115.84 Mc	100	115.84 Mc	100
Gold	1779	690	9830 t	39	5223 t	53	6267 t	64
Iron Ore	326	91	49 588 Mt	28	31 581 Mt	64	41 324 Mt	83
Lead	162	66	35.09 Mt	41	32.32 Mt	92	33.94 Mt	97
Manganese Ore	44	5	219 Mt	11	219 Mt	100	219 Mt	100
Mineral Sands								
Ilmenite	217	80	276.9 Mt	37	194.3 Mt	70	229.73 Mt	83
Rutile	195	58	33.0 Mt	30	23.3 Mt	71	28.4 Mt	86
Zircon	217	81	78.6 Mt	37	61.3 Mt	78	70.3 Mt	89
Nickel	214	67	18.5 Mt	31	13.5 Mt	73	16.9 Mt	91
Silver	257	121	89.29 kt	47	69.74 kt	78	77.88 kt	87
Uranium	112	38	1270 kt	34	1183 kt	93	1241 kt	98
Zinc	176	75	63.5 Mt	43	57.1 Mt	90	60.2 Mt	95

Abbreviations: Mt=million tonnes, kt=kilotonnes, t=tonnes, Mc=million carats.

Note: For classification as a mineral deposit there must be, at a minimum, an Inferred Resource compliant with the JORC Code (or equivalent) or, in some cases, a historical (pre-JORC) resource estimate.

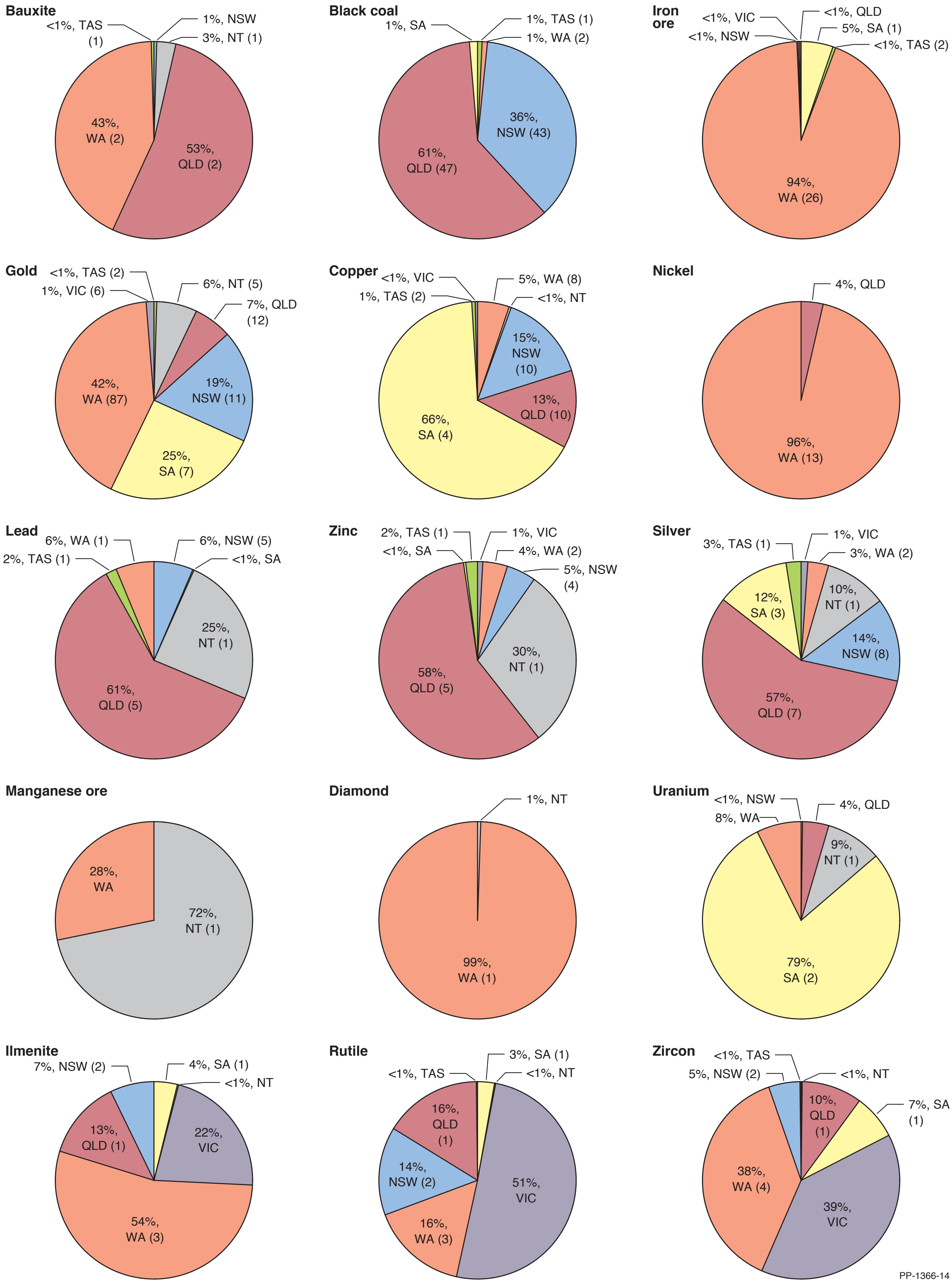


Figure 2 Distribution of EDR of major commodities by Australian jurisdiction as at December 2016. Where applicable, the number of mines in each jurisdiction is in brackets after the percentage of EDR in each jurisdiction.

The iron ore shipping terminal at Karratha, Western Australia. Photography from Peter Robey Photography.

4. World Rankings

Australia's EDR of gold, iron ore, lead, nickel, rutile, tantalum, uranium, zinc and zircon in 2016 were the world's largest, while antimony, bauxite, black coal, brown coal, cobalt, copper, diamond, ilmenite, lithium, magnesite, manganese ore, niobium, silver, thorium, tin, tungsten and vanadium all ranked in the top five worldwide (Table 7).

In 2016, Australia was also the top global producer for bauxite, iron ore, rutile and zircon (all bulk commodities), as well as lithium, which is important for battery storage technology. Australia was the second largest producer of gold, lead, rare earths and diamonds, the third largest producer of ilmenite, uranium and zinc, the fourth largest producer of antimony, black coal and manganese ore and the fifth largest producer for brown coal, cobalt, copper, nickel and silver (Table 7).

Table 7 World rankings of Australia's major mineral resources and production as at December 2016.

	World Ranking for Resources	% of World Resources	World Ranking for Production	% of World Production
Antimony	4	9	4	4
Bauxite	2	22	1	31
Black Coal	4	10	4	7
Brown Coal	2	24	5	6
Chromium	n.a.	n.a.	0	0
Cobalt	2	14	5	4
Copper	2	12	5	5
Diamond (ind.)	3	18	2	24
Fluorine	minor	minor	0	0
Gold	1	17	2	9
Ilmenite	2	19	3	13
Iron Ore	1	29	1	38
Lead	1	40	2	9
Lithium	3	18	1	41
Magnesite	5	4	8	2
Manganese Ore	4	13	4	9
Molybdenum	7	1	0	0
Nickel	1	24	5	9
Niobium	2	6	0	0
Oil Shale	n.a.	n.a.	0	0
Phosphate	10	2	minor	minor
PGEs	minor	minor	minor	minor
Potash	minor	2	0	0
Rare Earths	6	3	2	11
Rutile	1	50	1	42
Silver	2	16	5	5
Tantalum	1	unknown	unknown	unknown
Thorium	2	unknown	0	0
Tin	4	10	7	2
Tungsten	2	12	minor	minor
Uranium	1	29	3	10
Vanadium	4	11	0	0
Zinc	1	28	3	7
Zircon	1	67	1	31

Note: n.a.=not applicable because Australia has no Economic Demonstrated Resources of that particular commodity.

Sources: USGS (Mineral Commodity Summaries 2017), OECD Nuclear Energy Agency/International Atomic Energy Agency (The Red Book 2016), World Nuclear Association (World Uranium Mining Production, July 2017 update), Federal Institute for Geosciences and Natural Resources, Germany (Energy Study 2016) and Geoscience Australia.

Aluminium ingots and billets trucked from the Tomago smelter, near Newcastle, New South Wales. Photograph by Michelle Cooper.

5. Identified Resources of Major Commodities since 1975

Bauxite

Australia's EDR of bauxite were estimated to be 6005 Mt in 2016 (Table 3), down from a peak of 6464 Mt in 2013. Australia ranks second in the world (Table 7) behind the Republic of Guinea and ahead of Brazil, Vietnam, Jamaica and Indonesia. Australia was the world's leading producer of bauxite in 2016 (Table 7), the second largest producer of alumina and the sixth largest producer of aluminium. Australia's aluminium industry is underpinned by vast resources of bauxite at Cape York in Queensland (3188 Mt, 53% of national EDR), Gove in the Northern Territory (188 Mt, 3%) and a large number of deposits in the Darling Range southeast of Perth in Western Australia (2588 Mt, 43%).

Australia has large Ore Reserves of bauxite amounting to 2319 Mt (Table 2) in 2016 of which 806.5 Mt (35%) is attributable to 6 operating mines (Table 1). These mines produced 82 Mt of bauxite in 2016, slightly up from 2015 levels (81 Mt). Conversely, the USGS estimates that during 2016, global bauxite production decreased 11% owing to the Malaysian ban on bauxite mining due to environmental concerns.

At 2016 levels of production, average reserve life at operating mines is potentially 10 years and resource life could be 41 years (Table 1). If Ore Reserves at developing mines and undeveloped deposits are also considered, the reserve life of bauxite is potentially 28 years and if AEDR is used as an indication of long-term potential supply, then at 2016 rates of production, Australia's bauxite resources could last more than 70 years.

Figure 3 shows that annual production is a small fraction of the bauxite reserve (3.5% in 2016) with cumulative production over the last 15 years (1118 Mt) accounting for only 60% of the bauxite Ore Reserve from 2002 (1700 Mt). Figure 3 also shows that both Ore Reserves and production have gradually risen over the last 15 years. Ore Reserves of bauxite increased from 1700 Mt in 2002 to 2319 Mt in 2016 (a 36% increase) and production increased from 50 Mt to 82 Mt (a 64% increase). However, the production to Ore Reserve ratio has only varied between 2.7% to 3.8% over this time period, reflecting industry practice of delineating just enough new Ore Reserves to replace expected depletion going forward.

Australia's operating bauxite mines are known for their high quality ore which is determined not just by the aluminium content but also by other minerals present, such as iron oxides, titanium oxides and, in particular, the amount of reactive silica. The Darling Range bauxites and those at Weipa and Gove all have low reactive silica making them relatively cheap to process. In fact, the Darling Range mines have such low reactive silica (generally 1–2%) that they are still profitable even with the lowest grade bauxite of any commercial-scale operations in the world—approximately 30% Al_2O_3 compared to Weipa and Gove which average around 50% Al_2O_3.

Figure 4, again, demonstrates the vast Australian bauxite inventory by showing that even over the last 40 years, cumulative production (1981 Mt) has only mined out 66% of the 3000 Mt of resources assessed as economic back in 1975. Despite these vast resources, Figure 5 shows that over the last 40 years, bauxite production has increased more rapidly than the bauxite inventory. In 1975, bauxite production was 21 Mt which rose to 82 Mt in 2016, a 290% increase. Bauxite EDR has increased 100% over the same time period (3000 Mt in 1975 to 6005 Mt in 2016) and total resources of bauxite (EDR + subeconomic + inferred) have increased from 6678 Mt in 1976 to 9520 Mt in 2016, an increase of 43%.

Australia's aluminium industry continues to be a highly integrated sector of mining, refining, smelting and semi-fabrication and is of major economic importance nationally and globally. In recent years, however, processing costs have made some operations unviable, leading to the closure in 2012 of the Kurri Kurri aluminium smelter (New South Wales) and in 2014 of the Point Henry aluminium smelter (Victoria) as well as the Gove alumina refinery (Northern Territory). Conversely, there has been a move by industry to direct shipping ore with Rio Tinto supplying China from its Weipa and Gove operations and new, small-scale, operations aimed at supplying Chinese alumina refineries have recently started in Tasmania and Cape York. In Western Australia, Alcoa shipped 47 kt of bauxite ore to China for metallurgical testing in 2016.

Alumina refineries continue to operate in Western Australia's Darling Range at Kwinana, Pinjarra, Wagerup and Worsley and near Gladstone in Queensland at QAL Alumina and Yarwun. Aluminium smelters continue to operate at Tomogo in New South Wales, Bell Bay in Tasmania, Boyne Island in Queensland and Portland in Victoria.

The largest new bauxite development in Australia is Rio Tinto's Amrun project, previously known as South of Embley. It is located approximately 45 km southwest of Weipa. Government and environmental approvals were obtained in 2012 and 2013 and, in late 2015, the board of Rio Tinto approved the project including capital expenditure of US$1.9 billion. The project involves the construction of processing and port facilities as well as the mine with the majority of capital expenditure planned for 2017 and 2018.

Amrun is expected to start producing in the first half of 2019 ramping up to a planned output of 22.8 Mt per annum. It will partly replace depleted production from the East Weipa mine (now more than 50 years old) as well as adding some 10 Mt per annum of extra capacity. Rio Tinto has described Amrun as a long-life, low-cost, expandable asset that is strategically placed to satisfy increasing demand for seaborne bauxite in China and the Middle East as well as the company's own refineries in Australia.

Recent, smaller scale, developmental activity has also taken place in Queensland at Hey Point (Green Coast Resources Pty Ltd) which had its maiden shipment in 2016, Urquhart (Metallica Minerals Ltd), Skardon River, Bauxite Hills (both Metro Mining Ltd) and Binjour (Australian Bauxite Ltd) as well as in Tasmania at Bald Hill (Australian Bauxite), which commenced mining in late 2014.

At current rates of production, and even with increased rates of production, Australia has the potential to be produce bauxite for many decades into the future. However, Australia's alumina refineries and aluminium smelters are arguably vulnerable to the impacts of rising costs and, in the case of the smelters at Boyne Island, Portland, Bell Bay and Tomago they are particularly vulnerable to both high energy costs and insecurity of energy supply.

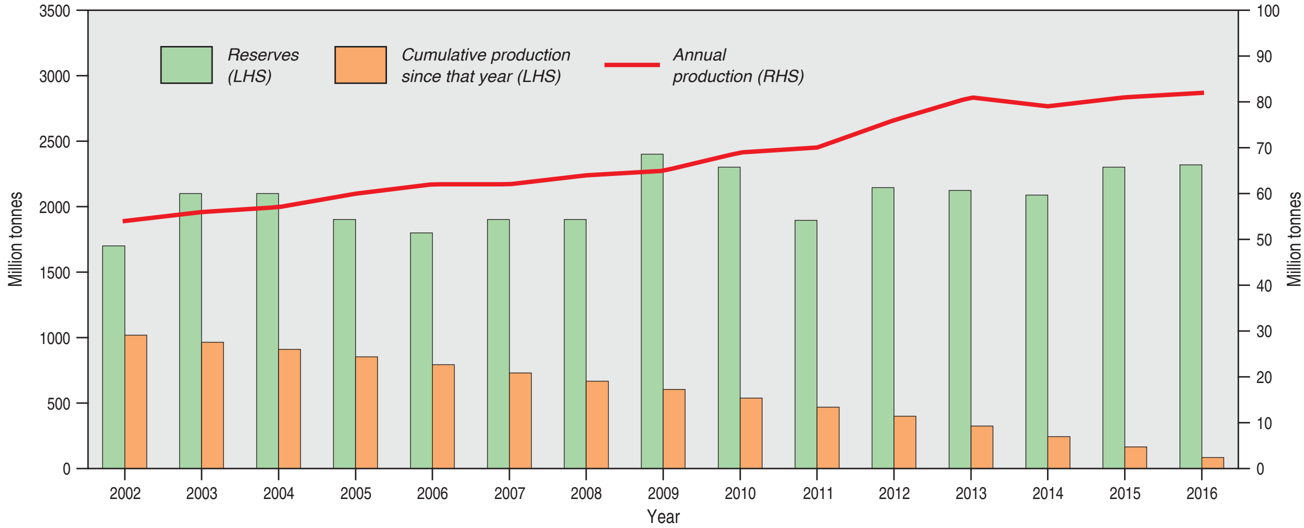


Figure 3 Bauxite Ore Reserves and annual production 2002–2016, as well as cumulative production since each year. LHS/RHS=refer to axis on left-hand side/right-hand side.

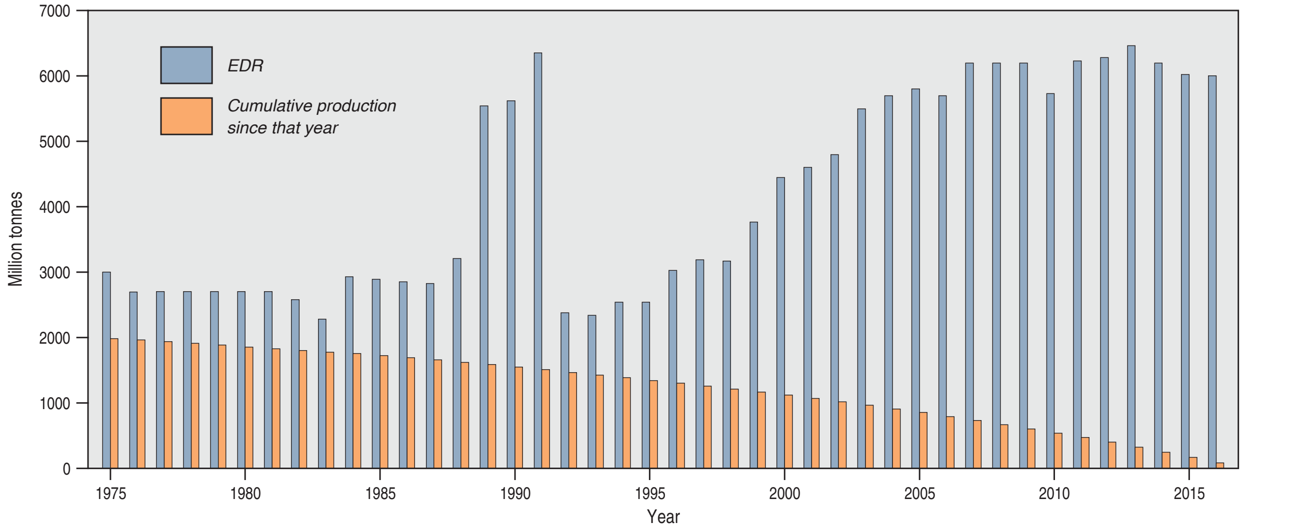


Figure 4 Economic Demonstrated Resources of bauxite 1975–2016, as well as cumulative production since each year.

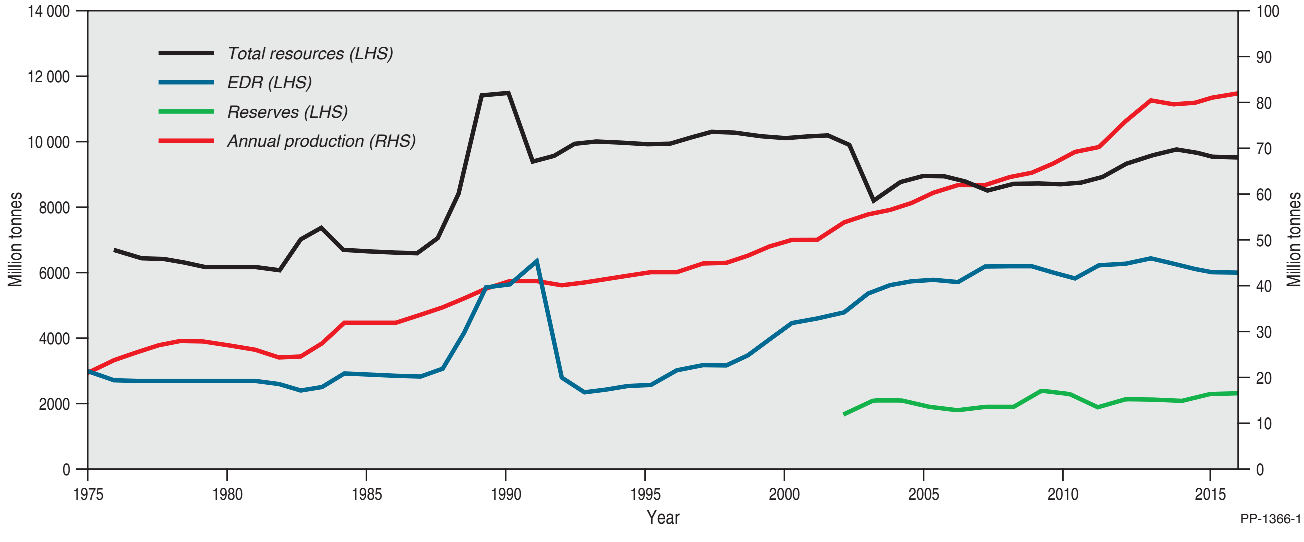


Figure 5 Trends in total resources, Economic Demonstrated Resources, Ore Reserves and annual production of bauxite, 1975–2016. LHS/RHS=refer to axis on left-hand side/right-hand side.

Notes: EDR of bauxite increased in 1989 as a result of the delineation of additional resources on the Cape York Peninsula. EDR decreased in 1992 because some Cape York deposits were reclassified to comply with the requirements of the JORC Code.

Black Coal

In 2016, the estimate of Australia's in situ EDR of black coal was revised upward to 85 753 Mt, an increase of almost 3% from the previous year (Table 3). Of this, 70 927 Mt is considered to be recoverable[3], which is a 4% increase from 2015. In addition, Australia has 104 151 Mt of Inferred Resources with 81 864 estimated to be recoverable (Table 3). In 2016, Australia was globally ranked fourth (Table 7), behind the United States of America (USA), China and India for recoverable economic coal resources and fourth (Table 7) as a producer, behind China, the USA and India.

Most of Australia's black coal EDR is located in Queensland (61%) and New South Wales (36%) with 34% and 29% of recoverable EDR located in the Bowen (Queensland) and Sydney (New South Wales) basins, respectively. These basins also dominate black coal production. Significant black coal resources are also found in the Surat, Clarence-Moreton and Galilee basins in Queensland and in the Gunnedah Basin in New South Wales.

In 2016, EDR for black coal increased at 26 deposits and decreased at 39 deposits, with most decreases owing to small quantities of mine depletion. There were six increases and two decreases greater than 100 Mt, with resource upgrades resulting in a net increase in EDR of 2617 Mt of black coal. Large additions to EDR came from four deposits in the Sydney Basin: Dartbrook (Australian Pacific Coal Ltd), Mount Arthur (BHP Billiton Ltd), Mount Thorley (Rio Tinto Ltd) and Warkworth (Rio Tinto Ltd). In the Bowen Basin, a BHP Billiton Ltd/Mitsubishi Corporation joint venture reported large additions to EDR at Goonyella, Peak Downs, Peak Downs East and Saraji East. In the Galilee Basin, the Milray project (Glencore plc) also reported increased EDR.

In 2016, Inferred Resources of recoverable black coal increased by 3149 Mt or 4%, with six increases and three decreases greater than 100 Mt. Large contributions to Inferred Resources from the Bowen Basin included Peak Downs and Peak Downs East and in the Surat Basin, the Columboola (Metro Mining Ltd) and Clifford (Stanmore Coal Ltd) projects reported large increases. In the Sydney Basin, Dartbrook (Australian Pacific Coal) and the United Wambo project (Glencore) also reported large increases in Inferred Resources. In 2016, the Hutton coking coal project (Valiant Resources Ltd) in the Bowen Basin reported a maiden in situ resource of 627.1 Mt of Indicated Resources and 4027.3 Mt Inferred Resources.

Australia has a very large Ore Reserve of black coal amounting to 19 800 Mt in 2016 (Table 2) of which 12 243 Mt (62%) is attributable to 93 operating mines (Table 1). These mines produced 566 Mt of black coal in 2016, a rise of 5% from 2015 levels (539 Mt). Conversely, during 2016, China reduced coal production and world prices consequently rose due to increased activity in the import market. Higher prices resulted in reduced demand and overall global coal production fell by 6.2% during 2016. According to BP plc, this is the largest decline on record[4].

At 2016 levels of production in Australia, average reserve life of black coal at operating mines is potentially 22 years and resource life could be 60 years (Table 1). If Ore Reserves at mines on care and maintenance, developing mines and undeveloped deposits are also considered, the reserve life of black coal is potentially 35 years. If AEDR is used as an indication of long-term potential supply, then at 2016 rates of production, Australia's black coal resources could last more than 100 years. Thus, Australia has the potential to produce black coal for many decades into the future.

Over the last 15 years, it can be seen in Figure 6 that Ore Reserves declined from 2002 to 2005 and then rapidly increased until 2012 from which point they have been at similar levels each year. In 2016, Australia mined 566.3 Mt of black coal (Table 1), which is a small fraction of the Ore Reserves at currently operating mines (5%) and a smaller percentage of total Ore Reserves (3%). Indeed, Figure 6 shows that over the last 15 years of mining, cumulative production (6781 Mt) amounts to only 39% of the 2002 Ore Reserve (17 400 Mt), yet the Ore Reserve is greater today than it was then, indicating that the exploited coal has been replaced in the inventory and more added.

However, while Ore Reserves have risen over the last 15 years production has increased at a faster rate (Figure 6). Ore Reserves of black coal have increased by 14% since 2002 but production has increased 63%, from 348 Mt to 566 Mt, over the same time period. As a ratio, production has increased from 2% of the Ore Reserve in 2002 to 3% in 2016, but it has fallen from the high of 3.4% in 2007.

Figure 7, also demonstrates the vast inventory of black coal in Australia by showing that even over the longer time period of 40 years, cumulative production (11 631 Mt) has only mined out 60% of 19 500 Mt of resources assessed as economic back in 1975. But again, Figure 8 also shows that over the last 40 years, black coal production has increased more rapidly than the inventory. In 1975, black coal production was 61 Mt which rose to 566 Mt in 2016, an increase of more than 800% but recoverable black coal EDR has increased only 264% over the same time period (19 500 Mt in 1975 to 70 927 Mt in 2016). As a ratio, annual production of black coal as a percentage of EDR has increased from 0.3% in 1975 to 0.8% in 2016.

While the increase in production has been more or less regular, the coal inventory has ebbed and flowed. Between 1998 and 2007, EDR for black coal declined due to the impact of increased rates of mine production and mining companies re-estimating Ore Reserves and Mineral Resources more conservatively to comply with requirements of the JORC Code. From 2008 onwards, black coal EDR increased significantly because of the discovery and delineation of additional resources as a result of high levels of exploration and through reclassification of resources.

[3] Recovery is the percentage of material of interest that is extracted during mining. Geoscience Australia has applied recovery factors to coal Mineral Resource estimates in order to improve understanding of Australia's resource potential. Unless otherwise stated by the company, deposits mined with open-cut methods are assumed to have a recovery factor of 90% and underground methods are assumed to have recovery factors of 50–75%. A coal Ore Reserve is reported at a higher level of confidence than a Mineral Resource and includes diluting materials, and allowances for losses that may occur during mining. Geoscience Australia does not apply recovery factors to Coal Reserves.

[4] BP Statistical Review of World Energy, June 2017.

Coal exploration expenditure in 2016 declined, falling 58% to \$124 million, the lowest spend since 2005. During 2016, there were rapid rises in coal prices, particularly premium coking coal which reached peak spot prices of more than US\$300/t in November 2016 and rose strongly again in April 2017. The price differential between thermal and coking coals grew, driving up the price of semi-soft coking and PCI coals (both of which can be used to reduce the overall amount of premium coking coal that is required in the steel-making process). The Office of the Chief Economist expects that metallurgical coal production and export volumes will increase during 2018, notwithstanding the possibility of wet weather conditions on the Queensland coast and potential industrial action in the Illawarra and Hunger regions of New South Wales, which would reduce production and exports[5]. Thus, higher prices and increased demand may stimulate increased exploration in coming years.

Despite the growing popularity of alternative energy technologies, coal continues to be important for global power generation. The percentage share of global power supplied by coal is decreasing but the World Coal Association predicts that, in absolute terms, the amount of coal-fired power generation will grow as the total amount of power generation increases worldwide, particularly in developing regions. The Office of the Chief Economist projects that the world demand for metallurgical coal imports will grow during 2018, with demand from China remaining high whilst demand from India increases significantly[6].

[5] Office of the Chief Economist, Resources and Energy Quarterly, December 2017, p. 34.
[6] Office of the Chief Economist, Resources and Energy Quarterly, December 2017, p. 31.

Operations at the Port Waratah coal terminal at Newcastle, New South Wales. Photograph by Michelle Cooper.

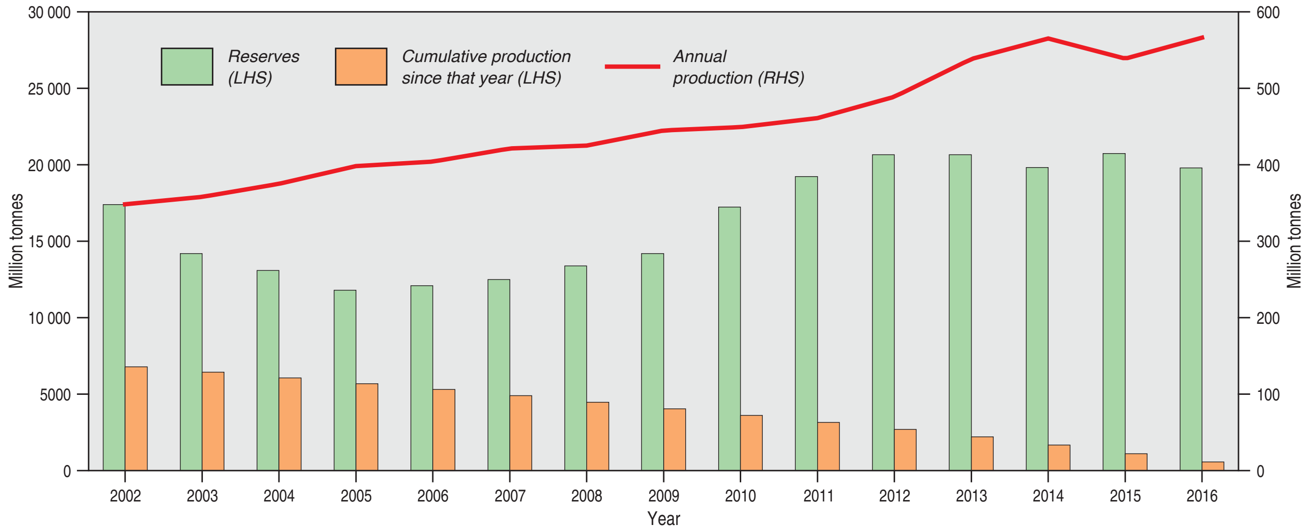


Figure 6 Black coal Ore Reserves and annual production 2002–2016, as well as cumulative production since each year. LHS/RHS=refer to axis on left-hand side/right-hand side.

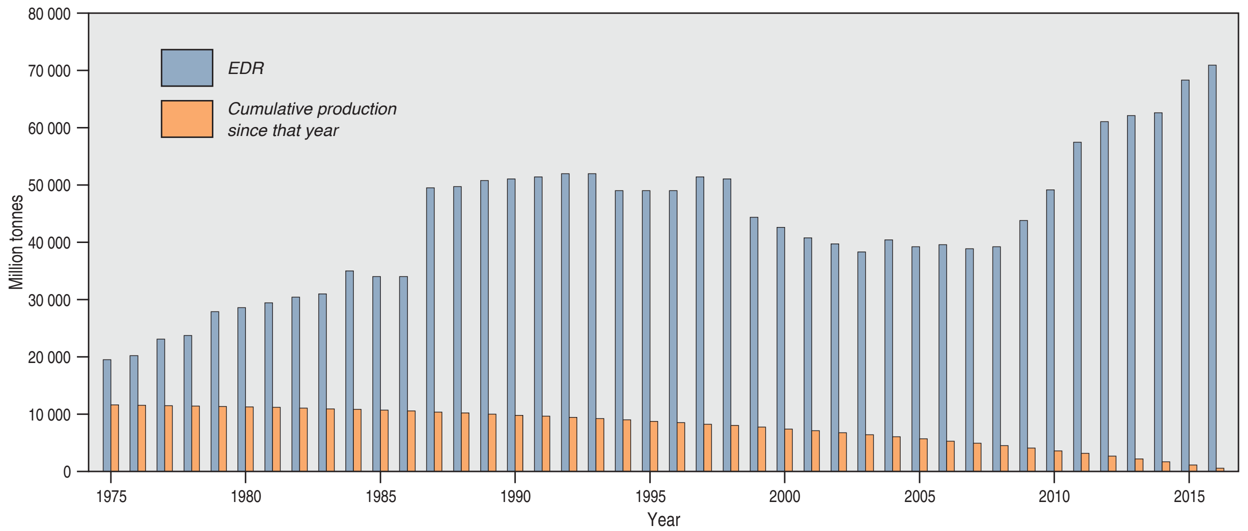


Figure 7 Economic Demonstrated Resources of recoverable black coal 1975–2016, as well as cumulative production since each year.

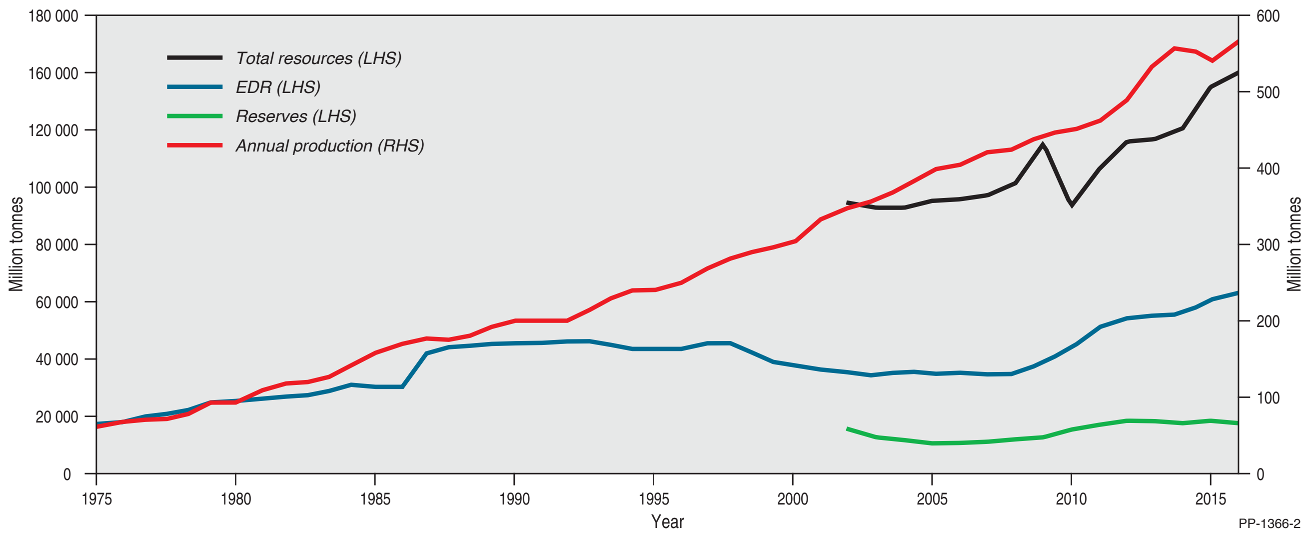


Figure 8 Trends in total resources, Economic Demonstrated Resources, Ore Reserves and annual production of recoverable black coal, 1975–2016. LHS/RHS=refer to axis on left-hand side/right-hand side.

Note: A major reassessment of New South Wales coal resources during 1986 by the NSW Department of Mineral Resources and the Joint Coal Board resulted in a large increase in black coal EDR as reported in 1987.

Iron Ore

Australia has significant deposits of both hematite and magnetite and thus Geoscience Australia estimates the national inventory of iron in two categories: (1) iron ore and (2) contained iron. Australia's EDR of iron ore decreased by 4% to 49 588 Mt in 2016 with the EDR of contained iron estimated to be 23 771 Mt, almost unchanged from the previous year (Table 3). Within this, magnetite resources have decreased by 16% to 17 845 Mt in 2016, accounting for approximately 36% of iron ore EDR. The fall in the national EDR of iron ore in 2016 was caused by the reassessment of resource deposit status and, most importantly, the continuing exploration inactivity by developing projects as a consequence of the lingering volatile market price of iron ore. State level increases in EDR are mostly attributable to brown field development and project expansion by existing producers, mainly in Western Australia, which has 94% of Australia's EDR (Figure 2), the majority of which is in the Pilbara region. Australia has the world's largest EDR with 29% of the world's iron ore (Table 7) followed by Russia (15%), Brazil (14%) and China (12%).

Australia has large Ore Reserves of iron ore amounting to 23 532 Mt (Table 2) in 2016 of which 6368 Mt (27%) is attributable to 29 operating mines (Table 1). These mines produced 858 Mt of iron ore in 2016, up 6% from 2015 levels (811 Mt). Western Australia produced almost 99% of this total (846 Mt) with the remainder produced by small operations in South Australia and Tasmania.

At 2016 levels of production, average reserve life at operating mines is potentially 7 years and resource life could be 19 years (Table 1). If Ore Reserves at mines on care and maintenance, developing mines and undeveloped deposits are also considered, the reserve life of Australia's iron ore is potentially 27 years and if AEDR is used as an indication of long-term potential supply, then at 2016 rates of production, iron ore resources could last almost 60 years. In 2015, this potential long-term resource life was 65 years with the fall a result of the 6% increase in production combined with the 4% decrease in AEDR.

Iron ore prices slightly recovered but continued to fluctuate in 2016, maintaining poor sentiment for greenfield exploration drilling. The production increase of 6% was mainly attributable to the major producers, Rio Tinto Ltd, BHP Billiton Ltd and Fortescue Metals Group Ltd, as they continue to achieve their capacity guidance through expansion and ramp-up of existing operations. Rio Tinto's mine expansion delivered a 6% increase in Pilbara production to 329.5 Mt. The company's Pilbara iron ore shipment met its 2016 target of 327.6 Mt and was expected to reach between 330 Mt and 340 Mt in 2017. BHP's Western Australia Iron Ore operations recorded a 2% increase to 257 Mt in the 2015–16 financial year, with the gain mainly due to a strong recovery after the wet season and from production ramp up at Jimblebar, and further increased production by 4% to 268 Mt in the 2016–17 financial year. Fortescue's 2016 production also recorded a slight increase of 2% from 165.4 Mt to 169.4 Mt, which corresponds to the 2% increase in the company's overall AEDR of 3675 Mt for the 2015–16 financial year.

Figure 9 shows that annual production is a small fraction of the iron ore Reserve (3.6% in 2016) but cumulative production over the last 15 years (6656 Mt) has accounted for all of the iron ore Reserve from 2002 (4100 Mt), plus another 60%, with cumulative production from 2003 and 2004 similarly exceeding the Ore Reserve for those years.

Figure 9 shows that both Ore Reserves and production have steadily risen over the last 15 years. Ore Reserves of iron ore in 2002 were 4100 Mt increasing 474% to 23 532 Mt in 2016 which is faster than production which has increased 359% (from 187 Mt to 858 Mt) over the same time period reflecting the major companies' plans to ramp up production in coming years.

Figure 10 demonstrates the vast Australian inventory of iron ore when EDR rather than just Ore Reserves are considered. Over the last 40 years, cumulative production (9731 Mt) has removed only 55% of 17 800 Mt of Mineral Resources assessed as economic back in 1975. Despite these vast resources, Figure 11 shows that over the last 40 years, iron ore production has increased more rapidly than the resource inventory, particularly from 2000 onward. In 1975, iron ore production was 98 Mt which rose to 858 Mt in 2016, a 756% increase. Iron ore EDR has increased 179% over the same time period (17 800 Mt in 1975 to 49 588 Mt in 2016) and total resources of iron ore (EDR + subeconomic + inferred) have increased from 35 000 Mt in 1976 to 152 083 Mt in 2016, an increase of 335%. As a ratio, production has increased from 0.6% of EDR in 1975 to 1.7% in 2016, the highest it has ever been.

Much of these increases occurred rapidly after a period of decline in iron ore EDR from 1994 through to 2003 which was caused by the combined impacts of increased rates of mine production and mining companies re-estimating reserves and resources to comply with the requirements of the JORC Code. Subsequent to this period, EDR increased rapidly due to large increases in magnetite resources (including reclassification of some magnetite deposits to economic categories), and increases in hematite resources, mainly at known deposits.

Iron ore-exploration expenditure in Australia during 2016 totalled $288 million, a 9% decrease on the $316 million spent in 2015. Exploration for iron ore in 2016 accounted for 20% of Australia's total mineral exploration expenditure.

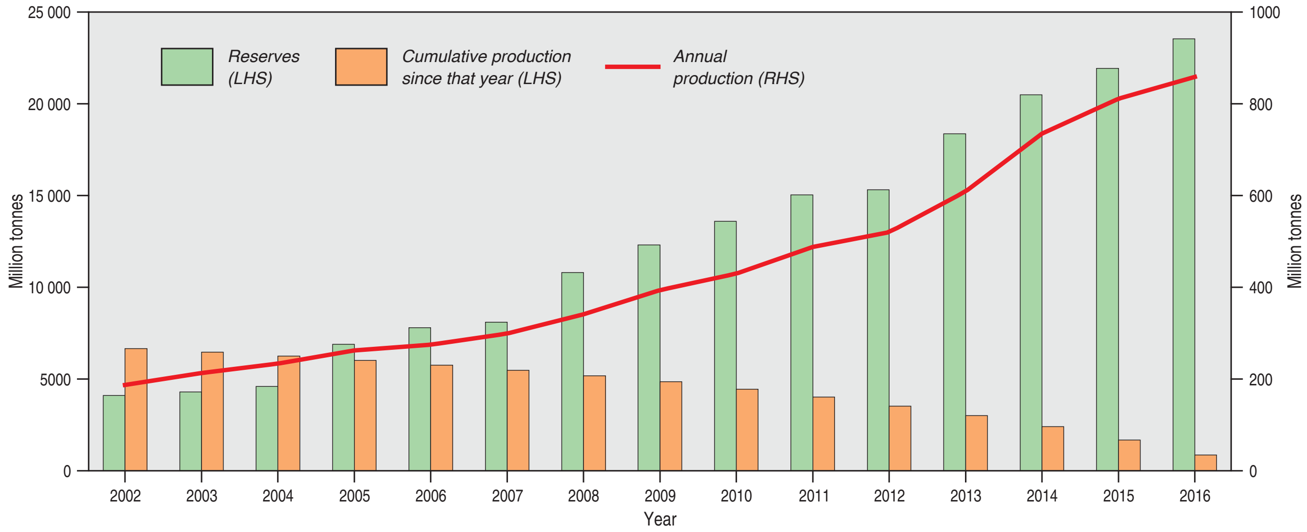


Figure 9 Iron Ore Reserves and annual production 2002–2016, as well as cumulative production since each year. LHS/RHS=refer to axis on left-hand side/right-hand side.

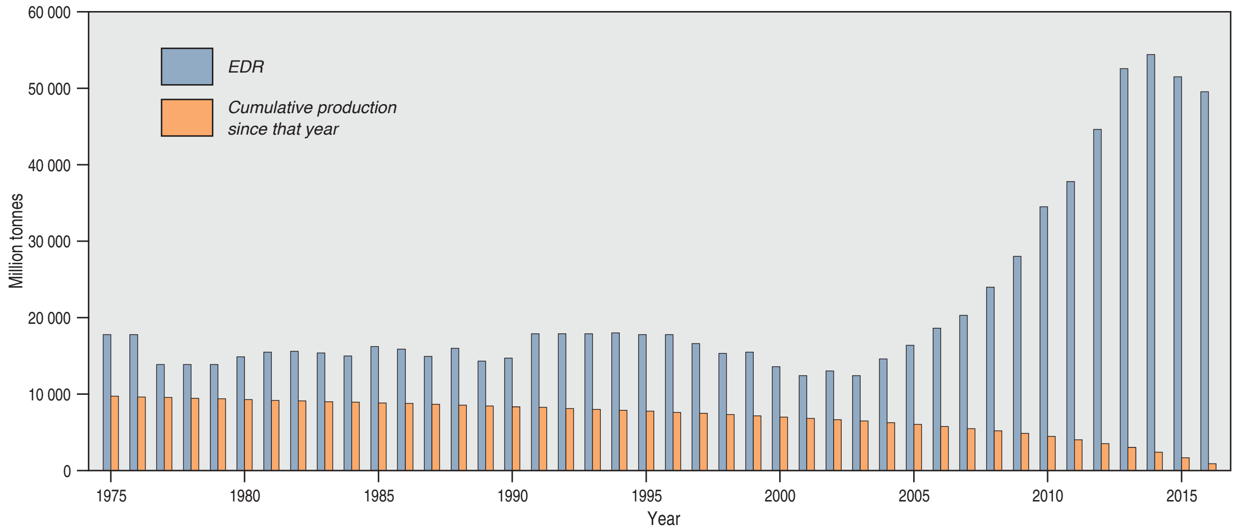


Figure 10 Economic Demonstrated Resources of iron ore 1975–2016, as well as cumulative production since each year.

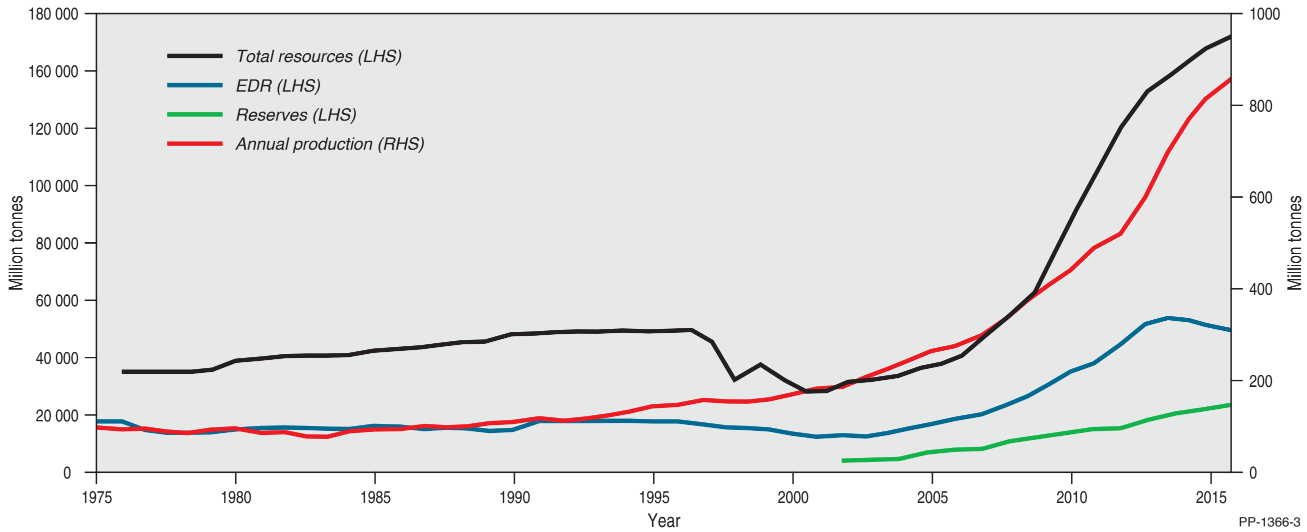


Figure 11 Trends in total resources, Economic Demonstrated Resources, Ore Reserves and annual production of iron ore, 1975–2016. LHS/RHS=refer to axis on left-hand side/right-hand side.

Gold

National EDR of gold went up 284 t or 3% in 2016 to 9830 t (Table 3) from 9546 t in 2015, with the majority of the rise recorded in Western Australia (+190 t) followed by Queensland (+69 t) and New South Wales (+45 t). All other jurisdictions recorded minor fluctuations in gold EDR. Accessible EDR is approximately 30 t less than EDR owing to some deposits being unavailable for exploration and mining (Table 3). These include Jabiluka, Koongarra and Coronation Hill. The USGS figures for world gold resources (57 000 t; Table 3) have not changed substantially in recent years and the Australian AEDR (9800 t) accounts for the largest resource by country with just less than 17% of the global total (Table 7), ahead of Russia (8000 t), South Africa (6000 t), the USA (3000 t) and Indonesia (3000 t).

Total Ore Reserves of gold reported in compliance with the JORC Code amounted to 3826 t of gold in 2016 (Table 2) of which 2750 Mt (27%) is attributable to 130 operating mines (Table 1). These mines produced 288 t of gold in 2016, up 3.5% from 2015 levels (278 t). Increases in gold production were seen in New South Wales (+6 t), Western Australia (+4 t), Victoria (+1 t) and Northern Territory (+0.3 t). Queensland, South Australia and Tasmania had minor falls in production.

At 2016 levels of production, average reserve life at operating mines is potentially 10 years and resource life could be 22 years (Table 1). If Ore Reserves at mines on care and maintenance, developing mines and undeveloped deposits are also considered, the reserve life of Australia's gold is potentially 13 years and if AEDR is used as an indication of long-term potential supply, then at 2016 rates of production, gold resources could last almost 35 years.

However, these ratios are strongly influenced by low-grade copper-gold deposits, which host the largest share of resources, whereas lode-gold deposits dominate production. (Additional production of approximately 20 t is sourced from epithermal deposits and as a by-product of base metal mining.) In 2016, AEDR for lode-gold deposits went up 248 t to 4077 t while production went up by about 6 t to 182 t yielding a resources/production ratio of 22 years (unchanged from 2015). For copper-gold deposits, AEDR rose 160 t to 5165 t and production went up 15 t to 86 t yielding a ratio of 60 years (3 years less than in 2015). While gold resources in copper-gold deposits are substantial, current and future mining rates of these large, generally low-grade, deposits are unlikely to lead to substantial increases in output. The state of gold production in Australia, therefore, continues to be dominated by lode-gold deposits and exploration success for these deposit types will need to continue to assure future production rates.

Inferred Mineral Resources of gold in Australia had a minor fall of about 254 t, or 5%, to total 4389 t. The largest rise in this resource category was seen in Western Australia (+54 t) and the largest fall was recorded in New South Wales (-167 t) with smaller rises and falls across the other states. Much of the loss was due to companies upgrading Inferred Resources to higher resource categories.

Figure 12 shows that annual production is approximately 7.5% of the gold Ore Reserve in 2016, roughly twice that of the bulk commodities. Cumulative production over the last 15 years (3873 t) has accounted for all of the gold Reserve, and more, from 2002 (3574 t). Cumulative production has similarly exceeded the Ore Reserve for 2003 and matched that for 2004, yet the Ore Reserve inventory remains steady, reflecting common practice in the Mining Industry of upgrading Mineral Resources to Reserves as needed. Both Ore Reserves and production have risen over the last 15 years (Figure 12). Ore Reserves of gold in 2002 were 3574 t increasing 7% to 3826 t in 2016 which is similar to production, which has increased 8% (from 266 Mt to 288 Mt) over the same time period.

Figure 13 demonstrates the large Australian inventory of gold when EDR rather than just Ore Reserves are considered, bearing in mind earlier comments that a large proportion of this inventory is in copper-gold deposits which are unlikely to contribute significantly to annual production. Even so, over the last 40 years, cumulative production (7963 t) has grossly exceeded the 156 t of Mineral Resources assessed as economic back in 1975. Indeed, cumulative production of gold has exceeded estimates of EDR for every year since 1975 up to 1998.

Figure 14 shows that over the last 40 years, gold production has risen significantly but the resource inventory has risen faster. In 1975, gold production was 16 t which rose to 288 t in 2016, a 1700% increase. Gold EDR has increased 6200% over the same time period (156 Mt in 1975 to 9830 t in 2016) and total resources of gold (EDR + subeconomic + inferred) have increased 5600% (254 t in 1976 to 14 499 t in 2016).

Indeed, the EDR of gold rose steadily from 1983 (394 t) to 2012 (9909 t) with only relatively minor falls of short duration (Figure 14). This rise in EDR corresponds to a period of sustained exploration expenditure averaging about $500 million per annum and of improvements to extraction technologies including carbon in pulp, carbon in leach and the treatment of refractory ores. In 2015 and 2016, gold EDR rose by 452 t and 262 t, respectively, following two consecutive years of losses (a 101 t loss in 2013 and a 696 t loss in 2014). The most recent rise in EDR is largely the result of favourable exchange rates raising the gold price in Australian dollars which has invigorated exploration in the gold sector as companies look to increase resource inventories. Much of this exploration expenditure was targeted around existing deposits leading to resource upgrades, especially converting Inferred Resources into higher resource categories.

World production from mining, according to the Thompson Reuters/World Gold Council, went up 41 t or 1% to 3264 t for the year. By these figures, Australia accounts for about 9% of world production (Table 7). Using USGS estimates of production by country, Australia's gold production continued to rank second in the world behind that of China (455 t) and ahead of Russia (250 t), the USA (209 t) and Canada (170 t). Imports of primary and secondary gold into Australia in 2016 totalled about 128 t or about 45 t more than in 2015. Total refined gold amounted to 344 t, up 42 t from 2015. Gold exports increased about 27 t to 344 t, with a value of $17.77 billion.

The monthly average gold price in US dollars over 2016 commenced at a low of US$1097/oz in January and concluded at US$1150/oz in December. Monthly fluctuations saw the average monthly price reach a high of US$1341/oz in August 2016. The average price over the year was about US$88/oz more than that in 2015. Owing to prevailing exchange rates, the price of gold in Australian dollars fluctuated between a high of $1779/oz (May 2016) and a low of $1578/oz (January 2016), finishing the year at $1600/oz. Overall the average price of gold in Australian dollars for 2016 was about $108/oz higher than in 2015.

Although equity markets remained difficult throughout the year and resulted in reduced exploration expenditures across most commodities, exploration expenditure on gold increased in 2016 to $617.6 million, an increase of $141.7 million compared to 2015.

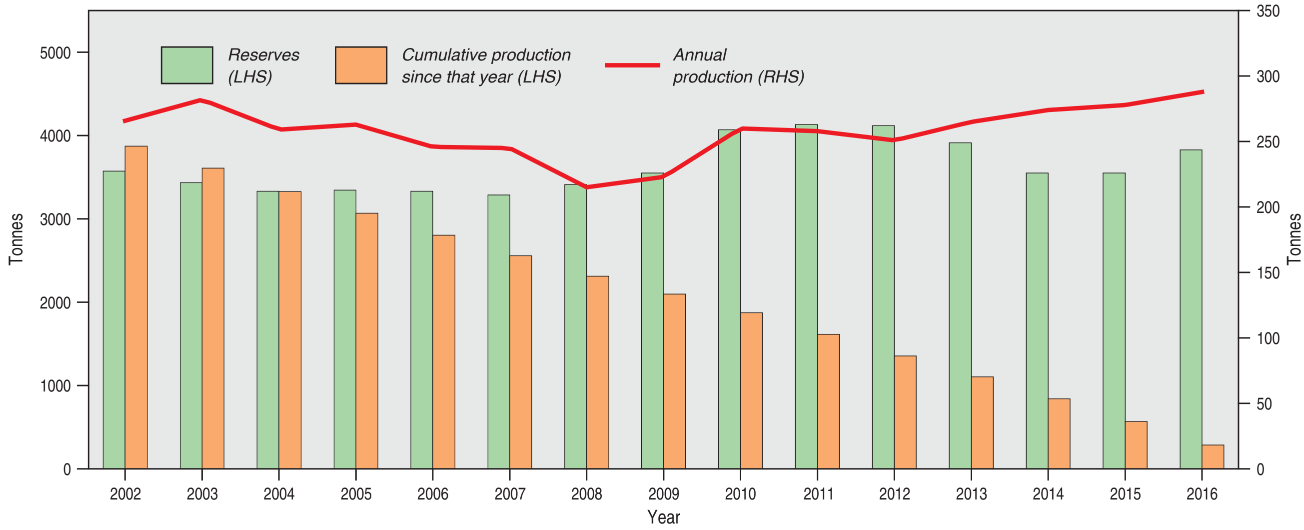


Figure 12 Gold Ore Reserves and annual production 2002–2016, as well as cumulative production since each year. LHS/RHS=refer to axis on left-hand side/right-hand side.

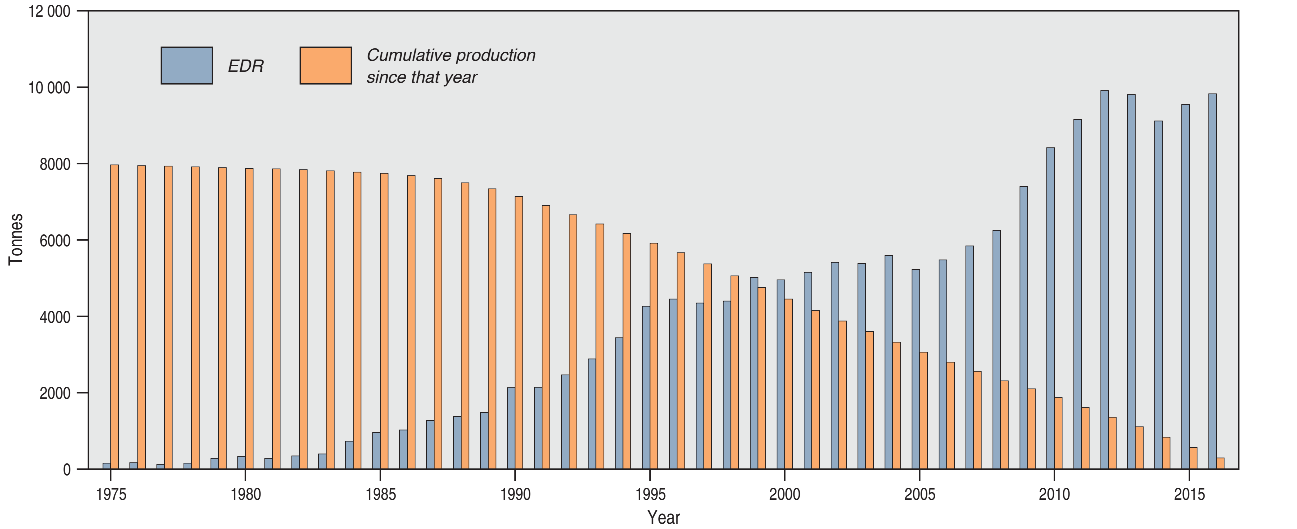


Figure 13 Economic Demonstrated Resources of gold 1975–2016, as well as cumulative production since each year.

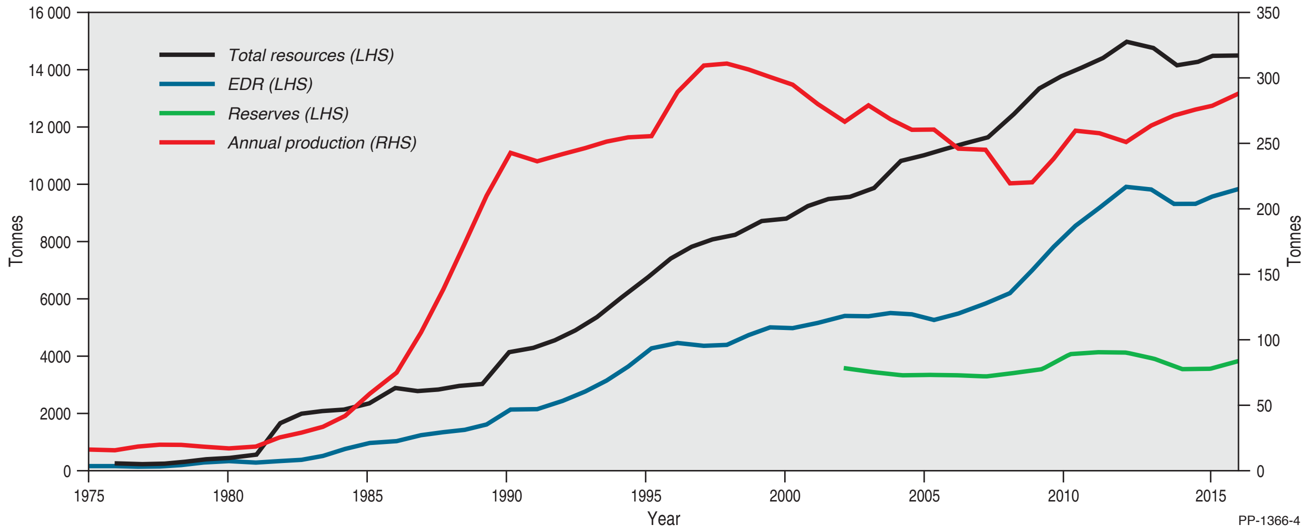


Figure 14 Trends in total resources, Economic Demonstrated Resources, Ore Reserves and annual production of gold, 1975–2016. LHS/RHS=refer to axis on left-hand side/right-hand side.

Copper

Australia's EDR of copper in 2016 was 87.78 Mt (Table 3) slightly down from 2015 (88.75 Mt). South Australia has 66% of the national total of EDR, mainly in the Olympic Dam deposit (which contains 56% of Australia's EDR), followed by New South Wales (15%) and Queensland (13%; Figure 2). Australia has the second largest economic resources of copper at 12% (Table 7) after Chile (29%) and ahead of Peru (11%) and Mexico (6%). Australia is also a major copper producer with mining and smelting operations at Olympic Dam in South Australia and Mount Isa in Queensland. Other significant production comes from the operations at Prominent Hill in South Australia; Northparkes, Cadia, Cobar and Tritton in New South Wales; Nifty, DeGrussa, Boddington, Telfer and Golden Grove in Western Australia; Ernest Henry, Mount Isa and Lady Annie in Queensland.

Australia has a large Ore Reserves of copper amounting to 24.0 Mt (Table 2) in 2016 of which 19.37 Mt (35%) is attributable to 34 operating mines (Table 1). These mines produced 0.948 Mt of copper in 2016, slightly down from 2015 levels (0.971 Mt). In contrast, the USGS estimates that during 2016, global copper production increased slightly (1.5%) partly owing to significant increases in production from a number of mines in the USA. Exports of copper ore and concentrates (1.817 Mt) and refined copper (0.452 Mt) had an export value of $7690 million in 2016 down from $8156 million in 2015 and down from $9048 million in 2014.

At 2016 levels of copper production, average reserve life at operating mines is potentially 20 years and resource life could be 73 years (Table 1). If Ore Reserves at mines on care and maintenance, developing mines and undeveloped deposits are also considered, the reserve life of copper is potentially 25 years and if AEDR is used as an indication of long-term potential supply, then at 2016 rates of production, Australia's copper resources could last more than 90 years. Thus, at current rates of production, and even with increased rates of production, Australia has the potential to produce copper for many decades into the future.

Figure 15 shows that annual production is equal to only 1% of the copper reserve in 2016 but cumulative production over the last 15 years (13.604 Mt) accounts for 66% of the copper Ore Reserve from 2002 (20.4 Mt). Figure 15 also shows that both Ore Reserves and production have increased over the last 15 years. Ore Reserves of copper increased from 20.4 Mt in 2002 to 24.0 Mt in 2016 (an 18% increase) but the increase in production has been lower (7%) over the same time period (0.883 Mt to 0.948 Mt). In general, the reserves/production ratio has remained steady over the last 15 years, reflecting steady near-term supply (Figure 1).

Figure 16 demonstrates the large Australian inventory of copper when EDR rather than just Ore Reserves are considered. Over the last 40 years, cumulative production (23.2 Mt) has grossly exceeded the 5.9 Mt of Mineral Resources assessed as economic back in 1975. Indeed, cumulative production of copper has exceeded estimates of EDR for every year since 1975 to 1992.

Figure 17 shows that over the last 40 years, copper production has risen significantly but the resource inventory has risen faster. In 1975, copper production was 0.22 Mt which rose to 0.948 Mt in 2016, a 330% increase. Copper EDR has increased almost 1400% over the same time period (5.9 Mt in 1975 to 87.78 Mt in 2016) and total resources of copper (EDR + subeconomic + inferred) have also increased 1400% (9.07 Mt in 1976 to 138.29 Mt in 2016).

The rise in Australia's EDR of copper over the last 40 years has not been uniform (Figure 16 and Figure 17). Indeed, following the adoption of the JORC Code by the Australian minerals industry, many companies first used this code in 1989 for reporting their resources. These re-estimated JORC-compliant mineral resources resulted in a sharp fall in copper EDR in 1989.

In 1993, there was a sharp increase in copper EDR mainly because of increased resources announced for the Olympic Dam deposit in South Australia. Additional resources were also reported for Ernest Henry in Queensland, Northparkes in New South Wales and other smaller deposits. Reassessments of copper resources by Geoscience Australia in 2002 and 2003 resulted in further transfers (reclassification) of Olympic Dam resources into EDR. In 2007 and 2008, copper resources again increased sharply at Olympic Dam where drilling outlined large resources in the south eastern part of the deposit. Since 2008, successful exploration has continued to yield new discoveries and delineate new resources, resulting in a steady increase of copper EDR, including the Carrapateena, Rocklands, DeGrussa, Hillside and Cadia East deposits.

Spending on copper exploration in 2016 was $136 million, an 11% increase on 2015 ($123 million), reversing the recent downtrend but still not reaching the levels seen in 2014 ($168 million). Exploration activity in 2016 included drilling at Walford Creek and Copper Canyon in Queensland, and at Collerina and Wirlong in New South Wales. Maiden resources were announced for Tollu (Redstone Resources Ltd), Calingiri (Caravel Minerals Ltd) and Monty (Springfield Joint Venture), all in Western Australia.

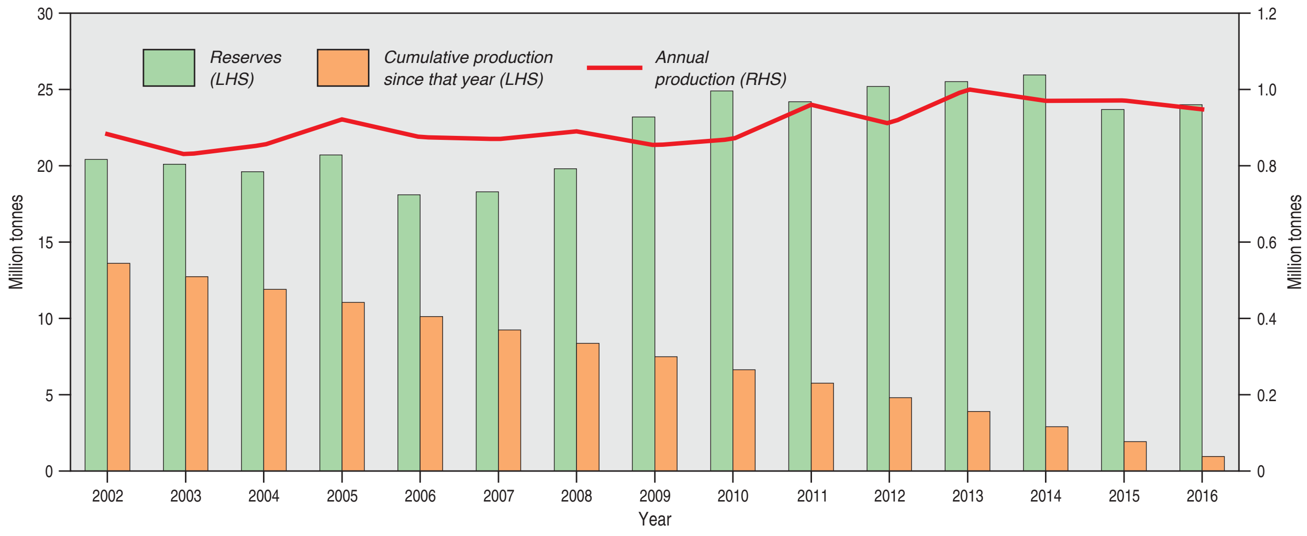


Figure 15 Copper Ore Reserves and annual production 2002–2016, as well as cumulative production since each year. LHS/RHS=refer to axis on left-hand side/right-hand side.

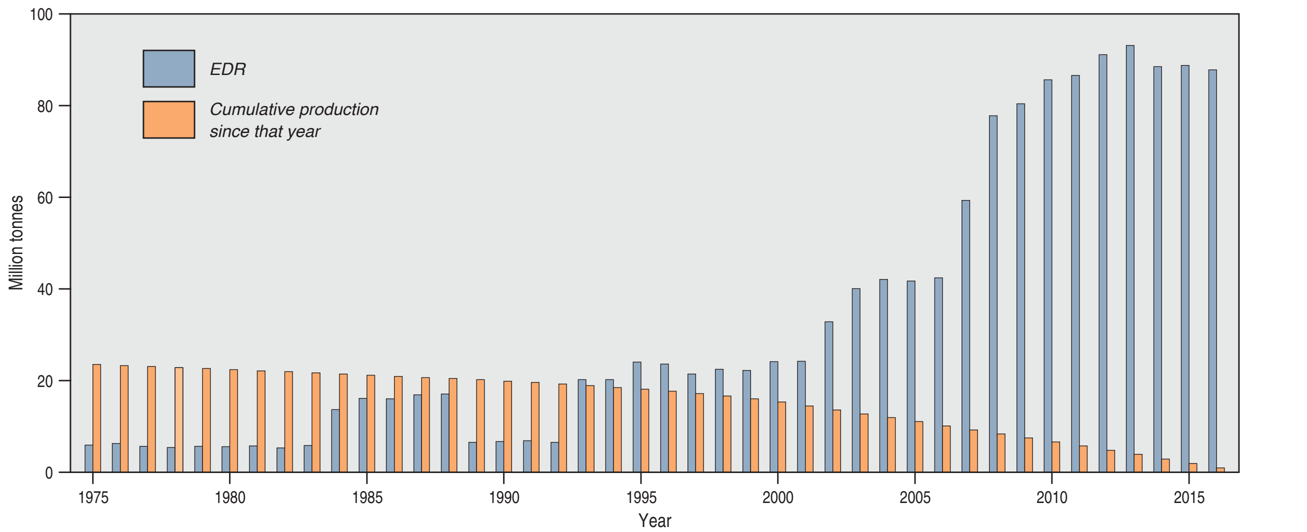


Figure 16 Economic Demonstrated Resources of copper 1975–2016, as well as cumulative production since each year.

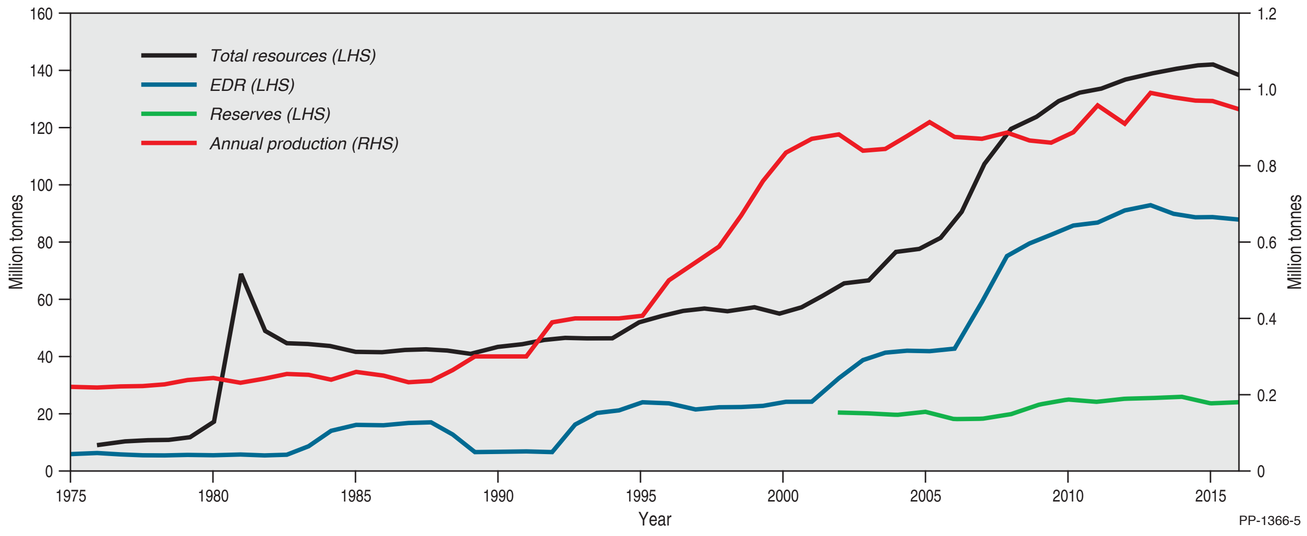


Figure 17 Trends in total resources, Economic Demonstrated Resources, Ore Reserves and annual production of copper, 1975–2016. LHS/RHS=refer to axis on left-hand side/right-hand side.

Uranium

Australia's EDR of uranium (equivalent to Reasonably Assured Resources that can be produced at costs of less than US$130/kg U) were estimated to be 1270 kt at December 2016 (Table 3), similar to the previous year's estimate of 1287 kt. Australia's EDR of uranium is the world's largest, accounting for 29% of the global estimate (Table 7) followed by Kazakhstan (12%), Russia (9%), Canada (8%) and Niger (7%).

Australia has large Ore Reserves of uranium amounting to 329 kt (Table 2) in 2016 of which 270 kt (82%) is attributable to three operating mines (Table 1). These mines, Olympic Dam and Four Mile in South Australia and Ranger in the Northern Territory, produced 6.314 kt U (7.446 kt U_3O_8) in 2016, a 12% increase on that reported in 2015 (5.637 kt U), largely due to production ramping up at Four Mile in South Australia. In addition, Australia has an estimated 915 kt of Inferred Resources of uranium and another 32 kt regarded as subeconomic (Table 3).

At 2016 levels of uranium production, average reserve life at operating mines is potentially 43 years and resource life could be 152 years (Table 1). If Ore Reserves at mines on care and maintenance, developing mines and undeveloped deposits are also considered, the reserve life of uranium is potentially 52 years. If AEDR is used as an indication of long-term potential supply, then at 2016 rates of production, Australia's uranium resources could last more than 190 years. Thus, at current rates of production, and even with increased rates of production, Australia could remain a top global producer for many decades into the future.

Figure 18 shows that annual production (6.314 kt) is equal to only 2% of the uranium Reserve (329 kt) in 2016 and cumulative production over the last 15 years (107.718 kt) accounts for 32% of the uranium Ore Reserve reported in 2002 (332.5 kt). Figure 18 also shows that both Ore Reserves and production have decreased slightly over the last 15 years but have experienced a number of rises and falls during this period. Ore Reserves of uranium were 332.5 kt in 2002 and rose to a peak of 447 kt in 2004 before falling away rapidly to a low of 228 kt in 2007, after which Reserves rose again to the current range (324–391 kt) by 2010. Production in 2002 was 6.85 kt and reached a peak of 9.51 kt before falling to a low in 2014 of 4.98 kt, with peaks and dips on the way. In the last two years, production has increased 27% from this low point.

When EDR, rather than just Ore Reserves, are considered, Figure 19 demonstrates the vast inventory of uranium in Australia by showing that even over the longer time period of 40 years, cumulative production (202.57 kt) has mined out only 83% of 243 kt of resources assessed as economic back in 1975—EDR that was estimated before the first resource assessments for Olympic Dam, the largest known deposit of uranium in the world.

Figure 20 shows that over the last 40 years, uranium production has increased more rapidly than the inventory. In 1975, uranium production was zero, but the following year saw Australia produce 0.359 kt which rose rapidly to range between about 3.2–4.5 kt in the 1980s. Production fell in the early 1990s and then rose rapidly again to the 2014 peak of 9.51 kt. In 2016, production is nearly 1700% higher than it was in 1976. Over this same time period, EDR has also risen but more slowly, by almost 400%, from 266 kt in 1976 to 1270 kt in 2016 in a series of steps that largely correspond to resource delineation at Olympic Dam. Total uranium resources (EDR + subeconomic + inferred) has increased almost 700% (279 kt in 1976 to 2217 kt in 2016).

The majority of Australia's uranium deposits were discovered from 1969 to 1975 when approximately 50 deposits, including 15 with significant resource estimates, were discovered. Since 1975, only another five deposits have been discovered and, of these, only three deposits (Kintyre in the Paterson Province of Western Australia, Junnagunna in Queensland and Four Mile in South Australia) have EDR. As a result, the progressive increases in Australia's EDR for uranium (Figure 19 and Figure 20) from 1975 to the present are largely because of the ongoing delineation of resources at known deposits. From 1983 onwards, the Olympic Dam deposit has been the major contributor to increases in Australia's EDR. The large increases shown in Figure 19 and Figure 20 occurred:

- in 1983, when initial resource estimates for Olympic Dam and Ranger No. 3 Orebody (Northern Territory) were made by the former Australian Atomic Energy Commission;
- in 1993, when further increases in EDR for Olympic Dam and the first assessment of resources for the Kintyre deposit were made by Geoscience Australia's predecessor, the Bureau of Mineral Resources;
- in 2000, when increases were due to continuing additions to the Olympic Dam resources;
- and from 2007 to 2009 when a major increase in EDR for Olympic Dam was made after drilling outlined major extensions to the southeast part of the deposit.

From 2010 to 2014, EDR generally decreased because of higher costs of mining and milling uranium ores (Figure 19 and Figure 20). In addition, prior to 2009, Reasonably Assured Resources in the cost category of less than US$80/kg U were considered to be economic. As a result of changes in uranium market prices and increases in costs, economic resources since 2009 were adjusted to include resources within the cost category of less than US$130/kg U.

Exports of uranium (7.446 kt U_3O_8) in 2016 had a value of $910 million, up from $802 million in 2015 but down from previous highs as market prices for uranium progressively decreased from 2011 to 2014. After a slight uptick in 2015, prices fell further in 2016, but may have stabilised, with industry sentiment being that this may be the bottom of the market. From 2011 to 2016, spot prices remained below the level required to stimulate exploration with exploration expenditure for uranium in 2016 totalling $23 million, down 90% from the relative highs of 2008 ($262 million).

The uranium spot market, however, only provides a short-term indicator of the outlook for uranium as this market is predicated on long lead times and significant infrastructure development costs for plant construction. As a result, uranium buyers and sellers generally negotiate private contracts. A number of companies in Australia are working through regulatory development and approvals processes and are upgrading their mineral resource assessments in anticipation of improving market conditions. The incoming Western Australian government announced a ban on uranium mining in June 2017, with the caveat that those projects already approved—Mulga Rock, Wiluna, Yeelirrie and Kintyre—would be able to proceed with development. Uranium mining remains banned in Queensland and New South Wales, limiting potential new discovery and growth of EDR.

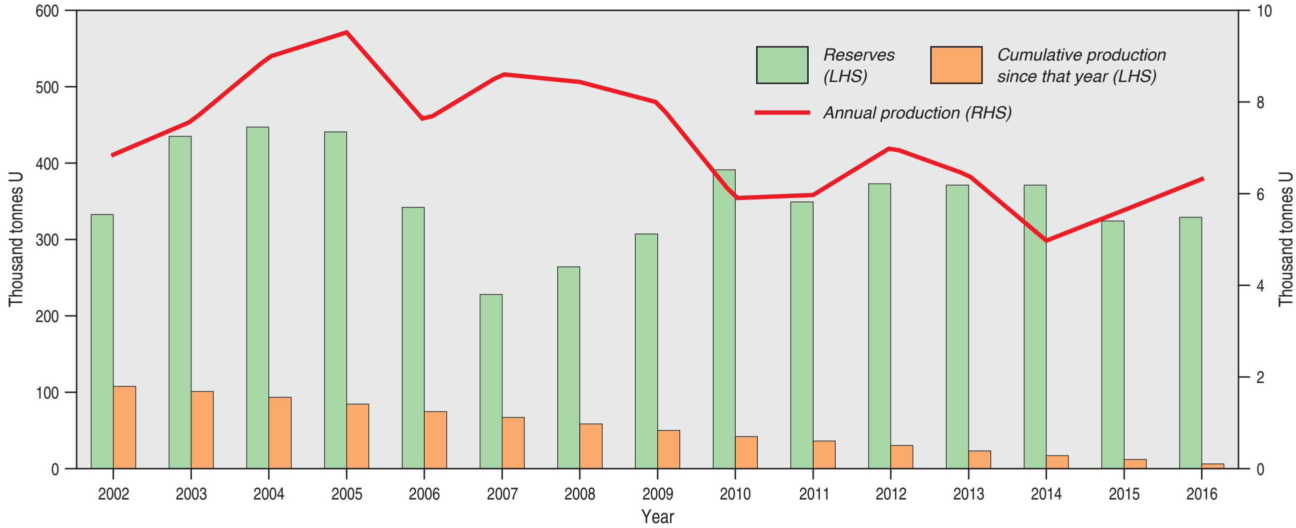


Figure 18 Uranium Ore Reserves and annual production 2002–2016, as well as cumulative production since each year. LHS/RHS=refer to axis on left-hand side/right-hand side.

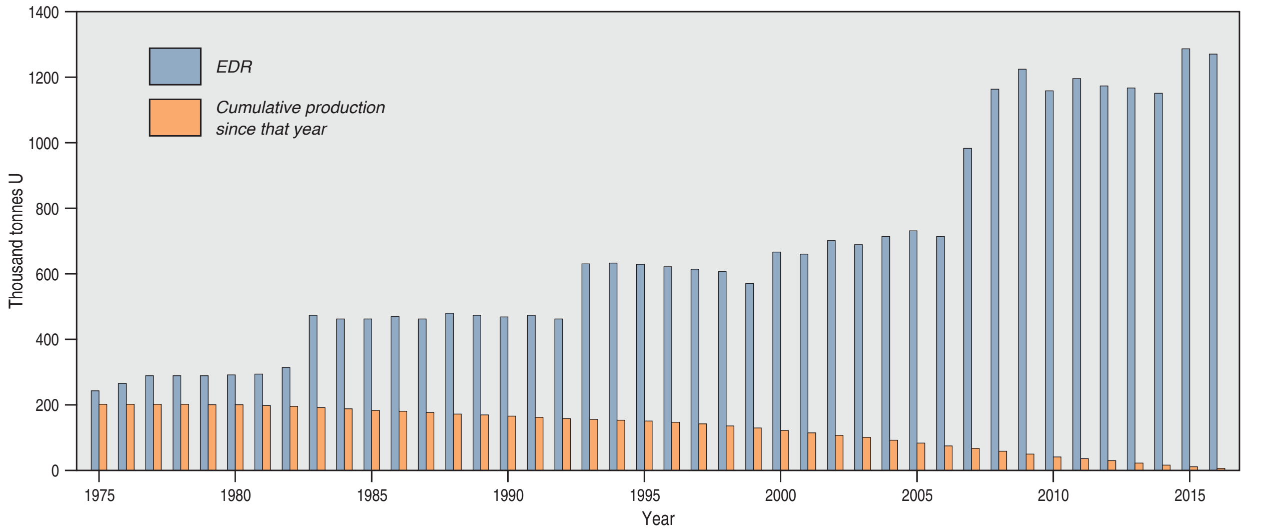


Figure 19 Economic Demonstrated Resources of uranium 1975–2016, as well as cumulative production since each year.

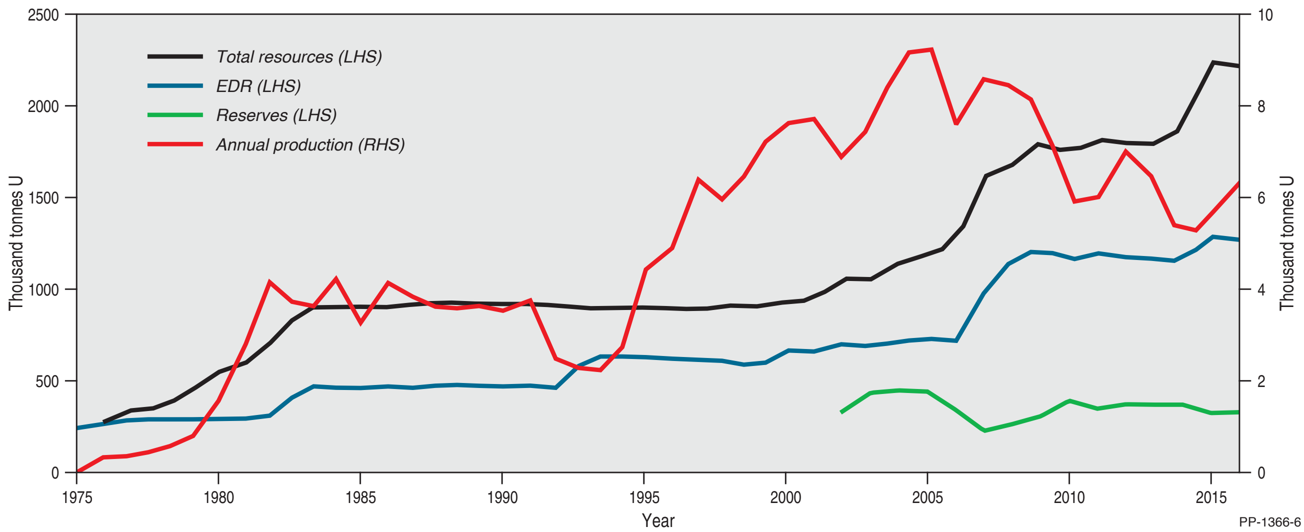


Figure 20 Trends in total resources, Economic Demonstrated Resources, Ore Reserves and annual production of uranium, 1975–2016. LHS/RHS=refer to axis on left-hand side/right-hand side.

Note: EDR from 2009 onward is equivalent to Reasonably Assured Resources recoverable at costs of less than US$130/kg U. Prior to 2009, EDR is equivalent to Reasonably Assured Resources recoverable at costs of less than US$80/kg U.

Nickel

Australia's EDR of nickel in 2016 was 18.5 Mt (Table 3) slightly down from 18.8 Mt in 2015. Western Australia holds the bulk (96%) of the national total of EDR with the remainder occurring in Queensland (Figure 2). Australia has the world's largest economic resources of nickel with 24% of known economic resources (Table 7), followed by Brazil (13%), Russia (10%) and New Caledonia (9%). Australia is the world's fifth largest nickel producer (Table 7) with all production occurring in Western Australia. Thirteen mines produced nickel in 2016 (Table 1) with the most significant producers being Murrin Murrin, Mount Keith, Leinster and the Forrestania mines.

In addition to the 13 nickel mines that operated in 2016, downstream processing continues in Australia. The Kalgoorlie smelter, part of BHP Ltd's Nickel West operation, is one of the largest nickel matte producers in the world (with a capacity of 110 kt per annum), receiving concentrates from the Cliffs, Mount Keith and Leinster mines and the Kambalda concentrator. The smelter also produces some 550 kt of sulphuric acid each year. The Kalgoorlie smelter is connected to the Kwinana Nickel refinery via rail. Kwinana Nickel is one of the largest producers of finished nickel in the world (capacity of 65 kt per annum) and also produces mixed nickel and cobalt sulphide, copper sulphide and ammonium sulphate. Continued low nickel prices have impacted on the Nickel West operation in recent years and BHP has announced its intention to divest the business despite potential new nickel production from the Venus underground and Yakabindie open cut mines and the announcement of the addition of a nickel sulphate line at the Kwinana refinery that will tap into the market for batteries. Glencore plc's Murrin Murrin refinery, 50 km east of Leonora, also produces finished nickel and cobalt briquettes as well as mixed nickel and cobalt sulphide and ammonium sulphate. Meanwhile, high costs, financial losses and permitting and industrial issues resulted in the Yabulu refinery in Townsville (previously run by Queensland Nickel Pty Ltd) being placed on care and maintenance in March 2016.

Australia's Ore Reserves of nickel were 6.0 Mt (Table 2) in 2016 of which 4.18 Mt (70%) is attributable to the 13 operating mines (Table 1). These mines produced 0.204 Mt of nickel in 2016, slightly down from 2015 levels (0.235 Mt). Similarly, the USGS estimates that during 2016 global nickel production also decreased slightly (1.3%) as significantly increased production in New Caledonia, Canada and Indonesia failed to offset reduced mining activity in Australia, the Philippines, Brazil, Russia and South Africa. Exports of nickel ore and concentrates (0.210 Mt) and intermediate and refined nickel (0.176 Mt) had a combined export value of $2298 million in 2016, 27% down from $3142 million in 2015 owing to lower nickel prices in 2016.

At 2016 levels of nickel production, average reserve life at operating mines is potentially 20 years and resource life could be 32 years (Table 1). If Ore Reserves at mines on care and maintenance, developing mines and undeveloped deposits are also considered, the average reserve life of nickel is potentially 29 years and if AEDR is used as an indication of long-term potential supply, then at 2016 rates of production, Australia's nickel resources could last about 90 years. Thus, at current rates of production, and even with increased rates of production, Australia has the potential to produce nickel for many decades into the future.

Figure 21 shows that annual production is equal to only 3.4% of the nickel reserve in 2016 but cumulative production over the last 15 years (3.027 Mt) accounts for just 13.6% of the nickel Ore Reserve from 2002 (22.2 Mt). Figure 21 also shows that Ore Reserves of nickel have decreased 17% from 22.2 Mt in 2002 to 18.5 Mt in 2016 but 2016 production levels (0.204 Mt) are similar to those of 2002 (0.210 Mt) notwithstanding that there has been some falls (to 0.165 Mt in 2009 following the global financial crisis) and rises (to 0.244 Mt in 2012 and 0.246 Mt in 2014) during this period.

Figure 22 demonstrates the large Australian inventory of nickel when EDR rather than just Ore Reserves are considered. Over the last 40 years, cumulative production (5.488 Mt) has grossly exceeded the 1.9 Mt of Mineral Resources assessed as economic back in 1975. Indeed, cumulative production of nickel has exceeded estimates of EDR for every year from 1975 to 1995.

Figure 23 shows that over the last 40 years, nickel production has risen significantly but the resource inventory has risen faster. In 1975, nickel production was just 0.076 Mt rising to 0.204 Mt in 2016, an increase of almost 170%. Nickel EDR has increased over 870% over the same time period (1.9 Mt in 1975 to 18.5 Mt in 2016) and total resources of nickel (EDR + subeconomic + inferred) have also increased more than 500% (7.43 Mt in 1976 to 46.0 Mt in 2016) since 1976.

The rise in Australia's EDR of nickel has, however, not been uniform over these 40 years (Figure 22 and Figure 23). The EDR for nickel increased during the period 1995 to 2001 by 18.2 Mt. This resulted mainly from progressive increases in resources of lateritic deposits at Bulong, Cawse, Murrin Murrin, Mount Margaret, Ravensthorpe, all in Western Australia, Marlborough in Queensland, and Syerston and Young in New South Wales. Australia's EDR of nickel doubled in 2000 compared to the level at the end of 1999. This dramatic rise was due to further large increases in resources at the Mount Margaret and Ravensthorpe deposits, and other lateritic deposits in the Kalgoorlie region of Western Australia. In addition, during the period 1995 to 2001, there were increases in Western Australian sulphide resources at Yakabindie and the discoveries of the Silver Swan and Cosmos high-grade sulphide deposits.

From 2001 onwards, the sharp rises in market prices for nickel led to increased expenditure on exploration and on evaluation drilling at many known deposits. This contributed to further increases in total EDR for sulphide deposits at Perseverance, Savannah, Maggie Hays, Anomaly 1, Honeymoon Well, deposits in the Forrestania area, as well as new deposits at Prospero and Tapinos in Western Australia, Avebury in Tasmania and remnant resources at several sulphide deposits in the Kambalda region including Otter-Juan and Lanfranchi groups of deposits. EDR increased at a slower rate from 2001 to 2008, mainly because of the absence of further discoveries of lateritic nickel deposits and as a result of increases in resources for some deposits being offset by companies reclassifying their lateritic nickel resources to lower resource categories pending more detailed drilling and resource assessments. Decreases in nickel EDR from 2009 onwards reflect reclassification of nickel resources in response to the very sharp falls in nickel prices following the 2008–09 global financial crisis followed by only a partial recovery in nickel prices from 2009 onwards.

Continued weakness in the price of nickel has resulted in low exploration activity, thus nickel EDR are not expected to increase in the near future. Spending on nickel (and cobalt) exploration in 2016 was $51.5 million, down from $66 million in 2015 continuing the downtrend from the peak of 2008 when $385 million was spent. Recent nickel exploration includes drilling at Stricklands (St George Mining Ltd), Delphi North (Talisman Mining Ltd), Neptune (Western Areas Ltd) and Fisher East (Rox Resources Ltd), all in Western Australia, as well as Red Hill (Impact Minerals Ltd) in New South Wales.

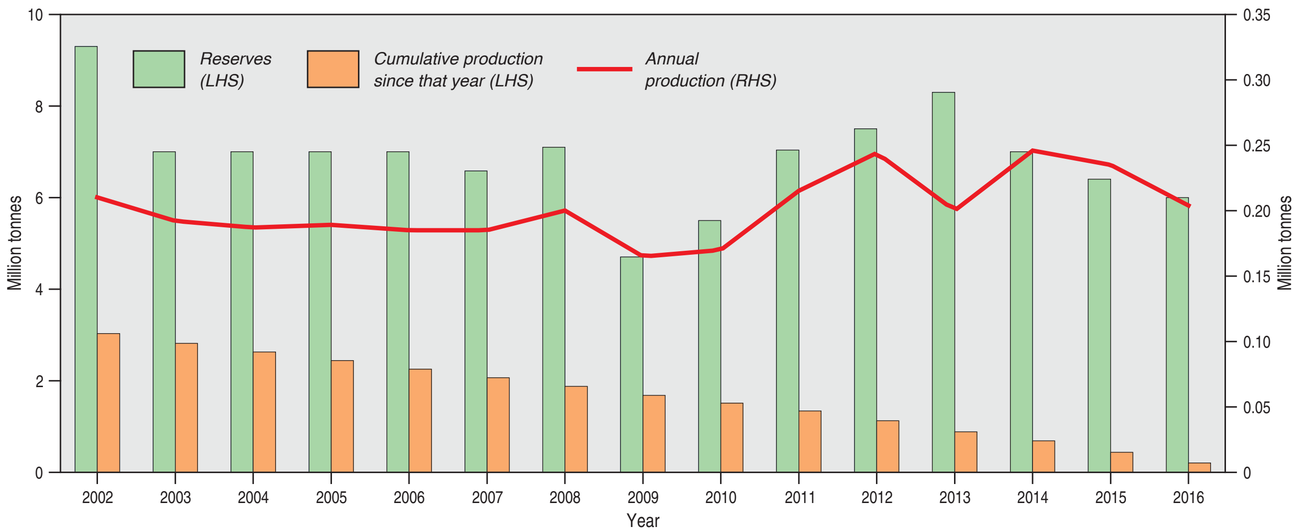


Figure 21 Nickel Ore Reserves and annual production 2002–2016, as well as cumulative production since each year. LHS/RHS=refer to axis on left-hand side/right-hand side.

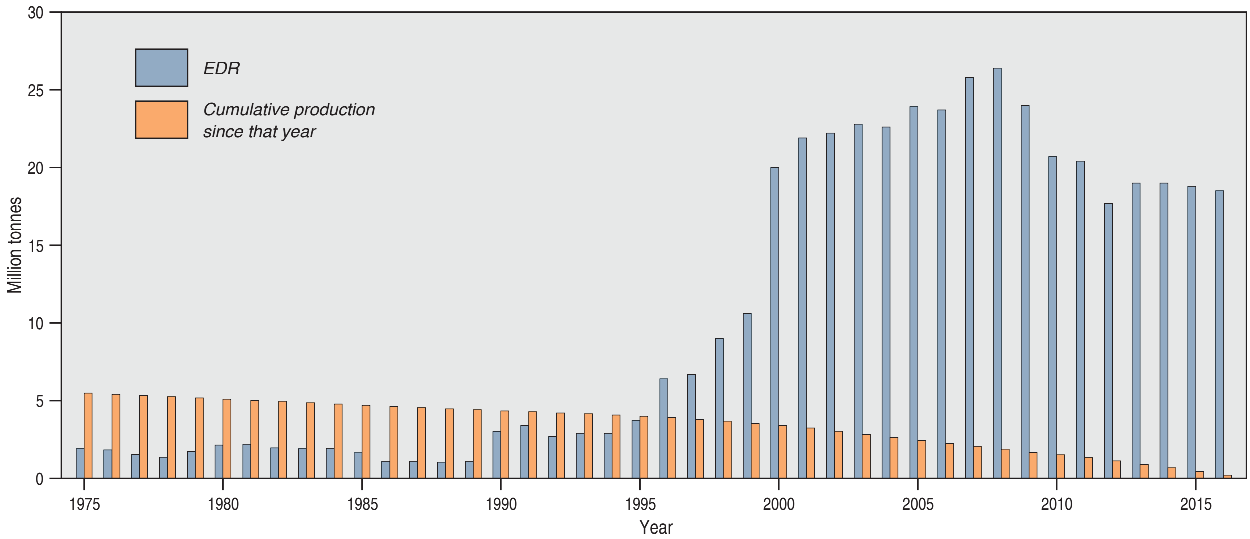


Figure 22 Economic Demonstrated Resources of nickel 1975–2016, as well as cumulative production since each year.

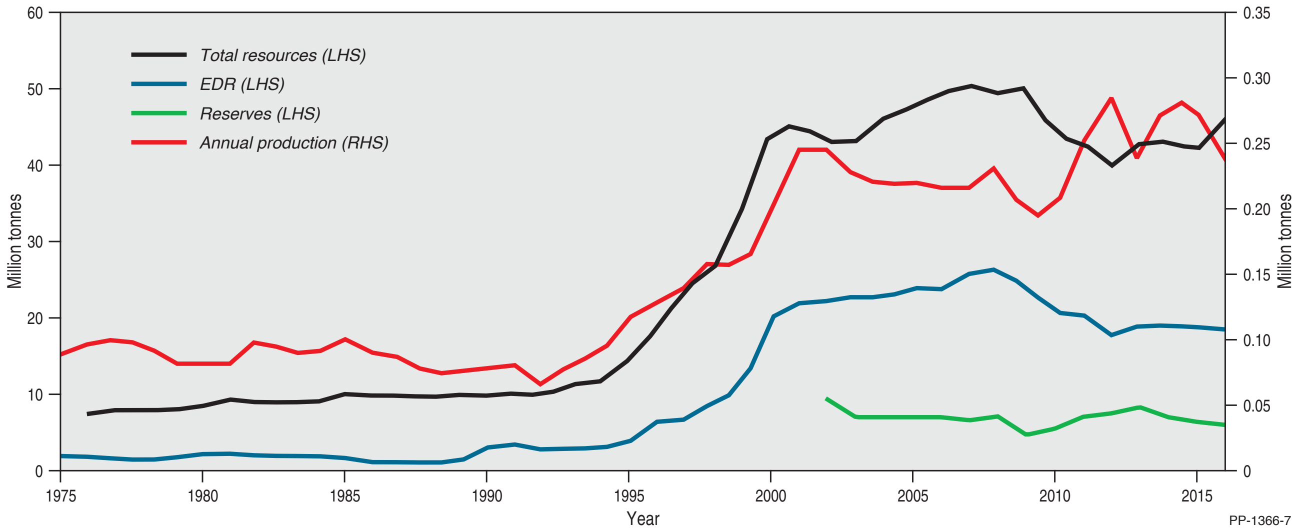


Figure 23 Trends in total resources, Economic Demonstrated Resources, Ore Reserves and annual production of nickel, 1975–2016. LHS/RHS=refer to axis on left-hand side/right-hand side.

Lead and Zinc

Lead and zinc typically occur together in many mineral deposits because they have very similar geochemical behaviours in hydrothermal fluids. Silver also commonly occurs with zinc and lead for similar reasons, and it also frequently occurs as a trace element in galena, the main ore mineral for lead.

In 2016, Australia's EDR of lead decreased slightly to 35.1 Mt from 35.3 Mt in 2015, whereas EDR of zinc increased slightly to 63.5 Mt up from 62.6 Mt in 2015 (Table 3). Queensland has 58% of the national total of EDR for zinc, 61% for lead and 57% for silver (Figure 2), mainly in the Mount Isa region. The Northern Territory has 30% of the national total of EDR for zinc, 25% for lead and 10% for silver (Figure 2), most of which are at the McArthur River mine. Globally, Australia is a major producer of lead and zinc (Table 7) and, in addition to mining activities, also produces lead bullion at Mount Isa (Queensland), smelts and refines these metals at Port Pirie in South Australia, and produces zinc metal at Risdon in Tasmania (one of the world's largest zinc refineries).

Australia's economic resources for both lead and zinc are the world's largest holdings at 40% and 28%, respectively, while Australia has the second largest holdings of silver (16%) behind Peru (Table 7). Other significant holders of lead resources are China (19%) and Russia and Peru (both 7%), with China and Peru also hosting significant zinc resources, 18% and 11%, respectively.

Australia has a large Ore Reserves of both lead and zinc. Lead Reserves in 2016 amounted to 11.52 Mt (Table 2) of which 10.06 Mt (87%) is attributable to 13 operating mines (Table 1). Zinc Reserves in 2016 amounted to 24.26 Mt (Table 2) of which 18.53 Mt (76%) is also attributable to 13 operating mines (Table 1). Twelve mines produce both lead and zinc with Peak (New South Wales) the thirteenth lead mine and Bentley (Western Australia) the thirteenth zinc mine.

These mines produced 0.45 Mt of lead and 0.88 Mt of zinc in 2016, significantly down from 2015 levels. In 2015, Australian mines produced 0.65 Mt of lead and 1.61 Mt of zinc, meaning that 2016 production has dropped more than 30% for lead and 45% for zinc because of Glencore plc's decision to decrease production from their deposits in northwest Queensland and the Northern Territory. Exports of lead concentrates (189 kt), lead bullion (153 kt) and refined lead (242 kt) had an export value of $1623 million in 2016 down from $1970 million in 2015. Similarly, exports of zinc concentrates (1.557 kt) and refined zinc (0.397 kt) were down with an export value of $2270 million in 2016 compared to $3061 million in 2015.

At 2016 levels of lead production, average reserve life at operating mines is potentially 22 years and resource life could be 66 years (Table 1). If Ore Reserves at mines on care and maintenance, developing mines and undeveloped deposits are also considered, the reserve life of lead is potentially 25 years and if AEDR is used as an indication of long-term potential supply, then at 2016 rates of production, Australia's lead resources could last almost 80 years. For zinc, the potential average reserve life and resource life at operating mines is slightly lower than lead at 21 years and 58 years, respectively. When all deposits are considered, the reserves/production ratio is 27 years and using AEDR, the long-term potential outlook is about 70 years at current rates of production. Thus, at current rates of production, and even with increased rates of production, Australia has the potential to produce lead and zinc for many decades to come.

Figure 24 and Figure 27 show that annual production is equal to only 4% of the lead and zinc reserves in 2016 but cumulative production over the last 15 years (9.83 Mt for lead and 20.9 Mt for zinc) accounts for 94% of the lead Ore Reserve from 2002 (10.4 Mt) and 88% of the zinc Ore Reserve from 2002 (23.8 Mt). These figures also show that Ore Reserves of lead and zinc have only slightly increased over the last 15 years, despite a number of peaks in previous years. Ore Reserves of lead increased from 10.4 Mt in 2002 to a high of 15.4 Mt in 2012 before falling to the 2016 level of 11.52 Mt, an 11% increase overall for the last 15 years. Zinc reserves followed a similar pattern to lead reserves over the same period with a 35% increase from 2002 (23.8 Mt) to 2012 (32.1 Mt) before falling to 24.3 Mt in 2016, an overall increase of just 2% over the last 15 years. As a ratio, annual production of both lead and zinc from 2002 to 2015 was equal to around 5–7% of the Ore Reserve but fell sharply in 2016 to less than 4%.

This fall in production is also seen in Figure 24 and Figure 27. From 2002 to 2015, lead production ranged between 0.57 Mt and 0.77 Mt but has fallen 30% to 0.45 Mt in 2016. From 2002 to 2015, zinc production generally increased from 1.47 Mt to 1.61 Mt (with a significant dip to 1.00 Mt in 2008) but is down almost 50% from the high of 2015, to just 0.88 Mt in 2016.

Figure 25 and Figure 28 demonstrate the large Australian inventory of lead and zinc when EDR rather than just Ore Reserves are considered. Over the last 40 years, cumulative production of both lead (23.4 Mt) and zinc (43.2 Mt) has exceeded the 13.9 Mt of lead resources and the 19.3 Mt of zinc resources assessed as economic back in 1975. Indeed, cumulative production of lead and zinc has exceeded estimates of EDR for every year since 1975 to 1992.

Figure 26 shows that over the last 40 years, lead production rose significantly (88%) from 1975 (0.41 Mt) to 2005 (0.77 Mt) but has fallen in 2016 (0.45 Mt) to levels only 10% greater those of the 1970s. Zinc production (Figure 29) similarly increased from 1975 (0.50 Mt) to a recent high of 1.61 Mt in 2015, a 220% gain, but loss of production to just 0.88 Mt means that zinc production in 2016 is only 76% greater than in 1975. The resource inventory, on the other hand, has risen faster. While lead production has increased 10% (but as much as 88% in 2005) since 1975, lead EDR has increased 150% and, since 1976, total resources (EDR + subeconomic + inferred) has risen more than 130% (Figure 26). Since 1975, zinc production has increased 76% (but as much as 220% in 2015) but zinc EDR has increased 230% whereas, since 1976, total resources have increased 125% (Figure 29).

These EDR gains for lead and zinc were irregular and even saw periods of loss. The adoption of the JORC Code in 1988 by the Australian mineral industry led to a re-estimation of mineral resources by many companies to align with the code and some reassessments of resource data for other deposits by Geoscience Australia's predecessor, the Bureau of Mineral Resources. This resulted in a fall in Australia's lead and zinc EDR in 1989. Increases in EDR for lead and zinc in 1993 resulted from the reclassification of paramarginal demonstrated resources into EDR for the McArthur River deposit in the Northern Territory and the George Fisher deposit in Queensland. Additional resources were also reported for the Century and Cannington deposits in Queensland. And increases in 2008 and 2009 were associated with the reassessment of resources at the McArthur River mine and the Dugald River deposit as well as the reporting of additional resources for George Fisher.

Exploration expenditure on zinc, lead and silver in 2016 was $47 million, down from $51 million in 2015 continuing the down trend from the peak of 2007 when some $232 million was spent.

Figure 24 Lead Ore Reserves and annual production 2002–2016, as well as cumulative production since each year. LHS/RHS=refer to axis on left-hand side/right-hand side.

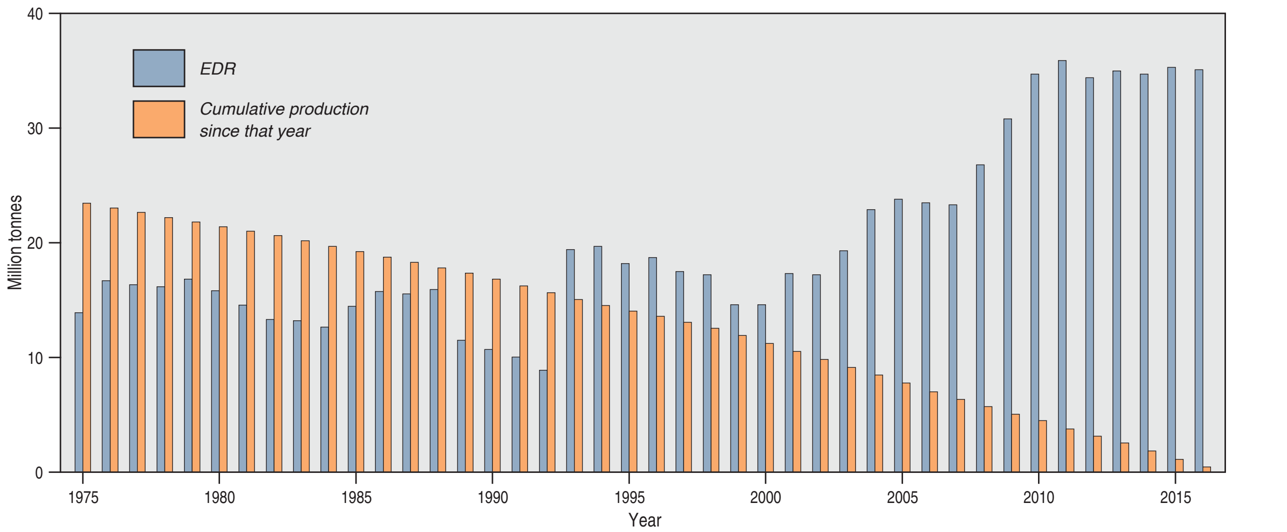


Figure 25 Economic Demonstrated Resources of lead 1975–2016, as well as cumulative production since each year.

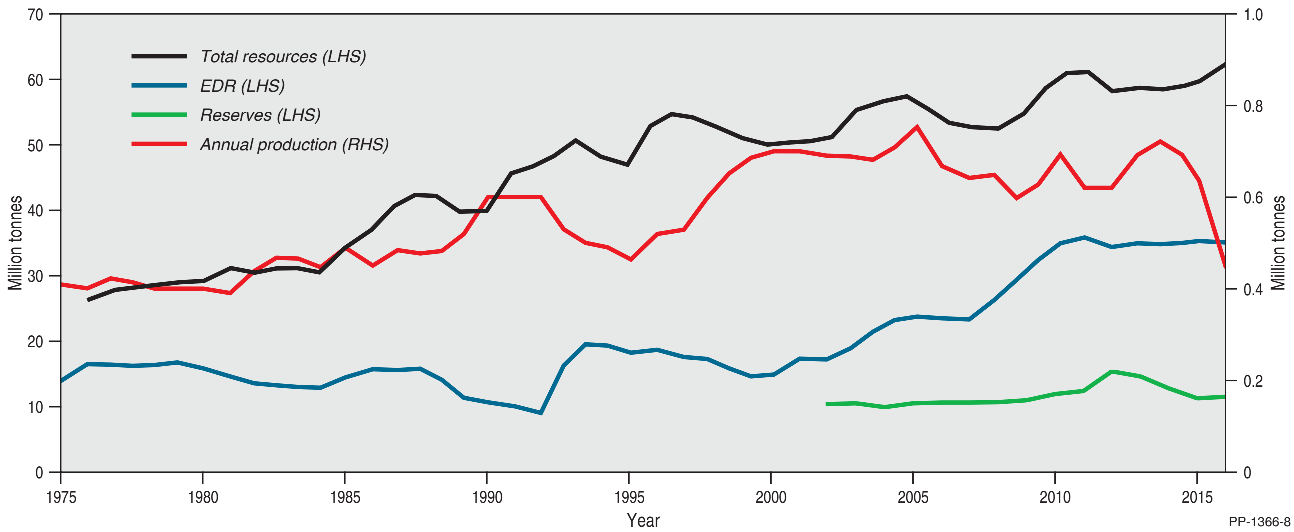


Figure 26 Trends in total resources, Economic Demonstrated Resources, Ore Reserves and annual production of lead, 1975–2016. LHS/RHS=refer to axis on left-hand side/right-hand side.

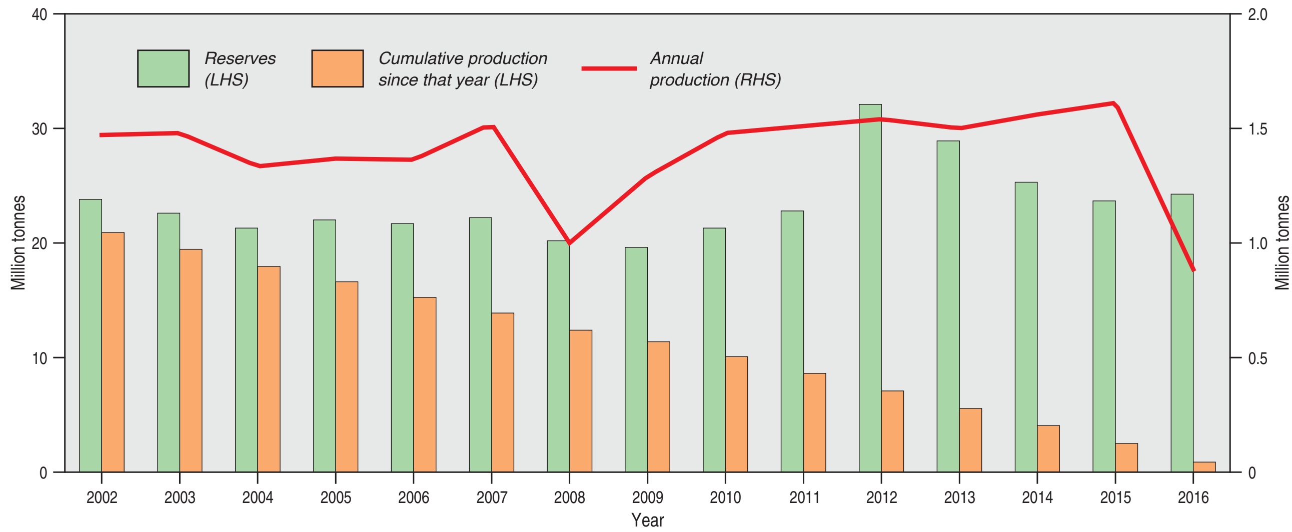


Figure 27 Zinc Ore Reserves and annual production 2002–2016, as well as cumulative production since each year. LHS/RHS=refer to axis on left-hand side/right-hand side.

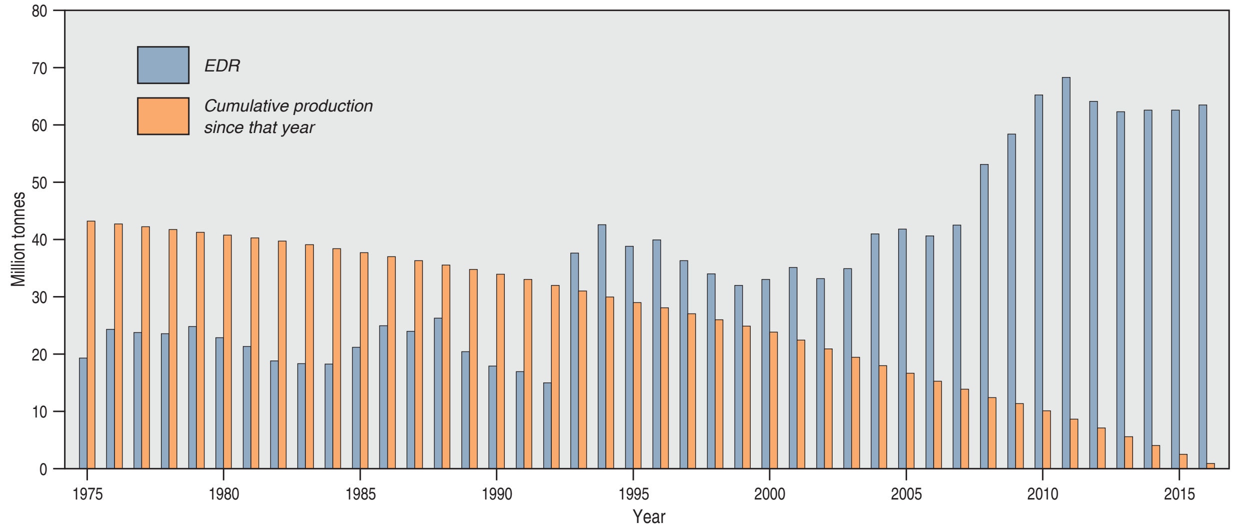


Figure 28 Economic Demonstrated Resources of zinc 1975–2016, as well as cumulative production since each year.

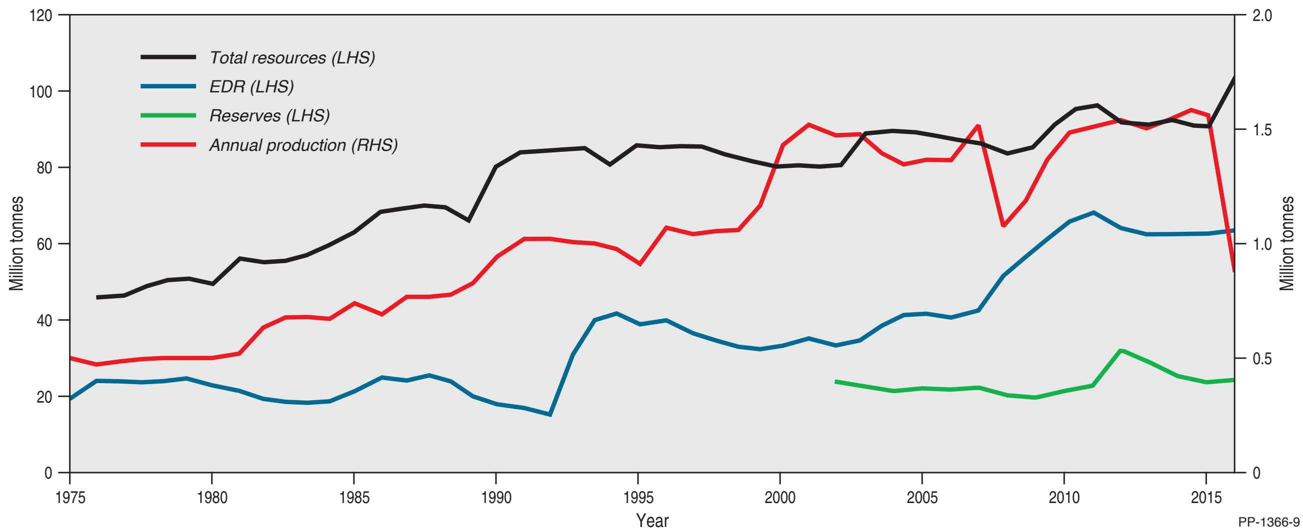


Figure 29 Trends in total resources, Economic Demonstrated Resources, Ore Reserves and annual production of zinc, 1975–2016. LHS/RHS=refer to axis on left-hand side/right-hand side.

Mineral Sands

The Murray Basin (Victoria, New South Wales and South Australia), Eucla Basin (South Australia and Western Australia) and Perth Basin (Western Australia) host the major share of Australia's mineral sand resources (ilmenite, rutile and zircon). Major economic resources have more recently also been identified in the Canning Basin (Western Australia). Notwithstanding this discovery, mineral sand exploration expenditure decreased again in 2016, to approximately $19 million, a fall of 42% in real terms since expenditure peaked in 2012. In 2016, an estimated 611 kt of ilmenite concentrate, 217 kt of rutile concentrate and 560 kt of zircon concentrate were exported from Australia, down 39%, 12% and 19%, respectively, on 2015 export figures.

Australia's EDR of mineral sands were estimated to be 276.9 Mt for ilmenite, 33.0 Mt for rutile and 78.6 Mt for zircon in 2016 (Table 3). These estimates represent increases of 11–12% on 2015 EDR figures[7]. Australia has the world's largest EDR of rutile (50%; Table 7) followed by Kenya (21%), South Africa (13%) and India (12%). Australia also has the world's largest EDR of zircon (67%; Table 7) followed by South Africa (18%) and the second largest EDR of ilmenite (19%; Table 7) after China (29%) and ahead of India (11%).

Australia has large Ore Reserves of mineral sands amounting to 56.5 Mt, 6.7 Mt and 20.0 Mt of ilmenite, rutile and zircon, respectively (Table 2). In 2016, there were seven operations producing ilmenite, rutile and zircon and an eighth producing just zircon (Table 1). These mines account for 26%, 31% and 24% of Australia's ilmenite, rutile and zircon Ore Reserves, respectively. These mines produced 1.4 Mt of ilmenite, 0.3 Mt of rutile and 0.6 Mt of zircon in 2016, a 55% increase for ilmenite from 2015 but largely unchanged for rutile and zircon. In addition, Australia has large Inferred Resources of ilmenite (235.1 Mt), rutile (34.1 Mt) and zircon (61.3 Mt) plus smaller amounts that are regarded as subeconomic (Table 3).

At 2016 levels of production, the average reserve life at operating mines is potentially 11 years for ilmenite, 7 years for rutile and 8 years for zircon (Table 1). Resource life for ilmenite, rutile and zircon at operating mines is almost triple the reserve life at 33 years, 18 years and 21 years, respectively (Table 1). If Ore Reserves at mines on care and maintenance, developing mines and undeveloped deposits are also considered, the reserve life for ilmenite, rutile and zircon is potentially 40 years, 22 years and 33 years, respectively, and if AEDR is used as an indication of long-term potential supply, then at 2016 rates of production, Australia's minerals sands resources could last more than a century.

Figure 30, Figure 33 and Figure 36 show that annual production for ilmenite (1.4 Mt), rutile (0.3 Mt) and zircon (0.6 Mt) are equal to only 2%, 4% and 3% of their respective Ore Reserves in 2016. However, cumulative production of ilmenite over the last 15 years is 24.9 Mt which is almost equal to the Ore Reserve of 25.1 Mt from 2002 (Figure 30). Cumulative production for rutile (4.3 Mt; Figure 33) and zircon (8.4 Mt; Figure 36) over the same time period actually exceeds the rutile and zircon Ore Reserves from 2002 (3.4 Mt and 5.3 Mt, respectively).

Figure 30 shows that ilmenite production has fallen 26% over the last 15 years from its 2002 level of 1.9 Mt and, despite a 55% increase on 2015 production, production in 2016 was down 42% from its 2006 peak of 2.4 Mt. Some heavy mineral sands producers closed operations at low-grade ilmenite deposits to concentrate on deposits with higher zircon content or those more readily amenable to beneficiation. Ilmenite reserves have, however, increased 125% over the last 15 years from 25.1 Mt in 2002 to 56.5 Mt in 2016, after recovering from a post global financial crisis low of 27.7 Mt in 2009.

Figure 33 shows a similar story of rising Ore Reserves for rutile. Rutile Reserves have doubled over the last 15 years from 3.4 Mt in 2002 to 6.7 Mt in 2016 having reached a peak of 10.1 Mt in 2013. Unlike ilmenite, production of rutile over this time period has increased 36% from 0.22 Mt in 2002 to 0.3 Mt in 2016. Peak production (0.47 Mt), however, was actually achieved in 2011, bouncing back after sharply lower levels of mineral sands production in 2009, due to flow-on effects of the global financial crisis in late 2008. Since the high of 2011, rutile production has fallen 36% over the last five years as prices for rutile and ilmenite have remained soft.

Figure 36 shows that Ore Reserves of zircon, like those of ilmenite and rutile, have also risen significantly (nearly 300%) over the last 15 years from 5.3 Mt in 2002 to 20.0 Mt in 2016. Zircon production has also declined 25% from its 2015 peak of 0.8 Mt but is still on a rising trend in which production has risen 50% from 0.4 Mt in 2002 to 0.6 Mt in 2016.

When EDR, rather than just Ore Reserves, are considered, Figure 31, Figure 34 and Figure 37 demonstrate the vast inventory of Australian mineral sands. Over the longer time period of 40 years, cumulative production of 66.7 Mt of ilmenite, 10.6 t of rutile and 20.0 Mt of zircon has removed more material than was estimated as EDR back in 1975 (58.4 Mt for ilmenite, 9.2 Mt for rutile and 15.7 Mt for zircon), yet, EDR has grown enormously since 1975 with all of the exploited mineral sands replaced many times over.

Increases in mineral sands EDR (as well as Inferred Resources) from 1996 to 2003 (Figure 32, Figure 35 and Figure 38) resulted from discovery and subsequent evaluation drilling of heavy mineral sand deposits in the Murray Basin which include the Ginkgo and Snapper deposits in New South Wales, Douglas-Bondi and Woornack deposits in Victoria, and the Mindarie project in South Australia. In addition, from 1998 onwards, there were progressive increases in resources at mineral sand deposits at Jacinth-Ambrosia and Cyclone in the Eucla Basin embracing parts of South Australia and Western Australia, in the North Swan Coastal Plain area north of Perth and the Blackwood Plateau region in Western Australia. From 2007 to 2012, the EDR of ilmenite declined (Figure 32) owing to reclassification of some resources to lower resource categories but has since increased owing to new resource delineation, particularly in Western Australia.

[7] Ilmenite, rutile and zircon 2015 Reserves and Resources estimates have been revised from those reported in Table 1 of Australia's Identified Mineral Resources 2016 due to a miscalculation. Ilmenite Ore Reserves for 2015 are revised from the previously reported 49.2 Mt to 41.6 Mt. Ilmenite EDR 2015 is revised from 267.8 Mt to 249.5 Mt. Ilmenite Inferred Resources are revised from 258.6 Mt to 276.4 Mt. Rutile Ore Reserves 2015 are revised from 10.8 Mt to 7.5 Mt. Rutile EDR 2015 is revised from 36.9 Mt to 29.6 Mt. Rutile Inferred Resources are revised from 43.1 Mt to 39.4 Mt. Zircon Ore Reserves are revised from 20.3 Mt to 15.0 Mt. Zircon EDR is revised from 81.4 Mt to 71.0 Mt. Zircon Inferred Resources are revised from 74.9 Mt to 73.5 Mt.

Over the last 40 years, the mineral sands inventory has increased rapidly. From 1975 to 2016:

- ilmenite EDR increased 370% from 58.4 Mt to 276.9 Mt (Figure 32);
- rutile EDR increased 260% from 9.2 Mt to 33.0 Mt (Figure 35); and
- zircon EDR increased 400% from 15.7 Mt to 78.6 Mt (Figure 38).

Mineral sands production over this time period, however, has seen slower increases for ilmenite and zircon and a decrease for rutile. From 1975 to 2016:

- Ilmenite production increased 40% from 0.99 Mt to 1.40 Mt (Figure 32);
- rutile production decreased 14% from 0.35 Mt to 0.30 Mt (Figure 35); and
- zircon production increased 58% from 0.38 Mt to 0.60 Mt (Figure 38).

Since 1976, total mineral sand resources (EDR + subeconomic + inferred) has increased almost 750% for ilmenite (Figure 32), 500% for rutile (Figure 35) and 650% for zircon (Figure 38). Thus, at current rates of production, and even with increased rates of production, Australia has the potential to remain a top global producer for many decades into the future.

Heavy mineral sands mining camp in the Eucla Basin, South Australia. Ilmenite and Rutile provide the titanium metal used by the aerospace industry. Photograph courtesy of Iluka Resources Ltd.

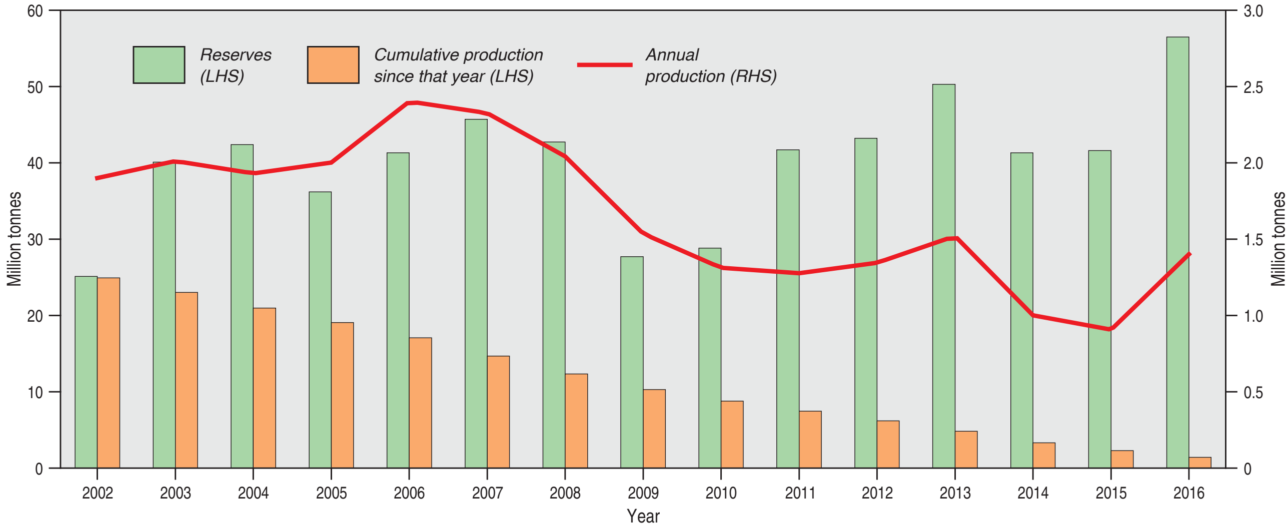


Figure 30 Ilmenite Ore Reserves and annual production 2002–2016, as well as cumulative production since each year. LHS/RHS=refer to axis on left-hand side/right-hand side.

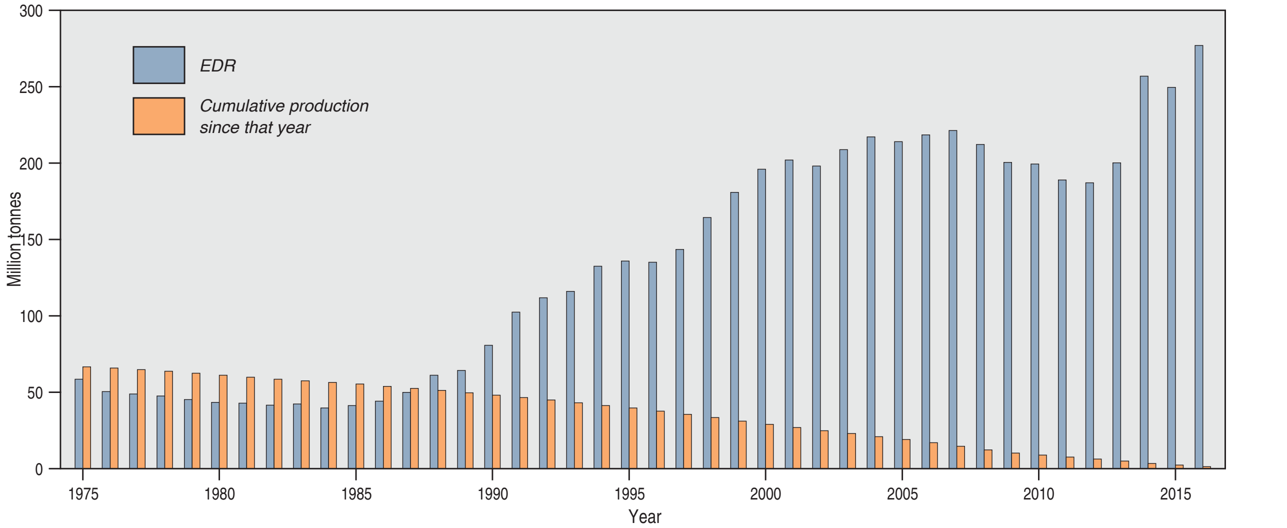


Figure 31 Economic Demonstrated Resources of ilmenite 1975–2016, as well as cumulative production since each year.

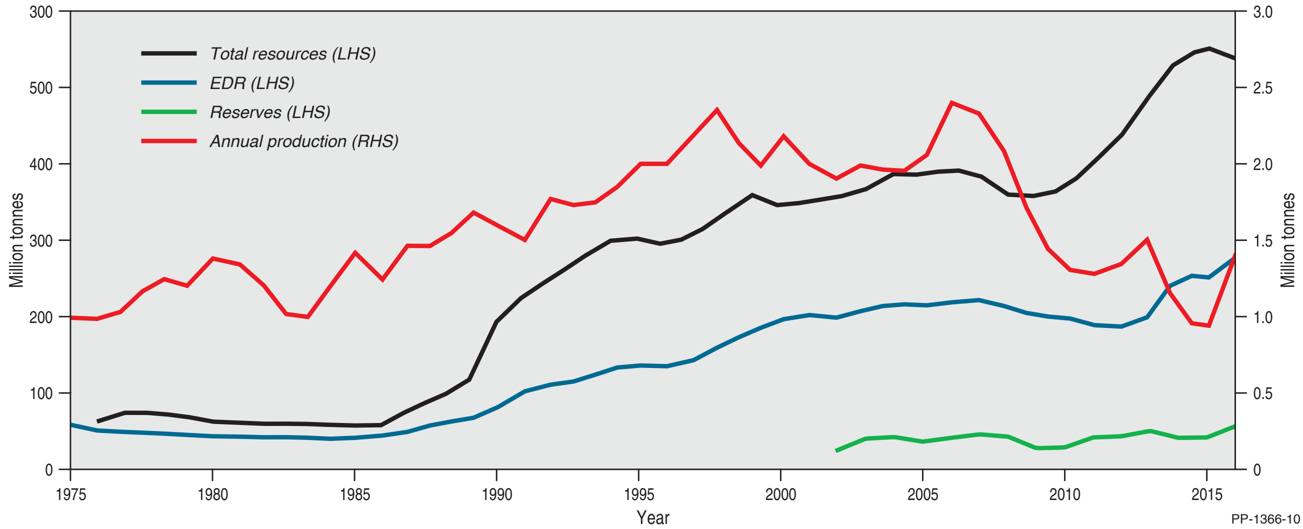


Figure 32 Trends in total resources, Economic Demonstrated Resources, Ore Reserves and annual production of ilmenite, 1975–2016. LHS/RHS=refer to axis on left-hand side/right-hand side.

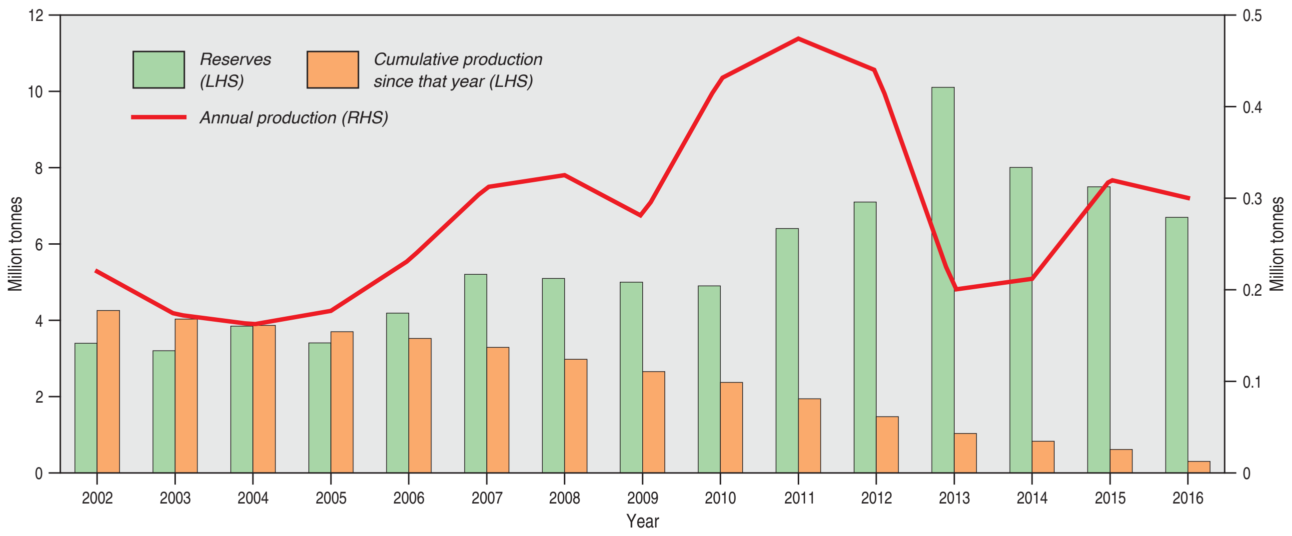


Figure 33 Rutile Ore Reserves and annual production 2002–2016, as well as cumulative production since each year. LHS/RHS=refer to axis on left-hand side/right-hand side.

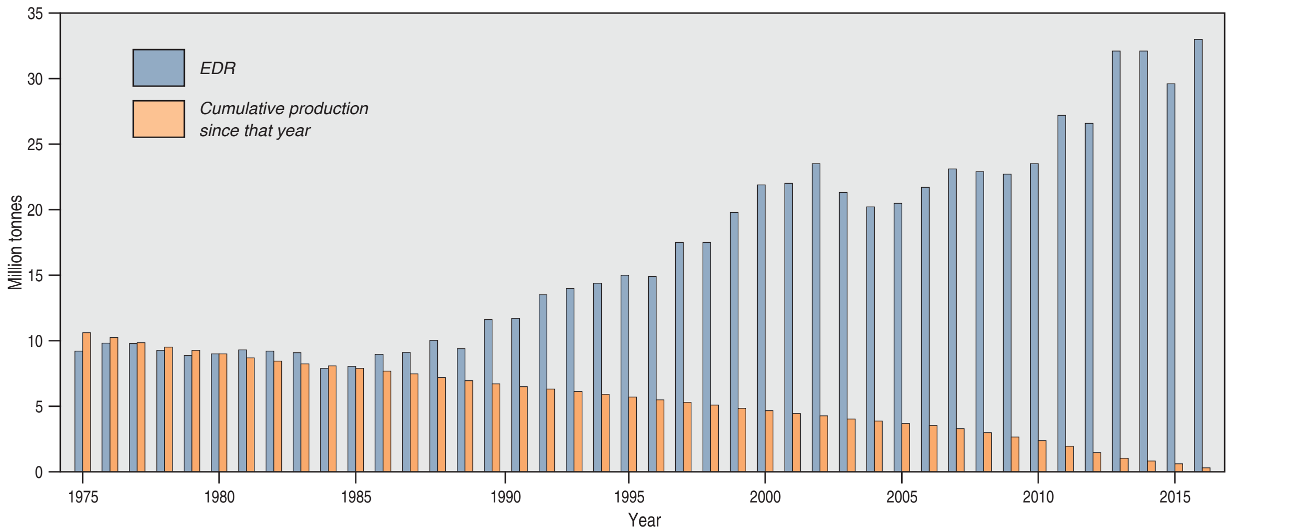


Figure 34 Economic Demonstrated Resources of rutile 1975–2016, as well as cumulative production since each year.

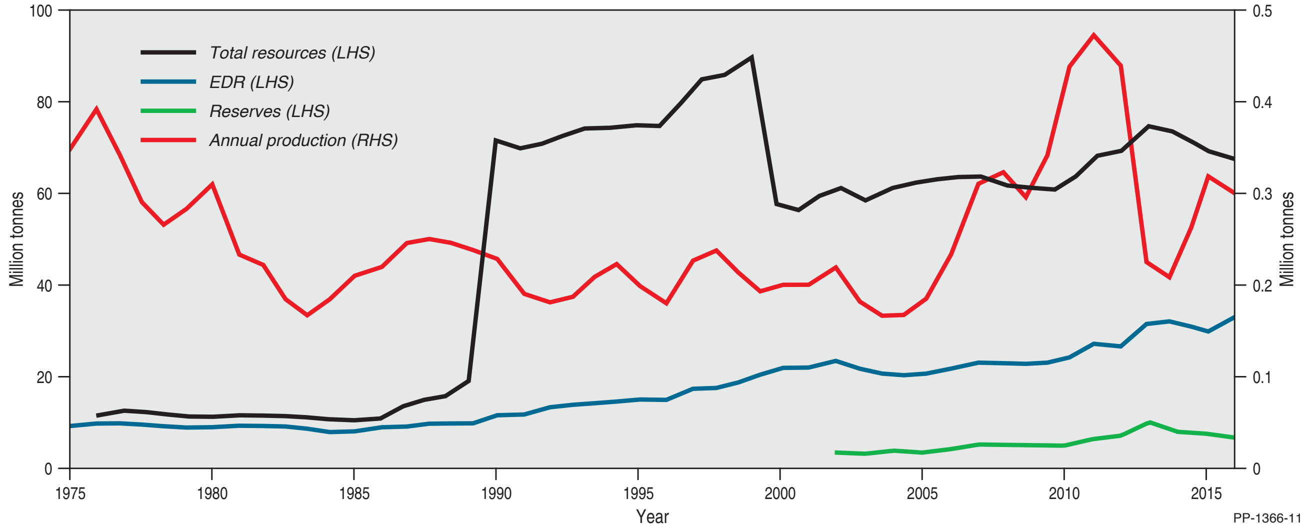


Figure 35 Trends in total resources, Economic Demonstrated Resources, Ore Reserves and annual production of rutile, 1975–2016. LHS/RHS=refer to axis on left-hand side/right-hand side.

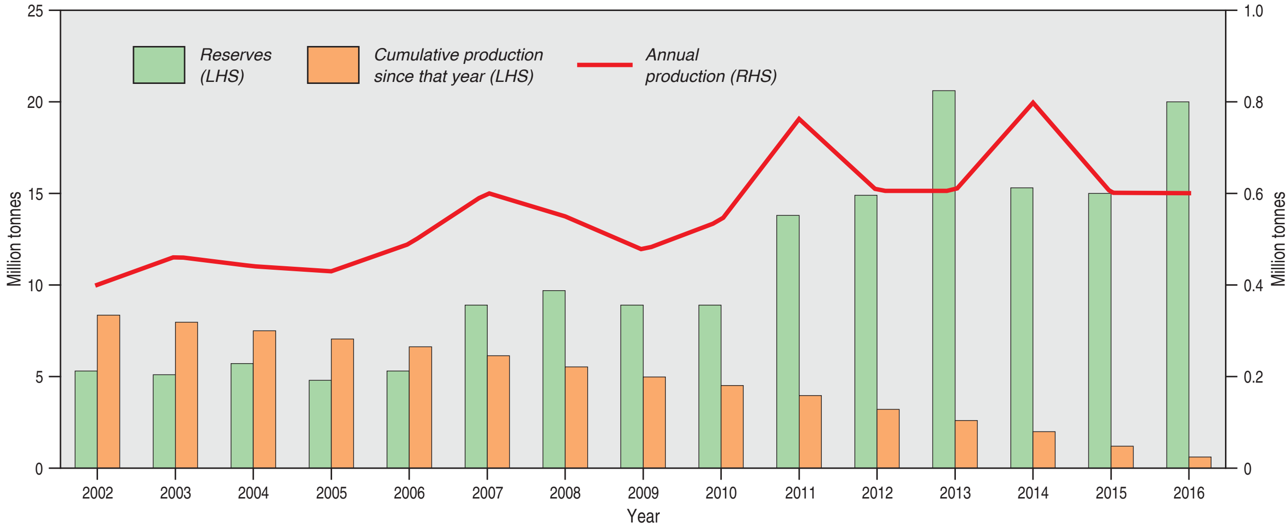


Figure 36 Zircon Ore Reserves and annual production 2002–2016, as well as cumulative production since each year. LHS/RHS=refer to axis on left-hand side/right-hand side.

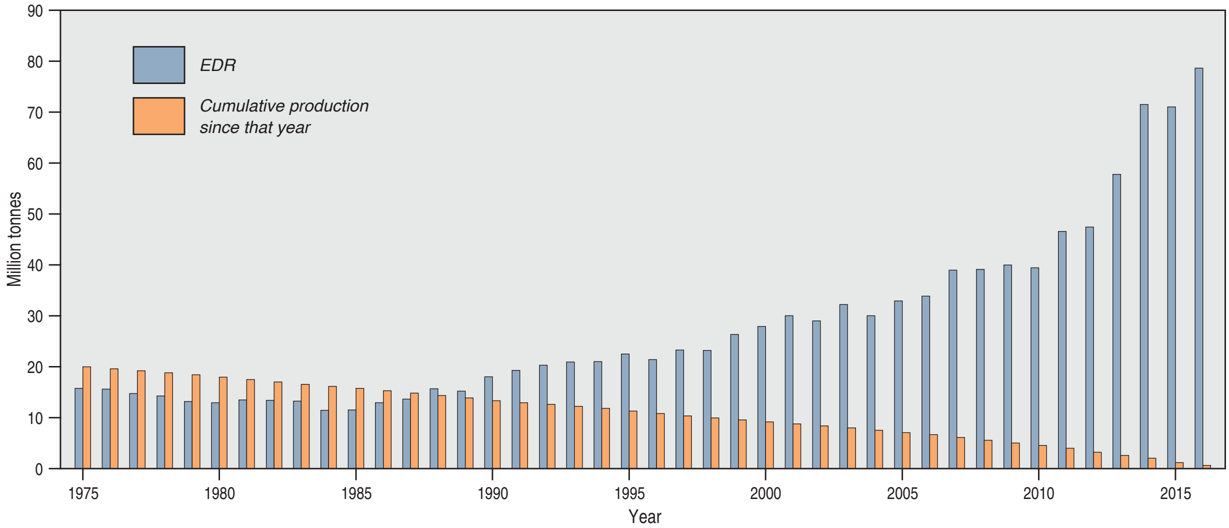


Figure 37 Economic Demonstrated Resources of zircon 1975–2016, as well as cumulative production since each year.

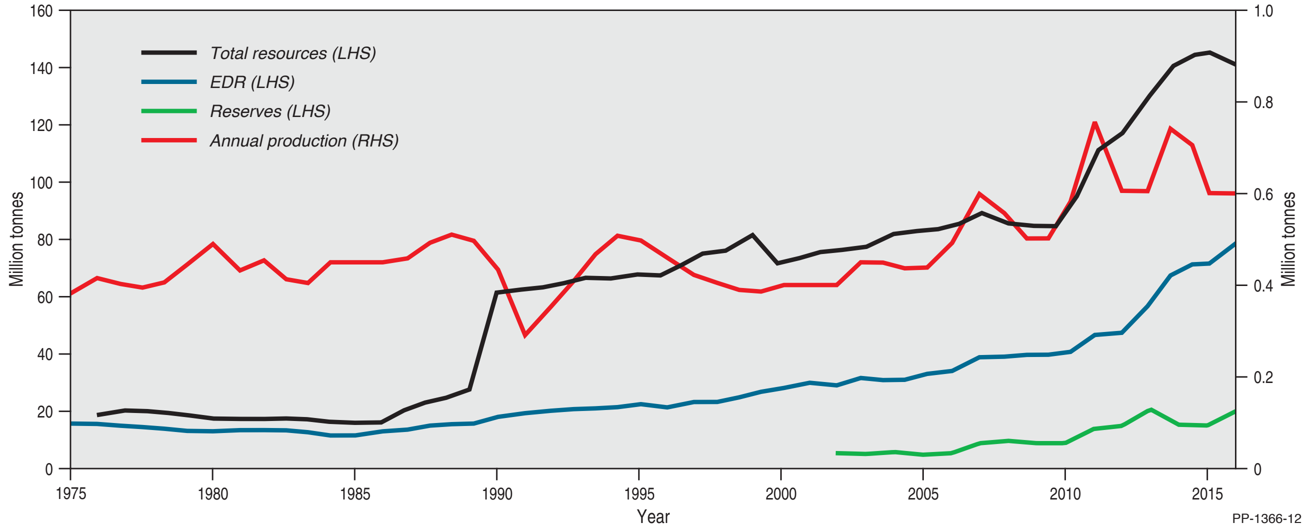


Figure 38 Trends in total resources, Economic Demonstrated Resources, Ore Reserves and annual production of zircon, 1975–2016. LHS/RHS=refer to axis on left-hand side/right-hand side.

Exploration drilling for lithium and tantalum at Pilgangoora, Western Australia. Photograph courtesy of Pilbara Minerals Ltd.

6. Identified Resources of Other Commodities

Brown Coal: The 2016 estimate of Australia's recoverable brown coal EDR remains unchanged from 2015 at 76 508 Mt (Table 3). Nearly all of Australia's recoverable brown coal EDR is located in Victoria with more than 93% in the Latrobe Valley. Australia is ranked second in the world in terms of recoverable brown coal, accounting for 24% of the world's lignite reserves (Table 7), behind Russia (29%) and followed by Germany (11%) and the USA (10%).

During 2016, brown coal production in Australia was estimated at 63.3 Mt (Table 3), ranking Australia fifth in the world (Table 7) behind Germany, China, Russia and the USA. Brown coal mined in Australia is used almost exclusively for domestic electricity generation in Victoria, where it is burnt in adjacent power plants; although a small mine at Maddingley, 50 km northwest of Melbourne, produces agricultural products. At 2016 rates of extraction, the accessible resource base will support over 1000 years of production.

In 2015, the Anglesea brown coal-fired power station on Victoria's south coast closed, leaving the Loy Yang and Yallourn power stations operating in the Latrobe Valley. The closure of the Hazelwood power station, in Victoria's LaTrobe Valley, will reduce Australian brown coal production rates from March 2017 onwards.

Diamond: In 2016, Australia's total EDR of diamond resources was 115.8 Mc (Table 3), down from 209.4 Mc in 2015. This is largely due to a decrease in Ore Reserves and Mineral Resources at the Argyle diamond mine resulting from mining and updated mine planning. Total production increased slightly over the same period from 13.6 Mc to 14.0 Mc. The Argyle lamproite pipe in the east Kimberley region of Western Australia was responsible for almost all diamond production in Australia. Production of diamond from stockpiles at the Ellendale mine in the west Kimberley ceased in 2016 following mine closure in June 2015. Mining operations at the Merlin mine in the Northern Territory recommenced in October 2016, but without significant production of diamond for the year.

Lithium: Australia's EDR of lithium was 2730 kt in 2016 (Table 3) up from 1610 kt in 2015. Australia ranks third globally (Table 7), behind Chile and China, with just over 18% of the world's economic resources and first for production (41%; Table 7). All of Australia's EDR of lithium occur within hard-rock pegmatite deposits. The Greenbushes deposit, which is the world's largest and highest grade spodumene deposit, contains just under 50% of Australia's lithium EDR (although the most recent Greenbush resource figures are for 2012). Other resources occur at Mount Cattlin, Mount Marion and Earl Grey in the Yilgarn region, and the two Pilgangoora deposits in the Pilbara region, all in Western Australia.

In May 2017, maiden resource figures were released for the Grants lithium deposit, near Darwin, Northern Territory. Industry activity in 2016 has seen the Pilgangoora, Mount Cattlin and Mount Marion projects advancing and maiden resource figures released for the Earl Grey deposit in the Forrestania region near Southern Cross. Lithium exploration continued in other parts of Australia, including the Bynoe pegmatite field near Darwin where significant lithium-bearing pegmatites (such as Grants) have been identified.

In March 2017, Talison Lithium Pty Ltd announced that it had approved the expansion of Greenbushes to double annual production, by early in the next decade, to approximately 160 kt of lithium carbonate equivalent. The expansion will supply a $400 million lithium processing plant that will be built at Kwinana, south of Perth.

Magnesite: In 2016, Australia's EDR of magnesite remained essentially unchanged from 2015 at 320.48 Mt (Table 3), representing approximately 4% of world total (Table 7). The Department of State Development, South Australia reported magnesite production of 6554 t in 2016, up from 2015 by approximately 1900 t. The Queensland Department of Natural Resources and Mines reported magnesite production of 462 901 t in 2015–16, down by approximately 200 000 t from the previous year. Australian magnesite is generally intended for the production of magnesia, for example Jindalee Resources Ltd's Arthur River deposit and Archer Exploration Ltd's Leigh Creek deposit.

Manganese Ore: Australia's EDR of manganese declined by 13 Mt in 2016 to 219 Mt (Table 3), ranking Australia's resources as the world's fourth largest (Table 7) behind South Africa, Ukraine and Brazil. All EDR occur in the Northern Territory and Western Australia. Australia's mine production of manganese ore was 3.2 Mt in 2016 (Table 3), ranked fourth behind China, South Africa and Gabon (Table 7). Two of Australia's manganese mines, Bootu Creek and Woodie Woodie, remained in care and maintenance with all current production coming from Groote Eylandt in the Northern Territory.

Molybdenum: Australia's EDR of molybdenum in 2016 was 210 kt (Table 3), an 11% increase from 190 kt in 2015, reflecting a resource upgrade at Kalman (Queensland) and the maiden resource at Calingiri (Western Australia). Australia ranks seventh globally but has less than 1.5% of the world's economic resources (Table 7), which are dominated by China, the USA and Chile. The bulk of Australia's EDR of molybdenum occurs in Queensland (66%), followed by Victoria (24%), Western Australia (5.7%) and the Northern Territory (2.3%). New South Wales also has molybdenum deposits but less than 1% of Australia's EDR.

Niobium: Australia's EDR of niobium remained steady in 2016 at 286 kt (Table 3) after increasing 40% in 2015 owing to new resource estimates at the Hastings deposit in Western Australia. The bulk (71%) of Australia's EDR of niobium occurs in the Toongi deposit, 20 km south of Dubbo in New South Wales. Paramarginal resources occur in the Mount Weld and Mount Deans deposits (both in Western Australia) and other resources occur at Narraburra in New South Wales and in the Greenbushes tantalum deposit in Western Australia. World data are scarce but Australia's resources of niobium could be the second largest in the world behind Brazil (Table 7).

Oil Shale: Resources of oil shale predominantly occur in a series of sedimentary basins around Gladstone, Mackay and Proserpine in central Queensland with paramarginal and submarginal (contingent) resources estimated at 2287 GL (14 385 million barrels) and inferred (prospective) resources estimated at 1472 GL (9261 million barrels). Australia currently has no EDR of oil shale, with all resources being assessed as subeconomic (Table 3).

Phosphate: Geoscience Australia assesses both phosphate rock (phosphorite and guano) and contained P_2O_5 which, as well as being a component of phosphate rock, can be found in other rock types in which alternative minerals are the primary target. Australia's EDR of phosphate rock was 1072 Mt in 2016 (Table 3), unchanged from 2015. Contained P_2O_5 EDR decreased slightly to 180 Mt (Table 3), owing to ongoing resource assessment on Christmas Island. The phosphorites of the Georgina Basin (Queensland and the Northern Territory) account for almost all of Australia's EDR of phosphate rock

and 90% of Australia's EDR of contained P_2O_5. The remaining phosphate rock occurs at Christmas Island. The rare earth deposit at Mount Weld (Western Australia) also has an EDR of contained P_2O_5. Australia has less than 2% of the world's economic resources of phosphate rock (Table 7) with Christmas Island and Phosphate Hill (Queensland) the only significant producers.

Platinum Group Elements: Australia's 2016 EDR of platinum group elements remains unchanged from 2015 at 5.3 t (Table 3). This represents <1% of the world total of 67 Mt (USGS estimate). The Western Australian Department of Mines and Petroleum reported that 687 kg of platinum and palladium was produced during 2015–16, up from 464 kg the previous year. In addition to public reports of resources of platinum group elements, Australian mineral deposits may contain unreported resources that are recovered as by-products to the primary commodity being mined (usually nickel sulphide ores).

Potash: Potash is a generic term covering a variety of potassium-bearing ores, minerals and refined products. Nearly all of Australia's potash resources occur in Western Australia, with the exception of Karinga Lakes in the Northern Territory and Lake Mackay which occurs on the border between the two jurisdictions. In addition, nearly all Australian potash resources occur in lake brines with resources also delineated at Kalium Lakes, Lake Chandler, Lake Disappointment, Lake Hopkins, and Lake Wells. Minor potash also occurs in the Dandaragan (greensands) deposit and the Oxley deposit, which is a new type of potash deposit hosted in ultrapotassic microsyenite lava flows. However, none of these resources have yet been upgraded to an Ore Reserve.

In 2016, Australia's EDR of potash was 56 Mt K_2O (Table 3), up from 32.4 Mt in 2015. The bulk of this increase was a result of significant industry activity at the Beyondie and the Lake Disappointment projects. At Beyondie, Kalium Lakes Ltd completed initial bore tests of the lake brine and released a positive prefeasibility study. Work continues with large-scale trial pilot ponds and purification plant trials in Germany and the project has now progressed to a bankable feasibility study. At Lake Disappointment, Reward Minerals Ltd has constructed pilot ponds and trenches for geotechnical evaluations and commissioned a project feasibility study. Industry activity also occurred at Lake Wells where Salt Lake Potash Ltd produced a positive scoping study in 2016 and Goldphyre Resources Ltd produced a maiden Inferred Resource for their (separate) Lake Wells project, with the company proceeding to install test production wells.

Australia's potash resources remain minor by world standards (2%, Table 7) with Canada, Russia and Belarus leading supply. Potash was not mined in Australia in 2016.

Rare Earths (REO & Y_2O_3): In 2016, Australia's EDR of rare earths remained essentially unchanged from 2015 at 3.43 Mt (Table 3). This accounts for approximately 3% of the world total (Table 7) of 120 Mt (USGS estimate), of which China holds the greatest proportion of any country (>36%). China also dominates world production (>83%) but Australia is the second largest supplier (11%; Table 7). In Australia, Lynas Corporation Ltd mines Mount Weld on a campaign basis, completing its second campaign in May 2017 and commencing a third in September. Mined mineral concentrate is supplied to the Lynas Advanced Materials Plant (LAMP) in Malaysia for the production of separated rare earth oxides and, in 2016, LAMP produced approximately 14 kt.

In early December 2017, Northern Minerals Ltd announced it had mined 205 kt of ore at its Browns Range Heavy Rare Earths Project and that construction of its pilot plant is progressing. Arafura Resources Ltd announced in September 2017 that it has progressed various pilot phases intended to demonstrate technical and operational viability at Nolans Bore. Alkane Resources Ltd's 2016 Annual Report confirmed their Dubbo project (Toongi) is ready for construction with a well-established flowsheet. In November 2017, Hastings Technology Metals Ltd announced the successful completion of a definitive feasibility study at Yangibana. These examples highlight that Australia has the potential to further its global standing as an alternative supplier to China of both light and heavy rare earths.

Silver: Australia's EDR of silver increased in 2016 to 89.3 kt (Table 3) from 88.7 kt in 2015. Australia has the second largest holdings of silver (16%; Table 7) behind Peru (21%) and ahead of Poland (15%) and Chile (13%). Queensland has 57% of the national total of EDR for silver (Figure 2), mainly in the Mount Isa region. Significant EDR of silver are also found in New South Wales (14%), South Australia (12%) and the Northern Territory (10%) where most of the silver is in the McArthur River mine (Figure 2). Exploration expenditure on zinc, lead and silver in 2016 was $47 million, down from $51 million in 2015.

Tantalum: Australia's EDR of tantalum was 75.7 kt in 2016 (Table 3), a 9% increase from 69.2 kt in 2015. World data are scarce, but Australia appears to rank first in the world ahead of Brazil for identified tantalum resources (Table 7). The bulk of tantalum EDR in 2016 was located in Western Australia, mainly at the Greenbushes (40%) and Wodgina (25%) deposits with smaller deposits at Pilgangoora, Tabba Tabba, Mount Cattlin and Dalgaranga. In 2016, industry activity in the Pilbara region resulted in a 350% increase to the EDR of tantalum at the Pilgangoora lithium-tantalum deposit. Outside of Western Australia, the Toongi deposit (Dubbo Project) in New South Wales contains 21% of Australia's tantalum EDR.

Tin: Australia's EDR of tin increased to 486 kt in 2016 (Table 3), up from 434 kt in 2015. Australia's resources are the world's fourth largest (Table 7) behind China, Indonesia and Brazil. The majority of Australia's EDR of tin is contained in the Renison Bell (60%) and Cleveland (9.5%) deposits in Tasmania and the Taronga (9.5%) deposit in New South Wales. All of Australia's EDR of tin occur in Tasmania (80.6%), New South Wales (9.4%) and Queensland (10%), although some tin (not reported) is produced as a by-product from Western Australian tantalum deposits. More than 95% of Australian tin production is from Renison Bell in Tasmania.

Tungsten: Australia's EDR of tungsten was 391 kt in 2016 (Table 3) down slightly from 403 kt in 2015 (reflecting the conversion of JORC 2004 Resources to JORC 2012 for two deposits). Australia has just over 11% of the world's economic resources (Table 7), ranking second behind China and ahead of Canada, Vietnam and Russia. Nearly half of Australia's EDR (48%) is contained within the O'Callaghans multi-commodity deposit in Western Australia. Australia's EDR of tungsten occur in Western Australia (53%), Tasmania (26%), Queensland (18%), the Northern Territory (2%) and New South Wales (<1%).

Vanadium: Australia's vanadium EDR increased by 17% in 2016 to 2111 kt (Table 3). This represents approximately 11% of estimated global vanadium resources, ranking Australia fourth in the world (Table 7). The economic impact of volatile prices and the nature of the vanadium market, which is supplied largely from secondary sources, have had a significant impact on the development of Australian vanadium projects. Australia's vanadium resources are mostly located in Western Australia at deposits such as Windimurra, Balla Balla, Barrambie and Gabanintha, and at Mount Peak, which occurs in the Northern Territory. Windimurra was Australia's sole producer but production ceased in February 2014 following fire damage to the plant.

7. Value of Australian Mineral Exports

In 2016, Australian mineral exports (excluding petroleum products) amounted to approximately $151 billion, almost 58% of all export merchandise and 46% of all exported goods and services (Table 8). As a proportion of gross domestic product (GDP), mining contributed 7.4% in the 2016–17 financial year.

Mineral export value has generally trended down from the highs of 2011 reflecting the large price falls for many commodities, particularly for iron ore and coal. Many commodity prices reached a low in late 2015/early 2016 and improved prices since then, together with greater iron ore production, has resulted in increased mineral export revenue in 2016 compared to the previous year. Gold has been the exception to the general downward price trend for commodities since 2011. In US dollars, the gold price also reached a peak price in 2011 before falling away, but in Australian dollars, the exchange rate has kept the price high resulting in strong production and export income.

Quarterly reports published by the Office of the Chief Economist show that the main mineral export earners in 2016 were iron ore (36%), black coal (26%), gold (12%), copper (5%), alumina (4%), aluminium (2%), nickel and zinc (both 1.5%; Table 9).

These same minerals were the main income earners in 2015 but, of these minerals, only iron ore and gold earned greater income in 2016 than in 2015. Iron ore export income improved by 10% and gold by 28%. Diamond and uranium export income also improved on 2015 levels, but for the remaining commodities covered by the Office of the Chief Economist, income was down.

Comparing export earnings to export volume, it is clear that processed mineral commodities are worth more per unit than raw minerals or concentrates, often significantly so. Bauxite in 2016, for example, was worth $42/t whereas alumina was worth $317/t. This is a 7-fold increase on the price of alumina; bearing in mind it takes 2–3 t of bauxite to make 1 t of alumina. It takes 2 t of alumina to make 1 t of aluminium metal, worth $2236/t in 2016, which is a further 7-fold increase on the price of alumina and a massive 53-fold increase on the price of bauxite. Similar value-adding is seen in the copper, iron and zinc industries and, to a lesser extent, in the lead sector. Thus any appraisal of the strength of Australia's minerals industry must also include domestic downstream processes, such as refining and smelting, in addition to mineral discovery, mining and raw material exports.

Table 8 Export value ($million) of mineral commodities, resources and energy, merchandise and goods and services, 2011 to 2016.

	2011	2012	2013	2014	2015	2016
Total Mineral Exports ($m)	168 532	151 528	163 291	158 940	142 169	151 475
Total Resources and Energy Exports ($m)	193 451	178 770	189 212	189 628	165 932	175 494
Total Merchandise Exports ($m)	263 231	249 662	263 489	266 768	250 410	259 065
Total Goods and Services Exports ($m)	314 272	301 404	318 388	326 700	315 658	330 313

Note: Total Mineral Exports includes metallic minerals, energy minerals (coal and uranium), gemstones, mineral sands and refined minerals (concentrates, bullion, ingot metals).

Source: Office of the Chief Economist (Resources and Energy Quarterly June 2017).

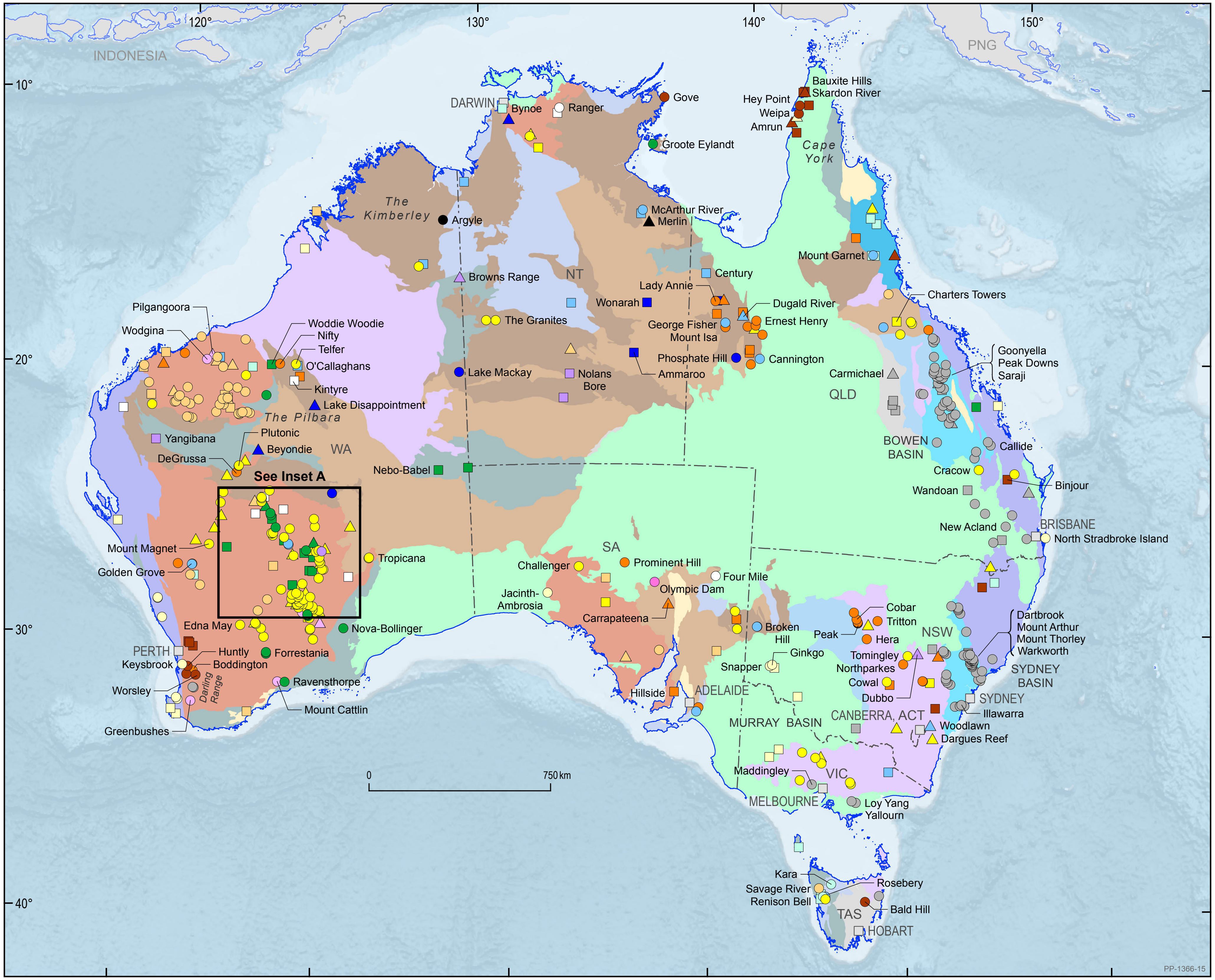
Table 9 Australian export volume and value of mineral and metal commodities 2016.

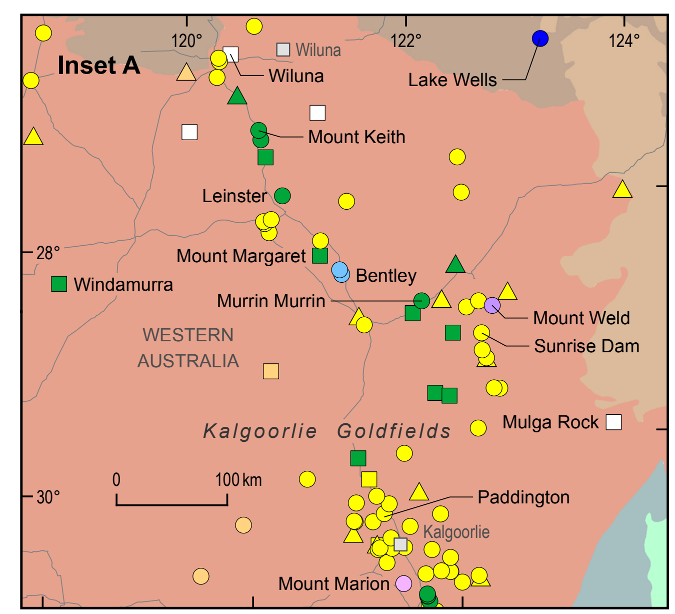
Commodity	Export volume	Unit	Export earnings ($million)	Value ($/t or $/c)	Percentage of total mineral export earnings
Aluminium—Bauxite	23 248	kt	983	42	0.6%
Aluminium—Alumina	17 864	kt	5664	317	3.7%
Aluminium—Ingot Metal	1425	kt	3187	2236	2.1%
Black Coal—Metallurgical	189 000	kt	23 962	127	15.8%
Black Coal—Thermal	202 000	kt	15 846	78	10.5%
Copper—Ore and Concentrates	1817	kt	4693	2582	3.1%
Copper—Refined	452	kt	2997	6630	2.0%
Diamonds—Unsorted	13 831 000	c	322	23	0.2%
Diamonds—Sorted Gem	69 000	c	319	4623	0.2%
Gold—Refined	329	t	17 767	54 003 040	11.7%
Iron—Ore	808 193	kt	53 698	66	35.5%
Iron—Crude Steel	638	kt	520	815	0.3%
Iron—Scrap	1573	kt	547	348	0.4%
Lead—Ore and Concentrates	189	kt	516	2730	0.3%
Lead—Refined	242	kt	587	2426	0.4%
Lead—Bullion	153	kt	520	3399	0.3%
Nickel—Ore and Concentrates	210	kt	288	1371	0.2%
Nickel—Intermediate and Refined	176	kt	2010	11 420	1.3%
Silver—Refined	36	t	35	972 222	<0.1%
Tin—Concentrate	15 707	t	135	8595	<0.1%
Uranium—Oxide (U_3O_8)	7446	t	910	122 213	0.6%
Zinc—Ore and Concentrates	1557	kt	1214	780	0.8%
Zinc—Refined	397	kt	1055	2657	0.7%

Note: Total Mineral Export earnings in 2016 were $151 475 million (Table 8).

Source: Office of the Chief Economist (Resources and Energy Quarterly June 2017).

Major Mines and Mineral Deposits in Australia





Geological regions

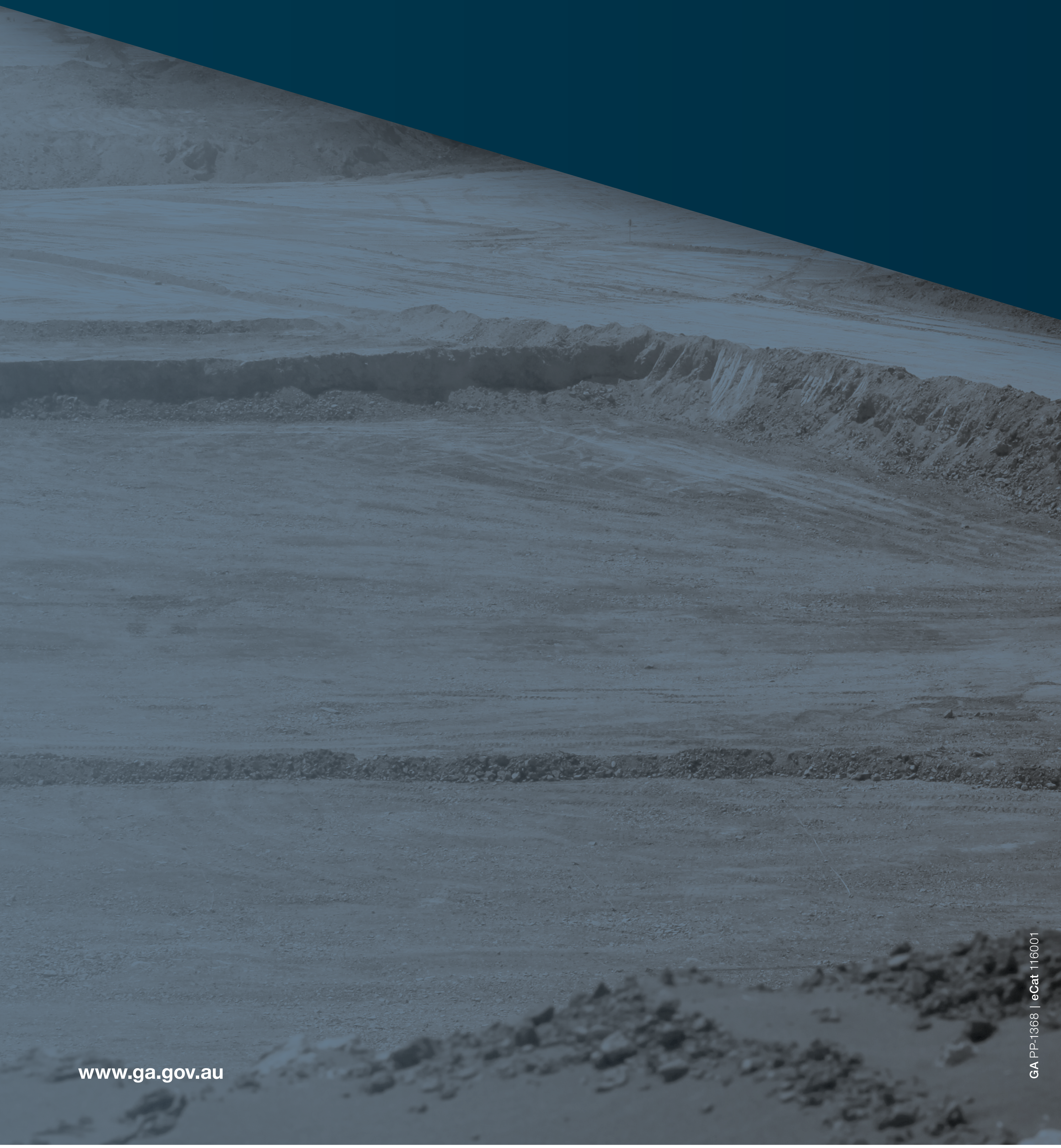
- *Cenozoic*
- *Mesozoic*
- *Permian*
- *Carboniferous*
- *Devonian*
- *Silurian*
- *Ordovician*
- *Cambrian*
- *Paleozoic*
- *Neoproterozoic*
- *Mesoproterozoic*
- *Paleoproterozoic*
- *Archean*

Commodity type

- *Base metals - Cu (Zn, Pb, Ag, Au)*
- *Base metals - Cu, Au, U*
- *Base metals - Zn, Pb (Cu, Ag)*
- *Bauxite*
- *Coal*
- *Diamond*
- *Heavy mineral sands*
- *Iron ore*
- *Light metals - Li, Mg*
- *Other metals - Sn, W, Ta*
- *Fertiliser elements - P, K*
- *Precious metals - Au, Ag*
- *Rare earth elements*
- *Steel making metals - Ni, Co, Mn, V*
- *Uranium*

Mine status

- *Operating mine*
- *Developing mine*
- *Mineral deposit*



www.ga.gov.au

GA PP-1368 | eCat 116001