



Australian Government  
Geoscience Australia

# AUSTRALIA'S IDENTIFIED MINERAL RESOURCES 2011







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Resources, Energy and Tourism Portfolio  
Minister for Resources, Energy and Tourism: the Hon. Martin Ferguson AM, MP

**Geoscience Australia**

Chief Executive Officer: Dr Chris Pigram



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Iron ore shipping terminal at Karratha, Pilbara region, Western Australia.

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## Executive Summary

*Australia's Identified Mineral Resources* is an annual national assessment that takes a long-term view of mineral resources likely to be available for mining. The highest category in the national inventory is Economic Demonstrated Resources (EDR) which, in essence, combines the Joint Ore Reserve Committee (JORC) Code categories of Ore Reserves and most of the Measured and Indicated Resources. JORC Code Ore Reserves of commodities are included for comparison, which provides a short to medium-term view of mineral stocks. The assessment also includes evaluations of long-term trends in mineral resources, world rankings, summaries of significant exploration results and brief reviews of mining industry developments.

Australia's EDR for the following 17 mineral commodities increased during 2010—antimony, recoverable brown coal, copper, diamonds, gold, iron ore, lead, molybdenum, niobium, phosphate rock, rare earth oxides, rutile, silver, tantalum, tin, tungsten and zinc. However, during the same period there was a decrease in the EDR for 10 commodities, bauxite, black coal, cobalt, manganese ore, ilmenite, nickel, platinum group elements, uranium, vanadium and zircon. EDR for cadmium, lithium, magnesite and shale oil remained at levels similar to those reported in 2009.

Australia's EDR of lead, rutile, zircon, nickel, silver, uranium and zinc remain the world's largest, while antimony, bauxite, black coal, recoverable brown coal, copper, gold, industrial diamond, iron ore, ilmenite, lithium, manganese ore, niobium, tantalum, tungsten and vanadium all rank in the top six worldwide.

Australia's EDR of **bauxite** were estimated to be 6.0 gigatonnes (Gt) in 2010, which ranks second largest in the world behind the Republic of Guinea with an estimated 7.4Gt. Australia's aluminium industry is underpinned by vast resources of bauxite in Queensland (Qld) on western Cape York, in the Northern Territory (NT) at Gove and in Western Australia (WA) in the Darling Range southeast of Perth. Rio Tinto Alcan's South of Embley project in Qld and the proposed expansion of BHP Billiton's Worsley alumina refinery from 3.5 million tonnes per annum (Mtpa) to 4.6Mtpa were well advanced in 2011. A number of projects on Australia's east and west coasts, which involved direct shipping of bauxite ore from areas close to existing infrastructure, were under consideration.

Recoverable EDR of **black coal** in 2010 decreased by 4.5% to 41.8Gt, which represents 6% of the world's economic recoverable black coal resources and ranks Australia as having the world's fifth largest resources. Queensland (59%) and New South Wales (NSW) (37%) had the largest share of recoverable EDR in Australia. The Bowen Basin in Qld contains 33% of Australia's recoverable EDR of black coal and the Sydney Basin in NSW contains 31%.

Recoverable EDR of **brown coal** in 2010 was 39.3Gt, a 5.8% increase over the 2009 estimate and represents about 19% of the world's recoverable brown coal. Australia has the world's second largest EDR of brown coal behind United States of America. All of Australia's brown coal EDR occurs in Victoria (Vic) with about 93% of the total located in the Latrobe Valley.

Australia's EDR of **copper** rose by 5 million tonnes (Mt) in 2010 to 85.6Mt, an increase of 7%, ranking Australia with the world's third largest economic resources of copper. South Australia (SA) has 70% of the national total, mainly in the Olympic Dam deposit, followed by NSW and Qld, each with 13% of EDR. In 2010, copper production rose by 2% and spending on exploration rose by 94% with expenditure in SA and Qld accounting for 60% of all copper exploration expenditure. The proposed major expansion at Olympic Dam, the development of underground mines at the Ankata deposit, Prominent Hill (SA) and Cadia East (NSW) were in progress during 2011.

**Gold** is mined from resources in all Australian States and the NT. Production in 2010 climbed to 260 tonnes from recent lows of 215 and 223 tonnes in 2008 and 2009, respectively. Australia's EDR of gold rose by 14%, or about one thousand tonnes (32 million ounces), to 8410 tonnes in 2010. Just short of 60% of the increase occurred in WA, which maintains the largest share of EDR with 3570 tonnes or 42% of the national total. According to figures estimated for the world by the United States Geological Survey (USGS), Australia has the largest demonstrated resources of gold followed by South Africa (about 6000 tonnes) and Russia (about 5000 tonnes). Also according to USGS figures, mine production of gold by Australia was second only to that of China (340 tonnes) during 2010. Gold prices continued to climb through 2010 and were undoubtedly a factor in increased exploration expenditure on the commodity, rising by \$161 million over 2009 figures to \$624 million.

Because of major changes in Australia's **iron ore** mining industry and the development of large magnetite deposits in WA and SA, Geoscience Australia has estimated national resources of iron in two categories:

- Iron ore (tonnes), and
- Contained iron (Fe) (tonnes).

EDR of iron ore increased by 23% to 34.5Gt during 2010 with the EDR of contained Fe estimated to be 17Gt. Western Australia has the largest share of these resources with 98% of Australia's EDR, the majority of which is in the Pilbara region. Australia ranked second in the world for economic resource of iron ore having 18%, behind China's 37%. Western Australia remains the largest producer of iron ore in Australia. Iron ore exploration expenditure in 2010 totalled \$553.1 million, a 6% increase on the \$521.2 million spent during 2009. Exploration in 2010 also accounted for 22% of total Australia's mineral exploration expenditure.

Australia's **lithium** EDR are estimated to be 483 kilotonnes (kt), which is about 8% of world economic resources and ranks Australia as having the world's fourth largest resources behind Chile, China and Argentina. The bulk of Australia's lithium resources are in the Greenbushes spodumene deposit in WA, the world's largest and highest grade spodumene deposit.

Australia's EDR of **magnesite** totalled 330Mt. South Australia has the largest share of these resources with 71% followed by Qld with 19%. The Kunwarara deposit in Qld is the world's largest known resource of ultrafine-grained cryptocrystalline to microcrystalline nodular magnesite.

Australia's EDR of **manganese ore** in 2010 increased by 2.2% to 185Mt, representing about 11% of the world's economic resources of manganese ore, the world's fifth largest. Groote Eylandt deposit in the NT contains 65% of Australia's EDR. Australia produces 16% of the world's manganese ore and is ranked second behind China.

The regions containing the major proportion of Australia's **mineral sands** resources (ilmenite, rutile and zircon) are the Perth Basin north of Perth in WA, the Murray Basin (NSW, Vic, and SA) and the newly emerging heavy mineral sands regions in the Eucla Basin (WA and SA). In 2010, EDR of ilmenite and zircon decreased by 0.4% to 199.5Mt for ilmenite and by 1.5% to 39.4Mt for zircon. However, EDR of rutile increased by 3.5% to 23.5Mt. Australia's rutile and zircon resources are ranked number one in the world, while ilmenite resources are the second largest worldwide behind China.

Australia's EDR of **molybdenum** rose by about 17% from 276kt in 2009 to 324kt in 2010, representing about 3% of the world's economic resources of molybdenum. Western Australia has the largest share of molybdenum EDR with about 68%, followed by Qld with 30%.

Australia's EDR of **nickel**, which is the world's largest economic resource, decreased by 13.8% from 24.0Mt in 2009 to 20.7Mt in 2010. Western Australia remains the largest holder of nickel resources with 90.8% of total Australian EDR made up of both sulphide and lateritic deposits. Nickel prices continued to recover during 2010 leading to increased production, with some nickel mines planned to re-open in 2011.

Australia's total EDR, excluding Christmas Island resources, of **phosphate rock** doubled to 492.1Mt in 2010. All of Australia's EDR occur as sedimentary phosphate rock (phosphorites) in the Georgina Basin at Phosphate Hill, and at Paradise South (both in Qld), and at Wonarah in the Northern Territory. Australia has less than 0.1% of the world's economic resources of phosphate rock.

**Potash** is a generic term covering a variety of potassium-bearing ores, minerals and refined products. Potash is not mined in Australia, which has only modest resources by world standards. Australia's fertiliser requirements are met through phosphate rock production and imports of potassium fertiliser. There has been an increase in potash exploration in Australia in recent years.

Australia's EDR of **rare earth oxides** in 2010 were 1.83Mt, unchanged from 2008. Significant resources of rare earths are contained in the monazite component of heavy mineral sand deposits, which are mined for their ilmenite, rutile, leucoxene and zircon content. Currently, extraction of rare earths from monazite is not viable because of the cost involved with the disposal of thorium and uranium present in the monazite.

**Shale oil** resources are predominantly in a series of sedimentary basins near Gladstone and Mackay and further north near Proserpine in central Qld. Australia currently has no EDR of oil shale, with all resources being assessed

as subeconomic. Queensland Energy Resources Ltd have commissioned a small-scale technology demonstration Paraho II™ oil shale processing retort at their Stuart Project, near Gladstone, Qld.

Australia's EDR of **tantalum** increased by 4% to 53kt in 2010, ranking Australia the second largest in the world behind Brazil. All of the EDR are located in WA with more than 92% associated with the Greenbushes and Wodgina deposits. Global Advanced Metals recommenced mining at its Wodgina mine, which had been on care and maintenance since December 2008.

Australia's EDR of **tin** increased by 203% to 358kt in 2010, ranking Australia's resources as the world's eighth largest. The bulk of the EDR occur in Tasmania (Tas) and in Qld.

Australia's EDR of **tungsten** more than doubled in 2010 to 403kt, ranking it the second largest with 15% of the world's economic resources. The bulk of the EDR occurs in WA with 56%, followed by Tas with 29% and Qld with 13%. The rise of tungsten prices over the past 18 months from below US\$200 a metric tonne unit (MTU) to around US\$460–480 a MTU has seen increased interest in tungsten and renewed activity at a number of Australian projects.

Australia's **uranium** resources are reported in the categories of the international classification scheme for uranium. Reasonably Assured Resources (RAR) that can be produced at costs of less than US\$130 a kilogram (kg) are equivalent to EDR (Australia's National Scheme). Australia's RAR of uranium that can be produced at costs of less than US\$130 a kilogram (kg) at December 2010 were estimated to be 1158kt, which was a decrease of 6% on the estimates for 2009. This decrease was caused by the impact of the increasing cost of mining and milling uranium ores. As a result, resources in some uranium mines and deposits are now assigned to higher cost categories compared with the estimates for 2009.

Australia's **vanadium** EDR declined by 34% in 2010 to 1762kt. Ranked as the world's fourth largest resources, the bulk of Australia's vanadium is located in WA. The economic impacts of volatile prices and the nature of the vanadium market, which is supplied largely from secondary sources, has a significant impact on Australia's vanadium EDR and the development of Australian vanadium projects.

Australia's total resources of **zinc, lead** and **silver** rose significantly in 2010. Strong recovery of zinc, lead and silver prices in the order of 8% to 10% in 2010 resulted in large increases in production of all three commodities. Zinc was up by 15%, lead by 26% and silver by 15%. Exploration expenditure for zinc-lead in 2010 was 39% higher than in 2009 at \$67 million. With the increased prices experienced in 2010 anticipated to continue, several zinc-lead operations embarked on plans to increase output and resume development or exploration. Australia's EDR of zinc, lead and silver in 2010 totalled 65.2Mt, 34.7Mt, and 77.2kt respectively and were ranked as the largest economic resources in the world.

**Resources to production ratios:** Ratios of Accessible Economic Demonstrated Resources (AEDR) to current mine production provide indicative estimates of the resource life. AEDR of most of Australia's major commodities can sustain current rates of mine production for many decades. Resource life based on ore reserves is lower, reflecting a shorter term commercial outlook.

Over the two decades up to 2010, there has been a significant trend towards lower AEDR/production ratio for coal and iron ore, which was the result of major increases in production and reassessment of resources. The decline in iron ore has been offset in the past few years by the development of large magnetite iron ore deposits in the Pilbara and mid-west regions of WA. These magnetite resources, which were previously considered to be subeconomic, have been re-assessed as economic.

Commodities with resource life duration of less than 50 years are manganese ore (about 15 years at current rates of production), diamonds and gold (30 years), silver (40 years), zinc and rutile (45 years).

The global financial crisis in late 2008 highlighted the fact that a long resource life for a particular commodity is not a guarantee that such resources will continue to be exploited in Australia. In an increasingly competitive and globalised commodity market, multinational mining companies are continuously seeking mineral deposits that will provide attractive returns on their investment. Such returns are influenced by the quality of the resources (grade and tonnage) as well as environmental, social and political factors, land access and the location and scale of competitor projects. Individual mine projects in Australia will be ranked by multinational companies against the investment returns from other deposits worldwide.

Australia's continuing position as a premier mineral producer is dependent on continuing investment in exploration to locate high quality resources and/or to upgrade known deposits to make them competitive on the world market, as well as investment in beneficiation processes to improve metallurgical recoveries.

## Introduction

Geoscience Australia and its predecessors have prepared annual assessments of Australia's mineral resources since 1975. The resource data and related information from *Australia's Identified Mineral Resources* provide input into Australian Government policy decisions and programs associated with the minerals sector and sustainable development of resources.

*Australia's Identified Mineral Resources 2011* presents estimates of Australia's mineral resources at end of December 2010 for all major and several minor mineral commodities (Table 1). This national minerals inventory is based on company published reports of Ore Reserves and Mineral Resources. The national resource estimates provide a long-term view of what is likely to be mined. National total for JORC Ore Reserves are compiled for each commodity, which provides the industry view of what is likely to be mined in the short to medium term. Mine production data are based on figures from the Bureau of Resources and Energy Economics. World rankings of Australia's mineral resources have been calculated mainly from information in publications of the United States Geological Survey. A summary of significant industry developments also is presented.

### National Resource Classification System

The mineral resource classification system used for Australia's national inventory is based on two general criteria:

- i) the geological certainty of existence of the mineral resource, and
- ii) the economic feasibility of its extraction over the long term.

For a full description of the system see Appendix 2 'National Classification System for Identified Mineral Resources'.

The description of the National Classification System shows how mineral resources reported by companies under the Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves (referred to as the Joint Ore Reserve Committee (JORC) Code) are used when compiling national total resources. The classification category Economic Demonstrated Resources (EDR) is used for national totals of economic resources and provides a basis for meaningful comparisons of Australia's economic resources with those of other nations. Long-term trends in EDR for bauxite, black coal (recoverable), iron ore, gold, copper, nickel, lead, zinc, mineral sands and uranium (recoverable) are presented and the reasons for significant changes in resource trends are noted.

### Accessible Resources

Some mineral deposits are not accessible for mining currently because of government policies or various environmental and land access restrictions such as location within National and State parks and conservation zones, military training areas or environmental protection areas as well as areas over which mining approval has not been granted by traditional owners. Accessible Economic Demonstrated Resources (AEDR), as shown in Table 1, represent the resources within the EDR category that are accessible for mining.

**Notes for Table 1**

**Abbreviations:** t = tonne; m<sup>3</sup> = cubic metre; L = litre; kt = 10<sup>3</sup>t; Mc = 10<sup>6</sup> carat; Mt = 10<sup>6</sup>t; Gt = 10<sup>9</sup>t; GL = 10<sup>9</sup>L.

- |   |   |
|---|---|
| <p>a) Joint Ore Reserves Committee (JORC) Proved and Probable Ore Reserves as stated in company annual reports and reports to Australian Securities Exchange.</p> <p>b) Economic Demonstrated Resources (EDR) includes Joint Ore Reserves Committee (JORC) Reserves, Measured and Indicated Mineral Resources.</p> <p>c) Total Inferred Resources in economic, sub-economic and undifferentiated categories.</p> <p>d) Accessible Economic Demonstrated Resources (AEDR) is the portion of total EDR that is accessible for mining. AEDR does not include resources which are inaccessible for mining because of environmental restrictions, government policies or military lands.</p> <p>e) Source: Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES).</p> <p>f) Sources: Geoscience Australia for Australian figures, United States Geological Survey (USGS) Mineral Commodities Summaries for other countries.</p> <p>g) World mine production for 2010, mostly United States Geological Survey (USGS) estimates.</p> <p>h) There are no JORC code ore reserve estimates available for brown coal.</p> <p>i) Raw coal.</p> <p>j) Geoscience Australia estimate.</p> <p>k) Saleable coal.</p> <p>l) Excludes USA.</p> <p>m) Source: Western Australian Department of Mines and Petroleum.</p> <p>n) 74 789t of chromite expressed as Cr<sub>2</sub>O<sub>3</sub> (Source: Western Australian Department of Mines and Petroleum).</p> <p>o) World production of 23Mt of 'marketable chromite ore' as reported by United States Geological Survey (USGS).</p> | <p>p) 326 856t of spodumene concentrate in 2010 (Source: Western Australian Department of Mines and Petroleum).</p> <p>q) Production for 2009-10 (Source: Department of Mines and Energy, Geological Survey of Queensland).</p> <p>r) Not reported by mining companies.</p> <p>s) Duchess mine (Queensland) produced 2.132Mt phosphate rock in 2009-10. Christmas Island produced 420 205t phosphate rock and 42 300t phosphate dust in 2009.</p> <p>t) Total Inferred Resource excludes a 'total potential' shale oil resource of the Toolebuc Formation, Queensland of 245 000GL that was estimated by Geoscience Australia's predecessor, the Bureau of Mineral Resources, and CSIRO in 1983.</p> <p>u) Source: World Energy Council (WEC) Survey of Energy Resources 2010.</p> <p>v) Latest production figures for end 2008 from World Energy Council (WEC) Survey of Energy Resources 2010.</p> <p>w) Source: Western Australian Department of Mines and Petroleum.</p> <p>x) Thorium resources reduced by 10 per cent to account for mining and processing losses.</p> <p>y) For all States except WA where actual figures not available.</p> <p>z) Source: Organisation for Economic Cooperation and Development/Nuclear Energy Agency (OECD/NEA) and International Atomic Energy Agency (IAEA) (2009). Compiled from the most recent data for resources recoverable at costs of less than US\$130/kg U.</p> <p>aa) Source: World Nuclear Association.</p> <p>n.a. = not available</p> |
|---|---|

**Table 1.** Australia's resources of major minerals and world figures as at December 2010.

COMMODITY	UNITS	AUSTRALIA						WORLD		
		JORC Reserves (a) (% of Accessible EDR)	Demonstrated Resources			Inferred Resources (c)	Accessible EDR (d)	Mine Production 2010 (e)	Economic Resources 2010 (f)	Mine Production 2010 (g)
			Economic (EDR) (b)	Para-marginal	Sub-marginal					
<b>Antimony</b>	kt Sb	54 (57%)	95	10	0	198	95	1.1	1800	135
<b>Bauxite</b>	Gt	2.3 (41%)	6.0	0.4	1.4	0.89	5.5	0.069	28	0.211(f)
<b>Black coal</b>										
in situ	Mt		56 135	1549	5688	78 963				
recoverable	Mt	17 238 (41%)	41 848	970	4184	58 046	41 749	449(i)	675 000(j)	6185(j)(k)
<b>Brown coal</b>										
in situ	Mt		44 189	44 896	18 727	114 923				
recoverable	Mt	n.a.(h)	39 254	37 045	15 942	95 155	34 150	69(j)	195 387(j)	1042(j)
<b>Cadmium</b>	kt Cd	0	0	0	0	37	0	0	660	22(l)
<b>Cobalt</b>	kt Co	362 (27%)	1191	228	147	1418	1191	3.85(m)	7259	87.55
<b>Copper</b>	Mt Cu	24.9 (29%)	85.6	1.9	0.8	43.3	85.6	0.870	640	16.2
<b>Chromium</b>	kt Cr	0	0	0	0	3450	0	50.4(n)	>107 700	(o)
<b>Diamond</b>										
gem & near gem	Mc	82.4 (58%)	143.3	0	0	19.7	143.3	4.9	n.a.	79
industrial	Mc	85.8 (58%)	149.1	0	0	20.6	149.1	5.1	634	49
<b>Fluorine</b>	Mt F	0	0	0.5	0	0.5	0	0	112(l)	2.6
<b>Gold</b>	t Au	4070 (49%)	8410	930	120	4450	8380	260	51 800	2510
<b>Iron</b>										
iron ore	Gt	13.6 (39%)	34.5	0.7	1.5	47.8	34.5	0.43	191	2.4
iron (contained Fe)	Gt Fe	7.1 (42%)	17.0	0.4	0.6	23.3	17.0	n.a.	89	n.a.
<b>Lead</b>	Mt Pb	11.9 (34%)	34.7	4.3	0.2	21.2	34.7	0.71	88	4.2
<b>Lithium</b>	kt Li	174 (36%)	483	0	0.1	90	483	(p)	12 900	25(l)
<b>Magnesite</b>	Mt MgCO <sub>3</sub>	37.5 (11%)	330	22	35	836	330	0.276(q)	8400	19.53(l)
<b>Manganese ore</b>	Mt	144 (78%)	185	23	132	135	178	6.5	1623	40
<b>Mineral sands</b>										
Ilmenite	Mt	28.8 (17%)	199.5	38.8	0.03	128.3	166.6	1.313	1246	10.2
Rutile	Mt	4.9 (24%)	23.5	7.0	0.06	30.1	20.2	0.430	48	0.7(l)
Zircon	Mt	8.9 (27%)	39.4	10.3	0.07	34.9	33.0	0.540	89.4	1.24
<b>Molybdenum</b>	kt Mo	220 (68%)	324	905	5	607	324	0	9800	234
<b>Nickel</b>	Mt Ni	5.5 (27%)	20.7	2.4	1.3	19.4	20.7	0.170	75.6	1.58
<b>Niobium</b>	kt Nb	0	134	15	0	419	134	(r)	2900	63
<b>Phosphate rock</b>	Mt	137 (28%)	492.1	704	0	1274	492.1	(s)	65 000	176
<b>PGE (Pt, Pd, Os, Ir, Ru, Rh)</b>	t metal	0.08 (66%)	4.4	132.6	35.3	145.5	0.12	0.781	66 000	380
<b>Rare earths (REO &amp; Y<sub>2</sub>O<sub>3</sub>)</b>	Mt	0.33 (18%)	1.83	0.35	34.48	24.19	1.83	0	114	0.13
<b>Shale oil</b>	GL	0	0	213	2074	1272(t)	0	0	763 139(u)	1.165(v)
<b>Silver</b>	kt Ag	27.7 (36%)	77.2	10.7	3.1	34.6	77.2	1.88	520	22.1
<b>Tantalum</b>	kt Ta	19 (36%)	53	15	0.2	30	53	0(w)	121	0.59
<b>Thorium</b>	kt Th	0	0	74.4(x)	0	397.3(x)	0	0	n.a.	n.a.
<b>Tin</b>	kt Sn	141 (39%)	358	21	27	373	358	6.6 (y)	5378	278
<b>Tungsten</b>	kt W	217 (54%)	403	0.9	1.4	110	403	0.018	2900	61
<b>Uranium</b>	kt U	391 (37%)	1158	22	0	559	1048	5.899	3508(z)	53.663(aa)
<b>Vanadium</b>	kt V	1172 (67%)	1762	10 324	1533	8447	1762	0	15 400	56
<b>Zinc</b>	Mt Zn	21.3 (33%)	65.2	3.4	1.0	24.4	65.2	1.48	260	12.0

## Trends in Australia's Economic Demonstrated Resources of Major Mineral Commodities

The trends in Economic Demonstrated Resources (EDR) for Australia's major mineral commodities have undergone significant and sometimes dramatic changes over the period 1975–2010 (Fig. 1). These 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, eg. carbon-based processing technologies for gold have enabled economic extraction from low-grade deposits which previously were uneconomic.
- Adoption of the Joint Ore Reserve Committee (JORC) Code<sup>1</sup> 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. Many companies re-estimated their mineral resources to comply with the JORC Code. The impacts of the JORC Code on EDR occurred at differing times for each of the major commodities.
- Increases in prices of mineral commodities driven largely by the escalating demand from China over the past decade.

Past trends and changes in EDR for a number of Australia's major mineral commodities are discussed below.

### Bauxite

Increases in bauxite EDR in 1989 resulted from delineation of additional resources in deposits on Cape York Peninsula ('a' on Figure 1). Decreases in bauxite EDR in 1992 resulted from reclassification of some resources within deposits on Cape York Peninsula to comply with requirements for the JORC Code ('b').

### Black Coal

A major re-assessment of New South Wales (NSW) coal resources during 1986 by the New South Wales Department of Mineral Resources and the Joint Coal Board resulted in a large increase in black coal EDR as reported in 1987 (refer 'c' on Figure 1).

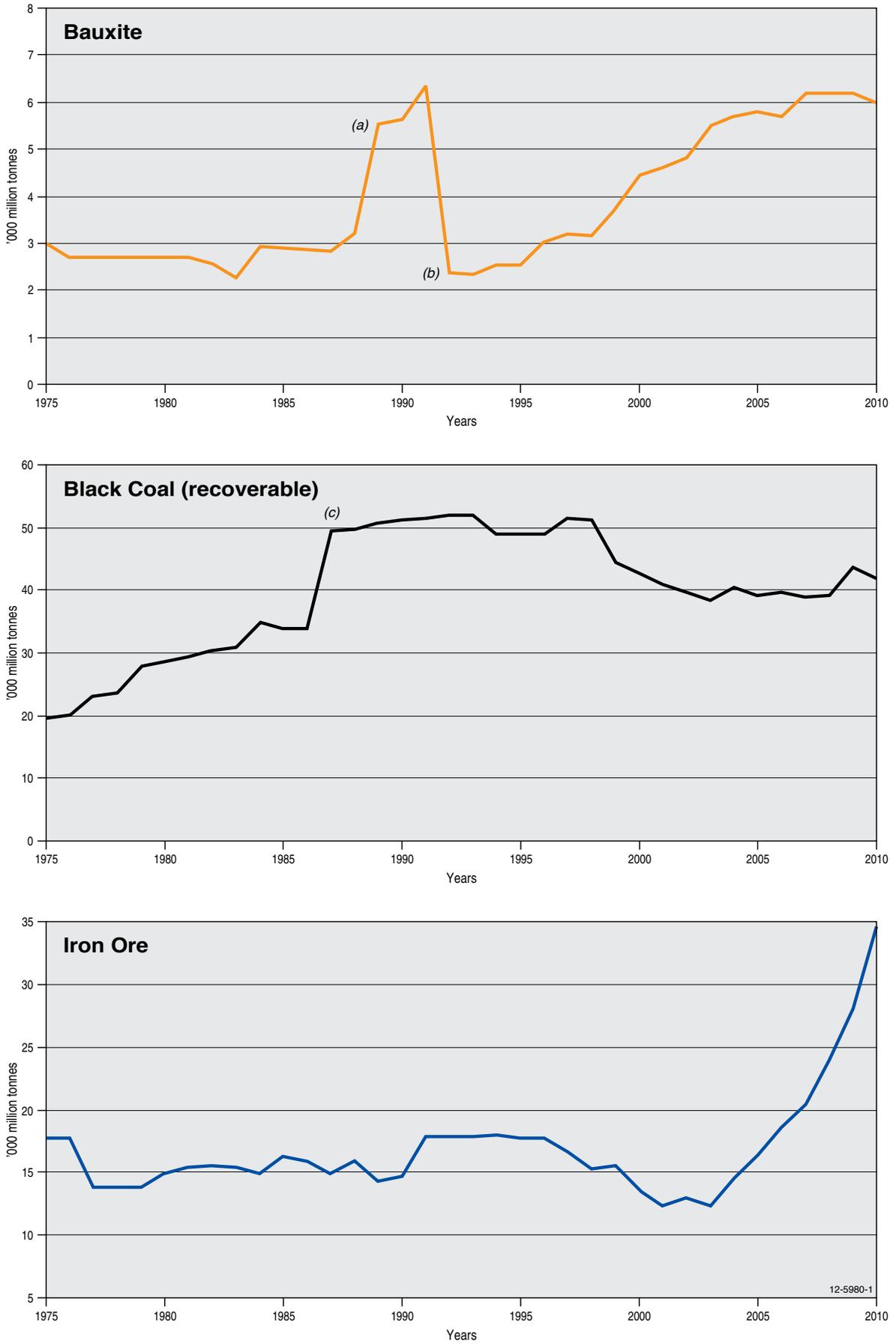
EDR for black coal has declined since 1998 because of the combined impact of increased rates of mine production and mining companies re-estimating ore reserves and mineral resources more conservatively to comply with requirements of the JORC Code. In 2009 black coal EDR increased significantly mainly because of the discovery and delineation of additional resources as a result of high levels of exploration and through reclassification of resources.

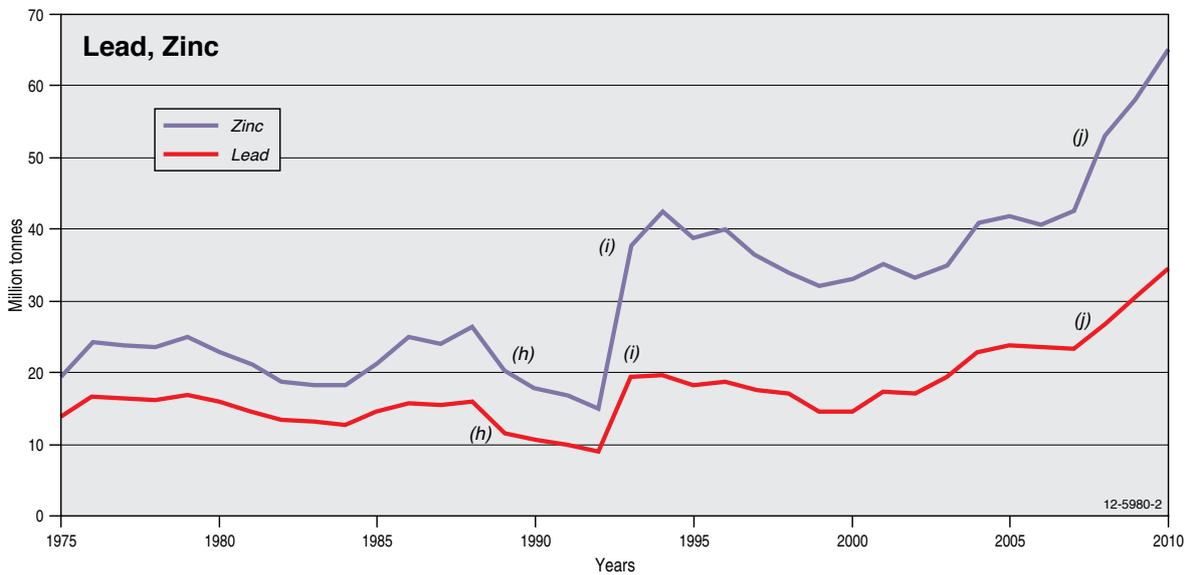
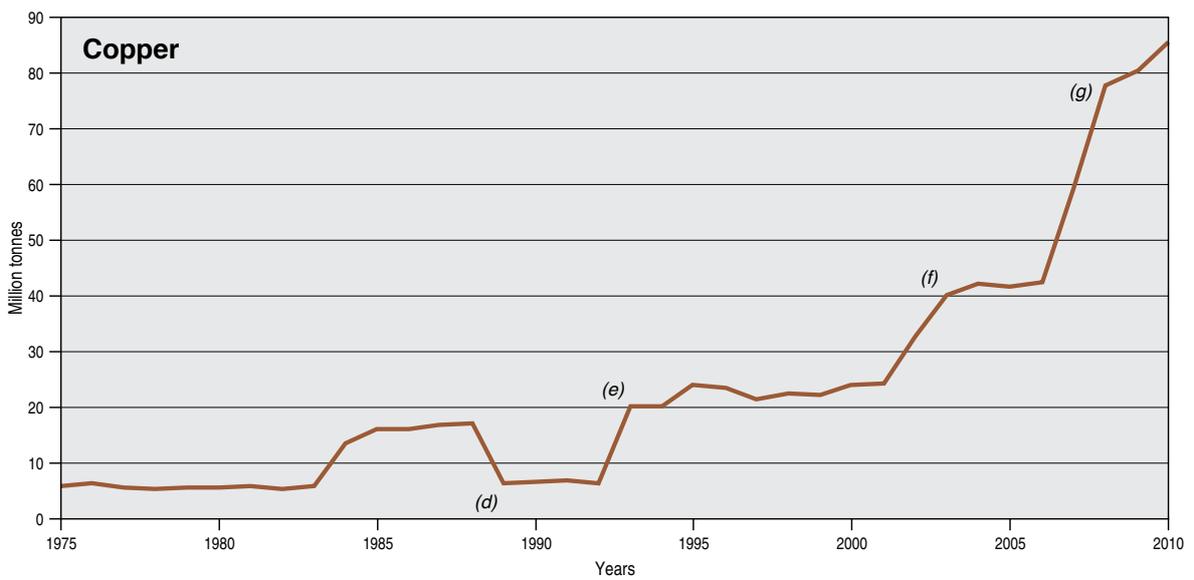
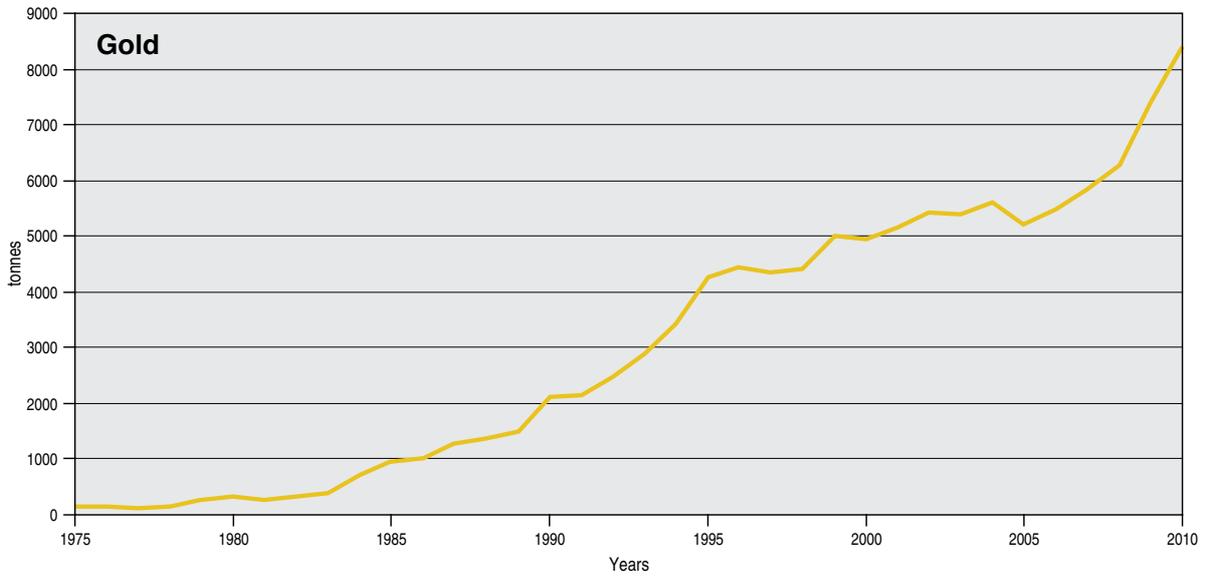
### Iron Ore

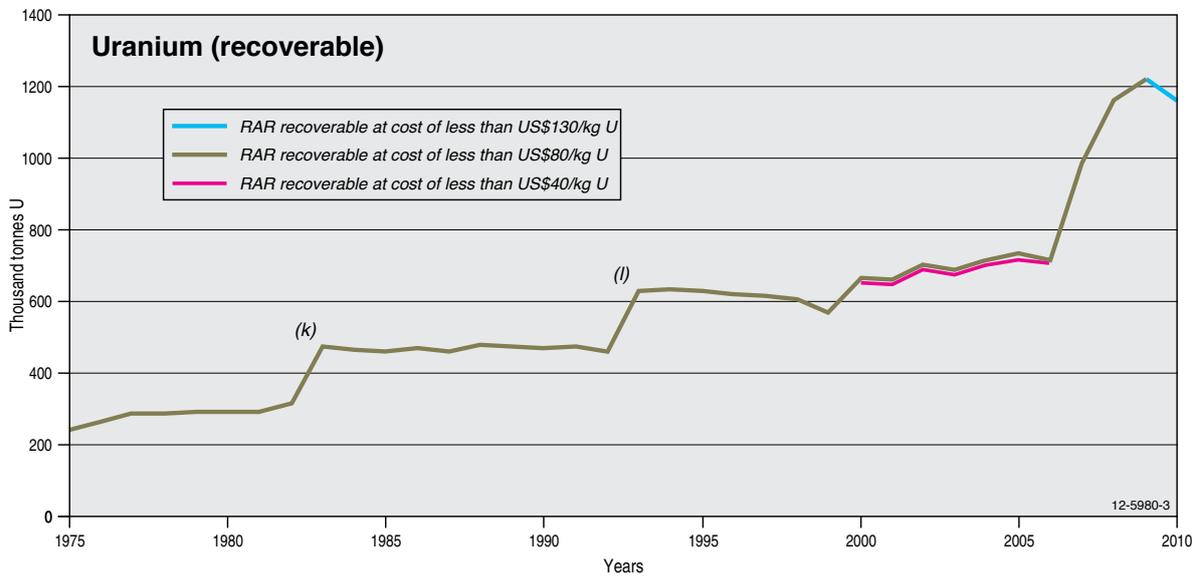
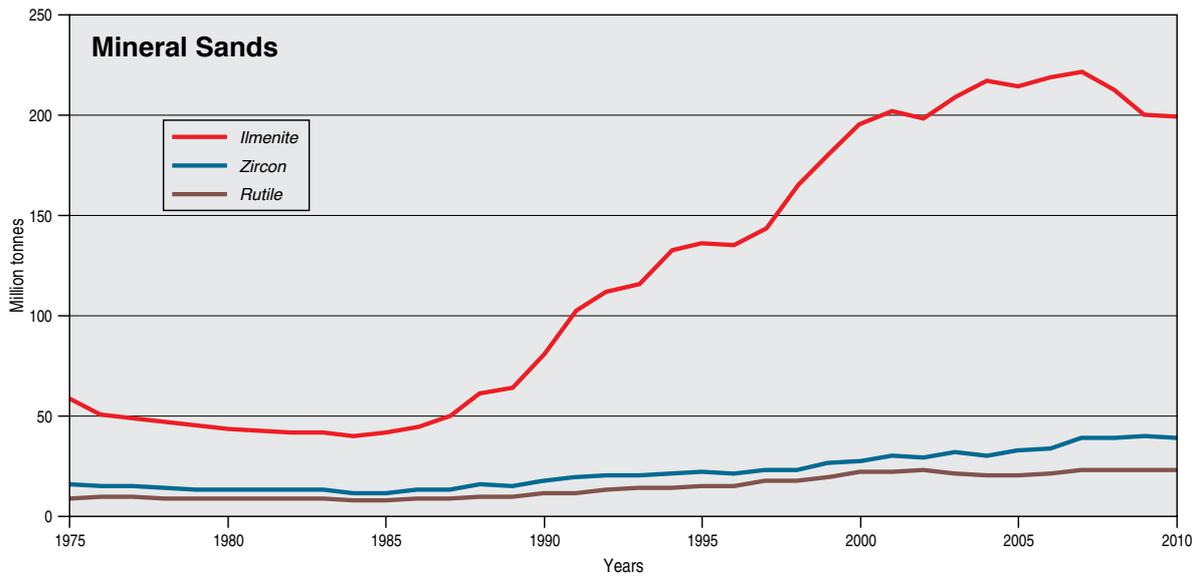
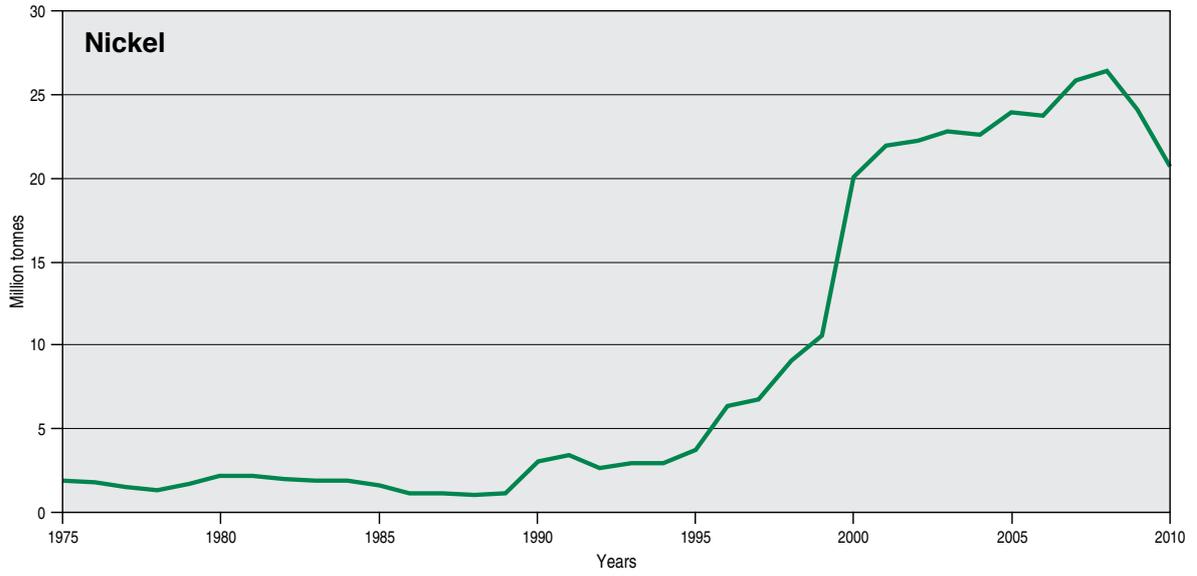
Australia's EDR of iron ore declined from 1994 through 2003 due to the combined impacts of increased rates of mine production and mining companies re-estimating reserves and resources to comply with requirements of the JORC Code. Post 2003, EDR increased rapidly to 34,500Mt in December 2010, due to large increases in magnetite resources (including reclassification of some magnetite deposits to economic categories), and increases in hematite resources, mainly at known deposits. Mine production increased rapidly from 168Mt in 2000 to 433.5Mt in 2010.

<sup>1</sup> In 1988, the Australian mineral industry adopted the Australasian Code for Reporting of Identified Mineral Resources and Ore Reserves (JORC Code). Many companies first used this code for reporting their mineral resources in 1989. The requirements of the Code differed significantly from the resource classification schemes used by companies prior to 1989.

Figure 1: Trends in Economic Demonstrated Resources for major commodities since 1975.







## Gold

Gold EDR has increased steadily since 1975 with a clear increase in the rate of growth since 1983. Much of the increase can be attributed to the successful introduction of the carbon-based processing technology which allowed the profitable processing of relatively low grade ore deposits. In addition, the higher than previous prevailing gold prices (denominated in US\$) supported high levels of exploration for gold to the extent that gold accounted for more than half of the total mineral exploration expenditure in Australia for many years. Increased exploration contributed to the increases in EDR.

## Copper

Following the adoption of the JORC Code by the Australian mineral industry, many companies first used this code in 1989 for reporting their copper resources. These companies re-estimated mineral resources to comply with the JORC Code which resulted in a sharp fall in Australia's copper EDR in 1989 ('d').

The sharp increase in copper EDR in 1993 resulted mainly from an increase in company announced resources for the Olympic Dam deposit in South Australia (SA). Additional resources were reported also for Ernest Henry in Queensland (Qld), North Parkes (NSW) and other smaller deposits ('e').

Re-assessments of copper resources by Geoscience Australia in 2002 and 2003 resulted in further transfers (reclassification) of Olympic Dam resources into EDR ('f'). In 2007 and 2008, copper resources increased sharply, mainly because of a large increase in resources for Olympic Dam ('g'). Drilling outlined large resources in the southeastern part of the deposit.

## Lead, Zinc

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 JORC Code, and some re-assessments of resource data for other deposits by Geoscience Australia's predecessor, the Bureau of Mineral Resources. This resulted in a sharp fall in Australia's lead and zinc EDR in 1989 ('h').

Increases in EDR for lead and zinc in 1993 resulted from the re-classification of Paramarginal demonstrated resources into EDR for McArthur River in the Northern Territory (NT) and George Fisher deposits (Qld). Additional resources were reported also for Century and Cannington deposits (Qld) ('i').

Increases in 2008 were associated with reassessment of resources at the McArthur River mine (NT), where an expansion from underground to open cut mining was approved, and reassessment of the Dugald River deposit (Qld) for which a new and increased resource estimate was released ('j').

## Nickel

The EDR for nickel increased during the period 1995 to 2001 by 18.2Mt. This resulted mainly because of progressive increases in resources of lateritic deposits at Bulong, Cawse, Murrin Murrin, Mount Margaret, Ravensthorpe (all in WA), Marlborough (Qld), Syerston and Young (NSW). Australia's EDR of nickel doubled in 2000 (compared to the level at the end of 1999)—this dramatic increase was due to further large increases in resources at the Mount Margaret and Ravensthorpe deposits, and other lateritic deposits in the Kalgoorlie region (WA). In addition, during the period 1995 to 2001 there were increases in resources of sulphide deposits at Yakabindie, and discoveries of the Silver Swan and Cosmos high-grade sulphide deposits (all in WA).

From 2001 onwards, the sharp rises in market prices for nickel led to increased expenditures 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 (WA), Averbury in Tasmania (Tas) and remnant resources at several sulphide deposits in the Kambalda (WA) region including Otter-Juan and Lanfranchi groups of deposits.

From 2001 onwards EDR increased at a slower rate due to 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.

## Mineral Sands

Increases in EDR of ilmenite from 1996 to 2003 resulted from discovery and subsequent evaluation drilling of heavy mineral sands deposits in the Murray Basin which include the Gingko and Snapper deposits (NSW), Douglas-Bondi and Woorack deposits in Victoria (Vic), and the Mindarie project (SA). In addition, from 1998 onwards there were progressive increases in resources at mineral sands deposits at Jacinth-Ambrosia and Cyclone in the Eucla Basin embracing parts of SA and WA, in the North Swan Coastal Plain area north of Perth, WA, and the Blackwood Plateau region in WA. The EDR of ilmenite declined after 2007 due to reclassification of resources to lower resource categories.

## Uranium

The majority of Australia's uranium deposits were discovered between 1969 and 1975—approximately 50 deposits (15 with significant resource estimates) were discovered during this short period. Since 1975, only another five deposits have been discovered—of these, only three deposits (Kintyre in the Paterson Province (WA), Junnagunna, (Qld) and Four Mile (SA) have Reasonably Assured Resources recoverable at less than US\$130/kg U (equates with EDR). As a result, the progressive increases in Australia's EDR for uranium from 1975 to the present (Fig. 1) were largely because of the on-going 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 on Figure 1 were because:

- In 1983, initial resource estimates for Olympic Dam and Ranger No. 3 Orebody (NT) made by the former Australian Atomic Energy Commission ('k').
- In 1993, further increases in EDR for Olympic Dam and first assessment of resources for the Kintyre deposit by Geoscience Australia's predecessor, the Bureau of Mineral Resources ('l').
- In 2000, increases were due to continuing additions to the Olympic Dam resources.
- From 2007 to 2009 major increase in EDR for Olympic Dam. Drilling outlined major extensions to the southeast part of the deposit.

Economic resources decreased in 2010 because of higher costs of mining and milling uranium ores. Resources in some deposits were re-assigned to higher cost categories than in previous years. In previous years, resources in the cost category of less than US\$80 per kg uranium were considered to be economic. As a result of increases in costs and uranium market prices, economic resources in 2010 were extended to include resources within the cost category of less than US\$130 per kg uranium.

## COMMODITY REVIEWS



Dragline moving overburden at the Ensham coal mine, Bowen Basin, Queensland.

# Bauxite

Paul Kay (paul.kay@ga.gov.au)

Bauxite is the main raw material used in the commercial production of alumina ( $\text{Al}_2\text{O}_3$ ) and aluminium metal globally, although some clays and other materials can be utilised to produce alumina. Bauxite is a heterogeneous naturally occurring material of varying composition that is relatively rich in aluminium. The principal minerals in bauxite are gibbsite ( $\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ ), boehmite ( $\text{Al}_2\text{O}_3 \cdot \text{H}_2\text{O}$ ) and diaspore, which has the same composition as boehmite, but is denser and harder.

Australia is the world's largest producer of bauxite, representing 33% of global production in 2010. The bauxite resources at Weipa in Queensland (Qld) and Gove in the Northern Territory (NT) have almost 50% available alumina and are amongst the world's highest grade deposits. Other deposits located in Western Australia's (WA) Darling Range, Mitchell Plateau and Cape Bougainville, the latter two of which have not been developed, are relatively low grade at around 30% available alumina.

More than 85% of the bauxite mined globally is converted to alumina for the production of aluminium metal. An additional 10% goes to non-metal uses in various forms of specialty alumina, while the remainder is used for non-metallurgical bauxite applications. In most commercial operations, alumina is extracted (refined) from bauxite by a wet chemical caustic leach process known as the Bayer process. Alumina is smelted using the Hall-Heroult process to produce aluminium metal by electrolytic reduction in a molten bath of natural or synthetic cryolite ( $\text{NaAlF}_6$ ).

Australia's aluminium industry is a highly integrated sector of mining, refining, smelting and semi-fabrication centres and is of major economic importance nationally and globally. The industry consists of five long term bauxite mines, seven alumina refineries, six primary aluminium smelters, 12 extrusion mills and two rolled product (sheet, plate and foil) mills. The industry in Australia is geared to serve world demand for alumina and aluminium with more than 80% of production exported. Transport, packaging, building and construction provide much of the demand for the metal in Australia.

## Resources

The long-term future of Australia's aluminium industry is underpinned by vast resources of bauxite located in the regions around Gove (NT) and particularly Weipa (Qld) adjacent to the Gulf of Carpentaria in northern Australia and in the Darling Range south of Perth, WA. Deposits in these regions rank among the world's largest identified resources in terms of extractable alumina content. Bauxite deposits identified in the 1960s at the Mitchell Plateau and Cape Bougainville in northern WA are not currently economic to develop, but represent a potential future resource. The lack of commercial energy supply and other large scale infrastructure in the Kimberley region remains a significant hurdle to development of these resources. The potential availability of natural gas from planned liquefied natural gas (LNG) processing plants in the region would improve the economics of a development proposal, particularly if this involved advanced beneficiation. The 2011 Australian Heritage Council recommendation to list the West Kimberley includes the Mitchell Plateau bauxite resource and has the potential to influence future development proposals.

Economic Demonstrated Resources (EDR) of 6.0 gigatonnes (Gt) in 2010 represented a small drop on the previous year, mainly as a result of small shifts in categorisation. The nett change in overall demonstrated resources was limited, with additions resulting from exploration and resource estimation drilling being offset by depletions created through mine production.

## Accessible EDR

About 95% of bauxite EDR is currently accessible for mining. Some areas within mining leases in the Darling Range in WA, in particular, are not available for extraction for environmental reasons. The ratio of Accessible Economic Demonstrated Resources (AEDR) to current mine production shows the resource life of existing bauxite operations is around 70 years. The potential exists for further mineral exploration and reserve delineation to extend the current resource life estimate, particularly in the vicinity of existing operations.



Conveyor and bauxite stockpiles at the Queensland Alumina refinery, Gladstone, Queensland.

## JORC Reserves

Approximately 41% of AEDR comprises Joint Ore Reserve Committee (JORC) Code ore reserves as reported by industry. The remaining represents resources assessed by Geoscience Australia as being economically recoverable from measured and indicated categories of mineral resources, as defined under the JORC Code and other classification systems used by companies not listed on the Australian Securities Exchange. The surface expression of bauxite and confidence in lateral continuity of thickness and grade make it possible in certain terrains to classify some Inferred Resources as EDR.

## Exploration

Data on exploration for bauxite specifically are not available nationally. Because of the scale of existing known resources, much of the exploration effort for bauxite is directed at extending brownfields occurrences close to existing infrastructure.

## Production

Australia was the leading producer of bauxite and alumina globally in 2010 and the fifth largest aluminium producer, with increased export volume and value recorded during the year, especially for bauxite. Based on Australian Bureau of Agricultural and Resource Economics and Sciences data, production totalled 69 million tonnes (Mt) of bauxite (33% of global production), 20Mt of alumina (25% of global) and 1.9Mt of aluminium (5% of global). The export value of each commodity for 2010 was bauxite \$205 million, alumina \$5232 million and aluminium \$4172 million, leading to a total export value of \$9608 million.

The economic significance of value adding or first stage manufacturing to secure enhanced export value is demonstrated through the high values compared to lower volumes for alumina and especially aluminium, and the large volume and relatively small value for bauxite.

## World Ranking

Based on United States Geological Survey (USGS) data for other countries, Australia's demonstrated bauxite resources of 6Gt rank second in the world after the Republic of Guinea, and ahead of Brazil, Vietnam, Jamaica and India.

## Industry Developments

Aluminium is a product of increasing importance for manufacturing because of its light weight, strength, durability and resistance to corrosion, as well as its capacity to be recycled. On a life cycle assessment basis, the high strength to weight ratio of aluminium results in significant fuel savings, particularly where substitution can be made for heavier transport related construction materials. The energy intensity of the aluminium industry is high, with electricity accounting for around 30% of total operating costs for aluminium production. As a result, changes in the price of energy have a direct and immediate impact on the profitability of aluminium production.

The expansion of Australian bauxite and alumina production in the past few years reflects high demand for the commodities, with significant investments being undertaken in planned and prospective projects.

Rio Tinto Alcan progressed feasibility studies into the expansion of the **Weipa** (Qld) bauxite production operations South of the Embley River in 2010, including the potential construction of a new beneficiation plant, ship loading facilities and a power station. Depleted bauxite reserves at the **Andoom** and **East Weipa** operations would be replaced on a staged basis by production from South of the Embley River, which would extend the Weipa mine life by 40 years. The project has been referred under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and an Environmental Impact Statement (EIS) will be prepared following government and public comment. Pending approvals, construction could commence as early as 2012.

At **Gove** in May 2011, following a \$700 million agreement with the Northern Land Council and traditional owners, Rio Tinto secured a 42 year extension of the leases covering the company's bauxite mining and alumina refining operations.

BHP Billiton completed the budget and schedule review for its **Worsley** Efficiency and Growth (E&G) project in June 2011, reflecting a complex project constrained within the existing footprint of the facility. Once completed, the E&G project will leave the Worsley alumina refinery in WA's Darling Ranges with a capacity of 4.6 million tonnes per annum (Mtpa), up from the existing 3.5Mtpa capacity.

The Wenlock River Basin on Cape York was declared a wild river in June 2010 under the Queensland Government's Wild River Legislation, leading to a review of the **Pisolite Hills** bauxite proposal by Cape Alumina. The company found that the buffer restrictions imposed through the legislation rendered the proposal uneconomic, but planned to complete an EIS and lobby for further government consideration.

Along with the well developed production areas around Weipa (Qld), Gove (NT) and the **Darling Range** (WA), bauxite occurrences on the Mitchell Plateau and Cape Bougainville (WA), Cape York (Qld), central New South Wales and Tasmania maintained sector interest. Independent bauxite development companies have moved forward with a number of projects on Australia's east and west coasts, particularly for direct shipping bauxite ore from areas close to existing infrastructure.

## Black Coal

Mike Huleatt ([mike.huleatt@ga.gov.au](mailto:mike.huleatt@ga.gov.au))

Coal is a sedimentary rock formed from vegetation which has been altered by temperature and pressure over millions of years. Black coal consists of anthracite, bituminous and sub-bituminous coals and ranges in age from 140 to 225 million years old. The higher rank black coals are mainly used as a fuel in the generation of electricity (thermal coals) and to produce coke (metallurgical or coking coals) for the iron and steel making process. Black coal is used also in cement manufacturing, alumina refineries, paper manufacture, food processing and the manufacture of chemicals. Black coal occurs in all States and the Northern Territory, but Queensland with 55%, and New South Wales with 25% and have the largest share of Australia's total identified resources. The main producers of black coal were Queensland (54%) and New South Wales (43%). In addition there are locally significant operations at Collie in Western Australia, Leigh Creek in South Australia and in the Fingal Valley and at Kimbolton in Tasmania. In Australia about 75% of black coal is produced from open-cut mines.

## Resources

A major review of Australia's black coal resource inventory was undertaken as part of the resource assessment process for the preparation of the December 2010 national resource estimates. Particular attention was paid to: resources which were reported prior to the Joint Ore Reserve Committee (JORC) Code; those which had not been updated or reconfirmed over the past decade; and those resources reported prior to 1990 that were of a general regional nature for which no spatial location was known and which could not be verified by more recent data.

Results of the review show that Australia's recoverable Economic Demonstrated Resources (EDR) in 2010 was reduced by 4.5% to 41 848 million tonnes (Mt). In situ EDR was reduced by 7.5% to 56 135Mt. Queensland (59%) had the largest share of recoverable EDR in Australia and was followed by New South Wales (37%). The Sydney Basin (31%), Bowen Basin (33%), Surat Basin (13%) and the Galilee Basin (8%) had the largest shares of recoverable EDR in Australia.

In 2010, estimates of Australia's recoverable Paramarginal Demonstrated Resources fell from 1800Mt to 970Mt mainly because of the removal of some resources from the national inventory following the comprehensive review of coal resources. Similarly there was a reduction in recoverable Subeconomic Demonstrated Resources from 5900Mt to 4184Mt.

There was a substantial reduction in both in situ and recoverable Inferred Resources following the review with the in situ Inferred Resources falling by about 46 000Mt to 78 963Mt and recoverable Inferred Resources falling by 20 000Mt to 58 046Mt. Almost all of these reductions resulted from the removal of historical estimates of Inferred Resources which were based on pre-1990 data. These historical figures had been included in the national inventory but were deleted from the latest estimates because the resource estimates could not be verified and were of a general regional nature for which no spatial location could be ascertained. It was considered that this lack of data, especially recent data, on these coals was sufficient reason to exclude them from the national inventory.

## Accessible EDR

Almost all black coal EDR is accessible with only a relatively small tonnage at Hill River (WA) being quarantined within State Reserves.

## JORC Reserves

JORC Code Reserves are 17 238Mt or 41% of Accessible EDR. Included in this tonnage are estimates by Geoscience Australia of reserves of some 1200Mt at operating mines for which no reserves were reported by the mining companies. BHP Billiton, Rio Tinto and Xstrata Coal manage about 66% of JORC Code Reserves in Australia. The estimated resource life of the JORC Code Reserves is 38 years at the 2010 rate of production.

## Exploration

Data published by the Australian Bureau of Statistics (ABS) on coal indicated that exploration expenditure for 2010 totalled \$340.7 million which is an increase of 9% from \$312.7 million in 2009. Expenditure in Queensland rose by 29% to \$287.8 million or 85% of all Australian coal exploration spending. In New South Wales coal exploration expenditure almost halved falling to \$37.4 million from \$73.7 million in 2009 while the State's share of Australian coal exploration spending fell from 23.6% in 2009 to 11% in 2010. Exploration also occurred in South Australia, Western Australia, Tasmania and Victoria but the ABS does not release details of expenditure in those States. In 2010, coal exploration expenditure contributed 13.8% to the total mineral exploration expenditure in Australia which was slightly less than the 15.5% achieved in 2009.

## Production and Trade

Australian production of raw black coal in 2010 was 449 Mt (445Mt in 2009). This yielded 356Mt of saleable coal, 3% more than the 345Mt produced in 2009. Of the total production of both raw and saleable coal 75% was from open cut mines. Queensland and New South Wales dominate Australian black coal production and in 2010 accounted for 54% and 43% respectively of total raw coal production and 55% and 42% respectively of saleable coal production. Black coal was also produced in Western Australia (8Mt raw), South Australia (4Mt raw) and



Haul trucks at the open-cut Meandu coal mine in Southeast Queensland.

Tasmania (0.64Mt raw) in 2010. Exports of black coal during 2010 were 159Mt of metallurgical coal an increase of 24Mt over the 135Mt exported in 2009 and 141Mt of thermal coal, 2Mt more than in 2009. Australian coal exports in 2010 were valued at \$42 969 million according to the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES). ABARES has forecast that Australia's production of thermal coal will rise to 320.7Mt in 2015–16 and exports will rise to 242Mt in the same year. Metallurgical coal production is projected to rise to 220Mt by 2015–16 and exports to rise to 213Mt.

## World Ranking

International data for world coal resources and production uses an aggregation of coal by rank, which is different to that adopted in Australia. In terms of resources, international estimates refer to anthracite plus bituminous coal as one group and sub-bituminous coal and lignite as a second. Australian statistics for both resources and production refer to black and brown coal where black coal includes anthracite, bituminous and sub-bituminous coal and brown coal refers to lignite. Using the international categories Australia has 9.2% of the world's proven reserves of anthracite plus bituminous coal and 8.6% of the world's proven reserves of sub-bituminous coal plus lignite. In terms of production (all coal) in 2010, Australia accounted for 6.3% of world output.

In terms of the Australian coal categories it is estimated that Australia has in the order of 6% of the world's recoverable black coal economic resources and ranks fifth behind the USA (31%), Russia (22%), China (14%) and India (8%). Similarly Australia produced about 6% of the world's black coal in 2010 and ranked fourth after China (51%), the USA (16%) and India (9%).

## Industry Developments

Development activity in the coal sector continued at high levels in 2010. ABARES provided a comprehensive overview of developments in its report *Major Development Projects—October 2010* which was released in November 2010. In that report ABARES recorded that seven coal mining projects in New South Wales were under construction or committed and there were five similar projects in Queensland. The report also noted that in New South Wales there was an additional 22 coal mining projects at a less advanced stage while in Queensland there were 43 less advanced projects and one in Western Australia.

In addition to the mining projects, ABARES recorded that there were seven coal infrastructure projects under construction or committed and a further 15 projects were less advanced. The infrastructure projects include port development and expansion and rail capacity expansions.

### Queensland

Queensland coal mine projects reported by ABARES as under construction or committed in October 2010 include:

- Expansion of the **Curragh** mine to an annual capacity of 8.5Mt with an expected start up in 2011,
- Expansion at the **Newlands Northern** underground operation scheduled for completion in 2011 to have a capacity of 3Mt,
- Expansion of the **Kestrel** operation to add 1.7 million tonnes per annum (Mtpa) of coking coal capacity due for completion in 2012,
- **Isaac Plains** expansion to add 1.6Mtpa of coking and thermal coal capacity,
- **Middlemount** Stage 1 construction is to have a run-of-mine capacity of 1.8Mtpa of coking coal with production scheduled for 2012.

The following brief project overviews are typical of the activity in projects reported by ABARES as being at a less advanced stage of development:

- Aquila Resources Ltd announced in July 2010 that a feasibility study of its **Washpool** hard coking coal project near Blackwater in the Bowen Basin had confirmed the technical and economic feasibility of the project. It envisaged open cut hard coking coal production of 1.6Mtpa over a 25 year mine life from Proven and Probable Reserves of 108.3Mt. Subsequently, Aquila announced that the project would proceed to a definitive feasibility study and that the production target for the study would be expanded to 2.6Mtpa with a 15 year mine-life.
- Stanmore Coal Ltd announced an initial Inferred Resource of 117Mt of coal at **The Range** project located in the Surat Basin 24 kilometres (km) south east of Wandoan. The resource estimate was subsequently increased to 219Mt from which it is anticipated that a low ash thermal coal could be produced. The company announced that a concept study had indicated that the project was likely to be both economically and technically viable. This led to applications being lodged with the Queensland Government for a Mining Lease and Environmental Authority.
- BHP Billiton announced US\$267 million of pre-approval capital expenditure to accelerate the development of the **Caval Ridge** and Hay Point Coal Terminal Stage 3 Expansion projects. The funds were for feasibility studies, the procurement of long-lead time items and initial project activities. Later in the year the Queensland Government gave conditional approval for the Caval Ridge mine which is part of the **Peak Downs** project. Production is anticipated to commence in 2014 and when operating at capacity will have an expected annual production of 5.5Mt of coking coal.

### New South Wales

New South Wales coal mine projects reported by ABARE as under construction or committed in October 2010 include:

- Construction of the **Mangoola** open cut mine which is expected to start production in 2011 with a capacity of 8Mtpa of thermal coal,
- Expansion of the **Mt Arthur** open cut which will add 3.5Mtpa of thermal coal capacity from 2011,
- The **Moolarben** Stage 1 which will generate up to 12Mtpa (8Mtpa open cut, 4Mtpa underground) of run-of-mine thermal coal by 2012,
- Expansion of the **Boggabri** open cut with additional capacity of 2.8Mtpa of thermal coal by 2013,
- Expansion of the **Wilpinjong** mine to add between 2 and 3Mtpa of thermal coal capacity by 2013,
- Expansion of the **Metropolitan** longwall operation to give an additional 1Mtpa capacity by 2014,
- **Ulan West** development with a capacity of 6.7Mtpa of thermal coal by 2014.

The following brief project overviews are typical of the activity in projects which are at a less advanced stage of development:

- Whitehaven Coal Ltd announced that production of coal from its **Narrabri Mine**, 28km south of the town of Narrabri, commenced on 28 June 2010 when the first continuous miner cut coal. While initial production will be 0.5 to 0.7Mtpa, at full production the mine output will be some 6Mtpa of PCI<sup>2</sup> coal and low ash thermal coal for export.
- In December 2010, NuCoal Resources NL announced the successful completion of a Development Concept Study on its **Doyles Creek** project in the Hunter Valley. The study indicated that a financially robust project could be developed at an estimated \$500 million capital cost. The positive outcome of the study resulted in the company moving to initiate a preliminary feasibility study which is scheduled for completion by mid-2012.
- Coalworks Ltd completed a Preliminary Feasibility Study into the development of the **Vickery South** coal mine, coal handling and preparation plant and mine infrastructure which indicated that a positive return could be achieved from the project at a production rate of between 2 and 3Mtpa. The main outcome of the study was a multi-seam open cut operation with a life of 18 years. Production was indicated as 2Mtpa of run of mine coal which would yield an average of 1.41Mtpa semi soft coking coal and 0.28Mtpa of export thermal coal at full production. Coalworks Ltd said that the preliminary feasibility study would provide the basis for a bankable feasibility study which, if positive, would result in construction commencing in late 2011 or early 2012 and first production by 2014.

### Western Australia

Rey Resources Ltd was in the process of preparing a feasibility study into the potential development of a mine at its **Duchess-Paradise** project in the Canning Basin. Rey is reportedly examining the possibility of a project capable of producing 2Mtpa of thermal coal from about 2013.

## Brown Coal

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Brown coal, also called lignite, is a low rank, high moisture content coal which is used mainly to generate electricity. In Australia brown coal occurrences are known in all States and are Tertiary in age (15 to 50 million years old). The Gippsland Basin in Victoria contains a substantial world class deposit of brown coal with seams up to 330 metres thick. In Australia brown coal is mined only in Victoria only where the Anglesea, Loy Yang, Yallourn and Hazelwood open-cut mines supply coal to nearby power stations. Brown coal is mined also at Maddingley to produce a fertiliser product. Other products produced from Victorian brown coal are briquettes for industrial and domestic heating and low ash and low sulphur char products.

### Resources

Recoverable Economic Demonstrated Resources (EDR) for 2010 totalled 39 254 million tonnes (Mt) which was a 5.8% increase over the 2009 estimate. The growth was due to some resource growth but mainly from reallocation from other resource categories. Recoverable Paramarginal Demonstrated Resources (PDR) fell by just over 5% to 37 045Mt and Subeconomic Demonstrated Resources (SDR) fell by 2% to 15 942Mt. Recoverable Inferred Resources fell by almost 6% to 95 155Mt. Victoria accounted for 96% of Australia's identified resources of brown coal. All EDR is located in Victoria and about 93% of the total EDR is located in the Latrobe Valley.

### Accessible EDR

Approximately 87% of brown coal EDR is accessible. Quarantined resources include the APM Mill site, which had a 50 year mining ban applied in 1980. Other quarantined resources include the coal under the town of Morwell and the Holey Plains State Park, both in Victoria. The resource life of the accessible EDR of 34 150Mt at the 2010 rate of production is just under 500 years.

<sup>2</sup> Pulverised coal injection

## JORC Reserves

There are no Joint Ore Reserve Committee (JORC) Code compliant brown coal reserves publicly reported. In the 2009 edition of AIMR, Geoscience Australia estimated, from published information, “reserves” at the operating mines to be about 4700Mt which would have a life of almost 70 years at the 2010 rate of production.

## Exploration

The Australian Bureau of Statistics does not report data relating to exploration expenditure for brown coal.

## Production

Australian brown coal production for 2009–10 was 68.75Mt, all from Victoria. The Latrobe Valley mines of Yallourn, Hazelwood and Loy Yang produce about 98% of Australia's brown coal. Locally significant brown coal operations occur at Anglesea and Maddingley.

## World Ranking

International data for world coal resources and production uses an aggregation of coal by rank, which is different to the methodology used in Australia. In terms of resources, international estimates refer to anthracite plus bituminous coal as one group and sub-bituminous coal and lignite as a second. Australian statistics for both resources and production refer to black and brown coal where black coal includes anthracite, bituminous and sub-bituminous coal and brown coal refers to lignite. Using the international categories Australia has 9.2% of the world's proven reserves of anthracite plus bituminous coal and 8.6% of the world's proven reserves of sub-bituminous coal plus lignite. In terms of production of all coal in 2010 Australia accounted for 6.3% of world output.

In terms of the Australian coal categories it is estimated that Australia has approximately 19% of the world's recoverable brown coal EDR and ranks second behind the USA (20%). Australia produces about 7% of the world's brown coal and is ranked as the fifth largest producer after Germany (16%), Russia (8%), Turkey (7%) and China (7%).

## Industry Developments

Brown Coal Innovation Australia (BCIA) funded R&D projects in brown coal low-emissions and product innovation technologies. Included in the 2010 program were projects aimed at emerging technologies for the capture of CO<sub>2</sub> at a lower energy and cost penalty compared with existing technologies and an international collaboration to enable gasification for brown coal-fired power generation. Other projects supported included trials to determine the merits of using brown coal to improve soil health and plant yields; research into processing methodologies to reduce spontaneous combustion of dried or dewatered brown coal; determining the best-performing, most cost-effective solvent absorbent technologies for the capture of CO<sub>2</sub> emissions from brown coal and a literature review of next generation high-efficiency, low-cost, integrated drying. BCIA also supported investigations into gasification systems for the production of power and high-value products from brown coal and announced funding for a project involving the CSIRO Advanced Coal Technology and Exergen Pty Ltd. That project will investigate high efficiency power generation using processed Victorian brown coal in an adapted diesel engine. A HRL Developments Pty Ltd project in association with Kawasaki Heavy Industries Ltd received funding to study the technical and economic merits at both a pilot and commercial scale of various options for the production of hydrogen from Victoria's **Latrobe Valley** brown coal.

In Western Australia, Blackham Resources Ltd continued exploration on the **Scaddan** and **Zanthus** projects, near Esperance, where their aim is to establish Australia's premier coal-to-liquid facility. Blackham Resources reported that combined resource for the deposits was 1.2 billion tonnes of lignite containing 9200 PJ of energy at shallow depth. The company notes that the projects have the potential to produce 600 million barrels of petroleum products consisting mainly of a clean diesel.

Mantle Mining Corporation Ltd reported that its work at the **Bacchus Marsh** brown coal project in Victoria had increased its confidence in the size of the coal tonnage targeted. Incorporating historic drill data into the database for the area had contributed to the increased confidence that the target of about 1.8 billion tonnes is at the upper end of their exploration target range of 1 to 2 billion tonnes.

# Copper

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Australia is a major copper (Cu) producer with mining and smelting operations at Olympic Dam in South Australia (SA) and Mount Isa in Queensland (Qld). Other significant copper producing operations are at Cadia-Ridgeway, Northparkes and Tritton in New South Wales (NSW), Ernest Henry and Osborne (Qld), Nifty, Telfer and Golden Grove in Western Australia (WA), and Mount Lyell in Tasmania (Tas). Copper and copper alloys are used in building construction, electrical cables and electrical equipment as well as in industrial machinery and equipment. An average car contains more than 20 kilograms (kg) of copper and suburban homes have around 200kg of copper.

## Resources

Australia's total demonstrated resources of copper rose by 7 million tonnes (Mt) in 2010 to 132Mt. Almost all of the increase occurred in SA.

Australia's Economic Demonstrated Resources (EDR) of copper rose by 5Mt to 85.6Mt, an increase of 7% on the EDR in 2009. South Australia has the largest EDR at 57.1Mt, which is 67% of the national total. Almost all of the SA EDR are associated with the Olympic Dam deposit, where EDR of 54.6Mt is unchanged from 2009 following a doubling of EDR during 2007 and 2008. New South Wales and Qld each have 13% of Australia's copper EDR. Queensland EDR rose 2Mt in 2009 as a result of increased or upgraded resources for Mount Elliott, Rocklands, E1 and Starra. The balance of Australia's copper EDR is largely in WA with 6%.

Inferred Resources rose by 13% to 43.3Mt in 2010 largely as a result of the two newly reported SA deposits of Carrapateena with 4.4Mt Inferred Resources and Hillside with 1.2Mt. South Australia holds 72% of Australia's Inferred Resources (mostly at Olympic Dam) followed by Qld 15%, WA 8% and NSW 4%.

## Accessible EDR

All copper EDR is accessible.

## JORC Reserves

Joint Ore Reserve Committee (JORC) Code Reserves account for around 29% of Accessible Economic Demonstrated Resources (AEDR). The remaining AEDR comprise those Measured and Indicated Resources reported by mining companies which Geoscience Australia considers will be economic over the long term. The copper resource life using national EDR divided by annual production is 98 years, but using the ore reserve and dividing by annual production gives a resource life of only 29 years.

## Exploration

Spending on exploration for copper rose by 94% in 2010 to \$261 million. Expenditure in SA of \$82 million was 31% of all copper exploration. Expenditure in Qld of \$76 million represented a further 29%. The main areas of expenditure in SA were in the search for further Olympic Dam style mineralisation in the Gawler Craton. In Qld expenditure was in the Mount Isa and Cloncurry districts. Western Australia had 25% of spending on copper exploration across a range of projects, largely focused on seeking volcanogenic massive sulphide (VMS) ore deposits, including at DeGrussa. New South Wales had 9%, with the remainder in the Northern Territory (NT) with 4% and in Victoria and Tasmania, both with 1%. Expenditure on exploration for copper made up 10% of all mineral exploration.

## Production

In 2010, Australia's mine production of copper totalled 870 kilotonnes (kt) of contained copper, 2% higher than in 2009 (853kt). Queensland continued as the top producer of copper with 280kt, largely from the Mount Isa region. This was 5% more than in 2009 and represented 32% of Australian production, but for a second year Qld production was significantly down on the historic average for the years 2000 to 2008 of around 400kt per annum (ktpa). South Australia held the second largest producer position with 244kt. Olympic Dam and the recently commissioned Prominent Hill mine produced almost all of SA's output, contributing 16% and 14% respectively of national production. Western Australia produced 169kt (19%), up 17%, mainly from Nifty, Golden Grove and



Break rig drilling an oversized rock in the excavation level of the underground Northparkes copper-gold mine in New South Wales (Rio Tinto).

Telfer. New South Wales produced 149kt (17%) in 2010, largely from Northparkes, Cadia, Ridgeway and Tritton. Tasmania produced 28kt, up 2%, mostly from Mount Lyell, but with some from Rosebery.

The value of Australia's exports of copper concentrates and refined copper in 2010 totalled \$7.6 billion, up 30% on the \$5.8 billion in 2009 but holding at 3% of the value of total merchandise exports. Australian dollar copper prices rose in 2010 breaking a run of three years of decreases, which, in turn, had followed three years of substantial rises prior to 2007. The average copper price was up 28% in 2010 to \$8165 a tonne compared to the average of \$6398 a tonne in 2009. The average copper price in the December quarter of 2010 was \$8727, 20% higher than in the corresponding quarter of 2009. Copper exports in 2010 increased 7% to 845kt partly contributed to by the 2% increase in copper production.

## World Ranking

Based on United States Geological Survey (USGS) data for other countries, Australia has the third largest world economic resources of copper (13%) after Chile (23%) and Peru (14%) and ahead of Mexico (6%), the USA, China, Indonesia and Russia with 5% each. As a producer, Australia ranks fifth in the world, with 5% of world copper production, after Chile (34%), Peru (8%) and China and the USA (both 7%).

## Industry Developments

**Olympic Dam (SA):** BHP Billiton reported that 132kt of copper cathode was produced during 2010. This was 15% less than in 2009 and 44% below the design capacity of 235ktpa. Production was greatly reduced following extensive damage to the Clark Shaft haulage system by a falling ore skip in October 2009. Ore hoisting continued at 25% of capacity from the secondary Whenan Shaft before the mine returned to full production during the June quarter 2010. Planned maintenance activities were brought forward during the repair period. Self-insurance claims associated with the Clark shaft incident totalled US\$297 million in 2010/11.

BHP Billiton continued to investigate a series of staged capacity expansion options for Olympic Dam. Project activity was scaled back in 2010 to securing required approvals. In December 2010, BHP Billiton submitted a supplementary Environmental Impact Statement (EIS) for review by the Australian, South Australian and Northern Territory Governments in response to more than 4000 public submissions on the project as outlined in

the draft EIS of May 2009. For the expansion project, the southern part of the deposit will be mined by a large open pit. Annual production of copper is forecast to increase four-fold to 750ktpa for Olympic Dam to become one of the world's largest mines. This will require major infrastructure for water, energy and transport as well as an expansion of the Roxby Downs township. The proposed expansion would be a progressive development, requiring construction activity over a period of 11 years. The project progressed to the feasibility study stage in March 2011.

**Mount Isa and Ernest Henry (Qld):** Copper-in-concentrate production in 2010 from Xstrata Plc's Mount Isa and Ernest Henry operations totalled 232kt, an increase of 18% on 2009. At Mount Isa, underground operations production was 158kt of copper-in-concentrate, a decrease of 3% on the previous year as a result of lower grades which was partially offset by higher tonnages of ore mined and milled and improved recoveries. At Ernest Henry, copper-in-concentrate production increased 110% to 75kt because of higher mining rates, mill head grades and throughput. The Mount Isa smelter produced 215kt of anode (214kt in 2009). Using anode from the Mount Isa smelter plus some anode from Xstrata's Altonorte smelter in Chile, the Townsville refinery produced a record 287kt of copper cathode, an increase of 3% on 2009.

At the Mount Isa underground copper operations underground drilling exploration in 2010 again focused on mineralisation associated with existing orebodies and this will continue into 2011. A concept study into a large scale zinc and copper open pit as an extension to the current Black Star open pit mine was commenced in the second half of 2010. A pilot plant leaching trial of the Mount Isa concentrator tailing commenced in late 2010 as part of a pre-feasibility study into potential recovery of residual copper and cobalt.

Conversion of Ernest Henry from an open pit to an underground copper-gold mine with magnetite credits continued. Construction of the large scale underground sub-level cave mine reached 11 066 metres of completed development by the end of 2010. Design, construction and initial production and testing of the 1.2Mtpa magnetite plant were also completed in 2010. Plant commissioning and export of the high-grade magnetite product from Townsville port is scheduled for 2011. Regional exploration drilling continued to focus on targets in the Cloncurry and Mount Isa region which have the potential to provide additional ore feed to the Ernest Henry and Mount Isa plants.

**Prominent Hill (SA):** 2010 was the first year of full production at Prominent Hill and OZ Minerals Limited reported 112kt of copper and 196 400 ounces (ozs) of gold contained in concentrate were produced. Gold production was more than double the original forecast because of higher than expected quantities of gold-only ore being processed. Plant commissioning was completed in April 2009 and for 2010, the plant throughput rate was 19% above design capacity. Prominent Hill concentrates are the highest grade copper-in-concentrate traded on the open market, with copper grades of around 50%. Prominent Hill concentrates are transported 120 kilometres (kms) by road to the Adelaide to Darwin railway and then to the Port of Darwin, which offers a shipping time of around two weeks to most Asian ports.

In July 2010, final board approval was granted for the development of an underground mine to access the **Ankata** deposit, originally known as the Western Copper Zone. The Ankata high grade ore will contribute an average of 25kt of copper and 12 000ozs of gold each year for five years, augmenting ore from the **Malu** open pit 800 metres away. The Ankata mineralisation was discovered in 2007 when drilling was carried out on the Western Gravity Ridge. Following deposit definition through a series of exploration programs finishing in early 2010, a feasibility study was completed in June 2010. Development of the Ankata decline is underway and full production is expected by the third quarter of 2012. In 2010, further near mine drilling revealed a new copper zone known as Kalaya, together with new copper intersections within the Munda zone and near the Papa zone. The Ankata decline will be used for further drill testing of the Munda and Kalaya zones from mid 2011.

**Cadia-Ridgeway (NSW):** Copper production was 26kt for **Cadia** and 17kt for **Ridgeway** for 2010. Ridgeway's production was 10kt less than in 2009 because of transition from the sub-level cave to the Ridgeway Deeps block cave, which has been completed. The Ridgeway gold-copper mine is located 3kms from the Cadia Hill open pit and the top of the Ridgeway deposit lies approximately 500 metres below the surface. **Ridgeway Deeps** was successful in ramping up to a design production rate of 6Mtpa. The **Cadia Hill** pit is nearing completion and has a forecast mine life to early 2013.

The **Cadia East** project feasibility study was completed by the end of 2009. In January 2010, the New South Wales Government granted Newcrest Mining Limited the approval to proceed with the construction of the A\$1.9 billion project. The Cadia East underground panel cave mine will be Australia's largest underground mine

and will underpin production from the Cadia Valley province for at least the next 30 years. Construction began in April 2010. Cadia East will enable production to increase to around 100kt of copper and 800 000ozs of gold per year with the first commercial production expected in mid-2012. The existing Cadia Valley processing plant capacity will be expanded from 24Mtpa to 26Mtpa.

**Carrapateena (SA):** In April 2010 Reuters reported that RMG Services Limited and Teck Resources were seeking buyers for the Carrapateena deposit estimated to have 4.4Mt of copper and 6 million ounces (Mozs) of gold. Subsequently, on 9 March 2011, OZ Minerals Limited purchased the Carrapateena deposit for US\$250 million and three weeks later released an Inferred Mineral Resource for the southern portion of Carrapateena of 203Mt at 1.31% Cu and 0.56g/t Au, equating to 2.7Mt of copper and 3.7Mozs of gold. Discovery of the Carrapateena deposit in 2005 by Rudy Gomez of RMG Services was co-funded by the South Australian Government's Plan for Accelerating Exploration (PACE) incentive program. Mineralisation has been intersected over a vertical height of approximately 1000 metres. The deposit is roughly cylindrical and its top is located 470 metres below the surface.

**DeGrussa (WA):** In mid-2009, Sandfire Resources NL discovered high-grade VMS copper-gold mineralisation at DeGrussa, located 900km north of Perth and 150km north of Meekatharra. The discovery hole included an intersection of 53.2 metres at 17.3% Cu and 2.5g/t Au. In September 2010 Sandfire reported for DeGrussa a Measured, Indicated and Inferred Resource totalling 10.67Mt at 5.6% Cu, 1.9g/t Au and 15g/t Ag containing 600kt of Cu, 0.66Mozs Au and 5.1Mozs Ag. By November 2010 the DeGrussa metal inventory increased to 644kt Cu and 0.72Mozs Au as the result of an increase in the oxide copper resource from in-fill drilling. Proposed early stage mining will include 151kt of direct shipping material grading 25.6% Cu and 2.6g/t Au.

**Hillside (SA):** In December 2010, Rex Minerals Limited released an updated estimate for the Hillside copper project of an Inferred Mineral Resource of 170Mt at 0.7% Cu and 0.2g/t Au, containing 1.2Mt Cu and 1.1Mozs Au. The maiden resource of 100Mt at 0.7% Cu and 0.2g/t Au was released in July 2010.

**Rocklands (Qld):** In August 2010, Cudoco Limited released an updated Measured, Indicated and Inferred Resource estimate for Rocklands, using a copper equivalent cut off of 0.15%, of 245Mt at 0.21% Cu, 0.04g/t Au and 177ppm Co, containing 510kt Cu, 0.34Moz Au and 43kt Co.

## Diamond

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Diamond is composed of carbon and is the hardest known natural substance, although it can be shattered with a sharp blow. It also has the highest thermal conductivity at room temperature of any known material. Diamonds form 150–200 kilometres below the Earth's surface at high temperatures (1050°C–1200°C) and pressures (45–55 kilobars). They are carried to the surface within kimberlite and lamproite magmas which intrude through the Earth's crust. These intrusions form narrow cylindrical bodies called pipes, but only a very small proportion has significant diamond content. When pipes are eroded, liberated diamonds can accumulate in alluvial deposits and may be found far from their source. This is because their hardness allows them to survive multiple episodes of erosion and deposition.

The quality of diamonds is subdivided into gem, near gem and industrial categories. In rare cases, up to 90% of diamonds in a deposit are of gem quality, but most economic deposits contain 20% to 40% gem quality diamonds. Current uses for diamond include jewellery, mining and exploration, stone cutting and polishing, computer chip manufacture, machinery manufacture, construction and transportation services. A large proportion of industrial diamond is manufactured and it is possible to produce synthetic diamonds of gem quality.

### Resources

Australia's Economic Demonstrated Resources (EDR) increased by 37% in 2010 for both gem/near gem and industrial diamonds to 143.3 million carats (Mc) and 149.1Mc respectively. This increase is associated with the reclassification of some resources from paramarginal to economic at the Argyle mine in Western Australia (WA) where transition work from open pit to underground operations continues.



Aerial view of the Argyle diamond mine and processing plant, Western Australia (Rio Tinto).

## Accessible EDR

All diamond EDR is accessible for mining.

## JORC Reserves

The Joint Ore Reserve Committee (JORC) Code reserves account for 58% of Accessible Economic Demonstrated Resources (AEDR). The remaining AEDR comprise those Measured and Indicated Resources reported by mining companies, which Geoscience Australia has assessed as being economic in the long term.

## Production

Australia produced 10Mc of diamond in 2010, 0.8Mc less than in 2009 and about one third of what has been produced during many previous years. Production during 2010 was almost entirely from Rio Tinto's Argyle mine, which produced 9.8Mc. Production at both of Australia's operating mines fell in 2010 due to processing difficulties at Ellendale and mining of lower ore grades at Argyle as the open pit operation reaches its final stages before the transition to underground mining. Argyle production is mostly industrial and cheap diamonds, but includes high value rare pink diamonds. Future targeted production from the underground operation at Argyle is expected to be about 20Mc per year.

## World Ranking

Based on United States Geological Survey (USGS) data for other countries, Australia's EDR of industrial diamond is 23.5% of current world economic resources and ranks second behind the Democratic Republic of the Congo (Kinshasa) with 23.6%. This compares with 18% of world EDR for industrial diamond and a rank of third in 2009. This increase can be attributed to the reclassification of some resources from paramarginal to economic at the Argyle mine in WA. No detailed data are available on world resources of gem/near gem diamond, but Australian stocks are among the largest for this category.

Australia ranks as the world's fifth largest producer of diamond by weight (gem/near gem and industrial combined) after Russia, Botswana, Congo and Canada. The ranking is the same for gem/near gem diamond, with Australia the fifth largest producer after Botswana, Russia, Canada and Angola. For industrial grade diamond, Australia is the fourth largest producer after Russia, Congo and Botswana.

## Industry Developments

**Argyle (WA):** During 2010, production continued at Rio Tinto's Argyle open cut operation, yielding 9.8Mc of diamonds, including valuable rare pink diamonds. This figure is 7% lower than 2009 production of 10.6Mc, and reflects lower ore grades encountered during the final stages of open cut. Development of the underground block cave mine continued in 2010, with minimal construction undertaken while surface mining continued. In September 2010, the Rio Tinto board approved the remaining US\$803 million to complete construction of the underground project, bringing the total cost of the development to US\$1.6 billion. Surface mining is expected to continue at Argyle until 2013 before transitioning to a wholly underground operation forecast to produce 20Mc a year until at least 2019. Production was lower than expected in the first half of 2011 due to extraction of lower ore grades from the North Pit and high rainfall.

**Ellendale (WA):** GEM Diamonds Limited continued production from the E9 pipe at Ellendale, with the E4 pipe remaining on care and maintenance. Production from the E9 pipe was 0.17Mc in 2010 from 4Mt of ore treated, compared with 0.2Mc produced in 2009, although 2009 also saw limited production from the E4 pipe. Carat production was lower than expected owing to processing complications arising from unusually high rainfall. Current life of mine at E9 is relatively short, with operations forecast to cease in 2014. To address this, work started in 2010 on a Resource Extension Programme, which aims to better define the mineral reserve and mine life at E9, define the opportunity for recommencing mining at E4 and assess the economic viability of the E7 and E11 satellite pipes, as well as carry out follow-up work on identified exploration targets. An average price of US\$475/carats was achieved in 2010, compared to US\$232/carats in 2009. An agreement brokered with the high-end jeweller, Tiffany and Co., in September 2010 negotiated a price increase of 25% for Ellendale fancy yellow diamonds. These yielded an average price of US\$2891/carats in 2010, compared with US\$2480 in 2009. The full effect of the negotiated price increase will be felt in 2011.

**Venus Smoke Creek (WA):** Discovery of alluvial diamonds in Smoke Creek in the late 1970s led to the discovery of the currently mined Argyle diamond pipe. Diamonds from Smoke Creek had a better quality distribution than the hard rock resource and were mined by Argyle Diamonds Limited. In November 2010 Venus Metals Corporation Limited announced an Inferred Resource of 17.9Mt containing 5Mc of diamonds, which was subsequently upgraded to 21.5Mt and 6Mc in September 2011. The Smoke Creek alluvial diamonds appear to be derived from erosion of the Argyle pipe, and therefore represent a possible new source of valuable pink diamonds.

**Webb (WA):** Meteoric Resources has signed a Heads of Agreement with North Australian Diamonds Limited to investigate geophysical anomalies located on Meteoric Resources' tenements in the western Arunta region. More than 50 magnetic anomalies have been recognised, which have many similarities to known kimberlite and lamproite pipes in other parts of Australia. Geophysical modelling indicates that the bodies have pipe-like geometries. So far, these anomalies are untested.

**Merlin (NT):** During 2010, work at North Australian Diamonds Limited's Merlin project focused on prefeasibility production trials aimed at assessing the economic viability of Merlin. A diamond parcel of 10 598 carats was recovered during these trials, with 24% of diamonds greater than one carat. The run of mine rough diamond parcel has been valued in excess of US\$330/carats. A contract for a definitive feasibility study was awarded in August 2011, with the results expected in early 2012. Resource definition drilling at Merlin took place in early 2010 and led to an increase of the known resource from 21.5Mt to 30Mt of Indicated and Inferred Resources for a total of 7.2Mc of contained diamonds. In mid-2011, 11.1Mt of this resource was upgraded to Probable Ore Reserves.

**Borrooloola (NT):** An exploration licence was granted to North Australian Diamonds Limited in September 2011 to test the diamond-bearing potential of gravels just south of the township of Borrooloola in the Northern Territory. The prospect is located at the only major alluvial concentration at a topographic depression in a known diamond-bearing catchment. Initial work is scheduled to occur in the second half of 2011.

# Gold

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The principle uses for gold (Au) are as an investment instrument for governments, central banks and private investors, and in the manufacture of jewellery. Because of its high conductivity and corrosion-resistance properties, gold is used in the electronics industry also, as well as in dentistry because the alloys used are strong and resistant to tarnishing.

Demand for gold has exceeded world mine production for many years and has necessarily drawn on recycling, sales by investors and, until recently, sales by central banks. Over most of the past two decades the central banks have sold down their stocks of gold. However, since early 2010, these banks have again become net purchasers of gold to augment their reserves. The continuing strong demand for gold from China and India, coupled with the ongoing economic uncertainty associated with the Eurozone and other debt crises, caused the price of gold to rise steadily from around US\$1080 an ounce in January 2010 to about US\$1700 an ounce in October 2011 (Figure 2). Strong increases in the gold price (in US\$) reflect the continuation of a trend since about 2002, which, with the exception of 2008, has been increasing at more than 10% a year and by more than 50% over the past two years. The rise in the gold price in AU\$ has not been as dramatic over the same period largely because of the relative increase in the value of the Australian dollar (2002 AU\$/US\$= 0.55; 2010 ≈0.95). Nonetheless, the increase in the gold price in AU\$ has been tracking at more than 15% a year since 2005.

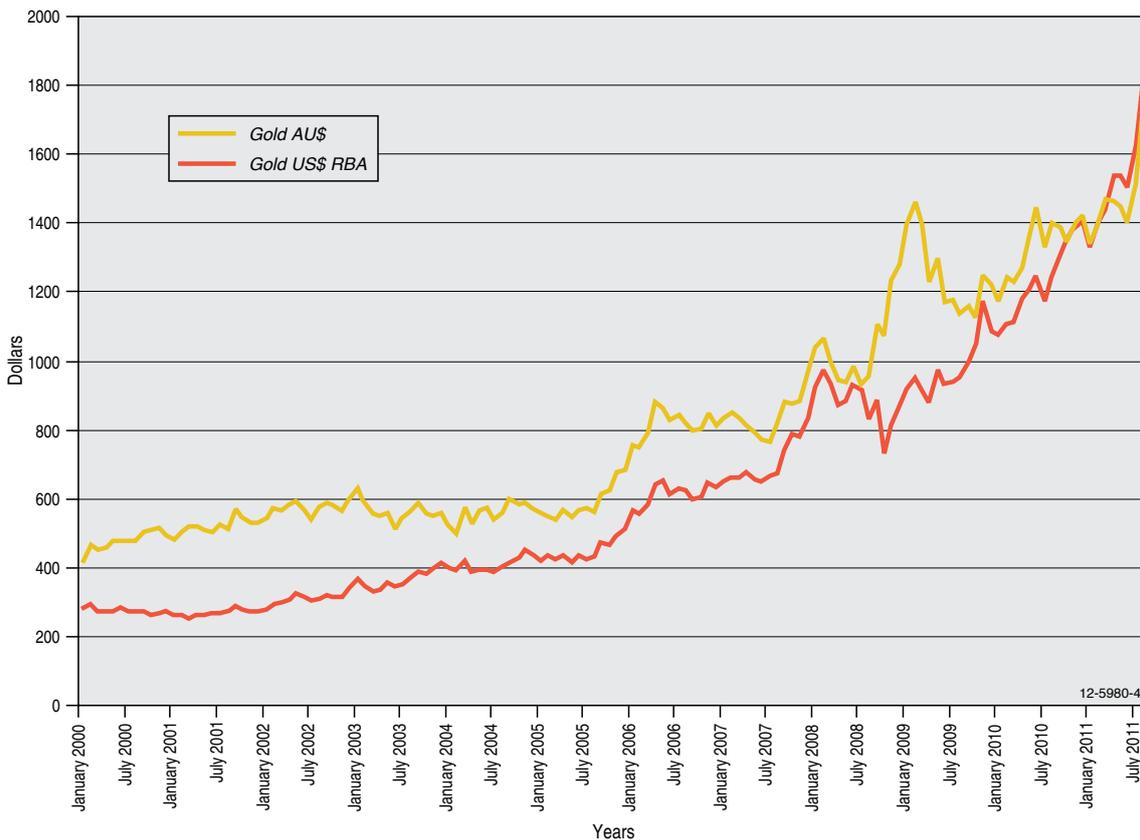


Figure 2. Monthly gold price in US\$ and AU\$ (dollars of the day) since January 2000. The data series were derived from Reserve Bank of Australia figures.

## Resources

Australia's gold resources are mined in all States and the Northern Territory (NT). As at December 2010, total Joint Ore Reserves Committee (JORC) Code resources of gold were about 13 800 tonnes (t), or 465 t more than at the end of 2009. Allowing for depletion of resources due to production (260 tonnes), new resources added to the national inventory in 2010 totalled 725 tonnes or 23 million ounces (Mozs).

Australia's Economic Demonstrated Resources (EDR) of gold increased by 1010 tonnes (32Mozs) to 8410 tonnes in 2010. Around 70% of Australia's total EDR are contained in just 15 deposits (Figure 3), with more than 50% of total EDR within the four largest, Olympic Dam in South Australia (SA), Cadia East in New South Wales (NSW) and Boddington and Telfer in Western Australia (WA). Although EDR increased in all States and the NT, more than half of the increase, about 590 tonnes, was in WA. Western Australia also continued to dominate total EDR of gold with approximately 3570 tonnes, or 42% of the national total. South Australia with 2310 tonnes largely from Olympic Dam and NSW with 1640 tonnes contributed the second and third largest quantities to the national EDR total respectively. Just under 50% of Australia's EDR of gold is derived from Ore Reserves as defined under the JORC code.

Submarginal Demonstrated Resources remained constant during 2010 at approximately 120 tonnes. In contrast, Paramarginal Demonstrated Resources decreased significantly to 930 tonnes, a decrease of 40% or 570 tonnes on the figures for 2009. Decreases occurred in all States and the NT and were directly attributable to the continuing increase in world gold prices during 2010. Western Australia saw the most significant decrease in Paramarginal Demonstrated Resources of 330 tonnes to a total of about 705 tonnes in 2010.

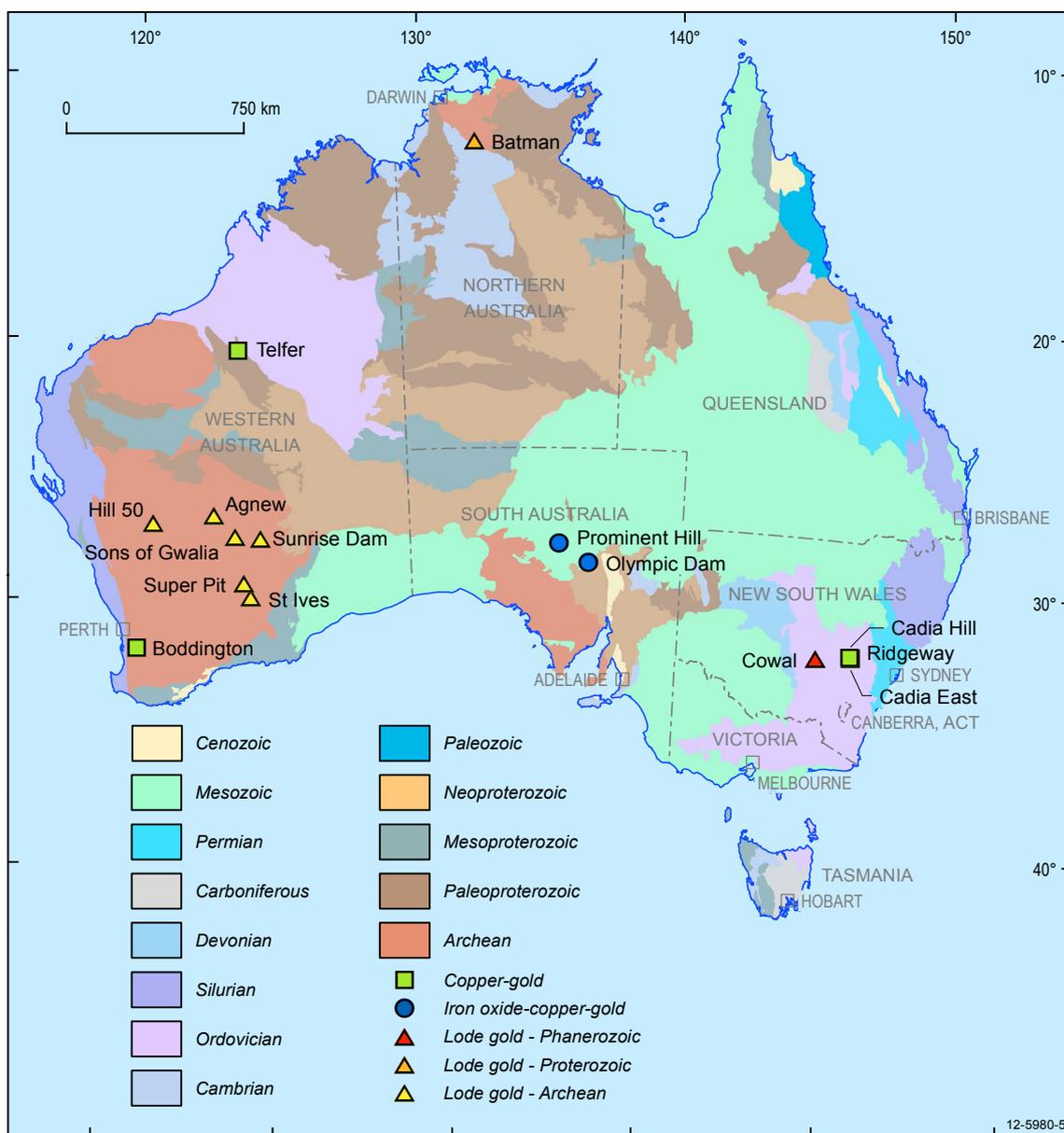


Figure 3. Gold deposits with the 15 largest totals of Proven and Probable Ore Reserves plus complementary Measured and Indicated Mineral Resources in 2010.

Nationally, Inferred Resources rose marginally to 4450 tonnes during 2010, an increase of about 19 tonnes or less than 1% on 2009 figures. While new Inferred Resources were defined during 2010, this was offset by the upgrade of existing Inferred Resources to categories with greater geological certainty through infill drilling. Changes to Inferred Resources at the State and Territory level were variable. However, WA with 1900 tonnes or 43% of the total and SA with 1070 tonnes or 24% of the total continued to maintain their dominance of the Inferred Resource category.

## Accessible EDR

Australia's EDR for gold are essentially unencumbered with around 30 tonnes or less than 1% currently unavailable for exploitation. Deposits which contain gold resources that are unavailable for mining include Jabiluka, Koongarra, and Coronation Hill, which are all located in the NT.

## JORC Reserves

Joint Ore Reserves Committee (JORC) Code Reserves comprise total gold resources in Proven and Probable Ore Reserves as defined in the JORC code. In 2010, JORC Reserves amounted to 4070 tonnes, an increase of about 520 tonnes over the 2009 figure. These reserves accounted for 49% of total EDR. While the majority of operating mines have JORC Reserves which are the basis for current mining and production, it is apparent that some operations were mining from Mineral Resources of lower economic certainty, such as Bendigo Mining (now Unity Mining) at Kangaroo Flat in Victoria (Vic). Periodically some operations have also undertaken what is considered trial mining as irregularly distributed, coarse gold, has precluded the establishment of JORC compliant resource figures, as is currently the case for Castlemaine Goldfields Ltd at Ballarat (Vic).

## Exploration

Total mineral exploration expenditure, as reported by the Australian Bureau of Statistics, increased by \$468 million to \$2491 million in 2010. Gold exploration attracted the largest share of Australia's total expenditure at approximately 25%, overtaking that for iron ore. Expenditure on gold increased \$161 million to \$624 million, or 35% more than the 2009 figures.

Exploration expenditure for gold increased in the NT and all States except SA. Almost 90% of the total expenditure increase occurred in WA which was up \$135 million on the 2009 figures to \$412 million. New South Wales attracted the second largest increase in expenditure of just over \$15 million, while expenditure on gold exploration in SA was estimated<sup>3</sup> to have decreased by about \$19 million in 2010. Total gold exploration expenditure during the first half of 2011 was up \$28 million on the corresponding period in 2010 with increases in WA (up \$40M), the NT (up \$6M) and Tasmania (up \$1M). The other States have recorded decreases of between \$1 million and \$13 million.

Expenditure on gold exploration between greenfields (new) and brownfields (existing deposits) projects is not shown in available statistics. However, the proportion of total mineral exploration expenditure between greenfields and brownfields remained essentially unchanged between 2009 and 2010 at 38% and 62% respectively.

## Production

The Perth Mint is the sole refiner of gold in Australia, acquiring raw material from domestic mine production, recycled materials and from overseas. Total refined gold for 2010 amounted to 350 tonnes, of which about 330 tonnes was exported, a decrease of 30 tonnes on 2009.

While domestic mine production increased to 260 tonnes in 2010, around 37 tonnes higher than 2009, it was still less than production highs of about 310 tonnes achieved in the late 1990s. Almost 70% of 2010 national mine production came from WA, followed by NSW with 12% (Table 2). Gold was a primary output of about 70 operations with many drawing resources from two or more deposits and/or from both open pit and underground sources. Several mines also produced gold as a by-product of processing other commodities such as in polymetallic base metal deposits at Rosebery, Olympic Dam and Prominent Hill.

<sup>3</sup> The figures for exploration expenditure on gold may only be considered an approximation as ABS assigns company provided expenditure on poly-metallic deposits (e.g. copper-gold) to the first named commodity.

**Table 2.** Gold production by State/Territory for the past five years. Western Australia continued to dominate Australian production figures in 2010.

	2006 Tonnes	2007 Tonnes	2008 Tonnes	2009 Tonnes	2010 Tonnes
Queensland	22	23	18	16	15
New South Wales	27	35	31	25	30
Victoria	6	6	5	8	7
Tasmania	5	4	5	4	4
South Australia	7	7	7	8	13
Northern Territory	14	17	15	10	10
Western Australia	165	156	134	152	181
<b>Australia</b>	<b>246</b>	<b>248</b>	<b>215</b>	<b>223</b>	<b>260</b>

Sources: Australian Bureau of Statistics and the Bureau of Resources and Energy Economics.

Gold deposits can be grouped into a number of deposit types. The resources and mine production in 2010 for each of these types is shown in Table 3. Lode gold deposits of Archean age, with grades typically of 1.5 grams per tonne (g/t) to more than 8g/t Au, accounted for almost 61% of production. Other copper-gold (18.4%) and Lode gold of Phanerozoic age (7.3%) were the second and third most important sources respectively. More than 60% of Australian EDR of gold are in relatively low grade 0.36g/t to 0.86g/t Au iron oxide or other copper-gold deposits. These deposits contributed only a little over 20% to the 2010 gold production figures.

In summary, Archean lode gold deposits dominate current mine production, however, lower grade copper-gold deposits of various styles comprise the majority of Australia's current resources.

Thus in order to maintain the current level of production over the intermediate to longer term:

- Significant new resources of higher grade deposit styles, most probably Archean lode gold, will need to be defined;
- Inferred Resources of Archean gold deposits (and other types) must be better drilled to transfer these to reserves; or
- Mining of lower grade deposits will need to occur at much higher rates than at present.



View of the Super Pit, the largest open-pit gold mine in Australia, Kalgoorlie, Western Australia.

**Table 3.** Economic Demonstrated Resources (EDR), Inferred Resources, and mine production of gold (in tonnes) for 2010, categorised by deposit type. Also shown are percentages of gold produced (in parentheses) by each deposit type. Lode gold deposits of Archean age dominate current mine production, but lower grade copper-gold deposits of various styles comprise the majority of Australia's current resources. Surbiton Associates Pty Ltd is gratefully acknowledged for providing the compiled data behind the mine production figures. Other Cu-Au/Au-Cu deposits include Telfer in Western Australia and the porphyry related mineralisation at Northparkes and Cadia in New South Wales.

Deposit Type	EDR Tonnes Au	Inferred Res. Tonnes Au	2010 Mine Prod. Tonnes Au
Lode Au Archean	2160 (25.9%)	1610 (36.2%)	158 (60.7%)
Lode Au Proterozoic	430 (5.1%)	300 (6.7%)	18 (6.9%)
Lode Au Phanerozoic	175 (2.1%)	665 (14.9%)	19 (7.3%)
Iron Oxide Cu-Au	2420 (28.8%)	1150 (25.8%)	12 (4.6%)
Other Cu-Au/Au-Cu	2970 (35.3%)	580 (13.0%)	48 (18.4%)
Au-Ag (inc. epithermal)	20 (0.2%)	29 (0.7%)	1 (0.4%)
Poly-metallic base metals	185 (2.2%)	90 (2.0%)	4 (1.5%)
Au-Sb (Paleozoic)	30 (0.4%)	22 (0.5%)	0.3 (0.1%)
Breccias (Paleozoic)	20 (0.2%)	1 (<0.1%)	0 (0%)
Layered Intrusions	0 (0%)	3 (0.1%)	0 (0%)

## World Ranking

Based on estimates provided by the United States Geological Survey (USGS), world economic resources of gold increased almost 5000 tonnes in 2010 to 51 800 tonnes. Australia, with EDR of 8410 tonnes (16%), had the largest share of the total, followed by South Africa with 6000 tonnes (12%) and Russia with 5000 tonnes (10%). Also based on USGS figures, world mine production of gold increased about 50 tonnes to 2510 tonnes in 2010. Australian mine production of 260 tonnes, or about 10% of world total, was ranked second behind China with

340 tonnes, but ahead of the United States of America with 230 tonnes, and Russia and South Africa, which each produced about 190 tonnes in 2010. Over the past decade, world mine production has fluctuated between a peak of 2620 tonnes in 2003 and a trough of 2264 tonnes in 2008. Over the same period, consistent increases in output for China, from 185 tonnes in 2001 to 340 tonnes in 2010, have been offset by declining production in South Africa from 402 tonnes to 190 tonnes, Canada from 160 tonnes to 90 tonnes and the USA from 335 tonnes to 230 tonnes. Estimated production rates for other countries over the same period are more irregular. Australia's mine production of gold peaked most recently about 1998 at 310 tonnes but declined steadily to 215 tonnes in 2008 before recovering a little in 2009 to 223 tonnes and more substantially in 2010 to 260 tonnes, which was still 50 tonnes below that achieved in 1998.

## Industry Developments

Continuing increases in the price of gold during 2010 provided additional impetus for the rebound in exploration, with expenditure for the year up about \$160M on the figure for 2009. During the year, the assessment of deposits, many with historic production, led to several feasibility studies, the purchase and upgrading of processing plants and widespread drilling programs. Many operating mines commenced enlarging open pits (referred to as cutbacks in open pits) or accessing panels in underground operations to extract material that previously was deemed uneconomic. These activities led to a substantial increase in the EDR for gold and are expanding production capacity.

## Activities

The following selected announcements provide an overview of significant industry activities for 2010.

### Queensland

Conquest Mining Limited announced the purchase of the remaining 40% of the **Pajingo Gold Mine**, southeast of Charters Towers, through the acquisition of HSK Gold Pty Ltd and the remaining 5% of North Queensland Metals. The company also announced board approval for development of the **Mt Carlton Mine**, northwest of Collinsville, and purchased an 800 000 tonnes per annum (tpa) semi autogenous grinding (SAG) mill for the project from Hillgrove Resources Limited.

Ivanhoe Australia Limited announced upgraded indicated and inferred resources for **Mt Elliott** south of Cloncurry of 570 million tonnes (Mt) at 0.44% Cu and 0.26g/t Au. The company also reported promising drill intersections at **Starra 222**, south of Mount Elliott, including 58 metres (m) at 1.04% Cu and 1.76g/t Au, and at **Barnes Shaft**, north of Mount Elliott, 29m at 3.21% Cu, 3.37g/t Au and 383 parts per million Cobalt.

Barrick (PD) Australia Ltd reported placing the **Osborne Mine**, south of Mount Elliott, on care and maintenance and subsequently sold the mine and related tenements to Ivanhoe Australia Limited.

Resolute Mining Ltd reported high grade gold intercepts from the **Welcome Breccia** at its Ravenswood Project, northeast of Charters Towers, including 113m at 7.7g/t Au from 316m and 55m at 10.54g/t Au from 420m.

Catalpa Resources Limited announced a 21% increase in mineral resources at **Cracow**, west of Maryborough, to 1.02Mozs.

### New South Wales

Newcrest Mining Ltd announced planning approval for the **Cadia East (Mine) Project**, southwest of Orange.

Alkane Resources Ltd announced that the **McPhillamys** deposit, southeast of Orange, would proceed to a Bank Feasibility Study. They also reported Indicated plus Inferred Mineral Resources of 60Mt at 1.32g/t Au and 0.08% Cu at a 0.5g/t Au cut-off.

Cortona Resources Ltd reported further high grade intercepts at **Dargues Reef**, southeast of Canberra, including 5.7m at 97.1g/t Au, 2.8m at 39.1g/t Au and 5.5m at 14.4g/t Au, and conclusion of a positive feasibility study.

## Victoria

Castlemaine Goldfields Limited announced the purchase of the **Ballarat Gold Project** from Lihir Gold Ltd. The company subsequently reported drilling results from the project including 6.4m at 61.2g/t Au from the Britannia-Makado Fault Zone and 8m at 7.3g/t Au from the Basking Fault zone in the Britannia Compartment.

Minotaur Exploration Ltd announced an Inferred Mineral Resource at **Golden Mountain**, south of Benalla, of 950 000 tonnes at 2.31g/t Au for 70 500 ounces (ozs) of Au at 1g/t cut-off.

Morning Star Gold N.L. reported that production had commenced at the **Morning Star Gold Mine** at Woods Point.

Greater Bendigo Gold Mines Limited signed an options agreement to purchase the Bendigo Creek Tailings Project northeast of Bendigo and poured its first gold from the **Maxwells Mine** at Inglewood.

## Tasmania

After acquiring the **Henty Gold Mine**, southeast of Rosebery, in July 2009, Bendigo Mining Limited (now Unity Mining) announced the discovery of two new mineralised zones, the Read Zone (best intersection of 5m at 105g/t Au); and the Newton Zone (best intersections of 23m at 11g/t Au and 10m at 12.2g/t Au).

BCD Resources NL announced a 14% increase in reserves at its **Tasmania Mine** at Beaconsfield to 949 000 tonnes at 9.7g/t Au for 294 000ozs.

## Northern Territory

Crocodile Gold Corporation announced increases in indicated mineral resources at **Howley**, northwest of Pine Creek, to 11.4Mt at 1.54g/t Au for 566 500 ozs, and commencement of commercial production from the Union Reefs Mill.

Vista Gold Corporation released the results of a positive preliminary feasibility study of the **Batman Deposit** at its Mount Todd Gold Project, southeast of Pine Creek, with proven and probable ore reserves of 60.05Mt at 1.05g/t Au for 2.03Moz at a 0.55g/t cut-off. The company also announced measured and indicated mineral resources at the near-by **Quigleys Deposit** of 6.07Mt at 0.92g/t Au for 179 000ozs.

Tanami Gold NL announced that it had acquired the **Groundrush Gold Project**, northeast of Tanami, from Newmont Asia Pacific and subsequently reported drill intersections from the **Southern Deposit** of up to 19m at 7.8g/t Au.

ABM Resources NL reported that it had acquired several gold projects from Newmont Asia Pacific, including **Twin Bonanza** and **Old Pirate**, southwest of Tanami. The company also announced drill intersections at **Hyperion**, northeast of Tanami, of 60m at 2.57g/t Au and 28m at 5.07g/t Au.

## South Australia

Rex Minerals Ltd announced an Inferred Resource for the **Hillside Deposit** south of Ardrossan on the York Peninsula of 100Mt at 0.7% Cu and 0.2g/t Au.

Southern Gold Ltd announced its first JORC compliant Inferred Resource for the **Golf Bore Deposit**, northwest of Tarcoola and northeast of the Challenger Gold Mine, of 3.2Mt at 1g/t Au.

Hillgrove Resources Ltd announced its intention to redevelop the **Kanmantoo Mine** southeast of Adelaide and increased reserves to 14.8Mt at 0.85% Cu, 0.17g/t Au and 3.1g/t Ag.

Exco Resources Ltd and Poly Metals Group Pty Ltd completed construction at the **White Dam** deposit northeast of Olary and produced its first gold from the project.

Havilah Resources NL announced the results of a positive feasibility study for the **Portia Gold Project** north of Olary and its intention to proceed with development.

## Western Australia

Regis Resources Ltd announced a maiden ore reserve for the **Garden Well Deposit**, north of Laverton, of 27.5Mt at 1.52g/t Au within mineral resources of 42.4Mt at 1.36g/t Au. The company also announced an initial ore reserve

for its **Eristoun Gold Project**, north of Laverton, of 2Mt at 2.41g/t Au for 157 500 ozs, and commencement of commercial operations of the 2Mtpa **Duketon gold plant**.

Eleckra Mines Limited (now Gold Road Resources Ltd) announced drill intersections of 5m at 146g/t Au and 6m at 35g/t Au from its **Central Bore Project**, 150 kilometres (kms) northeast of Laverton.

AngloGold Ashanti Ltd and Independence Group NL approved the development of the **Tropicana Gold Project**, 300kms northeast of Kalgoorlie, based on a bank feasibility study and Proven and Probable Ore Reserves of 48Mt at 2.2g/t Au for 3.4Mozs.

Avoca Resources Ltd (now Alacer Gold Corp) announced its takeover of Dioro and a positive mining scoping study for the **HBJ Superpit** south of Kalgoorlie based on a mineral resource estimate of 51Mt at 1.8g/t Au for 3Mozs. The company also reported increased mineral resources at **Higginsville** (Trident, Fairplay, Chalice) south of Kambalda of 14.3Mt at 3.4g/t Au for 1.57Mozs.

Focus Minerals Ltd announced the commissioning of its **Three Mile Hill** mill at Coolgardie, a maiden reserve for the **Mount Deposit** of 68 000 tonnes at 8.6g/t Au and upgraded resources at the **Tindals Mining Centre** of 2.04Mt at 4.9g/t Au for 324 000ozs.

Troy Resources NL reported that its **Sandstone** operations had moved to care and maintenance.

Beadell Resources Ltd announced a drill intersection at the **Hercules Shear Zone** in the 'Tropicana Belt' 300kms northeast of Kalgoorlie of 30m at 8.3g/t Au, including 10m at 23.1g/t Au.

Catalpa Resources Limited reported its first gold pour from the **Edna May Project**, west of Southern Cross, and subsequently that Ore Reserves had increased to more than 1Mozs.

Millennium Minerals Ltd announced a total Ore Reserve estimate for its **Nullagine Gold Project** of 8.2Mt at 1.7g/t Au for 567 000ozs and updated total resources to 17.54Mt at 1.11g/t Au for 1.25Mozs.

Northern Star Resources Ltd announced purchase of the **Paulsens Gold Mine** in the Pilbara region, resumption of production and drill intersections, including 2m at 71g/t Au and 3.3m at 13g/t Au.

## Iron Ore

Daisy Summerfield ([daisy.summerfield@ga.gov.au](mailto:daisy.summerfield@ga.gov.au))<sup>4</sup>

Iron (Fe) is a metallic element which constitutes about 5% of the Earth's crust and is the fourth most abundant element in the crust. Iron ores are rocks from which metallic iron can be economically extracted. The principal iron ores are hematite (Fe<sub>2</sub>O<sub>3</sub>) and magnetite (Fe<sub>3</sub>O<sub>4</sub>).

**Hematite** is an iron oxide mineral. It is non-magnetic and has colour variations ranging from steel silver to reddish brown. Pure hematite mineral contains 69.9% iron. Historically, it has been the dominant iron ore mined in Australia since the early 1960s. Approximately 96% of Australia's iron ore exports are high grade hematite, the majority of which has been mined from deposits in the Hamersley province of Western Australia (WA). The Brockman Iron Formation in Hamersley province is a significant example of high grade hematite iron ore deposits.

**Magnetite** is an iron oxide mineral generally black in colour and highly magnetic, the latter property aiding in the beneficiation of magnetite ores. Magnetite mineral contains 72.4% iron, which is higher than hematite. Despite this, the common presence of impurities in magnetite ores makes them lower grade and more costly to produce concentrates used in steel smelters. Magnetite mining is an emerging industry in Australia with large deposits in the Pilbara region (WA) being developed. The largest project is the \$5.2 billion Sino Iron project being developed by the Chinese company Citic Pacific. To date, the other major magnetite development is the \$2.6 billion Karara joint venture project owned by Gindalbie Metals and Chinese steel producer, Ansteel.

<sup>4</sup> Geoscience Australia wishes to acknowledge the contribution by Western Australia Geological Survey, Primary Industries and Resources South Australia (PIRSA), the Geological Survey of Queensland and Aden McKay for the provision of iron ore data and other relevant information

## Mining and Processing Hematite and Magnetite Ores

High grade **hematite ores** are referred to as direct shipping ore (DSO) because they are mined and beneficiated using a relatively simple crushing and screening process before being exported for use in steel making. Australia's hematite DSO from the Hamersley region (WA) averages from 56% to 62% iron. **Magnetite ores** require initial crushing and screening the same as hematite ores, but also includes a second stage of processing. This second stage relies on the magnetic properties of the ore and involves large scale magnetic separators being used to separate the magnetite and produce a concentrate. Consequently, the types of magnetite mineralisation, including either coarse or fine-grained magnetite, are important economically. Metallurgical tests on both coarse-grained and fine-grained magnetite ores (Accent Resources, 2009)<sup>5</sup> show that the coarse-grained magnetite banded iron formation (BIF) (mass concentrate recovery is 45.9% at 69.2% iron) performed better with regard to mass recovery when compared to fine-grained magnetite (mass concentrate recovery is 29% at 69.6% iron). Size requirements also differ for both mineralisation types such that fine-grained magnetite BIF 80% passing size require 45 microns, while coarse-grained magnetite BIF 80% passing size require 75 microns, which results in less grinding energy.

Further processing involves the agglomeration<sup>6</sup> and thermal treatment of the concentrate to produce pellets which can be used directly in blast furnaces or in direct reduction steel-making plants. The pellets contain 65% to 70% iron, being a higher iron grade than hematite DSOs currently being exported from the Hamersley region. Additionally, the magnetite pellets contain lower levels of impurities, particularly phosphorous, sulphur and aluminium when compared to hematite DSOs. These pellets are premium products which attract higher prices from steel makers, offsetting the higher costs of producing magnetite pellets.

## Worldwide Production Trends

**Hematite ores** represent 60% of total world production of iron ores. The largest producers are Australia and Brazil. **Magnetite ores** account for 40% of iron ore production worldwide and are mined and processed extensively around the world. China has large resources of low iron grade magnetite ores (23 Gigatonnes (Gt) of economic resource of iron ore with average grade approximately 30% Fe) and considerable experience in mining and concentrating these ores. In the USA, total economic resources are estimated to be 6.9Gt of ore with average grade of 30% Fe (USGS, 2011)<sup>7</sup>. Resources in the USA are mainly low grade taconite type ores (magnetite and iron silicate) from the Lake Superior districts which require beneficiation and pelletising prior to commercial use. Upgrading these ores through pelletising has increased over the years and by the mid 1980s accounted for more than 95% of USA production.

In recent years, a trend worldwide has been the gradual depletion of the highest grade hematite ores with iron grades of DSO declining and the levels of impurities generally increasing. The demand for premium quality steel in China and India continues to grow. An increasing number of steel mills are blending high quality magnetite pellets with premium grade hematite ores to increase the quality of steel products and improve productivity in their blast furnaces.

## Resources

In previous years, Geoscience Australia has reported estimates of Australia's national resources of iron as tonnes of iron ore because these resources were dominantly hematite ores. However, as a result of on-going exploration and assessment of magnetite deposits, Australia has now identified substantial reserves and resources in both hematite and magnetite ores. Because of the high average grades (% Fe) of hematite ores when compared to the average grades for magnetite ores, it is necessary to report national resources in terms of 'contained Fe'. Accordingly, for 2010, Australia's national resources of iron are reported in two categories:

- Iron ore (tonnes), and
- Contained Fe (tonnes).

<sup>5</sup> Accent Resources Ltd, Report (presentation) on annual general meeting 2009.

<sup>6</sup> Agglomeration is the process where magnetite grains are aggregated into pellets using a chemical binding reagent. Pellets are produced in a pelletising plant.

<sup>7</sup> USGS, 2011. Mineral Commodity Summaries 2011. United States Geological Survey. [http://minerals.usgs.gov/minerals/pubs/commodity/iron\\_ore/mcs-2011-feore.pdf](http://minerals.usgs.gov/minerals/pubs/commodity/iron_ore/mcs-2011-feore.pdf)

**Iron ore:** In 2010, Economic Demonstrated Resources (EDR) of iron ore increased by 23% to 34.5Gt mainly because of increased resources for some deposits, including in the WA mines Balmoral Central, Marillana, Roy Hill, Robe River, Mount Whaleback, Karara, West Pilbara, Hamersley, Solomon, Mining Area C, Gabanintha and Jack Hills. Resource definition of existing deposits and the inclusion of new magnetite deposits have also contributed to the increase in EDR. Paramarginal Demonstrated Resources have increased from 0.3Gt to 0.7Gt. Inferred Resources increased by 65% to 47.8Gt because of large increases at Hamersley, Balmoral Central, Karara, Mining Area C, and Solomon mines. The inclusion of 19 new deposits also contributed to the high Inferred Resources for 2010. Western Australia has about 98% of Australia's total Identified Resources of iron ore with the majority of the resources occurring in the Pilbara Region.

**Contained Fe:** As at December 2010, Australia's EDR was estimated to be 17Gt contained Fe, Paramarginal Resources were 0.4Gt contained Fe, and Inferred Resources 23.3Gt contained Fe.

### Accessible EDR

Almost all of the 34.5Gt EDR is accessible except for 18 million tonnes (Mt) at Orebody 23 in the Newman District (WA) and 30% of the Windarling resource (WA). Both have been quarantined for environmental reasons. At current rates of mine production, accessible EDR for iron ores is sufficient for approximately 80 years.

### JORC Reserves

The total Joint Ore Reserve Committee (JORC) Code reserves of iron ore were estimated to be 13.6Gt representing 39% of accessible EDR. Contained iron is 7.1Gt or 42% of the EDR of contained Fe. At the current rate of mine production, JORC Code reserves are sufficient for about 31 years.

A total of 19 new deposits, mostly occurring in WA, were added to Australia's iron ore resource base during 2010. They are Cashmere Downs (Cashmere Iron), Magnetite Range (Accent Resources), Steeple Hill (Fairstar Resources), Extension (Iron Holdings), Mount Forrest (Mindax) Boundary (IOH), Buckland Hills, Fingers, Hawsons, Hercules (Iron Clad), Koodaideri South, Mount Dove, Mount Padbury, North Star, Warrawanda, Yerecoin (Giralia Resources), Weld Range, Spearhole (Dynasty Metals) and Bilberatha Hill (Venus Metals Ltd).

### Exploration Expenditure

Australian Bureau of Statistics data indicates that exploration expenditure for iron ore in 2010 totalled \$553.1 million, a 6% increase on the \$521.2 million spent in 2009. About \$502.4 million, or approximately 90%, was spent in WA and accounted for 22% of the total mineral exploration expenditure of \$2469 million in Australia in 2010.

### Production

The Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) reported that Australia's iron ore production in 2010 was 433.5Mt (393.9Mt in 2009) with 97% produced in WA. Exports in 2010 totalled 401.9Mt (362.4Mt in 2009) with a value of \$47 166 million. In 2010 ABARES predicted that Australia's iron ore production would increase to 619Mt by 2016 and exports are projected to rise to 582Mt. ABARES states that the projected increases are in response to high demand from developing countries including China, which ABARES expects will increase its steel consumption by 8% per year to 995Mt by 2016, and India, which it expects to increase demand for steel at an average of 14% per year to 75Mt over the same period. ABARES also expects Brazil will increase its steel consumption by 5% per year as a result of new infrastructure developments for Federation International Football Association (FIFA) in 2014 and the Olympic games in 2016.

### World Ranking

In 2010, Australia had about 18% of world EDR of iron ore and was ranked second after China (37%). In terms of contained iron, Australia has about 19% of the world's EDR and is ranked first with Brazil second (18%). Australia produces around 18% of the world's iron ore and is ranked second behind China (37%).

## Industry Developments

### Western Australia

**Rio Tinto Iron Ore:** The company is undertaking a US\$200 million expansion project for the Cape Lambert port to increase its capacity to 330 million tonnes per annum (Mtpa) in support of its Pilbara operations. The project will be carried out in 4 stages with the final stage in 2016. The company's new Mesa A mine is ramping up to a capacity production rate of 20 Mtpa. Rio Tinto also has significant iron ore expansion projects in the Pilbara region, including the newly opened Brockman 4 and Western Turner Syncline mines as well as development projects such as the \$1.2 billion Hope Downs 4 iron ore open cut mine, 30km north of Newman. The target production rate for Hope Downs 4 is 15Mtpa with an anticipated production start in 2013. Its development is based on Proven Reserves of 73Mt at 63% iron, and Probable Reserves of 64Mt at 63.2% Fe, utilising a 59.5% Fe cut-off grade. Rio Tinto will also commit \$425 million to fully cover the capital costs of the rail, rolling stock and power infrastructure for this project. The Brockman 4 mine expansion project includes an increase output from 22Mtpa to 40Mtpa.

**BHP Billiton:** The company announced a capital investment of \$US6.6 billion to increase infrastructure facilities at Port Hedland and develop a new mine at Jumblebar in early 2014 which will have a capacity of more than 220Mtpa of iron ore. The project joint venture partners, including Itochu Minerals and Energy of Australia, Mitsui-Itochu Iron and Mitsui Iron Ore Corporation, will contribute an additional \$US800 million towards the Jumblebar project.

BHP has also reported that its RGP5 (Rapid Growth Project 5) was 90% completed. This development will provide an additional 50Mtpa capacity and is expected to be commissioned in late 2011.

**Fortescue Metals Group (FMG):** The company reported 10 000Mt of total resources for its projects in the Pilbara region. The additional resources from its numerous deposits, including Firetail (estimated 50Mt Indicated Resource) and Serenity (an increase of 100Mt in Inferred Resource), have contributed to the increased resources. The Mount MacLeod initial Inferred Resource of 121Mt has also contributed to the overall total resource, as well as 1000Mt of initial Inferred Resource from the new Nyidinghu project 35km south of the FMG's Cloudbreak operation and 624Mt of Inferred Resources at an average grade of 58.7% Fe from Eliwana and Flying Fish deposits in Western Hub.

**Mount Gibson Iron Ltd:** Development of the Extension Hill hematite DSO project commenced in December 2010 with mine production planned to increase to 3Mtpa. Mount Gibson also announced that the company had entered into an agreement with Glencore International to purchase 48% of life of mine production (1.44Mtpa) based on production of 3Mtpa .

**Murchison Metals Ltd:** The scoping study for Rocklea project indicated a high possibility for an economically robust project capable of supporting a 10Mtpa production rate. The discovery of the new Brindal deposit at the Jack Hills project has increased Jack Hills mineral resource to 3200Mt. The previously announced Stage 2 Jack Hills Expansion Project with a projection of up to 25Mtpa production of DSO and beneficiated feed ore (BFO) is still progressing. Murchison Metals consider that there is potential to increase the production by up to 30Mtpa, subject to installation of other infrastructure.

**Sinosteel Midwest Corporation:** The Koolanooka/Blue Hills DSO project commenced operations in April 2010 at a production rate of about 1.5Mtpa over 5 years. Sinosteel is planning a 15Mtpa DSO operation at Weld Range.

**Atlas Iron Ltd:** An increase of 50% in DSO Reserves to 79.3Mt at 57.8% Fe is estimated for the company's North Pilbara projects, which comprise Wodgina and Pardoo. Atlas is currently exporting iron ore at a rate of 6Mtpa and states that it aims to increase its export to 12Mtpa by December 2012 once mining at Mount Dove, Abydos and Mount Webber commence. The discovery of the new Hercules deposit near Wodgina has the potential to increase the mine life in the north Pilbara.

**CITIC Pacific Mining:** The first production and export of iron ore concentrate from the \$5.2 billion Sino Iron Project is proposed for mid 2012. The company plans to export 27.6Mtpa of magnetite concentrates and pellets. The first (one of four) large in-pit crushing system was installed and briefly operated in July 2011. Infrastructure includes a 450 megawatt gas fired power station, a desalination plant and a port at Cape Preston. Some of the other

infrastructure, such as one of the in-pit crushing systems, was installed in July 2011. Each of these crushing systems has the capacity to crush 4250 tonnes of magnetite ore per hour.

**Gindalbie Metals Ltd:** Gindalbie Metals announced its initial shipment of hematite lump ore from the Karara Iron project in the mid-west region of WA in late March 2011. The stage 1 target production of 2Mtpa is expected to increase after on site processing infrastructure is completed. Also, approval was initiated on a scoping study for the expansion of the Karara project to increase production from 10Mt to 16Mtpa.

**BC Iron Ltd:** Mining at the 3Mtpa Nullagine project commenced in November 2010 with iron ore export shipments commencing in February 2011. The company aims to increase the production rate to 5Mtpa by June 2012 and, as a result, increase the tonnage export rate to approximately 3.5Mt.

**Golden West Resources Ltd:** The company has announced its initial iron ore reserve for the C3, C4, Joyners Find and Bowerbird deposits of 69.2Mt at 60.3% Fe. Golden West Resources says that the reserve creates a potential mine life of 10 years at a production rate of approximately 7Mtpa. It was proposed that these deposits be mined in stages with initial production of 1Mt for stage I before going to a full scale production of 10Mtpa in stage III.

**Ferrowest Ltd:** The planned Yogi Mine at Yalgoo Iron project will produce merchant pig iron and mining of DSO from the Yogi and Western Hematite deposits. The company aims to commence production in 2014. A recent investment of \$20 million by TFA International Pty Ltd will accelerate the development process of the Yalgoo Iron Project, including a definitive feasibility study. A component of the definitive feasibility will be to increase the target production rate of magnetite concentrate from 1.5Mtpa to 4.5Mtpa.

**Iron Ore Holdings Ltd (IOH):** The pre-feasibility study conducted on Iron Valley has confirmed technical viability for a 4 stage mine development. Stage 1 and 2 will deliver up to 15Mtpa for six years. It is noted from the 3 August 2011 report that the pre-feasibility resource figure was based on the total resources of 480Mt. Another development for IOH is the significant increase of Buckland Hills Inferred Resource from the Bungaroo South deposit. A concept study was also conducted for Bungaroo which projected a 15Mtpa production rate for 15 years mine life.

**Brockman Resources:** The definitive feasibility study conducted for Marillana has confirmed the project capability to produce approximately 17Mt of dry iron ore at an average grade of 60.5% to 61.5% Fe per year over 25 years of mine life. The projected annual production will increase to 21Mt for some years over the life of the mine. The Marillana Detrital total Ore Reserves containing hematite was estimated to be approximately 1Mt at 42.4% Fe. The other highlight for Brockman Resources was the significant drilling results for their Duck Creek and West Hamersley prospects in West Pilbara. For Duck Creek, significant DSO grade mineralisation was intersected at surface or shallow depths, including 20m at 56.6% Fe from 1m and 17m intervals at 56.8% Fe from surface. Likewise, at West Hamersley, a 13m interval at 55.6% Fe (62.9% CaFe) from 7m and 9m at 58.8% Fe (60.5% CaFe) from surface was also recorded.

**Mindax Ltd:** The Mount Forrest Iron Project is progressing to the mining phase and is aiming for production by 2013 for its DSO resource, followed by its magnetite resource production in 2015. The company has announced total Indicated and Inferred DSO resources of 19Mt. Its magnetite resource is 1430Mt at 31.5% Fe.

**Mineral Resources Ltd:** The \$120 million Stage 1 Yilgarn Project commenced mining in July 2011 with a target of having the initial ore delivered to Fremantle Port in the last quarter of 2011. Mineral Resources Ltd has previously announced its intention to increase the production rate target to 10Mtpa.

**Moly Mines Ltd:** The Spinifex Ridge project, 50km northeast of Marble Bar, commenced mining in late 2010 with an annual production rate of 1Mtpa DSO. An initial shipment of 54 500 tonnes of iron ore fines to China occurred in December 2010 with plans to increase shipment sizes as mine production rates continue to increase. The projected total iron ore shipments for the calendar year is approximately 900 000 wet tonnes.

**FerrAus Ltd:** The company's Davidson project has increased its Indicated Resource to 50Mt through the upgrade of Dugite and Tiger Inferred Resources, giving rise to overall total resources for its Pilbara Project of 347Mt which includes 66.2Mt of the Inferred Resources.

**Legacy Iron Ore Limited:** The company announced that its maiden Inferred Resource was 617Mt at 32.1% Fe, following its first drilling program and phase II is underway.

**Pluton Resources Ltd:** The company has numerous projects in Australia but current development is centred on its Irvine Island project in the Kimberley region. A pre-feasibility study for Irvine Island was completed for 40Mt production in stage 1 for a mine life of 11 years. This projection was based on the Probable Reserves of 143Mt at 28% Fe. The pre-feasibility studies also indicated that production would commence in 2013/14, subject to approval by relevant government agencies.

**Hemisphere Resources Ltd:** Hemisphere has reported its initial Indicated Resource of 4.3Mt at 55.8% Fe for the Yandicoogina South Channel Iron deposit, 80km north of Newman, in the Pilbara region. Mining studies for this project have commenced and aim for initial production early 2013.

**Macarthur Minerals Ltd:** The company has progressed the development of its hematite DSO deposit from its Lake Giles project in the Yilgarn region. It is proposed to commence production at a rate of 2Mtpa in either late 2012 or early 2013. The project start-up is subject to approval from relevant government agencies.

**Winmar Resources Ltd:** There was a 70% increase in Inferred Resources from its June 2010 estimate to 241.6Mt at 54.3% Fe for the Winmar deposit at the company's Hamersley Iron project. An additional highlight was the return of anomalous drilling results (e.g. 28m at 50.6% Fe) outside the Winmar deposit, which potentially increases the exploration target to between 350Mt and 400Mt.

**Aquila Resources:** Definitive feasibility study results have indicated the viability of a more than \$5 billion project for the West Pilbara Iron project. The project aims to produce 30Mtpa of iron ore over 15 years with target production start up in late 2013 and an initial shipment in mid 2014. Total estimated resource as of the September quarter was approximately 1220Mt. The proposed commencement of mine construction is during the March quarter in 2012 with a 15 years mine life.

**Fairstar Resources Ltd:** The company stated in its quarterly reports for March and June 2011 that it is fast tracking the development of the Steeple Hill Iron Project (SHIP), and aims to start production of its alluvial hematite DSO deposit in 2011. In the 2011 June quarter the estimated Indicated Resource for SHIP was 136Mt at 58% Fe.

**Flinders Mines Ltd:** A definitive study is to commence in 2012 for the company's \$640 million Pilbara project. This study will define the project objective for an initial start up production rate of 15Mtpa in 2014. The company has announced that, the Pilbara Iron project estimated resource is 747.6Mt inclusive of 272.5Mt at 56.2% Fe Indicated Resources and 475.1Mt Inferred Resources at 54.9% Fe.

**Zenith Minerals Ltd:** The company has announced initial Inferred Resources of 392.9Mt at 29.5% Fe at its Mount Alexander Magnetite project. Positive scoping study results indicate a production rate of around 8Mtpa capacity, producing high grade iron concentrate at 68.6% Fe with a 20 years mine life.

**Jupiter Mines Ltd:** Feasibility studies for Jupiter Mines' \$1.6 billion magnetite project at Mount Ida in Central Yilgarn began in mid 2011. The study was based on estimated Inferred Resource of 530Mt at 31.9% Fe. The study outcome indicates a production rate capacity of magnetite ore of 10Mtpa of magnetite concentrate grading at 68% Fe from an open pit mine extracting 25Mtpa for a 20 year mine life. Another development is a feasibility study for the company's Mount Mason DSO project. That study is based on the estimated Inferred Resource of 5.75Mt at an average grade of 59.9% Fe producing hematite DSO of 1.5Mtpa with commissioning of the project in 2013.

**Altura Mining Ltd:** The company's Mount Webber Iron joint venture project with Atlas Iron Ltd in the Pilbara has reported an increase to its reserve of 25.2Mt DSO grading at an average of 57.5% Fe for its Ibanez and Gibson prospects. The project is planned for development with initial production rate of 3Mtpa in 2013.

**Buxton Resources Ltd:** The company has announced a significant iron discovery at its Zanthus Project, 230km east of Kalgoorlie. The company also reported that drilling confirmed a magnetic anomaly defining a potentially large magnetite deposit which included up to 60m wide with a depth between 20m and 50m grading from 32.7% to 33.9% Fe.

**Apollo Minerals Ltd:** Significant intervals were intersected at Mount Oscar Iron Ore project, including a 101m at 33.6% Fe, 112m at 33.9% Fe and 66m at 31.2% Fe. According to the company, the metallurgical test results from this deposit indicates high potential for producing magnetite concentrate grading at more than 60% Fe with less than 8% Al<sub>2</sub>O<sub>3</sub> and SiO<sub>2</sub>.

## South Australia

**OneSteel Ltd:** The total resource for the Middleback Range Project is 117Mt at 59% Fe for hematite, including reserves of 46.2Mt at 60.9% Fe, and 238.9Mt at 38.5% Fe for magnetite, which includes reserves of 83.4Mt at 40.9% Fe. OneSteel Iron Chieftain Project hematite resource contains approximately 18.2Mt at an average grade of 58% Fe, inclusive of Probable and Proven Reserves of 7.7Mt at 60.5% Fe. Information on individual deposits and their development was not available at the time this report was written. An additional highlight for this period was the acquisition of the Peculiar Knob Project from Western Plains Resources Ltd (WPG). The project has a proposed production rate of 3Mtpa for an expected initial mine life of 5 years.

**IMX Resources:** The company reported an increase of 139% to 8.37Mt at 46.7% Fe and 0.03% Cu for a combined Indicated and Inferred resources for Cairn Hill phase II. A project planning and optimisation study for Phase II of the Cairn Hill project is well underway with the target commencement of phase II production in early 2012. Cairn Hill Magnetite-Copper-Gold project made a first ore shipment to China of about 62 053 tonnes in December 2010.

**Centrex Metals Ltd:** The company has announced that approval has been received for its Wilgerup Hematite mine development project on Eyre Peninsula. The company has reported that the proposed Wilgerup Mine is anticipated to produce DSO hematite of between 1Mtpa and 1.5Mtpa for 7 years. The commissioning of the mine was deferred to coincide with the completion of the company's joint venture Spencer Deep Water Port project, which is expected to be completed in 2014.

**Ironclad Mining Ltd:** The \$26 million Stage 1 Wilcherry Hill Mine Project aims to commence mining in late 2011 and produce 1Mtpa of DSO initially, progressing to 2Mtpa in the 2nd year. The company has reported that it has a total combined resource of 69.3Mt, including Indicated Resource of 48.2Mt at 25.5% Fe.

**Royal Resources Ltd:** The company has announced increased resource of 568.6Mt at 25.6% Fe at its Razorback Ridge magnetite project. This resource estimate includes Indicated Resource of 437.1Mt at 26% Fe.

## Tasmania

**Grange Resources Ltd:** A pre-feasibility study at the company's Southdown Project indicates a development cost of \$2.57 billion and expected production of 10Mtpa of magnetite concentrates from 2014. The projected mine life is 19 years with the potential to extend to 40 years.

**Shree Minerals:** The company reported that the Nelson Bay River (NBR) Project feasibility study is progressing on schedule. An upgrade of the resources for Nelson Bay River has confirmed approximately 12.6Mt at an average grade of 36.1% Fe with Indicated Resource of 1.8Mt at 38.6% Fe and Inferred Resource of 10.8 at 35.6%. The feasibility study proposed mining the DSO deposit as an open pit mine initially with a target production rate of 400 000 tonnes per annum for an initial mine life of 10 years.

## Northern Territory

**Sherwin Iron:** At its Roper River project, the company has announced a significant resource increase of 58% to 168Mt at 44.7% Fe which includes 112.4Mt of Inferred Resource and 55.7Mt of Indicated Resource.

**Western Desert Resources:** A notice of Intent for the Roper Bar DSO phase I project was lodged by the company for mining and infrastructure development, including a slurry pipe line for transporting DSO and ore concentrate to its proposed export facilities on Maria Island. An assessment of the project has projected a 1.5Mtpa production rate in 2012, increasing to 2Mtpa by 2013. The company reports that the current JORC Code resource at Roper Bar is 310Mt, including 14.5Mt high grade DSO.

**TNG Limited:** The scoping study for the company's Mount Peak ferro-vanadium project indicates development costs of more than \$43 million for stage I with a projected initial production rate of 2Mtpa over 23 years of mine life. The study baseline resource was 139Mt of Inferred Resource. The predicted total production over the mine life is approximately 107Mt, yielding 27 182 kilotonne (kt) Fe and 349kt V<sub>2</sub>O<sub>5</sub>.

## Queensland

**Xstrata Copper:** An initial shipment of iron ore concentrate from the Ernest Henry Mining (EHM) magnetite plant occurred in June 2011. The magnetite plant is part of the \$589 million Ernest Henry copper-gold underground mine project. The EHM mine life has been extended until 2024 as the result of plans to construct the EHM underground mine and its magnetite plant. Initial production is projected to be 1.2Mtpa of magnetite concentrate. The mine has a total Proven and Probable magnetite raw estimated resource of 17Mt.

**Kimberley Metals Ltd:** The company's Constance Range deposit is part of the South Nicholson Basin iron formation in northwest Queensland and has Inferred Resources of approximately 236.37Mt, excluding the nearby Boodjamulla (Lawn Hill) National Park which contains resource totalling 59.59Mt. Further development of the company's Constance Range deposit will be based on the result of future scoping studies planned by the company.

**Cerro Resources:** The company has announced an initial Inferred Resource of 25.4Mt at 36.6% Fe for its Mount Philp Hematite Iron Project in northeast Queensland.

## Industry Developments

### Iron and Steel

Operating and proposed Direct Reduced Iron (DRI) and steelworks in Australia include:

**Bluescope Steel Ltd:** Steel production at Port Kembla (NSW). The company has announced a shutdown of its No. 6 blast furnace at Port Kembla and closure of the Western Port hot strip mill in Victoria (Vic). The company also announced its annual steel production would be reduced to 2.6Mt.

**OneSteel Ltd:** Steel production at Whyalla (SA), Rooty Hill and Mayfield (NSW) and Laverton North (Vic). The company has announced a total raw steel production of 2.15Mt for 2010, a 6% increase from the previous year. This is in spite of production at its Whyalla Steel Mill dropping to 910 000 tonnes from its annual rate of 1.15Mt because of a break down in its blast furnace.

**Ferrowest Ltd:** The company has reported that its Yalgoo (WA) project is planning to produce 1Mt a year of merchant pig iron at 96% Fe from 2014 using the Midrex Technologies ITmk3 process. The magnetite concentrate used to produce the merchant pig iron in the form of nuggets will be source from the company's Yogi magnetite deposit about 14km east of Yalgoo.

**Boulder Steel Ltd:** The \$4 billion Gladstone Steel Project (Qld) is planned to use blast furnace/basic oxygen furnace technology to produce 5Mtpa of steel slabs and billets for export to Asia.

## Lithium

**Roy Towner (roy.towner@ga.gov.au)**

Lithium (Li) is recovered from the mineral spodumene ( $\text{Li}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2$ ) and lithium-rich brines.

It is used in a range of products such as ceramics, glass, batteries and pharmaceuticals. Lithium demand has expanded significantly in recent years as a result of its increasing use in rechargeable batteries for portable electronic devices such as mobile phones, computers and rechargeable power tools as well as in batteries and electric motors for hybrid and electric cars.

Lithium recovered from the production of spodumene from the Greenbushes mine in southwest Western Australia (WA) has been used in the production of specialty glasses, glass bottles, ceramics and ceramic glazes. Spodumene is a feedstock for the production of lithium carbonate used in the chemical industry. These chemical industry applications include greases, aluminium production, air conditioning systems and catalysts.

### Resources

Australia's Economic Demonstrated Resources (EDR) are estimated to be 483 kilotonnes (kt) of lithium in 2010, which is unchanged from 2009. The bulk of Australia's lithium resources are in the Greenbushes' spodumene deposit, 250 kilometres (km) south of Perth, WA. It is the world's largest and highest grade spodumene deposit.

Other EDR of lithium occur at Mount Marion about 40km southwest of Kalgoorlie, and Mount Cattlin, about 2km north of Ravensthorpe, both in WA. Resources at Mount Marion, which occur in a number of outcropping spodumene pegmatites, amount to be about 42kt, while resources at the Mount Cattlin spodumene deposit total about 63kt.

In 2010, Subeconomic Resources of lithium, all in the submarginal category and all in WA, total less than one kilotonne.

Inferred Resources of lithium total 90kt, which is unchanged from 2009, and are associated with Greenbushes and the Mount Cattlin and Mount Marion pegmatite deposits in WA.

### Accessible EDR

All of Australia's EDR of lithium is accessible.

### JORC Reserves

Joint Ore Reserve Committee (JORC) Code reserves comprise total lithium in Proved and Probable Ore Reserves as defined in the JORC Code. In 2010, JORC Code reserves of 174kt accounted for approximately 36% of Accessible Economic Demonstrated Resources (AEDR). At Australia's 2010 rate of spodumene production, lithium reserves in the JORC Code categories are adequate for about 18 years.

### Exploration

There are only a few companies exploring for lithium mainly in WA and Queensland but no statistics are available on exploration expenditure.

### Production

According to the Western Australian Department of Mines and Petroleum, the Talison Lithium Limited's Greenbushes operation produced 326 856 tonnes of spodumene concentrate in 2010, containing between 4.8% and 7.5% lithium oxide (Li<sub>2</sub>O).

### World Resources

According to estimates by the United States Geological Survey (USGS) which have been modified by Geoscience Australia for Australia's resources, world lithium resources in 2010 totalled about 12 900kt. The resource data does not include Canada. According to the USGS, Chile holds approximately 7500kt, or 58% of the total world resources, followed by China with 3500kt, Argentina with 850kt, Australia with 483kt and Brazil with 64kt.

Lithium resources occur in two distinct categories, lithium minerals and lithium-rich brines. Canada, China and Australia have significant resources of lithium minerals, while lithium brine is produced predominantly in Chile, followed by Argentina, China and the USA. Lithium brines are the dominant feedstock for lithium carbonate production.

World production in 2010 was estimated by the USGS to be 25.3kt of contained lithium, excluding the USA production for commercial reasons. Based on the USGS data, Chile produced about 8.8kt to remain the world's largest producer in 2010 followed by Australia, China and Argentina.

### Industry Developments

According to Talison Lithium Limited, global demand for lithium is expected to more than double from 2010 levels by 2014, mainly driven by increased consumption for lithium-ion batteries for use in mobile technology, energy grid stabilisation and electric vehicles. Lithium batteries are the preferred choice for electric car manufacturers over the nickel metal hydride batteries because of their higher power output, durability and cost.

Talison Lithium Limited produces two categories of lithium concentrates at the Greenbushes Lithium Operations in WA:

- i) Technical-grade lithium concentrates which have low iron content for use in the manufacture of, among other applications, glass, ceramics and heat-proof cookware; and
- ii) A high yielding chemical-grade lithium concentrate which is used to produce lithium chemicals that form the basis for manufacture of, among other applications, lithium-ion batteries for laptop computers, mobile phones, electric bicycles and electric vehicles.

The company does not produce lithium chemical products, selling lithium concentrate instead to customers for processing into lithium chemicals, primarily lithium carbonate.

In late 2009 and through 2010, demand for Talison Lithium Limited's technical-grade lithium concentrates rebounded strongly following a slowdown in early 2009, particularly in the glass sector from traditional markets such as Europe, the USA and Japan. The company also experienced a substantial increase in demand for its chemical-grade lithium concentrates, particularly from Chinese lithium chemical producers for use in lithium-ion battery industries. Consequently, both the company's chemical-grade plant and technical-grade plant have been operating at full capacity since July 2009.

Following completion of its Stage 1 expansion in December 2010, the total nameplate capacity at the Greenbushes operation increased to approximately 315 000 tonnes per annum (tpa) lithium concentrate. In early 2011, the company announced a further expansion to 740 000tpa lithium concentrate involving a new purpose built chemical-grade production facility at a cost of about \$70 million. This plant is expected to be commissioned in the second quarter of 2012. In the six months ending 31 December 2010, Talison Lithium Limited mined 164 277 tonnes of lithium concentrate. The lower-grade spodumene is exported to China where it is converted into a range of lithium chemicals. The higher-grade spodumene is exported to Europe, Asia and the USA. The Greenbushes mine has a reported lithium mineral reserves of 31.4 million tonnes (Mt) grading 3.1% Li<sub>2</sub>O and a combined Measured and Indicated Resource of 70.4Mt grading 2.6% Li<sub>2</sub>O. Based in these lithium mineral reserves, the mine life has been extended by 10 years to 22 years.

Talison Lithium Limited was studying the possibility of building a 20 000tpa lithium-carbonate equivalent plant in Australia to produce battery-grade lithium carbonate at a capital cost of between \$160 million and \$200 million.

In September 2010, Galaxy Resources Limited commenced production from the Dowling Pit at its **Mount Cattlin** lithium-tantalum mine (hard-rock spodumene) near Ravensthorpe in WA. In the December 2010 quarter, the company mined 74 310 tonnes of ore grading 1.02% Li<sub>2</sub>O, and made its first shipment of 6500 tonnes of spodumene to China in March 2011. When in full production, the project will produce 137 000tpa of 6% Li<sub>2</sub>O spodumene concentrate and 56 000 pounds of tantalite contained concentrate for an expected mine life of 16 years. Construction by Galaxy Resources of its lithium carbonate plant within the Yangtze River International Chemical Industrial Park in Jiangsu Province in China is expected to be commissioned in late 2011. This plant will have the capacity to produce 17 000tpa of battery-grade lithium carbonate. The Mount Cattlin deposit has a reported JORC compliant resource of 18.188Mt with an average grade of 1.08% Li<sub>2</sub>O and 156 parts per million (ppm) of tantalum pentoxide (Ta<sub>2</sub>O<sub>5</sub>) containing an estimated 197 000 tonnes of Li<sub>2</sub>O and 6.26 million pounds of Ta<sub>2</sub>O<sub>5</sub> above a cut-off grade of 0.4% Li<sub>2</sub>O.

Reed Resources Ltd and joint venture partner Mineral Resources Limited have completed a pre-feasibility study into the production of battery-grade lithium carbonate from the spodumene concentrates produce from their **Mount Marion** lithium deposit, 40km southwest of Kalgoorlie, WA. The lithium carbonate production process would involve conventional sulphate roast-water leaching of spodumene concentrate followed by precipitation and purification of lithium carbonate. Both companies have received approval for the final mining proposal from the Western Australian Department of Mines and Petroleum, allowing construction of the minerals processing plant at Mount Marion. Mine production is expected to commence in the September quarter of 2011 at an initial rate of 240 000tpa of spodumene concentrate grading at 6% Li<sub>2</sub>O, containing about 14 400 tonnes of Li<sub>2</sub>O. The Mount Marion deposit consists of a series of shallow dipping, parallel sheets of spodumene-bearing pegmatites within mafic-ultramafic volcanic rocks. The pegmatite sheets are more than 20 metres thick. The deposit has a total contained Li<sub>2</sub>O resource of 146 000 tonnes.



The Parkhurst plant in Rockhampton converts magnesite from the Kunwarara and Yaamba mines to calcined, dead-burned and electrofused magnesia products (Queensland Magnesia).

## Magnesite

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Magnesite (magnesium carbonate  $\text{MgCO}_3$ ) is marketed in three main forms:

- Crude magnesite, primarily for use in chemicals and agriculture;
- Dead-burned magnesia, a durable refractory used in the cement, glass, steel and metallurgical industries; and
- Caustic calcined magnesia, for use in making oxychloride and oxysulphate cements for flooring and wallboards, mouldings and acoustic tiles as well as various environmental and chemical applications.

### Resources

Economic Demonstrated Resources (EDR) of magnesite remained unchanged in 2010 at 330 million tonnes (Mt). South Australia (SA) remained Australia's largest holding of EDR with 235Mt of magnesite, which is unchanged from 2006. The bulk of these resources occur as interbeds of sedimentary magnesite within the Skillogalee Dolomite at the Witchelina and Mount Hutton deposits, up to 30 kilometres (km) northwest of Leigh Creek. The average magnesite grade is 40% magnesium oxide (MgO).

Queensland (Qld) has Australia's second largest inventory with 63Mt of magnesite EDR. The bulk of this resource occurs at Kunwarara 70km northwest of Rockhampton, where Queensland Magnesia Pty Ltd has global resources of 1200Mt of magnesite bearing material. Within this global resource, which has an Inferred Resource of 500Mt of magnesite, several high-grade magnesite zones have been classified as EDR. The Kunwarara deposit occurs as sheet-like lenses of magnesite with an average thickness of 7.6 metres (m) extending over an area of about 63 square kilometres. It contains four high-grade zones of very high-density bone-type, low iron ultrafine-grained cryptocrystalline to microcrystalline nodular magnesite.

The third largest inventory of EDR is in Tasmania (Tas) where the Arthur River deposit has a measured resource of 13.2Mt with an average magnesite grade of 43.4% MgO. The resource is part of a much larger global resource of 195Mt in the Arthur-Lyons River area, about 53km south of Burnie.

The remainder of Australia's EDR occurs in the Winchester deposit 70km south of Darwin in the Northern Territory (NT), at Thuddungra 80km northwest of Young in New South Wales, and at Bandalup 20km east of Ravensthorpe in Western Australia.

Subeconomic Demonstrated Resources of 57Mt of magnesite remained unchanged from 2006. All of these resources occur at Triple Four in central Qld and at Main Creek in northwest Tas.

Inferred Resources of magnesite increased slightly in 2010 to 836Mt (826Mt in 2009) with Qld accounting for 56% followed by SA with 35% and Tas with 5%. The remaining resources are in New South Wales, the Northern Territory and Western Australia.

## Accessible EDR

All magnesite EDR is accessible for mining.

## JORC Reserves

Joint Ore Reserves Committee (JORC) Code reserves comprise total magnesite in Proved and Probable Ore Reserves as defined in the JORC Code. In 2010, JORC Code reserves of 37.5Mt (unchanged from 2009) accounted for approximately 11% of Accessible Economic Demonstrated Resources (AEDR). At Australia's 2009–10 rate of production, magnesite resources in the JORC Code reserves categories are adequate for almost 135 years.

## Exploration

Data associated with exploration expenditure for magnesite are not published by the Australian Bureau of Statistics.

## Production

The bulk of Australia's magnesite production was by Queensland Magnesia Pty Ltd which supplied high-grade electrofused and dead-burned magnesia to the global refractory market, as well as calcined magnesia for a wide range of applications. In 2009–10, the company produced a total 275 819 tonnes of magnesite (344 962 tonnes in 2008–09). About 1618 tonnes of magnesite was produced from the Myrtle Springs region in SA in 2009.

## World Ranking

According to Geoscience Australia and United States Geological Survey (USGS) data, Australia has about 4% of the world's EDR of magnesite, which total 8400Mt. Russia, China and North Korea jointly accounting for almost 63% of the world's EDR. The Kunwarara deposit in Qld is the world's largest known resource of ultrafine-grained cryptocrystalline to microcrystalline nodular magnesite.

According to USGS data, world production of magnesite totalled 19.53Mt. The world's largest producers of magnesite in 2010 were China (57%), Turkey (11%), North Korea (6%) and Russia (5%).

## Industry Developments

Korab Resources Limited has received a number of offers to establish a syndicate with the view to developing the **Winchester** magnesite deposit (NT), initially as a supplier of magnesium oxide (MgO) based building products. MgO is used extensively in Canada, Asia and the USA to produce low-cost, high-strength building materials which do not expand or shrink when submerged in water or heated and are potential substitutes for fibro-board, plaster-board, chipboard and ceramic tiles. MgO-based products are fire-resistant to 1200°C. The project has a JORC Code Indicated Resource of 12.2Mt grading 43.1% MgO and an Inferred Resource of 4.4Mt grading 43.6% MgO.

Beacon Hill Resources Plc plans to mine magnesite at the **Arthur River** deposit, which it acquired through the acquisition of Tasmania Magnesite NL in 2009, in northwest Tas at a proposed production rate of 300 000 tonnes per annum. The company is undertaking a scoping study which it anticipates completing by early 2012. The study will include capital and operating cost estimates for a mine design, transport logistics and infrastructure, and the costs associated with the calcining of the magnesite at several locations. The Arthur River Project has a defined JORC compliant Measured Resource of 13Mt of magnesite and an Inferred Resource of 10Mt.

# Manganese Ore

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Manganese (Mn) is the twelfth most abundant element in the Earth's crust. Of approximately 300 minerals containing manganese, only about a dozen are of economic significance. The two main manganese minerals are pyrolusite (MnO<sub>2</sub>) and rhodochrosite (MnCO<sub>3</sub>). Manganese is the fourth most used metal in terms of tonnage after iron, aluminium and copper. Manganese is essential to iron and steel production by virtue of its sulphur-fixing, deoxidising and alloying properties. After its application in steel production, the most important market for manganese is dry cell batteries in the form of electrolytic manganese dioxide (EMD). It is an additive also in plant fertilisers and animal feed and as a colorant for bricks.

In Australia, there are three operating mines and one tailings re-treatment plant. The Woodie Woodie mine is located about 400 kilometres (km) southeast of Port Hedland in Western Australia (WA). A manganese tailings processing plant also operates near the Woodie Woodie mine. The Northern Territory (NT) has two manganese mines, on Groote Eylandt in the Gulf of Carpentaria, and at Bootu Creek 110km north of Tennant Creek.

Manganese ore processing plants are operated by TEMCO at Bell Bay in Tasmania (Tas) and by Delta plc at Newcastle in New South Wales (NSW).

## Resources

In 2010, Australia's Economic Demonstrated Resources (EDR) of manganese ore increased by 2.2% to 185 million tonnes (Mt), mainly because of rises in EDR at Woodie Woodie and Bootu Creek (Table 4). Paramarginal Demonstrated Resources (PDR) remained unchanged at 23Mt and Submarginal Demonstrated Resources (SDR) also remained unchanged at 167Mt. Inferred Resources decreased 1.5% to 132Mt, mainly because of a reduction of Inferred Resources at the Woodie Woodie deposit.

**Table 4.** Resources of manganese ore in States and Northern Territory.

	DEMONSTRATED			INFERRED
	Economic	Paramarginal	Submarginal	Undifferentiated
	Manganese Ore Mt	Manganese Ore Mt	Manganese Ore Mt	Manganese Ore Mt
Queensland	0	0	0	0.2
Western Australia	36.4	23.1	167.0	92.6
Northern Territory	148.2	0	0	39.6
Australia	184.6	23.1	167.0	132.4

## Accessible EDR

All manganese ore EDR (185Mt) is accessible. The resource life is about 14 years at current rates of production of beneficiated manganese ore.

## JORC Reserves

Manganese ore Joint Ore Reserve Committee (JORC) Code reserves are 144Mt (78% of accessible EDR). The resource life based on JORC reserves, and at the current rate of production of beneficiated manganese ore, is about 11 years.

## Exploration

Data relating to exploration expenditure for manganese are not published by the Australian Bureau of Statistics on either a State or National basis.

## Production

The Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) reported that Australia produced 6.5Mt of beneficiated manganese ore in 2010 (4.5Mt 2009). Exports of manganese ores for 2010 totalled 5.5Mt valued at \$1509 million (4.7Mt at \$999 million in 2009).

## World Ranking

Australia has 11% of the world's EDR of manganese ore and is ranked fifth behind the Ukraine (25%), South Africa (16%), Brazil (15%) and China (14%). Australia produces 16% of the world's manganese ore and is ranked second behind China (35%).

## Industry Developments

### Northern Territory

**GEMCO:** In 2010 the installed plant capacity at GEMCO was 4.1 million tonnes per annum (Mtpa) of manganese concentrates. During 2010 the company's annual production record was achieved, with 3.1Mt of saleable manganese ore produced by the Groote Eylandt mine.

**OM Holdings Ltd:** The September and December quarters of 2010 saw record production rates of approximately 230 kilotonne (kt) in each quarter, leading to a record total production rate of 830 kilotonne per annum (ktpa) for the Bootu Creek mine in 2010. OM Holdings is planning an aggressive exploration program to replace the scheduled 2.5Mt of resource that will be mined and processed at Bootu Creek and will target resources at Renner Springs and Helen Springs.

### Western Australia

**Consolidated Minerals Ltd:** The Woodie Woodie mine has a heavy media separation plant which has increased mine capacity to 2.5Mtpa. The plant produces lump products which are transported to Port Hedland where blending occurs prior to shipment overseas. The Woodie Woodie product has high manganese content and very low phosphorus, while having very low degradation and high thermal stability.

**Mineral Resources Ltd:** A 400ktpa tailings re-treatment plant operates at Woodie Woodie and a 240ktpa plant operates at Peak Hill. The project produces a greater than 50% ferruginous manganese product for export through Port Headland. The collaborative project with Hancock Prospecting at Nicholas Downs had its first shipment of 25kt of manganese ore depart for China in November 2010.

**Mesa Minerals Ltd:** The Ant Hill project is located 400km south of Port Hedland. The trial shipments of ore to Chinese customers received positive feedback. However, the mine has remained on care and maintenance since February 2010.

## Mineral Sands

**Yanis Miezitis** ([yanis.miezitis@ga.gov.au](mailto:yanis.miezitis@ga.gov.au))

The principal components of heavy mineral sands are rutile ( $\text{TiO}_2$ ), ilmenite ( $\text{FeTiO}_3$ ), zircon ( $\text{ZrSiO}_4$ ) and monazite ( $[\text{Ce}, \text{La}, \text{Th}] \text{PO}_4$ ). Rutile, ilmenite, leucoxene (an alteration product of ilmenite) are used predominantly in the production of titanium dioxide pigment. The titanium-bearing minerals rutile and leucoxene are sometimes blended to produce 'HiTi' ('High grade titanium' with a  $\text{TiO}_2$  content of 70% to 95%) and is used as a feedstock to produce titanium dioxide, make titanium metals for the aerospace industry and to manufacture welding rods. Less than 4% of total titanium mineral production, typically rutile, is used in making titanium sponge metal. Zircon is used as an opacifier for glazes on ceramic tiles, in refractories and for the foundry industry. Recently there has been renewed interest in monazite as a source of thorium for possible use to generate electricity in thorium nuclear reactors.

## Resources

Economic Demonstrated Resources (EDR) of ilmenite decreased by 0.4% to 199.5 million tonnes (Mt) in 2010, down from 200.4Mt in 2009. About 53.4% of Australia's EDR of ilmenite is in Western Australia (WA) and 19.3% is in Queensland (Qld) with the remainder in Victoria (Vic) 14.6%, New South Wales (NSW) 9.7% and South Australia (SA) 3.0%.

EDR of rutile, which includes some leucoxene in WA, increased by 3.5% from 22.7Mt in 2009 to 23.5Mt in 2010. Victoria has the largest share of Australia's rutile EDR with 35.8% followed by Qld (23.7%), NSW (19.1%), WA (18.2%) and SA (3.0%).

EDR of zircon decreased from 40.0Mt in 2009 to 39.4Mt in 2010 with WA (30.8%), Vic (25.0%) and Qld (20.6%) accounting for most of Australia's zircon EDR. The balance was in SA (14.2%) and NSW (9.3%).

Australia's Subeconomic Demonstrated Resources of ilmenite, rutile and zircon in 2010 amounted to 38.8Mt of ilmenite, which was an increase of 28.5% on 2009, 7.1Mt of rutile, unchanged from previous year, and 10.4Mt of zircon, unchanged from the 2009 figure.

Inferred Resources of ilmenite increased by 0.9% in 2010 to 128.3Mt. Victoria has the largest proportion of inferred ilmenite resources with 46.2% of the Australian total followed by NSW (21.7%), WA (13.2%) and Qld (12.0%).

Inferred Resources of rutile decreased to 30.1Mt from 31.3Mt in 2009. Victoria has the largest share of Australia's inferred rutile resources with 54.6% of the Australian total followed by NSW (29.5%), Qld (6.1%), SA (6.1%) and WA (3.1%).

Inferred Resources of zircon increased to 34.9Mt from 34.3Mt in 2009. Victoria is the main holder of zircon Inferred Resources with 59.1% of the Australian total, followed by NSW (18.4%), WA (8.2%) and Qld (8.1%).

## Accessible EDR

A significant portion of mineral sands EDR is in areas quarantined from mining because they are largely incorporated in national parks. Geoscience Australia estimates that around 16% of ilmenite, 14% of rutile and 16% of zircon EDR is unavailable for mining. Deposits in this category include Moreton Island, Bribie Island and Fraser Island, the Cooloola sand mass, the Byfield sand mass and the Shoalwater Bay area, in Qld and the Yuraygir, Bundjalung, Hat Head and Myall Lakes National Parks in NSW.

- About 17% of Australia's ilmenite Accessible EDR (AEDR), 24% rutile AEDR and 27% zircon AEDR comprise Reserves as defined under the Joint Ore Reserve Committee (JORC) Code.
- About 83% of Australia's ilmenite AEDR, 76% rutile AEDR and 73% zircon AEDR comprises published JORC Code compliant Measured and Indicated Resources. Some of these resources are in deposits of operating mines and mines being developed as well as in deposits which have published scoping/feasibility studies with positive results and deposits which are of comparable size and grade to those being mined elsewhere in Australia. It is not possible to make a more detailed analysis of these resources on an individual deposit scale because of a lack of resource data.

## JORC Reserves

Approximately 17% of ilmenite, 24% rutile and 27% zircon of AEDR comprise JORC Code Reserves. The remaining AEDR represents resources assessed by Geoscience Australia from the Measured and Indicated categories of industry reported mineral resources as defined under the JORC Code and other classification systems used by companies not listed on the Australian Securities Exchange.

## Duration of Resources

At the rate of production in 2010, Australia's AEDR of ilmenite, rutile and zircon is sufficient for an average of 127 years for ilmenite (109 years in 2009), 47 for rutile (69) and 61 for zircon (71). However, resources in the JORC Code reserves categories are adequate for only 22 years for ilmenite (18 years in 2009), 11 for rutile (18), and 16 for zircon (18). Variations in resource life based on the AEDR are due to the changing levels of production

of the three commodities. For example, lower production in response to a fall in demand because of global recessions may give an impression of an increase in resource life not necessarily related to an increase in resources. Such trends may be reversed with resumption of demand and, as a consequence, represent snapshots at that time of the resource life.

## Exploration

Expenditure on exploration for mineral sands in 2009 amounted to \$28.4 million but expenditure for 2010 is not available.

## Production

In 2010, Australia produced 1.313Mt of ilmenite, 430 000 tonnes of rutile, 160 000 tonnes of leucoxene and 540 000 tonnes of zircon compared with 1.534Mt of ilmenite, 280 000 tonnes of rutile, 166 000 tonnes of leucoxene and 476 000 tonnes of zircon in 2009. About 1.816Mt of ilmenite, 584 000 tonnes of rutile and 811 000 tonnes of zircon were exported in 2010, with exports exceeding production for all of these commodities in 2010. Australia also produced 557 000 tonnes of synthetic rutile in 2010 compared with 616 000 tonnes in 2009.

According to Iluka Resources Ltd<sup>8</sup>, there was a recovery in demand in 2010 across the company's entire product range of heavy mineral sand commodities from the depressed conditions experienced in 2009. This occurred to such an extent that Iluka was not able to meet all customer requirements for supply and expects to face a similar challenge in 2011.

## World Ranking

According to Geoscience Australia and the United States Geological Survey (USGS) data, Australia's EDR of rutile and zircon represent the world's largest economic resources with 49%, and 44%, respectively. Australia also has the second largest share of the world's ilmenite with 16%, behind China, which has 31%. Other major country rankings include India (13%), South Africa (10%) and Brazil (7%) for ilmenite, South Africa (17%) and India (16%) for rutile and South Africa (24%) and Ukraine (7%) for zircon.

In 2009, world production of ilmenite increased by 12.1% to 10.2Mt, rutile increased by 40.9% to 727 000 tonnes, and zircon increased by 4.3% to 1.244Mt. Australia is the largest producer of rutile with about 59% of the world production followed by South Africa with 18% and Sierra Leone with 9%. Australia is the third largest producer of ilmenite with 13% after South Africa with 21% and Canada with 13%, and is the largest producer of zircon with 43% followed by South Africa with 31% and China with 11%.

## Industry Developments

Companies which produced heavy mineral sands during 2010 were Iluka Resources Ltd, Bemax Resources Ltd, Tiwest Joint Venture and Doral Mineral Sands Pty Ltd, all in WA, and Sibelco Australia Limited in Qld. Iluka and Bemax also produced heavy minerals in the Murray Basin in Vic and NSW and at the Matilda Zircon Limited deposits on the Tiwi Islands off the Northern Territory (NT).

Iluka Resources Ltd heavy mineral sand operations in WA are located in two regions, the mid-west region north of Perth and in the State's southwest region south of Perth.

The coastal mid-west region north of Perth comprises the main mines of **Eneabba** (two wet concentrators, five mining units) and **Gingin** (wet concentrator, one mining unit). The region includes the company's Narngulu facility at Geraldton comprising mineral separation, zircon finishing and synthetic rutile plants as well as port operations and storage facilities at Geraldton. Iluka has upgraded its Narngulu plant to process heavy mineral concentrates (HMC) from its **Jacinth-Ambrosia** deposits in the Eucla Basin in SA.

Eneabba mining operations were idled and zircon production from the southwest region was transported to Narngulu in the mid-west. Iluka Resources continued to idle two of its four ilmenite upgrading kilns during 2010 and a third in 2011 because of inadequate returns from ilmenite upgrading (synthetic rutile manufacturing) activities in recent years. During 2010, the company developed the **Tutunup South** deposit which is operating

<sup>8</sup> Iluka Resources Ltd 2011. Iluka Review 2010. 48 pp.



Opening the ore face at the Kulwin heavy mineral sands mine, Murray Basin, Victoria (Iluka Resources).

and will provide ilmenite feedstock for synthetic rutile production at Narngulu and allow recommencement of operations at a second synthetic rutile kiln in 2012.

The production of heavy mineral sand commodities in 2010 from the company's mining and processing activities in WA, now referred to as the Perth Basin, amounted to 41 500 tonnes of rutile, 347 500 tonnes of synthetic rutile, 255 800 tonnes of ilmenite, and 46 200 tonnes of zircon.

In the Eucla Basin in SA, Iluka Resources operates the **Jacinth-Ambrosia** mine and owns the **Tripitaka**, **Typhoon** and the newly discovered **Atacama** deposits. Mining at the Jacinth-Ambrosia mine reached full-scale production rates of 300 000 tonnes per annum (tpa) of zircon concentrates in the first half of 2010. Production from the Jacinth-Ambrosia mine during 2010 amounted to 150 900 tonnes of zircon, 10 200 tonnes of rutile and 120 800 tonnes of ilmenite. The heavy mineral concentrates from the Jacinth-Ambrosia mine are transported 270 kilometres (km) by road to the Port of Thevenard near Ceduna, SA before being sent about 2500km by sea to Geraldton for mineral separation at Iluka's upgraded Narngulu Plant 2 in the mid-west region. On 28 January 2011 Iluka announced resources for its Atacama deposit as 29.2Mt grading at 11.3% heavy minerals with a heavy mineral assemblage comprising 75% ilmenite (includes leucosxene), 15% zircon and 2% rutile at a heavy mineral cut-off grade of 5%. The Atacama deposit differs from the Jacinth-Ambrosia deposit in that it contains a zircon component in the heavy mineral concentrate of around 15% which compares with around 50% for the Jacinth-Ambrosia deposit.

Iluka Resources **Douglas** project near Horsham in western Vic is based on the resources of three main deposits, **Bondi Main**, **Bondi West** and **Bondi East**. The infrastructure includes a single mining unit, a wet concentrator and a mineral separation plant at Hamilton to produce the final specification rutile and zircon. The capacity of the mineral separation plant was upgraded to process additional feedstock from the Murray Basin Stage 2 development at Kulwin, 30km west of Ouyen in northwest Vic. Production from the Murray Basin operations in 2010 totalled 198 400 tonnes rutile, 56 800 tonnes ilmenite and 156 600 tonnes zircon.

The Murray Basin Stage 2 development is based on a group of deposits at Ouyen in northwest Vic, with two-thirds of Iluka's heavy mineral resources in Murray Basin at **Kulwin**, **Woonack**, **Rownack**, **Rainlover**, and **Pirro** along with another group at Euston in NSW named **Castaway**, **Kerribee**, **Earl**, **Dispersion** and **Koolaman**. Full scale production of heavy mineral concentrates from the Murray Basin Stage 2 at the Kulwin mine was reached by mid 2010. Mining and concentration activities at Kulwin are expected to cease in the first quarter of 2012 and the mining unit and concentrator plant at Kulwin will be relocated to Woonack, Rownack and Pirro deposits approximately 25km away.

In 2010, Iluka completed a scoping study for the Balranald project to progress the project to a pre-feasibility study. The Balranald project comprises the deposits of **West Balranald** and **Nepean** in south western NSW. The deposits are large, but also deeper than other deposits which Iluka Resources has mined in the Murray Basin. The Balranald deposit contains approximately 14.5Mt of heavy mineral resources, with rutile assemblages ranging from 12% to 15%. The pre-feasibility study is expected to take two years and include:

- Evaluation of various mining methods;
- Ground water management studies;
- Engineering options; and
- Transport and logistics studies.

The heavy mineral resources/reserves held by Bemax Resources Limited (a controlled entity of Cristal Australia Pty Ltd) are located in old shorelines in two provinces – the Murray Basin of Vic and NSW, and the southwest region of WA.

The company's operations in the Murray Basin include the **Ginkgo** and **Snapper** mines and a mineral separation plant at Broken Hill in western NSW. A floating wet concentrator was successfully floated at the Snapper mine in November 2010. A dredge was transported from the USA and arrived at the Snapper mine in early November 2010 before being re-assembled and floated in December 2010. The construction of all mine equipment and facilities was completed by the 31 December 2010 and operational commissioning has commenced with the dredge successfully feeding ore to the floating wet concentrator at consistent rates.

Bemax Resources last reported in 2009 that its total resource in the Murray Basin amounted to 95.1Mt of contained heavy mineral. Bemax no longer publishes its resources for individual deposits and regions and the resources for the Murray Basin in 2010 are not known.

Production from Bemax's **Ginkgo** and **Snapper** mines in the Murray Basin in 2010 totalled 239 355 tonnes of ilmenite, 32 564 tonnes of zircon, 84 863 tonnes of rutile.

Bemax's heavy mineral sand mining in the southwest region of WA continued at **Gwindinup**, about 30km south of the company's mineral separation plant at Bunbury. The production at the **Wonnerup** mine is expected to begin in 2012. Heavy mineral production from Bemax's operations in the southwest region in 2010 amounted to 143 013 tonnes of sulphate and secondary ilmenite and leucosene and 15 468 tonnes zircon.

The heavy mineral sand mines on North Stradbroke Island, are owned by Sibelco Australia Limited. There has been no published information on the production of heavy minerals or resources of heavy minerals since 2008.

Exxaro Resources Ltd has a 100% shareholding in Australia Sands which has as a principal asset 50% ownership in the Tiwest Joint Venture with Tronox Incorporated. Tiwest operates an integrated titanium dioxide project in WA incorporating a dredging and dry-mining heavy mineral sands operation at Cooljarloo, dry separation and synthetic rutile plants at Chandala and a titanium dioxide pigment plant at Kwinana. Production in 2010 was approximately 462 000 tonnes of ilmenite, 70 000 tonnes of zircon, 36 000 tonnes of rutile, 26 000 tonnes of leucosene, 180 000 tonnes of synthetic rutile and 114 000 tonnes of TiO<sub>2</sub> pigment. In October Tiwest, commissioned a major expansion project at its Kwinana pigment plant, increasing production capacity by 40 000 tonnes per annum (tpa) to around 150 000tpa.

Matilda Zircon Ltd recommenced the mining the **Tiwi Islands** heavy mineral sand deposits in the NT in June 2010 and by October 2010 had completed mining the small high-grade deposit at **Leithbridge West**. The larger **Leithbridge South** deposit was developed over the 2010–11 wet season but a fire in June 2011 damaged the concentrator and pre-concentrator which had to be rebuilt resulting in mining of the deposit being delayed until early 2012.

Matilda Zircon also obtained project approvals and extractive industry licences from local shires for its **Keysbrook** heavy mineral deposit in southwest WA. Construction at **Keysbrook** is planned for 2012 with mining to start in 2013. The Keysbrook mine is expected to have a mine life of 8 years.

Gunson Resources Ltd released a definitive feasibility study on its **Coburn** heavy mineral sand deposits south of Geraldton (WA) in January 2010. The study considered a mine life of 23.5 years with annual production rates of 40 000 tonnes of zircon, 90 000 tonnes of ilmenite, 9000 tonnes rutile and 7000 tonnes leucosene.

The company reported that in 2011, the net present value for the project increased substantially to \$223.7 million (previously \$139 million) as the prices of zircon and titanium dioxide minerals increased rapidly, in some cases to more than double those prevailing in early 2010. Gunson Resources has signed a non-binding agreement with a major East Asian industrial group to provide funding for the project<sup>9,10</sup>.

Image Resources NL holds heavy mineral sand resources in North Perth Basin and in Eucla Basin, WA. The company carried out extensive drilling programs in North Perth Basin to upgrade the Indicated Resource of its **Atlas** deposit to a status of Measured Resources<sup>11</sup>. On 25 August 2011 Image Resources announced to the Australian Securities Exchange that on the basis of positive results from a scoping study of its heavy mineral sand deposits, it had committed to a feasibility study of its deposits in North Perth Basin and had targeted 2014 as a possible date for heavy mineral production<sup>12</sup>.

Image Resources also released a resource figure for its **Cyclone Extended** deposit in the Eucla Basin amounting to 86.3Mt containing 1.638Mt of heavy minerals at a cut-off of 1% heavy minerals containing 345 000 tonnes zircon, 154 700 tonnes rutile, 617 800 tonnes HiTi (70%–95% TiO<sub>2</sub>), and 395 700 tonnes altered ilmenite (55%–70% TiO<sub>2</sub>).

In March 2010, Diatreme Resources Ltd released a scoping study on its **Cyclone** heavy minerals deposit in the Eucla Basin which indicated potential for a profitable mine producing about 280 000 tonnes of concentrate annually mining ore at a rate of 9 million tonnes per annum (Mtpa). In October 2010, the company reported an updated Measured, Indicated and Inferred Resource for the deposit amounting to 132.1Mt at 2.33% heavy minerals, containing 3.1Mt heavy minerals. The new resource contains 998 000 tonnes zircon, 388 000 tonnes rutile, 551 000 tonnes HiTi, and 382 000 tonnes altered ilmenite (55-70% TiO<sub>2</sub>). On 21 June 2011, Diatreme released an updated independent valuation of its Cyclone deposit<sup>13</sup>.

The **Cyclone Extended** deposit forms a southeast extension of the Cyclone deposit. In September 2010, Image Resources and Diatreme Resources Ltd signed a memorandum of understanding to cooperate in advancing the development of both the Cyclone and Cyclone Extended deposits.

Astron Ltd's Donald project in the Murray Basin in Vic comprises the **Donald (WIM 250)** and **Jackson (WIM 200)** deposits located 240km west-north-west of Melbourne. On 1 December 2011 the company announced Measured, Indicated and Inferred Resource for the deposits totalling 2630Mt grading at 5.3% heavy minerals. The heavy mineral concentrate was reported to grade at 19% zircon, 33% ilmenite, 7% rutile and 12% leucoxene. Astron reported that the zircon content amounted to about 37Mt. These resources are located within a larger resource totalling Measured, Indicated and Inferred Resources at 4040Mt grading at 4.8% heavy minerals<sup>14</sup>.

In July 2010 Astron Ltd announced that a Probable Reserve within the Donald project amounted to 305Mt at 6.3% heavy minerals, which equates to 19.215Mt of heavy minerals at 19% zircon, 32% ilmenite, 19% leucoxene and 4.4% rutile. The project is planned to be a 7.5Mtpa mining operation, producing 500 000tpa of heavy mineral concentrate for export to China.

On 25 October 2011, Sheffield Resources Ltd announced Indicated and Inferred Resources for its **Ellengail Project** totalling 118.25Mt grading at 2.4% heavy minerals amounting to 2.8Mt of heavy minerals<sup>15</sup>. The heavy mineral concentrate is estimated to grade at 10.5% zircon, 7.6% rutile, 6.9% leucoxene and 62.6% ilmenite. The heavy mineral deposits of the project are located in the Eneabba region north of Perth, WA and include the **Ellengail** and **Yandanooka** deposits.

<sup>9</sup> Gunson Resources Ltd, 2011. Significant developments – Coburn zircon project. Australian Securities Exchange release, 23 November, 2011. 3 pp.

<sup>10</sup> Gunson Resources Ltd, 2011. Annual Report 2011. 64 pp.

<sup>11</sup> Image Resources NL, 2010. Atlas Measured Resource overall grade increases from 6.3%HM to 7.4%HM. Australian Securities Exchange release, 27 October, 2011. 5 pp.

<sup>12</sup> Image Resources NL, 2011. Feasibility study to commence. Australian Securities Exchange release, 25 August 2011. 8 pp.

<sup>13</sup> Diatreme Resources Ltd, 2011. Updated independent technical review and valuation of the Cyclone deposit – Eucla Basin. Australian Securities Exchange release, 21 June 2011. 29 pp.

<sup>14</sup> Astron Ltd, 2011. Donald mineral sands project – resource update. Australian Securities Exchange release 1 December 2011. 3 pp.

<sup>15</sup> Sheffield Resources Ltd, 2011. 1Mt contained HM inferred resource at Ellengail. Australian Securities Exchange release, 25 October 2011. 11 pp.

Metallica Minerals Limited's wholly-owned subsidiary, Oresome Australia Pty Ltd, reported that it has commenced the permitting and statutory approval process for its **Urquhart Point** heavy mineral sands project in Cape York, Qld, with the release of the draft terms of reference for the project's environmental impact study, together with its initial advice statement. The **Urquhart Point** project is approximately 5km southwest of the Weipa Township on the Gulf of Carpentaria. The zircon and rutile deposit has an Indicated Resource of 2.8Mt at 7% heavy mineral sands to a maximum depth of three metres.

## Molybdenum

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Molybdenum (Mo) is used in steels and superalloys to enhance strength, toughness and corrosion resistance. The main commercial source of molybdenum is molybdenite ( $\text{MoS}_2$ ) but it is found also in minerals such as wulfenite ( $\text{PbMoO}_4$ ) and powellite ( $\text{CaMoO}_4$ ). Molybdenum is mined as a principal ore and is recovered as a by-product or co-product of copper and tungsten mining.

### Resources

Australia's Economic Demonstrated Resources (EDR) of molybdenum rose by about 17% from 276 kilotonnes (kt) in 2009 to 324kt in 2010. The bulk of the increase occurred at Ivanhoe Australia Ltd's Merlin deposit in northwest Queensland (Qld) with a small increase in South Australia (SA). Western Australia (WA) has Australia's largest molybdenum EDR with about 68%, followed by Qld with 30% and the remaining 2% is in the Northern Territory (NT) and SA.

Subeconomic Demonstrated Resources (SDR) account for about 74% of the total Demonstrated Resources with Qld accounting for 91% of SDR followed by WA with 9%.

In 2010, both the Paramarginal Resources and the Submarginal Resources remained unchanged from 2009 at 905kt and 5kt respectively.

Inferred Resources of molybdenum increased by 31% from 462kt in 2009 to 607kt in 2010 as a result of increased resources at Anthony and Julia Creek deposits in Qld. Queensland and WA account for 71% and 26% of Inferred Resources respectively.

### Accessible EDR

All of Australia's EDR of molybdenum is accessible.

### JORC Reserves

Joint Ore Reserve Committee (JORC) Code reserves comprise total molybdenum in Proved and Probable Ore Reserves as defined in the JORC Code. In 2010, JORC Code reserves of 220kt (unchanged from 2009) accounted for approximately 68% of Accessible Economic Demonstrated Resources (AEDR).

### Exploration

Data on exploration expenditure for molybdenum are not available nationally.

Further drilling by Ivanhoe Australia Ltd at the **Merlin** molybdenum-rhenium (Re) deposit in northwest Qld has resulted in increased resource at a cut-off grade of 0.3% Mo comprising Indicated Resource of 6.5 million tonnes (Mt) at 1.34% Mo, 23.3 parts per million (ppm) Re, 0.33% copper (Cu), 8.3 grams per tonne (g/t) silver (Ag) and Inferred Resource of 0.2Mt at 0.85% Mo, 15.1ppm Re, 0.44% Cu, 8.2g/t Ag. The Merlin deposit consists of high-grade molybdenite in a breccia zone within shales which are overlain by discrete copper and zinc rich polymetallic sulphides zones of the Mount Dore orebody. The Merlin deposit is the world's highest grade molybdenum and rhenium deposit. The company announced that further drilling on its Cloncurry tenements resulted in additional high-grade intersections. At the southern end of the Merlin deposit, high-grade molybdenum mineralisation was encountered close to the surface at **Little Wizard**. The company reported an Indicated Resource for Little Wizard of 15 000 tonnes grading 6.49% Mo, 83.9ppm Re, 2.3% Cu and 25g/tAg.

Following drilling campaigns conducted between 2008 and the end of 2010, Aussie Q Resource Ltd announced a revised resource for its **Greater Whitewash** molybdenum-copper project near Monto in central Qld. Using a 425ppm MoEq<sup>16</sup> cut-off grade, the company reported an Indicated Resource of 185Mt grading 263ppm Mo, 1189ppm Cu for 49kt of contained Mo and 2200kt contained Cu, and an Inferred Resource of 56Mt grading 239ppm Mo, 1123ppm Cu for 13kt of contained Mo and 63kt contained Cu. The project comprises the Gordon's, Whitewash and Whitewash South prospects which are a single contiguous system, Windmill Hill prospect located to the south on the same strike line, and the Whitewash Southwest prospect which is located west of the Whitewash South prospect. Mineralisation in the Greater Whitewash project occurs as veins within molybdenum-copper porphyry confined wholly within the granodiorite.

In September 2010, Zamia Metals Limited reported a JORC compliant Inferred Resource of 132Mt grading 0.04% Mo at a cut-off grade of 200ppm Mo for 118 million pounds of contained Mo for its **Anthony** molybdenum deposit, north of Clermont, Qld. The deposit is a porphyry molybdenum system in which the molybdenite occurs in veins cutting altered igneous rocks and the surrounding schists. The deposit is oxidised to a depth of 60 to 80 metres. In February 2011, the Inferred Resource was updated to 173Mt grading 0.43% Mo at a cut-off grade of 200ppm Mo for 163 million pounds of contained Mo.

Havilah Resources NL reported a combined JORC compliant Indicated and Inferred Resource of 11.3Mt grading 0.89% Cu, 0.64 g/t Au and 500ppm Mo for 5.68 million kilograms of contained molybdenum for its **North Portia** deposit located 30 kilometres (km) north of its Kalkaroo deposit in SA. The vein and breccia style of mineralisation at the North Portia deposit is hosted in a 150 metre sequence of carbonate-rich weakly metamorphosed siltstones and shales.

## Production

There was no molybdenum production in Australia in 2010.

## World Ranking

According to United States Geological Survey (USGS) data, world economic resources of molybdenum in 2010 are estimated to be about 9800kt with China holding 44% of the resources followed by the USA with 28%, and Chile with 11%.

The USGS estimates that world molybdenum production in 2010 amounted to 234kt compared with 221kt in 2009. China, the USA, Chile and Peru accounted for about 86% of global outputs in 2010 with China producing 94kt, followed by the USA with 56kt, Chile with 39kt and Peru with 12kt.

## Industry Developments

World molybdenum price soared in 2007, reaching a high of US\$38 per pound (lb) in September 2008 from a low of about US\$5/lb in 2001. After the global financial crises in October 2008, the averaged price declined sharply to US\$8/lb and continued at that level through the first half 2009. This led to a tightening of global supplies as many companies ceased operation. However, increased demand from China, Japan and Korea resulted in prices increasing, with the average price from the second half 2009 to September 2010, fluctuating from US\$15 to US\$18/lb.

Metallic Minerals Limited's **Wolfram Camp** tungsten-molybdenum project 90km west of Cairns in Qld has been under care and maintenance since late 2008. In early 2011, the company's 76% owned-subsiary, Planet Metals Limited completed the sale of the project to Deutsche Rohstoff AG (DRA). DRA is planning to restart production at the Wolfram Camp mine by the end of 2011. Full-scale production at a maximum annual output of 2400 tonnes of 65% WO<sub>3</sub> concentrate (equal to 1230 tonnes of pure tungsten) and 166 tonnes of 50% Mo concentrate is expected to be achieved in 2012. The project has resource estimate of 1.42Mt grading 0.6% tungsten oxide (WO<sub>3</sub>) and 0.12% Mo. This comprises 0.78Mt grading 0.56% WO<sub>3</sub> and 0.13% Mo in the Indicated Resource category and 0.64Mt grading 0.65% WO<sub>3</sub> and 0.11% Mo in the Inferred Resource category.

<sup>16</sup> MoEq = Mo + Cu/3.8 + Ag\*28.8 based on the following metal prices of Mo of US\$37150/t, Cu of US\$9781/t and Ag of US\$33.38/troy oz.

Moly Mines Ltd has completed its engineering works feasibility study on its **Spinifex Ridge** project about 50km northeast of Marble Bar in the Pilbara region of WA. The project comprises a 10 million tonnes per annum (Mtpa) operation utilising an ore head grade of 0.07% Mo and 0.11% Cu, at a proposed capital set-up costs of between \$528 million and \$558 million. The company, through its major shareholder Hanlong Mining Investment Pty Ltd and supported by the Hanlong Group from Sichuan, China, was working towards the completion of all financing arrangements through the China Development Bank by the end of 2011. The project has a combined Proven and Probable Reserves of 451Mt grading 0.05% Mo, 0.08% Cu and 1.3g/t Ag.

Thor Mining PLC announced that it was re-examining its 2007 Definitive Feasibility Study on its **Molyhil** tungsten-molybdenum project, 250km northeast of Alice Spring in the NT following the significant improvement in tungsten prices. The revised study, which will focus on contract provision of infrastructure and services where practicable, is expected to be completed in the December quarter of 2011. If the study has a favourable outcome, the company may initiate developmental activities during 2012. The project has a reported total Proven and Probable Reserves of 2.21Mt grading 0.47% WO<sub>3</sub> and 0.21% MoS<sub>2</sub>.

In September 2010, Ivanhoe Australia Ltd started work on a portal, a 2.4km long decline and 0.5km access cross cuts and drives into the **Merlin** deposit. The highest ore values for the deposit occur from 150m to 500m below the surface. The deposit is contained within the Mount Dore Mining Leases with a Plan of Operation that allows mining development to commence. A pre-feasibility study is due to be completed by end of 2011 after a Scoping Study on the Merlin deposit indicated that, for an initial 9-year mine-life operation, the project could produce about 5300 tonnes per annum (tpa) of Mo and 7.5tpa of Re for an initial capital cost of \$319 million.

Ivanhoe Australia Ltd expects to access the **Little Wizard** orebody from the Merlin decline. This high-grade resource was not included as part of the Merlin Scoping Study and, as such, provides a significant upside financial opportunity for the company's Merlin development plan. The mineralisation consists of massive coarse-grained molybdenite which may be readily upgraded to a marketable grade molybdenum-rhenium concentrate by crushing and using either gravity or flotation processes. This high-grade concentrate could be sold to a toll roaster capable of maximising the rhenium recovery and payable metal.

Following the improvement in molybdenum prices D'Aguilar Gold Limited, through its subsidiary Barlyne Mining Pty Ltd, has begun reassessing its **Anduramba** molybdenum project, 150km west of Brisbane, Qld. The deposit contains a JORC compliant Indicated Resource of 21Mt grading 567ppm Mo, 5.68ppm Ag and 159ppm Cu, and an Inferred Resource of 10.6Mt grading 488ppm Mo, 2.81ppm Ag and 94ppm Cu.

Zamia Metals Limited plans to complete a scoping study for the molybdenum mining and processing operation by the end of 2011 and is carrying out metallurgical test on both the sulphide and the oxide material at its **Anthony** deposit to determine the optimum processes for producing saleable products.

## Nickel

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More than 80% of nickel production is used in alloys. When alloyed with other elements, nickel imparts toughness, strength, resistance to corrosion and various electrical, magnetic and heat resistant properties. About 65% of world nickel output is consumed in the manufacture of stainless steel, which is used widely in the chemical industry, motor vehicles, the construction industry and in consumer products such as sinks, cooking utensils, cutlery and white-goods.

### Resources

Australia's Economic Demonstrated Resources (EDR) of nickel decreased by 13.8% from 24.0 million tonnes (Mt) to 20.7Mt in 2010 as a result of mining companies updating their resources. About 84% of Australia's EDR is in 15 deposits. Australia's EDR of nickel can be subdivided as follows:

- About 27% of Australia's EDR comprise Reserves as defined under the Joint Ore Reserve Committee (JORC) Code.

- About 32% is made up of published JORC Code compliant Measured and Indicated Resources in operating mines, in deposits being developed for mining and in deposits which have published scoping/feasibility studies with positive results.
- The remaining 41% of Australia's EDR are in deposits with Measured and Indicated Resources of similar tonnage, grade and ore type which are being mined elsewhere in Australia, but have not completed a scoping/feasibility study.

Western Australia (WA) retains the largest nickel resources with 90.8% of total Australian EDR. New South Wales (NSW) is the second largest with 4.8%, followed by Queensland (Qld) with 3.9% and Tasmania (Tas) with 0.5%. The EDR in WA comprises both sulphide and lateritic deposits, while EDR in NSW and Qld are associated with laterite deposits.

Subeconomic Demonstrated Resources, which accounted for about 8.1% of total Identified Resources, decreased from 9.9% during 2010. The Paramarginal Resources decreased from 3.0Mt to 2.4Mt, while the Submarginal Resources decreased from 1.9Mt to 1.3Mt in 2010. WA has 67.6% of the subeconomic nickel resources.

Inferred Resources decreased from 21.2Mt to 19.4Mt in 2010. WA maintained its dominant share of Australia's Inferred Resources with 92.3% followed by NSW with 2.9%.

The ratio of Inferred Resources to EDR in 2010 was 1.01:1.

### Accessible EDR

Currently, all nickel EDR is accessible for mining. At the rate of production in 2010, Accessible Economic Demonstrated Resources (AEDR) of nickel is sufficient for about 122 years.

### JORC Reserves

About 27% of AEDR is made up of Joint Ore Reserve Committee (JORC) Code Reserve. The remaining 73% of EDR represents resources assessed by Geoscience Australia from the Measured and Indicated categories of industry reported mineral resources, as defined under the JORC Code and other classification systems used by companies not listed on the Australian Stock Exchange.

Total JORC Code Reserves of nickel are adequate for 32 years at current rates of production.

### Exploration

Expenditure on nickel-cobalt exploration for 2010 as reported by the Australian Bureau of Statistics was \$235.7 million, an increase of 26.5% on 2009. WA attracted most of this expenditure with \$227.8 million.

### Production

All of Australia's nickel production in 2010 was from WA and amounted to 170 kilotonnes (kt), up from 165kt in 2009, as reported by the Australian Bureau of Agricultural and Resource Economics and Sciences. The value of all nickel products exported was \$4.008 billion. Australia was the world's third-largest producer behind Russia and Indonesia, accounting for 10.8% of estimated world mine production of nickel.

### World Ranking

Based on figures published by the United States Geological Survey and the latest Australian resource figures, world economic resources of nickel increased to 75.6Mt in 2010 from 68.6Mt in 2009. Australia's share of world economic resources of nickel was 28.4% in 2010. It remained the largest holder of economic resources followed by Brazil (11.9%), New Caledonia (9.7%), Russia (8.2%) and Cuba (7.6%).

Russia was the largest producer with 265kt (16.8%), followed by Indonesia with 232kt (14.7%), Australia with 170 (10.9%) and Philippines with 156kt (9.9%).

## Industry Developments

During 2010 the nickel price continued to recover from the 2008/2009 global financial crisis from an average of US\$18 439 a tonne in January 2010 to US\$26 035 a tonne in April 2010 before retreating to US\$24 111 a tonne in December 2010. The average price for nickel in 2010 was about US\$21 800 a tonne, an increase from about US\$14 700 in 2009 (London Metal Exchange cash prices). In its annual report for 2011, BHP Billiton stressed the importance of the Chinese market on global demand and prices for all mineral commodities, including nickel. During 2010, China represented 59% of global seaborne iron ore demand, 39% of copper demand, 38% of nickel demand, 41% of aluminium demand, 42% of energy coal demand and 10% of oil demand. China's requirement for these commodities has been driving global materials demand for the past decade.

The major sulphide nickel mines, which are owned by BHP Billiton's Nickel West, continued operating at **Leinster**, **Mount Keith** and **Cliffs** north of Kalgoorlie, WA. Smaller sulphide nickel mines continued to be operated by Xstrata Nickel Australia Pty Ltd, Mincor Resources NL, Panoramic Resources Ltd, Western Areas NL and Independence Gold NL. Minara Resources NL's **Murrin Murrin** lateritic nickel mine also continued to operate. In February 2010, BHP Billiton sold its **Ravensthorpe** operation to First Quantum Minerals Australia Nickel Pty Ltd which announced in October 2010 that it would recommission the mine in the second half of 2011. First Quantum began production of nickel at Ravensthorpe in October 2011.

## Nickel Sulphide Deposits

BHP Billiton's has reported that, its WA operations produced 170 500 tonnes of nickel during 2010 with most sourced from the Mount Keith, Leinster and Cliffs mines. Production was up from 113 400 tonnes in 2009. Nickel production is affected increasingly by restrictions in hydrogen supply at Nickel West's Kwinana refinery, which is resulting in an increasing proportion of nickel matte being exported to overseas customers.

Most of the nickel ore treated at the Kambalda, Leinster and Mount Keith concentrators is smelted at the Kalgoorlie nickel smelter into nickel matte containing about 66% nickel. The mill and concentrator at Kambalda are supplied with third party ore and produce concentrate containing about 13% nickel. About 43% of the nickel matte was sold to overseas customers during 2009/10 compared with 60% in 2010/11. The nickel matte not sold overseas was refined at BHP Billiton's Kwinana nickel refinery to produce London Metal Exchange (LME) accredited nickel briquettes, nickel powder and other intermediate products such as cobalt-nickel-sulphide. The Kwinana nickel refinery has a capacity of 65 000 tonnes per annum (tpa) of nickel metal. BHP Billiton reported that a new hydrogen plant is being built at its Kwinana refinery and is expected to be completed in the second quarter of 2012.

OJSC MMC Norilsk noted in its annual report for 2010 that there was no nickel production from any of its **Cawse**, **Black Swan**, **Lake Johnston**, **Waterloo** and **Honeymoon Well** projects in WA. During 2010 the company was investigating the possibility of preliminary enrichment of the ores processed at the Lake Johnston operations and Tati Nickel in South Africa. The Lake Johnston operations 500 kilometres east of Perth, WA, include the **Maggie Hays** mine which re-opened in 2011. The company investigated options for adapting existing nickel processing facilities at Cawse for the use of a new hydrometallurgical technology. The plant was expected to be reoriented towards the processing of sulphide feedstock from Norilsk's Australian sulphide nickel deposits. Norilsk is planning to produce a nickel hydroxide with a nickel content of about 50%, which bypasses smelting by directly refining the semi-product. The use of this technology is expected to reduce the costs of refined metal. It also reported that exploration expenditure in Australia in 2010 was minimal with spending mainly on geophysical and geochemical surveys in the Lake Johnston area and drilling and geophysical work on Honeymoon Well. The company reported that its capital investments in Australia in 2010 amounted to US\$10 million spent on the acquisition of a power plant for the Cawse enrichment plant and to finance the restart the Lake Johnston operation.

Xstrata Nickel Australasia operates the **Cosmos** nickel project in WA made up of a concentrator at Cosmos and mines at **Alec Mairs**, **Tapinos** and **Prospero**. Another operation, the **Sinclair** mine, which has its own concentrator, is about 100 kilometres southeast of the Cosmos operations. Xstrata announced in its 2010 Annual Report that metal in concentrates produced in 2010 from the Cosmos operation, amounted to 16 961 tonnes

nickel, 687 tonnes of copper and 245 tonnes of cobalt<sup>17</sup>. Total ore milled in the period increased by 10% to 383 293 tonnes. The concentrate is transported by truck to the coastal town of Esperance and shipped to the Xstrata nickel smelter in Sudbury, Ontario.

Western Areas NL nickel mine at the **Flying Fox** deposit in WA produced 8121 tonnes of nickel in concentrate in 2009. Western Areas reported that, by the end of 2010, the main decline at Flying Fox had advanced to 1073 metres below the surface and was well advanced into the T5 orebody. The planned decline development reached the base of the T5 orebody during the March quarter of 2011. Open cut mining at the company's **Spotted Quoll** deposit advanced to a depth of 100 metres and open cut mining is expected to be completed by the March quarter 2012. The company also announced that stage one of a feasibility study for the underground operation at the Spotted Quoll deposit was completed during December 2010 and indicated promising financial returns with a mine life of eight years. All ore mined at Spotted Quoll is treated at the Cosmic Boy concentrator, which was upgraded during the first half of 2010 to a capacity of 550 000tpa. The nickel concentrate from the Cosmic Boy plant is delivered under off-take contracts to BHP Billiton in Kalgoorlie and to the Jinchuan Group in China.

During 2010, Panoramic Resources Ltd's underground mine operation at **Savannah** in WA produced 6661 tonnes of nickel, 3626 tonnes of copper, and 364 tonnes of cobalt. Nickel concentrates produced at the Savannah plant are contracted for sale to the Jinchuan Group in China. In 2010, **Lanfranchi** (WA) produced 10 264 tonnes of nickel and 851 tonnes of copper. Panoramic Resources has commenced work to optimise production from three production nickel channels in the Lanfranchi area (Helmut/Deacon, Schmitz and Lanfranchi) and has discovered additional nickel mineralisation down plunge from the **Helmuth South** deposit. Feasibility work has commenced also on the **Cruickshank Orebody**, six kilometres northeast of the Lanfranchi operations. The ore from the Lanfranchi operation is processed at the Kambalda nickel concentrator owned by BHP Billiton.

Mincor Resources NL nickel production for 2010 was reported under two groups of operations in WA. They are the North Kambalda operation made up of the **Otter Juan, Coronet, McMahan** and Mincor's 70% interest in the **Carnilya Hill** mine. The operations yielded a combined production in 2010 of 3973 tonnes of nickel, 367 tonnes of copper and 70 tonnes of cobalt. The Southern Kambalda operations produced 3988 tonnes of nickel, 382 tonnes of copper and 73 tonnes of cobalt, from the **Mariners** and **Miitel** operations.

Independence Group NL reported total production for 2010 of 9483 tonnes nickel and 652 tonnes copper from its **McLeay, Victor South, Moran** and **Long** mines in WA. The first ore was mined in the first quarter of 2010 from the newly delineated Moran deposit.

Fox Resources Ltd continued metallurgical testing for a possible local indigenous bacterial heap leaching operation to treat nickel and copper resources from the **Radio Hill** mine and the nearby **Sholl** deposit in WA. In mid-2010 the company announced updated Indicated and Inferred Resources of 4.22Mt at 0.65% Ni and 0.76% Cu for its Radio Hill mine. An Indicated and Inferred Resource of 5.78Mt at 0.54% Ni and 0.67% Cu was also reported for the Sholl B2 deposit. In September 2011<sup>18</sup>, Fox Resources released a preliminary scoping study, revised from March 2011 for its heap leaching project. The heap leaching operation is expected to have a net present value of \$73 million (8% discount rate) and an internal rate of return of 31% over the nine year life of the mine. The project is estimated to produce a net operating cash flow of \$125 million with project revenues of \$815 million over the initial mine life.

During 2010, Minmetals Resources Ltd commenced an extensive technical study of the **Avebury** mine in Tas to assess options for possible restart of operations in the future<sup>19</sup>.

### Lateritic Nickel Deposits

The annual production for 2010 from the Murrin Murrin lateritic nickel plant in WA operated by Minara Resources Ltd was 28 378 tonnes nickel and 1976 tonnes cobalt. The company continued drilling and scoping studies on the viability of processing ore from the **Mount Margaret-Marshall Pool** lateritic nickel deposits as a feed for the Murrin Murrin operation. Minara Resources' capital program for 2010 focused on completion of key

<sup>17</sup> Xstrata plc, 2011. Preliminary full year results 2010. 80 pp.

<sup>18</sup> Fox Resources Ltd, 2011. Quarterly activities report for the period ending 30 September 2011. 18pp.

<sup>19</sup> Minmetals Resources Ltd, 2011. Bigger, stronger and ready to grow. 2010 Annual report. 166pp.

projects which were causing a bottleneck, including the high density slurry project (increasing ore leach throughput) and adding the sixth autoclave and second flash vessel in the nickel reduction area of the plant. Additionally, during the 2010 September quarter, development of the **Murrin Murrin East** orebody commenced which is expected to improve the delivered grade of nickel to the plant over the next five to eight years. Minara is planning to lift its nickel production to between 33 000 and 37 000 tonnes of nickel metal. In October 2011, Minara Resources was taken over by Glencore Investment Pty Ltd and was removed from listings of the Australian Securities Exchange.

First Quantum Minerals Australia Nickel Pty Ltd acquired the Ravensthorpe lateritic nickel operation in WA from BHP Billiton in February 2010. In a media release on 3 November 2011, First Quantum reported that:

- The plant is performing well and ramping up as planned towards commercial operations before the end of 2011.
- First production of nickel contained in mixed hydroxide was achieved on 4 October 2011.
- Re-constructed plants consistently achieving design throughputs.
- Both Atmospheric Leach and Pressure Acid Leach plants have been brought on line.

First Quantum Minerals is planning to produce 39 000tpa of nickel metal for the first five years and 28 000tpa for the remainder mine life of about 30 years.

The NORNICO project (Qld) is owned by Metallica Resources Ltd and includes five key nickel laterite deposits at **Greenvale, Lucknow, Kokomo, Minnamoolka** and **Bell Creek**. NORNICO's combined resource base of Measured, Indicated and Inferred Resources stood at 49Mt at 0.81% Ni, 0.09% Co, using a 0.7% Ni equivalent cut-off grade (Ni equivalent is calculated using  $Ni\% + 2Co\%$  when the resource was estimated in early 2011). Metallica Resources currently is conducting studies into the feasibility, permitting and mineable resource, as well as ongoing detailed metallurgical testwork and scandium market development. In April 2011, Metallica decided to change NORNICO's development strategy from a 180 000tpa heated atmospheric acid leach process to a conventional high pressure acid Leach (HPAL) process with its own acid-power plant at greatly increased feed rates. A specialist Brisbane based engineering firm, Ausenco Vector, is preparing an analysis for a HPAL processing facility with acid and power plant sited on the Greenvale minesite. Mining studies are focused on defining the optimal mineable resource base to underpin a 20 year mining and processing operation, currently envisaged to be in the 500 000 to 1 million tonnes per annum range. There has been significant customer interest in the company's potential to become a scandium producer.

Metals X Ltd completed the first phase of a feasibility study for the **Wingellina** lateritic nickel deposit in WA in mid-2008 and confirmed a project concept for the construction of a nickel and cobalt operation producing approximately 40 000tpa nickel and 3500tpa cobalt with an initial mine life of 40 years at an operating costs of less than US\$3.50/lb of nickel after cobalt credits. Based on a nickel price of US\$20 000, cobalt price of \$45 000 and an exchange rate of US\$0.85, the estimated after tax net value of the project was \$3.4 billion. In July 2010 Metals X signed a Mining Agreement with the Ngaanyatjarra Land Council for the Wingellina project. The agreement is subject to regulatory approvals and a mining lease being granted. It is also awaiting completion of final water, environmental and the majority of its technical studies<sup>20</sup>.

The previous partner (Vale Inco) in Heron Resources Ltd's **Kalgoorlie Nickel Project** (KNP) in WA withdrew from the project in July 2009 after spending \$34.5 million on feasibility studies. Vale Inco completed a pre-feasibility study on four lateritic nickel deposits of the KNP project and Heron released a summary of the results in February 2009. That summary stated that the study investigated a project sized for up to 36 000tpa of nickel intermediate product with a mine life of 34 years. A high pressure acid leach operation was considered to be the best leaching technology with nickel and cobalt extractions of 96% nickel and 93% cobalt. Cash operating cost was estimated to be US\$4.42 a pound of nickel (including cobalt credits) and the capital cost was estimated to be US\$1.5 billion. Heron Resources completed further metallurgical studies and a detailed mining study which considered optimising individual pits and the sequence for mining. This study evaluated the project performance over three production rate scenarios of 2.5Mt (Vale Base Case), 3.75Mt and 5Mt a year of leach feed. The company announced on 7 July 2011 that it had entered into a collaborative research agreement with the Commonwealth Scientific and Industrial Research Organisation (CSIRO) to undertake a detailed mineralogical and metallurgical study of the ore types at the KNP.

<sup>20</sup> Metals X Ltd, 2011. Annual Report 2011. 126 pp.

The **Barnes Hill** project in Tas is a joint venture between Metals Finance and Proto Resources and Investments Ltd which owns the tenements. The project is based on a lateritic nickel deposit located in northeast Tas and has an Indicated Resource of 5.674Mt of ore grading at 0.820% Ni and 0.060% Co. The Indicated Resource includes a Probable Reserve of 3.956Mt at 0.840% Ni and 0.060% Co. In addition, the Barnes Hill deposit has an Inferred Resource of 933 000 tonnes at 0.770% Ni and 0.059% Co. Metals Finance has the right to earn a 50% equity interest in the project through the completion of flow sheet designs, engineering and feasibility studies, procuring the funding required for implementation of the project and bringing it into production. When production starts, Metals Finance will be the operator for the joint venture.

## Niobium

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Niobium (Nb) and tantalum often are found together in the same ores, namely columbite and tantalite, as a result of their very similar chemical properties. Niobium is used with iron and other elements in stainless steel alloys. Niobium-titanium alloy wire is used in the medical sector for magnetic resonance imaging. Niobium alloys are strong and are often used in pipeline construction. The metal is used in superalloys for jet engines and heat resistant equipment. At cryogenic temperatures (minus 150°C), niobium is a superconductor.

### Resources

Australia's Economic Demonstrated Resources (EDR) of niobium increased by 16.5% in 2010 to 134 kilotonnes (kt) (up from 115kt in 2009). The bulk of the EDR of niobium is associated with the **Toongi** deposit, 20 kilometres (km) south of Dubbo in New South Wales (NSW). This deposit is a sub-volcanic intrusive trachyte body (vertical) with dimensions of approximately 900 metres (m) by 600m, which has been drilled out to a depth of 55m to provide a Measured Resource of 35.7 million tonnes (Mt) grading 0.46% Nb<sub>2</sub>O<sub>5</sub>, and between 55m to 100m for an Inferred Resource of 37.5Mt grading 0.46% Nb<sub>2</sub>O<sub>5</sub>.

The other source of niobium EDR is the **Hastings Rare Metals** deposit located 18km southeast of Halls Creek, Western Australia (WA). This deposit, owned by Augustus Minerals Limited, is hosted by a fine-grained volcanoclastic unit (informally known as the Niobium Tuff) within a sequence of thick volcano-sedimentary rocks. The Niobium Tuff can be traced over a strike length of 3.5km and varies in width up to 35m. The deposit has a Joint Ore Reserve Committee (JORC) Code compliant resource of 22.08Mt (grading 0.79% ZrO<sub>2</sub>, 0.31% Nb<sub>2</sub>O<sub>5</sub>, 0.023% Ta<sub>2</sub>O<sub>5</sub> and 0.1% Y<sub>2</sub>O<sub>3</sub>) comprising an Indicated Resource of 8.83Mt grading 0.31% Nb<sub>2</sub>O<sub>5</sub> from the surface to 100m depth and an Inferred Resource of 13.25Mt grading 0.32% Nb<sub>2</sub>O<sub>5</sub> from 100m to 250m depth. These resources are based on a 1500 parts per million (ppm) Nb<sub>2</sub>O<sub>5</sub> cut-off grade.

Paramarginal Resources totalling 15kt (unchanged from 2009) accounts for all the Subeconomic Demonstrated Resources and occur in the **Mount Weld** carbonatite deposit in the eastern goldfields, WA.

Inferred Resources are estimated to be 419kt (543kt in 2009). WA is the largest holder of Inferred Resources with 72% associated with the Mount Weld and the Hastings Rare Metal deposits. NSW holds the remaining 28%, which occurs in the Toongi deposit.

### Accessible EDR

All of Australia's EDR of niobium is accessible.

### JORC Reserves

JORC Code reserves comprise total niobium in Proved and Probable Ore Reserves as defined in the JORC Code. In 2010, there were no reserves of niobium reported under the JORC Code.

### Exploration

Exploration for niobium is occurring in WA and NSW, but there are no statistics available on exploration expenditure for niobium.

## Production

Currently there is no production of niobium in Australia. However, in previous years niobium concentrates were recovered as a by-product of tantalum mining.

## World Ranking

Based on incomplete world estimates published by the United States Geological Survey (USGS) for 2010, the largest holder of world's niobium resources of 2900kt are in Brazil while Canada has 46kt. USGS data also estimates that world production of niobium in 2010 was 63kt, a slight increase on 2009 production of 62.9kt and was dominated by Brazil with 58kt and Canada with 4.4kt.

## Industry Developments

Historically, Global Advanced Metals (GAM) Pty Ltd (formerly Talison Minerals) **Greenbushes** mine in WA produced tantalite-columbite concentrate for export. Columbite  $\text{Fe}(\text{Nb},\text{Ta})_2\text{O}_6$  is the main niobium ore mineral. The company's primary tantalum plant at Greenbushes has been under care and maintenance since 2008 while its secondary processing plant treats primary tantalum concentrates from the **Wodgina** mine, in the Pilbara region of WA. According to the Western Australian Department of Mines and Petroleum, no tantalite was produced in 2010 compared to 115kt produced in 2009.

Galaxy Resources Limited commenced production from its **Mt Cattlin** lithium tantalum mine in December quarter 2010. In December 2010, GAM agreed to purchase 200 000 pounds of contained tantalum pentoxide over the next 5 years from the Galaxy Resources Mt Cattlin operation. GAM plans to upgrade this material for sale at its Greenbushes operations. When in full production, Galaxy Resources Limited expects to produce 137 000 tonnes per annum of spodumene and 56 000 pounds per annum of tantalite contained concentrate, essentially as a by-product.

Alkane Resources Ltd is in advanced process of developing a Memorandum of Understanding (MoU) with a niobium consumer to form a Joint Venture to produce ferro-niobium from niobium concentrate for specialised alloy markets from the Dubbo Zirconia Project (based on the **Toongi** deposit). In May 2011, the company signed an MOU with a large chemical company to produce some 15 to 20 kilotonnes per annum of zirconium oxychloride, also using ore from the Toongi deposit.

# Phosphate

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Phosphate rock is a general term which refers to rock with high concentrations of phosphate minerals, most commonly of the apatite group. It is the major resource mined to produce phosphate fertilisers for the agriculture sector. Phosphorous also is used in animal feed supplements, food preservatives, anti-corrosion agents, cosmetics, fungicides, ceramics, water treatment and metallurgy.

There is no substitute for phosphate.

Australia's commercial resources of phosphate are in northwest Queensland (Qld) at Phosphate Hill, 140 kilometres (km) southeast of Mount Isa and on the remote offshore territory of Christmas Island in the Indian Ocean. Phosphate Hill is a world-class rock phosphate resource which is close to the surface and easy to access and mine. The rock is ideal for the manufacture of high analysis mono-ammonium phosphate (MAP) and di-ammonium phosphate (DAP) fertilisers for domestic and international use.

Christmas Island is a source of quality rock phosphate which is exported to the Asia-Pacific region with products used widely in the palm oil sector of the region. Higher-grade rock phosphate is used by Australian manufacturers of MAP fertiliser.

DAP and MAP fertilisers have different ratios of phosphorous (P) and nitrogen (N), and have slightly different applications. Both products are generally produced as granules with a diameter of between 2–4 millimetres.

DAP (20% P and 18% N) is used on broad-acre crops such as cereal, legume, fodder and horticultural crops as well as for dairy and newly established pastures. MAP (22% P and 10% N) assists with early crop growth and enhances phosphorous uptake in broad-acre crops.

## Resources

Excluding Christmas Island resources, Australia's total Economic Demonstrated Resources (EDR) of phosphate rock in 2010 was 492.1 million tonnes (Mt), compared with 248.6Mt in 2009. Australia's EDR occur in sedimentary phosphate rock (phosphorites) at Phosphate Hill (Qld) which has an average grade of about 24% P<sub>2</sub>O<sub>5</sub>, at Paradise South (Qld), which has an average grade of about 15% P<sub>2</sub>O<sub>5</sub>, and Wonarah in the Northern Territory (NT) which has an average grade of about 21.3% P<sub>2</sub>O<sub>5</sub>.

There is no publicly available information on phosphate rock resources for Christmas Island.

About 46% of Australia's total demonstrated resources of 1196Mt occurs in the Georgina Basin in Qld and the NT and are classified as paramarginal. The remaining 33% of demonstrated resources occur in Western Australia (WA) within carbonatite at Mount Weld, 26 kilometres (km) southeast of Laverton, and at Balla Balla magnetite deposit 100km west- south-west of Port Hedland.

About 80% Australia's inferred phosphate resources, which total 1274Mt, occur as phosphorites in the Georgina Basin. These resources are distributed between Qld and the NT. The remaining 20% occur in WA, mainly associated with the Mount Weld deposit.

## Accessible EDR

All of Australia's EDR of phosphate is accessible.

## JORC Reserves

Joint Ore Reserve Committee (JORC) Code Reserves comprise total phosphate in Proved and Probable Ore Reserves as defined in the JORC Code. In 2010, JORC Code Reserves of 137Mt (81.6Mt in 2009) accounted for approximately 28% of Accessible Economic Demonstrated Resources (AEDR).

## Exploration

Although specific data on phosphate rock exploration expenditure are not reported by the Australian Bureau of Statistics, there has been an increase in company exploration for phosphate, particularly in Qld and the NT, as a consequence of increased world demand for fertilizers.

Arafura Resources Limited announced the results of its drilling at **Nolans Bore** in the NT including 143m at 3.6% rare earth oxides (REO), 19.8% P<sub>2</sub>O<sub>5</sub> and 0.56lb/t U<sub>3</sub>O<sub>8</sub> from 23m, 27m at 4.1% REO, 25.6% P<sub>2</sub>O<sub>5</sub> and 0.58lb/t U<sub>3</sub>O<sub>8</sub>, and 19m at 5.4% REO, 27.1% P<sub>2</sub>O<sub>5</sub> and 0.90lb/t U<sub>3</sub>O<sub>8</sub>.

Minemakers Ltd reported the results of its drilling in the March quarter 2010 at the **Wonarah** deposit, 200km east of Tennant Creek, NT, including 8m at 35.4% P<sub>2</sub>O<sub>5</sub> including 7m at 37.3% P<sub>2</sub>O<sub>5</sub>, 9m at 30.3% P<sub>2</sub>O<sub>5</sub>, including 3m at 35.2% P<sub>2</sub>O<sub>5</sub>, 12m at 30.4% P<sub>2</sub>O<sub>5</sub>, including 6m at 37.6% P<sub>2</sub>O<sub>5</sub> and 9m at 33.1% P<sub>2</sub>O<sub>5</sub>, including 7m at 36.5% P<sub>2</sub>O<sub>5</sub>.

Swift Venture Holdings Corporation, a Singapore-based company, has acquired a 70% option over GBM Resources Ltd's phosphate resources at the **Bungalien** project, Qld, which is located 50km north of the Phosphate Hill deposit. Drilling at Bungalien has returned phosphate values ranging from 10% to 22% P<sub>2</sub>O<sub>5</sub>.

## Production

There are two main locations for the production of phosphate rock, Phosphate Hill (Qld) and Christmas Island in the Indian Ocean.

The Queensland Department of Mines and Energy estimates that Incitec Pivot's production from Phosphate Hill in 2009–10 amounted to 2.132Mt of phosphate rock (compared with 1.958 in 2008–09). Phosphate Resources Ltd

produced 420 205 tonnes of phosphate rock and 42 300 tonnes of phosphate dust in 2009 from its Christmas Island operation.

Several small operations near Bendleby in South Australia (SA) produced about 2547 tonnes of phosphate rock in 2010 (5670 tonnes in 2009), which is used mainly in domestic industrial applications.

## World Ranking

The United States Geological Survey (USGS) estimated that total world resources of phosphate rock are 65 000Mt. Australia's EDR comprises less than 0.01% of the world's resources. Morocco and Western Sahara jointly hold about 76%, followed by China with 6%, Algeria 3%, and Syria with 2.8%.

USGS estimated that world production of phosphate rock totalled 176Mt in 2010 (166Mt in 2009), with China producing 65Mt, the USA 26.1Mt and Morocco and Western Sahara 26Mt.

## Industry Developments

Phosphate rock prices, which were influenced by the global financial crisis in 2008, fell substantially in early 2009 to US\$110 a tonne but were still significantly above the long term average price of US\$50. By early 2010, the price for Moroccan 31–33% P<sub>2</sub>O<sub>5</sub> rock had increased from US\$100 and US\$110 a tonne Free-on-Board (FOB) to between US\$140 and US\$150 a tonne FOB. The Chinese demand for phosphate grew by about 18% in 2009 continued and to strengthen in 2010 as a result of China importing phosphate rock to supplement domestic production. By early 2011, the price for Moroccan 31% to 33% P<sub>2</sub>O<sub>5</sub> was reported in the range of US\$180 and US\$205 a tonne FOB.

Legend International Holdings Inc. (Legend) plans to commence mining of rock phosphate as early as 2012 at its **Paradise North** (Qld) deposit containing 7.3Mt grading 28.1% P<sub>2</sub>O<sub>5</sub> for direct shipping ore, direct application rock phosphate and single superphosphate. The company will seek tenders for the construction of up to a 1 million tonnes per annum (Mtpa) rock concentrate flotation beneficiation plant at its **Paradise South** deposit capable of producing 32–34% P<sub>2</sub>O<sub>5</sub> phosphate rock concentrate. Legend has reported that the combined resources of the Paradise North and Paradise South deposits are 81Mt grading 18.1% P<sub>2</sub>O<sub>5</sub>. Both Paradise North (formerly known as Lady Jane) and Paradise South (formerly known as Lady Annie) deposits are located about 70km north of Mount Isa.

Legend is seeking prospective joint venture partners for a proposed Phosphate Fertiliser Complex to be constructed at Mount Isa. The Mount Isa Complex will consist of a sulphuric acid plant, phosphoric acid plant, ammonium phosphate plant and an aluminium fluoride plant. The complex will have an initial combined production capacity of MAP and DAP in the order of 600 000 tonnes per annum (tpa).

The Wengfu Group Ltd of China (Wengfu), which completed an extensive feasibility study in June 2010 into the potential of doubling production at the proposed Paradise Phosphate Project, confirmed that development of the project was technically and economically viable. The feasibility study, which included designs for a 2Mtpa phosphate rock flotation beneficiation plant to be built at Paradise South, covered two development scenarios with the production volumes of:

- 600ktpa MAP/DAP, 15ktpa Aluminium Fluoride, and
- 1200ktpa MAP/DAP, 30ktpa Aluminium Fluoride.

In mid 2011, Legend submitted an Environmental Impact Statement for assessment to the Queensland Department of Resource Management for the Paradise South project which covered mining, beneficiation, supporting infrastructure and transport. Approval is expected in first quarter 2012.

Legend has signed a Memorandum of Understanding (MoU) with Xstrata Zinc regrading the supply of sulphuric acid to the company's proposed phosphoric acid plant in Mt Isa.

In mid 2011, the company also signed a MoU with Alcoa of Australia Limited to investigate the viability of supplying Alcoa with aluminium fluoride produced at Legend's proposed Paradise Phosphate project with Legend receiving from Alcoa aluminium hydroxide for the aluminium fluoride production process. Legend International is proposing to build either a 15ktpa or 30ktpa aluminium fluoride (AlF<sub>3</sub>) unit at the site of its proposed chemical

plant. The current demand for aluminium fluoride in Australia is approximately 30 000 tonnes which is typically sourced from China.

Following the completion of its scoping study in April 2010, Krucible Metals Ltd has submitted an Environmental Management Plan to the Queensland Government for approval and was negotiating with the Traditional Owners, the Yulluna People, for an approved Native Title Agreement to develop a quarry style operation for its **Korella Phosphate** deposit (formerly known as PHM South). The deposit is located 150km southeast of Mount Isa and immediately adjacent to Incitec Pivot Ltd's Phosphate Hill Mine. The company reported an Inferred Resource of 19.3Mt grading at 19%  $P_2O_5$  based on a cut-off grade of 10%  $P_2O_5$  with a high grade zone containing 5Mt grading 30.8%  $P_2O_5$  at a cut-off grade of 25%  $P_2O_5$ . Cadmium content is in the order of 2 parts per million (ppm) to 5 ppm.

Korab Resources Limited plans to commence development of a phosphate deposit located at **GeolSec** near Rum Jungle, 65km south of Darwin in the NT. Subject to receiving all the necessary approvals the company plans to develop a simple quarrying operation with no processing other than grinding and bagging to supply the agricultural sector with a finely ground-up rock phosphate to be used for direct application as an organic fertiliser. The proposed start-up cost is expected to be in the order of \$200 000 to \$300 000. Initial production will be about 15ktpa increasing to 30ktpa by 2013.

Phosphate Australia Limited is in contact with several international companies associated with the fertilizer industry with the aim to secure a strategic partner to assist with the pre-feasibility study of its **Highland Plains** project in the NT. The project has reported JORC Code compliant Inferred Resource of 56Mt at 16%  $P_2O_5$  at a cut-off grade of 10%. Within this global resource, there is a higher grade zone (referred to as the Western Mine Target Zone) which comprises a JORC Code compliant Inferred Resource of 14Mt at 23%  $P_2O_5$  at a cut-off grade of 15%  $P_2O_5$ . In 2011, the company signed a MoU with China National Electric Engineering (CNEEC) aimed at possibly establishing a binding agreement for the provision of engineering, procurement and construction services to the project. CNEEC has expertise in power plant design and construction as well as extensive experience in the design and construction of port facilities and pipelines. A key milestone for a binding agreement will be the completion of a bankable feasible study by Phosphate Australia Limited. The company is planning for the production of 3Mtpa of premium-grade beneficiated rock phosphate to be transported by a slurry pipeline to a barging facility on the Gulf of Carpentaria.

Minemakers Ltd has completed its direct shipping ore feasibility study into its **Wonarah** phosphate project in the Georgina Basin in the NT which found that the phosphate rock was suitable for fertiliser manufacture. However, because of a lack of control in the spot or short term contract markets in combination with future prices and a rapidly rising Australian dollar, the company has moved its emphasis from a simple direct shipping ore operation. It is also considering development of a downstream process involving either an on-site superphosphoric acid (SPA) production plant or full development, which would include a phosphate fertiliser and chemical production either on site near Tenant Creek or near Darwin. The project involves mining two deposits, known as Arruwurra and Main Zone. The project currently has JORC Code compliant resource of 620Mt grading 18%  $P_2O_5$ , based on a cut-off grade of 10%  $P_2O_5$  with an Indicated Resource of 289Mt grading 18.5%  $P_2O_5$  and an Inferred Resource of 331Mt grading 17%  $P_2O_5$ .

Minemakers owns 6.67% of JDCPhosphate Inc, a Florida-based company which has patented an improved dry kiln method of producing phosphoric acid (referred to as SPA) without using sulphuric acid. Merchant wet acid grade phosphoric acid production uses sulphuric acid. Operating and capital cost estimates are favourable compared to those associated with wet acid production. The process which appears to be particularly suited to Wonarah phosphate would allow the company to mine a relatively lower grade product, undertake relatively simple beneficiation on site and also construct the kilns at Wonarah. The SPA could be transported in tankers to near Tennant Creek and then railed to Darwin. Asia currently imports more than 3Mt of  $P_2O_5$  as acid, and demand is anticipated to increase. JDCPhosphate is raising capital to construct and operate a demonstration plant in Florida and aims to have it completed around the end of 2012.

A New Zealand fertiliser company has successfully produced a single superphosphate by blending Wonarah direct shipping ore with Moroccan phosphate rock.

Minemakers terminated its non-binding MoU signed with the Verte Group Pty Ltd who were to seek equity funding for the development of a direct shipping ore mine and a large rock phosphate beneficiation plant at the mine site as well as a 260km railway from Wonarah to the Adelaide to Darwin railway near Tennant Creek.

In February 2011, Minemakers and the Arruwurra Corporation who are the Traditional Owners signed a Mining Agreement giving approval to the development of the Wonarah phosphate deposits. The agreement provides a clear process for financial benefits to the Traditional Owners, the protection of sacred sites and skills training in the mining, processing and freight operations for local indigenous people.

In mid 2011, Minemakers signed a non-binding MoU with Bombay Stock Exchange listed NMDC Limited to establish a pathway for the development of Wonarah project. The MoU could lead to a full joint venture agreement between the two companies in which NMDC would acquire 50% equity in the project, as well as have responsibility for arranging project finance for the full development of the project.

Arafura Resources Ltd is preparing a bankable feasibility study on its **Nolans Bore** rare earth-phosphate-uranium-thorium deposit, located 135km northwest of Alice Springs in the NT. The study will consider establishment of the Nolans Bore Mine, a transfer station on the Darwin to Adelaide railway, and a proposed Rare Earths Complex at Whyalla in SA. The Whyalla complex will have two processing streams, one for rare earths and another for phosphate. Nolans Bore has a combined JORC Code compliant Measured, Indicated and Inferred Resource totalling 30.3Mt to a depth of 130m which grades at 2.8% REO, 12.9% P<sub>2</sub>O<sub>5</sub>, 0.44 pounds per tonne U<sub>3</sub>O<sub>8</sub>, and 0.27% Th using a 1% Rare Earth Element cut-off grade.

Kimberley Rare Earths Limited, which acquired 25% of the **Cummins Range** rare earth oxide-uranium-phosphate deposit, 130km southwest of Halls Creek, WA, in early 2011, plans to carry out an extensive drilling campaign to upgrade the resources from Inferred to Indicated. The deposit currently has a JORC Code compliant Inferred Resource of 4.17Mt at 1.72% total rare earth oxide (TREO), 11.0% P<sub>2</sub>O<sub>5</sub>, 187ppm U<sub>3</sub>O<sub>8</sub> and 41ppm Th at a cut-off grade of 1% TREO. The mineralisation of principally apatite and monazite is up to 50m thick and occurs as a sub-horizontal feature within weathered regolith which has developed over carbonatite and pyroxenite rocks.

In August 2010, Atlas Iron Limited completed the merger with Aurox Resources Limited which owns the **Balla Balla** deposit, 110km southwest of Port Hedland, WA. The deposit consists of a significant titanomagnetite orebody containing resources of iron, vanadium and titanium, as well as a phosphate resource of 89.69Mt grading 3.74% P<sub>2</sub>O<sub>5</sub>. The phosphate, which is in the form of apatite, occurs in the waste rock immediately above the titanomagnetite and will require extensive beneficiation because most phosphate rock is sold worldwide at a grade close to 30% P<sub>2</sub>O<sub>5</sub>.

On **Christmas Island**, Phosphate Resources Ltd shipped around 616 000 tonnes of phosphate during 2010–11, compared with 566 645 tonnes during 2009–10. The company's current resource statement and lease term provide for a 2019 completion date for mining operations. However, the company has not received Australian Government approval for land clearing on parts of its approved mining leases.

## Platinum Group Elements

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The platinum group elements (PGE) comprise platinum (Pt), palladium (Pd), iridium (Ir), osmium (Os), rhodium (Rh) and ruthenium (Ru). The elements of most commercial significance are platinum, palladium and, to a lesser degree, rhodium. The PGE properties of commercial importance are their resistance to corrosion and oxidation, high-melting points, electrical conductivity and catalytic activity in the chemical, electrical, electronic, glass and motor vehicle industries. The emerging commercial importance of PGEs is in applications associated with the motor vehicle industry resulting from increasing global emission controls, development of lead-free petrol and efforts to improve fuel efficiency. Other applications include the use of platinum-rhodium alloys to oxidise ammonia to nitric acid in the production of fertilisers, while platinum is used extensively in jewellery.

According to figures published by Matthey (2011)<sup>21</sup>, the main demand for platinum in 2010 was autocatalyst applications which increased by 43% to 3.13 million ounces. The gross industrial demand for platinum increased by 48% to 1.69 million ounces, but demand in the jewellery section fell by 14% to 2.42 million ounces. Gross demand for palladium increased by 23% to 9.63 million ounces in 2010, its highest ever level. Gross demand for palladium from the autocatalyst sector in 2010 increased by 35% to 5.45 million ounces as economic recovery drove vehicle production higher in all regions.

## Resources

Australia's Economic Demonstrated Resources (EDR) of PGEs decreased from 5.2 tonnes to 4.4 tonnes in 2010 as a result of reclassification of resources.

Western Australia (WA) and the Northern Territory (NT) hold all of Australia's resources of EDR. However the EDR of PGEs in individual deposits within State jurisdictions is often unrecorded resulting in the overall distribution of the PGE EDR being unknown.

In 2010, the Paramarginal Resources increased from 132.3 tonnes to 132.6 tonnes while the Submarginal Resources remained the same at 35.3 tonnes. The Paramarginal Resources are shared mostly between WA (87%) and New South Wales (NSW) (10%), while most of the Submarginal Resources are in WA.

Inferred Resources increased by 200 kilograms (kg) to 145.5 tonnes with WA having most of these resources (86.6%) followed by NSW (11%).

Total Identified Resources of PGEs, which represents EDR plus Paramarginal, Submarginal and Inferred Resources, total about 318 tonnes. Of this amount, deposits which have only PGE resources account for about 60% of the total resources, although all of Australia's production is as by-product from PGE resources associated with nickel sulphide deposits in WA.

## Accessible EDR

Currently, 120kg of the published PGE EDR is accessible for mining while the balance of 4.3 tonnes occurs within national parks. The reason for the low Accessible EDR figure for PGEs is that PGE resources are generally not reported by companies.

## JORC Reserves

About 3% of Accessible Economic Demonstrated Resources (AEDR) of PGEs comprise Joint Ore Reserve Committee (JORC) Code reserve. The remaining 97% of EDR represents resources assessed by Geoscience Australia from the Measured and Indicated categories of industry reported mineral resources, as defined under the JORC Code and other classification systems used by companies not listed on the Australian Stock Exchange. The reason for the low reserve figure is that many companies don't report the PGE content in nickel reserves.

## Exploration

Expenditure for PGEs is not reported separately and much of the PGE resources are associated with nickel deposits. Areas of activity in 2010 where PGEs were a significant component of exploration targets included the WA regions in the eastern goldfields of the Yilgarn, the East Kimberley and West Pilbara as well as the West Musgrave in the border region of WA, the NT and South Australia (SA).

<sup>21</sup> Matthey, J. 2011 Platinum 2011. Johnson Matthey Public Limited Company. Precious Metals Marketing. [http://www.platinum.matthey.com/uploaded\\_files/PT\\_2011/complete\\_publication.pdf](http://www.platinum.matthey.com/uploaded_files/PT_2011/complete_publication.pdf)

## Production

Australia's PGE production (Pd and Pt) in 2010 was very minor by world standards amounting to 781kg. This production is exclusively from nickel sulphide deposits hosted by Archean komatiitic rocks in the Yilgarn Craton of WA.

## World Ranking

Based on figures published by the United States Geological Survey and the latest Australian resource figures, world economic resources of PGEs was 66 000 tonnes in 2010. Australia's share of world EDR was less than 0.1% in 2010. South Africa has most of the world's EDR with 63 000 tonnes (95%), followed by Russia with 1100 tonnes (1.7%), and the USA with 900 tonnes (1.4%).

The world's supply of PGEs in 2010 was dominated by South Africa (75% Pt, 37% Pd) and Russia (13% Pt, 44% Pd), with minor contributions from Canada, Zimbabwe, the USA and Colombia. Johnson Matthey (2011) stated that the global supply of PGEs was 7.29 million ounces of palladium and 6.06 million ounces of platinum in 2010.

## Industry Developments

About two thirds of Australia's Identified Resources of PGEs are in the following deposits in which PGEs are the major commodity:

**Munni Munni**, WA—published Measured, Indicated and Inferred Resources of 23.6 million tonnes (Mt) at 1.5 grams per tonne (g/t) Pd, 1.1g/t Pt, 0.1g/t Rh, 0.2g/t gold (Au), 0.09% nickel (Ni), and 0.15% copper (Cu). In June 2010, Platina Resources Limited reported that it was reviewing its Munni Munni deposit to identify a coherent zone of higher grade mineralisation within the current Munni Munni resource estimate and to include copper and nickel, which previously had not been assessed with the PGE content in the mineralised zones. Investigations were carried out into the potential open cut component of the Munni Munni deposit.

**Panton**, WA—14.3Mt at 2.19g/t Pt, 2.39g/t Pd, 0.31g/t Au, 0.27% Ni, and 0.07% Cu. Platinum Australia Limited<sup>22</sup> reported that in view of the high prices for platinum and palladium, it had engaged consultants to review the design, capital and operating cost of the open pit and underground mine plan.

**Fifield**, NSW—Platinum Australia Limited<sup>23</sup> announced Indicated and Inferred Resources totalling 13.1Mt at 0.7g/t Pt for its Owendale North, Cincinnati and Milverton deposits at Fifield. The company also published a scandium (Sc) resource of 4.8Mt at 344g/t Sc. Historical production from Fifield amounted to about 640kg of PGEs.

**Weld Range–Parks Reef** PGE (with minor Au) deposit, WA—a published Inferred Resource amounted to 14.76Mt at 1.1g/t Pt+Pd+Au which occurs in a truncated lateritic profile overlying low-grade primary PGE mineralisation in ultramafic rocks<sup>24</sup>. The Weld Range PGE deposit is adjacent to the very large Weld Range lateritic nickel-cobalt deposit which has an Inferred Resource of 330Mt at 0.75% Ni and 0.06% Co. Dragon Mining Limited announced in September 2009 that its wholly owned subsidiary had entered into an agreement to acquire the Weld Range tenements covering the lateritic nickel-cobalt deposit and the separate PGE dominant deposit. The Weld Range lateritic nickel-cobalt deposit has recently attracted attention as a chromium resource with a published Inferred Resource of 63.5Mt at 5.2% chromium (Cr), 38% iron and 0.38% Ni at a cut-off grade of 4% Cr. A scoping study was released by Weld Range Metals Ltd in August 2010 which concluded that Stage 1 of the project is technically and economically feasible using processing equipment and technology currently used by the steel industry. The company also stated it was planning to proceed with a definitive feasibility study.

<sup>22</sup> Platinum Australia Limited, 2011. Platinum Australia operations update. 21 June 2011, 10 pp.

<sup>23</sup> Platinum Australia Limited, 2011. Platinum and scandium resource estimate for Owendale project, NSW, Australia. Announcement to the Australian Securities Exchange, 7 November 2011. 10 pp.

<sup>24</sup> Parks, J, 1998. Weld Range platinum group element deposit. In: *Geology of Australian and Papua New Guinean Mineral Deposits* (eds: Berkman, D.A. & Mackenzie, D.H.), The Australasian Institute of Mining and Metallurgy: Melbourne, 279–286.

PGE resources are present also in deposits where other commodities are dominant, mainly komatiitic nickel-cobalt sulphide deposits as well as lateritic nickel deposits. They include:

**Radio Hill** nickel mine, WA—Fox Resources Ltd reported that remaining Indicated and Inferred Resources of palladium amounted to 1.275Mt at 0.493g/t. Details are not available on production of palladium in 2009. In mid 2010 the company announced updated Indicated and Inferred Resources of 4.22Mt at 0.65% Ni and 0.76% Cu for its Radio Hill mine. An Indicated and Inferred Resource of 5.78Mt at 0.54% Ni and 0.67% Cu was reported also for the nearby Sholl B2 deposit, but no details were given for palladium content. The mine is on care and maintenance while the company is investigating options for heap leaching nickel and copper. On 15 November 2011 the company announced it has signed a non-binding Memorandum of Understanding (MOU) with Jiangxi Jiangli Sci-Tech Co. Ltd regarding the development of the Radio Hill and Sholl nickel-copper bacterial heap leaching project in the Pilbara region of WA. Under the proposed agreement contemplated by the MOU, Jiangli, a Chinese cooperative, is to provide \$30 million to Fox for the initial phase of the project and other associated project activities required at Radio Hill Mine. As part of the agreement, Fox will provide Jiangli with 100% of the nickel and copper sulphide concentrates produced from its Radio Hill and Sholl projects over their initial nine year mine life.

**Waterloo** nickel mine, WA—the resources for this deposit were reported last in 2004 as 653 000 tonnes at 2.795% Ni, 0.194% Cu and 0.858g/t PGE. Recorded production amounts to 185 000 tonnes at 2.76% Ni in 2007 and 57 818 tonnes Ni in 2006 but there are no details on production of PGEs. The mine's owner, OJSC MMC Norilsk Nickel, placed the mine on care and maintenance in November 2008 because of prevailing low nickel prices and reduced world demand.

**Nyngan** lateritic nickel-cobalt-scandium-platinum deposit, NSW—Jervois Mining Limited reported in June 2005, a resource of 16Mt at 0.87% Ni, 0.06% Co of which there is 3Mt at 290 parts per million (ppm) scandium (Sc) and 0.22g/t Pt. The scandium-rich portion of this deposit was updated in June 2009 as Measured Resources of 2.718Mt at 274ppm Sc and Indicated Resources of 9.294Mt at 258ppm Sc.

**The Horn** nickel sulphide deposit, WA—in April 2008, Breakaway Resources Limited reported a small Inferred Resource for The Horn nickel deposit of 600 000 tonnes at 1.39% Ni, 0.3% Cu and 0.5g/t Pd+Pt. In early 2009, the company reported that massive and matrix nickel sulphide mineralisation at The Horn deposit had been drilled over a 500 metre (m) strike length and remained open along strike. Geological mapping undertaken during the March quarter of 2009 confirmed the presence of nickeliferous gossans within a structurally bound, high magnesium oxide (MgO) ultramafic unit immediately south of the known mineralisation. The **Revolution** prospect<sup>25</sup>, located immediately north of Breakaway's The Horn Nickel deposit includes PGE bearing disseminated nickel mineralisation (12m at 0.96% Ni, 311ppm Cu and 424 parts per billion (ppb) Pt + Pd from 192m and 4m at 1.14%Ni, 1003ppm Cu and 749ppb Pt + Pd from 209m in drill hole LWDD0809).

**Yarrawindah Brook**, WA—an Inferred Resource of 2.9Mt at 0.79g/t PGE was announced by Washington Resources Ltd in March 2006.

Other PGE deposits with recorded resources which have had historic interest but did not record exploration or assessment activity during 2010 include:

**Nebo-Babel** nickel-copper-PGE deposit, WA—a news article in The West Australian newspaper, dated 10 February 2007 reported that the Nebo-Babel nickel-copper-PGE deposit, discovered by Western Mining Corporation in mid-2000 has a preliminary resource of 393Mt grading 0.3% Ni, 0.3% Cu and 0.18g/t PGE. The deposit was later acquired by BHP Billiton Limited as a result of its takeover of Western Mining Corporation in mid-2005.

**Syerston** lateritic nickel-cobalt-platinum deposit, NSW—in April 2000, Black Range NL announced a total platinum resource of Measured, Indicated and Inferred Resources of 108.3Mt at 0.21g/t Pt which occurs partly within the Syerston nickel-cobalt deposit.

**Coronation Hill**, Kakadu National Park, NT, —the Coronation Hill deposit has an Inferred Resource of 6.69Mt at 6.42g/t Au, 1.01g/t Pd and 0.3g/t Pt which was reported in 1990. The deposit occurs within the Kakadu National Park and is inaccessible for mining.

<sup>25</sup> Breakaway Resources Limited, 2011. Activity report for the quarter ended 31 December 2010. ASX Release 28 January 2011, 12 pp.

**Adamsfield**<sup>26</sup>, 70 kilometres west of Hobart, Tasmania,—it is located within the Franklin-Gordon Wild Rivers National Park. A small near surface Inferred Resource amounts to 14 500 tonnes of ore at 6.5g/t iridium (Ir), 7.3g/t osmium (Os) and 0.13g/t Pt (using a cut off grade of 1g/t Os+Ir).

**Thomson River**, Victoria—in 1981 CRA Exploration Pty Ltd estimated resources as 40 000 tonnes averaging 3.2g/t Pt, 3.6g/t Pd, 2.7% Cu, 9.5g/t Ag and 2.5g/t Au. Intermittent mining since the discovery of the deposit about 1864 produced around 13 200 tonnes of ore, from which only about 10kg of platinum was extracted.

## Potash

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The term potash refers to potassic fertilisers, which are potassium chloride (KCl or sylvite), potassium sulphate [ $K_2SO_4$  or sulphate of potash (SOP), which usually is a manufactured product], and potassium-magnesium sulphate [ $K_2SO_4 \cdot 2MgSO_4$  or either langbeinite or double sulphate of potash magnesia (SOPM or K-Mag)]. Muriate of potash (MOP) is an agriculturally acceptable mix of KCl (95% pure or greater) and sodium chloride (halite) for fertilizer use, which includes minor amounts of other nontoxic minerals from the mined ore and is neither the crude ore sylvinite nor pure sylvite.

### Resources

Historically Australia has always been deficient in known resources of potash. For this reason Geoscience Australia has not compiled national scale resource information on potash because there has not been sufficient to record. Also, exploration has not located commercially significant resources of potash.

However, sharp increases in the price of potash prior to the global financial crisis in late 2008 and the first half of 2009 encouraged exploration for potash and resources have been published recently for Lake Disappointment, Lake Chandler and in the Western Australia (WA) portion of Lake Mackay.

### JORC Reserves

Currently there are no Joint Ore Reserve Committee (JORC) Code reserves for potash resources.

### Exploration

Interest in exploration for potash continued in 2010 in Lake Disappointment, Lake Mackay, south Carnarvon Basin, Perth Basin and Canning Basin in WA as well as the Adavale Basin in Queensland (Qld) and in the Barrow Creek area in the Northern Territory (NT).

### Production

According to the United States Geological Survey (USGS), about 93% of the world potash production in 2009 was consumed by the fertilizer industry. Potassium chloride is the main fertilizer product, containing an average 61% of  $K_2O$  equivalent. In 2010, the main producers of potash were Canada with 9.5 million tonnes (Mt) followed by Russia (6.8Mt) and Belarus (5.0Mt). The three accounted for about 65% of the world production of 33Mt, which was up from 20.8Mt in 2009.

In Australia, some minor historic production of potash include an operation at Buladelah Mountain, New South Wales, where alunite  $KAl_3(SO_4)_2(OH)_6$ , was mined between 1890 and 1926 and again from 1935 to 1952, for a total production of 75 000 tonnes. Crude potash in form of soluble salt glaserite  $(K,Na)_2SO_4$ , was produced from Lake Chandler (WA) during 1943 to 1950 for a total of 9218 tonnes of glaserite.

In 1973, Geoscience Australia's predecessor, the Bureau of Mineral Resources, reported that Texada Mines Pty Ltd was working towards becoming Australia's first local potash producer in the form of langbeinite  $K_2Mg_2(SO_4)_3$  at Lake Macleod in northwest WA. The planned capacity of the proposed plant was variously reported to be from 80 000 to 200 000 tonnes per annum (tpa). There is no record of production of potash from the proposed operation.

<sup>26</sup> Shree Minerals Limited, 2009. Shree Minerals Limited Prospectus. 160 pp.

Australia imports all its potash requirements and according to the Australian Bureau of Agriculture and Resource Economics and Sciences (ABARES) Australian Commodity Statistics 2010, the imports of potassium fertiliser amounted to 210.6 kilotonne (kt) in 2007–08 and 339.8kt in 2008–09.

## World Ranking

According to the USGS the countries with the largest economic resources of potash ( $K_2O$ ) were Canada 4.4 gigatonnes (Gt), which represents about 46% of the total world resource, followed by Russia with 3.3Gt (35%) and Belarus with 0.75Gt (8%).

## Industry Developments

**Lake Disappointment:** Located in the Gibson Desert of WA about 320 kilometres (km) east of Newman, Lake Disappointment is a modern playa lake covering approximating 1600 square kilometres. Potash mineralisation occurs in lacustrine sediments of the lake and in the entrained brine.

On 13 March 2007, Reward Minerals Ltd published a lower estimate of 7705Mt Indicated Resource at 3.17 kilograms per tonne (kg/t)  $K_2SO_4$  containing 24Mt  $K_2SO_4$  and an upper estimate of 8635Mt at 3.17kg/t  $K_2SO_4$  containing 27.37Mt  $K_2SO_4$ . The difference between the upper and lower figure is the result of assumptions about the depth and area for the lake margins.

On 23 December 2011, Reward Minerals Ltd advised that it had reached agreement with the Western Desert Lands Aboriginal Corporation (WDLAC) and the Martu people on the terms of a Mining and Indigenous Land Use Agreement (ILUA) for the company's Lake Disappointment potash project. The company is planning to advance the project as rapidly as possible by recommencing activities on the project, including undertaking a resource upgrade as well as feasibility activities and a Clearance Heritage Survey scheduled to occur in March 2012.

**Lake Chandler:** On 29 January 2009, ActivEX Limited announced a JORC Code compliant Inferred Resource of 5.779025Mt of ore at 5.73%  $K_2O$  at its Lake Chandler potash deposit situated 45km north of Merredin and 300km east of Perth in WA. The company reported in its 2010 annual report that it carried out a scoping study on a nominal throughput of 200 000tpa to give the project a mine life of 25 years. The company concluded that the study showed that, with the softness of the potash market, the project would be only marginal under current economic conditions.

**Lake Mackay:** Situated in the Gibson Desert and straddling the WA-NT border 50km north of the Tropic of Capricorn, Lake MacKay is a modern, playa lake with a surface area of more than 2250 square kilometres. Reward Minerals reported in its 2009 annual report that it has delineated a JORC Code compliant, Inferred Resource at Lake MacKay of 4780.4 million bench cubic metres (BCM) at 4.3kg of  $K_2SO_4$  (SOP) per BCM for a total of 20.56Mt of  $K_2SO_4$ .

The resource estimate was calculated on the basis of lakebed sediment volume of BCM to a depth of two metres and the water soluble potassium sulphate content of the sediments that lie within the company's tenement holdings.

The company reported that the next stage of development at Lake Mackay would involve the construction of pilot ponds and pump testing as well as flow sheet development for the compilation of a feasibility study. The company reported that the programs would depend on agreement with the traditional land owners<sup>27</sup>.

**Dandaragan Greensands Project:** Potash West NL is exploring the potential for producing potash from greensand deposits in the Perth Basin which are located between 50 and 230km north of Perth<sup>28</sup>. The company is investigating the possibility of using conventional magnetic separation techniques to separate glauconite from greensands and is conducting laboratory scale testing to produce marketable potash products from glauconite concentrate<sup>29</sup>.

<sup>27</sup> Reward Minerals Ltd, 2011. Reward Minerals Ltd annual report 2010. 64 pp.

<sup>28</sup> Potash West NL, 2010. Prospectus, 96 pp.

<sup>29</sup> Potash West NL, 2012. Potash West succeeds in producing potash from WA glauconite deposits. Announcement to the Australian Securities Exchange, 23 January 2012, 3 pp.

**Karinga Creek Project:** Rum Jungle Resources Ltd in a joint venture with Reward Minerals Ltd was analysing potassium, magnesium and sulphate levels in aquifers surrounding Karinga Creek Salt Lakes, about 225 kilometres southwest of Alice Springs in the NT<sup>30</sup>.

## Rare Earths

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The rare earth elements (REEs) are a group of 17 metals which make up the lanthanide series of elements: lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), lutetium (Lu), in addition to scandium (Sc) and yttrium (Y), which show similar physical and chemical properties to the lanthanides. The REEs have unique catalytic, metallurgical, nuclear, electrical, magnetic and luminescent properties. Their strategic importance is indicated by their use in a number of emerging and diverse technologies that are becoming increasingly more significant (Table 5). Applications range from routine (e.g., lighter flints, glass polishing mediums, car alternators), to high-technology (lasers, magnets, batteries, fibre-optic telecommunication cables), to those that have futuristic purposes (high-temperature super-conductivity, safe storage and transport of hydrogen for a post-hydrocarbon economy, environmental global warming and energy efficiency issues). Over the past two decades, the global demand for REEs has increased significantly in line with their dramatic expansion into high-technological, environmental, and economic environments<sup>31</sup>.

During the past couple of years scandium bearing lateritic nickel-cobalt (Ni-Co) deposits have attracted increasing attention in response to anticipated rise in demand for scandium. Zirconia stabilised with scandium rather than yttrium as an electrolyte for Solid Oxide Fuel Cells (SOFCs) reduces the operating temperature of the fuel cell significantly, thereby providing a much longer life. SOFCs are expected to play a major role in the developing battery powered transportation industry as well as in stationary applications, such as in household electricity generation or as a substitute for coal fired power plants<sup>32</sup>.

The group of REEs is variously, and inconsistently, reported by companies as light REEs consisting of lanthanum, cerium, praseodymium, neodymium and, sometimes, scandium. Heavy REEs may start with samarium, followed by europium through to lutetium. However, the heavy REEs are sometime subdivided further into middle REEs comprising samarium, europium, gadolinium, terbium and dysprosium with the remainder of the group, holmium to lutetium, referred to as the heavy REEs. Because of inconsistent reporting, the component elements of light, medium and heavy REEs are best noted in each case. The resources of REEs are usually reported as rare earth oxides (REO). Kingsnorth<sup>33</sup> grouped lanthanum to neodymium as light REEs or Ceric, samarium to gadolinium as medium REEs and terbium to lutetium plus yttrium as heavy REEs or Yttric.

The rare earths are a relatively abundant group of elements which range in crustal abundance from cerium, which is the 25<sup>th</sup> most abundant element at 60 parts per million (ppm), to lutetium, the 61<sup>st</sup> most abundant at 0.5ppm.

<sup>30</sup> Rum Jungle Resources Ltd, 2011. Karinga Creek potash update. Announcement to the Australian Securities Exchange 20 December, 2010. 6 pp.

<sup>31</sup> Hoatson, D.M., Jaireth, S. and Miezitis, Y., 2011. The major rare earth-element deposits of Australia: geological setting, exploration, and resources. Geoscience Australia, 204 pp.

<sup>32</sup> EMC Metals Corporation of Canada in a press release on 8 February 2010 on the Toronto Stock Exchange.

<sup>33</sup> Kingsnorth, K., 2010. The challenges of meeting 'Energy' rare earths demand. IEA Standing Committee on Long-Term Co-operation Paris, 17<sup>th</sup> May 2010

**Table 5.** Applications for rare earth elements in the emerging technology areas.

Application	Rare Earth Element
<b>Light Weight Magnets</b>	
<b>Cars</b> Light weight magnets in motors for windows, windscreen wipers, starter motors, alternators, etc	
<b>Electronics</b> Magnets in disc drives for computers, data storage, portable music players (eg iPods), video recorders, consoles, video cameras, speakers	Nd, Pr, Sm, Dy, Tb
<b>Wind turbines</b>	
<b>Catalyst</b>	
Automotive catalyst	
Clean diesel	La, Ce, Nd, Pr, Sc
Oil refining	
<b>Hybrid vehicles</b>	
Electric motors and generators	Nd, Pr, Dy, Tb
Hybrid batteries	La, Nd, Ce
<b>Compact fluorescent lights, energy saving lamps</b>	Eu, Tb, Y, Sc
<b>Polishing powders</b>	
<b>TV and computer screens</b> LCD, Plasma, cathode ray tube (CRT)	
<b>Optical lenses</b>	Ce, La, Pr, Sc
<b>Precision optical and electronic components</b>	
<b>Glass additives</b>	
<b>CRT screens</b> to stabilise glass from cathode ray	
<b>Small optical lenses</b>	Ce, Er, Gd, Tb, La, Nd, Yb, Pm, Sc
<b>Phosphors</b> TV and computer screens	
<b>Ceramics</b>	Dy, Er, Pr, Gd, Ho, Ce, La

## Resources

Geoscience Australia's latest estimate of Australia's rare earths reported as rare earth oxides (REO) amounted to 1.83 million tonnes (Mt) of Economic Demonstrated Resources (EDR), 0.35Mt Paramarginal and 34.48Mt in the Submarginal Resource categories.

About 18% of Australia's EDR comprise Reserves as defined under the Joint Ore Reserve Committee (JORC) Code.

About 82% comprises published JORC Code compliant Measured and Indicated Resources in operating mines, deposits being developed for mining and in deposits which have published scoping/feasibility studies with positive results.

There is a further 24.19Mt REO in the Inferred Resources category. About 53Mt REO (predominantly lanthanum and cerium) of the Submarginal and Inferred Resources are in the Olympic Dam iron oxide-copper-gold deposit in South Australia (SA). The REO at Olympic Dam are not recovered in current mining operations and are in the tailings storage facility at the mine site. About 5910 tonnes of mostly in the subeconomic and inferred categories were reported in 2010. In addition, about 56 140 tonnes of Paramarginal and Inferred Resources were reported as REEs.

Significant resources of rare earths are contained in the monazite component of heavy mineral sand deposits, which are mined for their ilmenite, rutile, leucoxene and zircon content (Table 6). Monazite is a rare earth thorium phosphate mineral found within heavy mineral sand deposits in Australia. Using available information, Geoscience Australia estimates Australia's monazite resources to be in the order of 6.1Mt. Assuming the REO content of monazite to be about 60%, the heavy mineral deposits could hold a resource of around 3.67Mt contained REO. Currently, extraction of rare earths from monazite is not viable because of the cost involved in the disposal of thorium (Th) and uranium (U) present in the monazite.

**Table 6.** Distribution of types of rare earth elements in monazite from different parts of the world (modified after Mukherjee 2007<sup>34</sup>).

REO	GUANGDONG CHINA Weight %	TAIWAN Weight %	AUSTRALIA Weight %	FLORIDA, USA Weight %	INDIA Weight %
La <sub>2</sub> O <sub>3</sub>	23	21	23.2	17.4	22
CeO <sub>2</sub>	42.7	47.9	46.3	43.7	46
Pr <sub>6</sub> O <sub>11</sub>	4.1	5.4	4.9	4.9	5.5
Nd <sub>2</sub> O <sub>3</sub>	17	18.7	18.3	17.1	20
Sm <sub>2</sub> O <sub>3</sub>	3	3.3	2.5	4.9	2.5
Eu <sub>2</sub> O <sub>3</sub>	<0.1	0.54	0.04	0.16	0.016
Gd <sub>2</sub> O <sub>3</sub>	2	1.6	1.7	6.5	1.2
Tb <sub>4</sub> O <sub>7</sub>	0.7	0.19	0.22	0.26	0.06
Dy <sub>2</sub> O <sub>3</sub>	0.8	0.35	0.56	0.59	0.18
Ho <sub>2</sub> O <sub>3</sub>	0.12	0.03	0.08	0.11	0.02
Er <sub>2</sub> O <sub>3</sub>	<0.3	0.03	0.06	0.04	0.01
Tm <sub>2</sub> O <sub>3</sub>	TR	-	-	0.03	Tr
Yb <sub>2</sub> O <sub>3</sub>	0.24	0.07	0.04	0.21	Tr
Lu <sub>2</sub> O <sub>3</sub>	<0.14	-	-	0.03	Tr
Total REO	55	48-62	58.5	-	58
<b>Other Elements</b>					
Y <sub>2</sub> O <sub>3</sub>	2.4	0.19	1.57	3.18	0.45
ThO <sub>2</sub>	4	0.41	6.4	-	9.5

## Production

Historically, Australia has exported large quantities of monazite from heavy mineral sands mined in Western Australia (WA), New South Wales (NSW) and Queensland (Qld), for the extraction of both rare earths and thorium. Between 1952 and 1995, Australia exported 265 kilotonne (kt) of monazite with a real export value (2008 dollars) of \$284 million (Australian Bureau of Statistics 2009)<sup>35</sup>.

Small-scale production of rare earths has taken place in Australia but records on these activities are incomplete. The following information on historical attempts to establish a rare earth production industry in Australia is drawn from Cooper 1990<sup>36</sup>. In the 1950s, Zircon Rutile Ltd at Byron Bay, NSW, processed a small quantity of monazite to produce cerium oxide for use in glass polishing. In 1969, Rare Earth Corporation of Australia Ltd, operating at Port Pirie SA, began producing cerium, lanthanum, yttrium and thorium compounds from locally produced

<sup>34</sup> Mukherjee, T.K., 2007. Thorium resources in India, its mining, separation and chemical processing. IAEA Technical meeting on 'Thorium based fuels and fuel cycle options for pressurized heavy water cooled reactors, light water reactors and high temperature gas-cooled reactors. 22 to 25 October, 2007. Istanbul, Turkey.

<sup>35</sup> ABS, 2009. International trade, Cat. No.5465.0, Canberra.

<sup>36</sup> Cooper W., 1990. Queensland mineral commodity report. Queensland Government Mining Journal, September 1990. Department of Resource Industries, 383-389.

monazite. However, the plant ceased operations in mid 1972 because of a lack of working capital and difficulty breaking into world markets for processed rare earths.

In January 1987, it was announced that the French chemical company Rhone-Poulenc proposed to build a two-stage monazite processing plant at Pinjarra in WA to produce rare earths from monazite, but the project was suspended. Deckhand Pty Ltd, a wholly owned subsidiary of Currumbin Minerals, was blocked in 1988 on environmental grounds from establishing a rare earths processing plant at Lismore, NSW. SX Holdings Ltd of SA was planning to establish a plant at Port Pirie to process monazite with a 2000 tonnes per annum (tpa) cracking and separation plant but the project did not proceed.

Barrie (1965)<sup>37</sup> reported that a pegmatite deposit six kilometres (km) east of the Cooglegong crossing, WA was worked in 1913 and 1930 and yielded about 2 tonnes of gadolinite (yttrium iron beryllium silicate (Ce,La,Nd,Y)<sub>2</sub>FeBe<sub>2</sub>Si<sub>2</sub>O<sub>10</sub>). An analysis of Cooglegong gadolinite yielded 45.78% of yttrium trioxide (Y<sub>2</sub>O<sub>3</sub>) and 4.81% of other REO. It should be noted that gadolinite does not contain more than trace amounts of gadolinium.

In 2007, mining operations commenced at the Mount Weld deposit in WA and around 98 000 cubic metres of ore has been stockpiled pending the completion of a concentration plant at the mine site. There has been no recorded production of REO in Australia during the period 2007 to 2009.

Globally, the production and resources of rare earths are dominated by China, which accounts for about 94% of production and is expected to fall to 70% by 2015 (Roskill, 2011<sup>38</sup>) followed by India with about 2%. These figures are only approximate because the production for the Commonwealth of Independent States, which is made up of former members of the Soviet Union, is not available.

The main consumers of rare earths are China, the USA, Japan, Korea and Thailand with China reportedly accounting for about 70% of the world's consumption in 2011 (Roskill op. cit.).

According to Roskill (op. cit.), all the growth in demand between 2005 and 2010 came from China (11% a year) while growth in the rest of the world fell by almost 4% a year, largely as a consequence of the global economic downturn in 2009 and tightening of the Chinese export quota in 2010, which restricted availability. In the years to 2015, the main demand driver will be the use of rare earths in neodymium-iron-boron (NdFeB) magnets. Demand for these magnets is forecast to grow at 11–13% per year as potential markets expand to include applications in permanent magnet motors for electric vehicles and wind turbines. Magnets could account for almost one third of demand by 2015. Strong growth in demand is forecast also for rare earths in nickel-metal hydride (NiMH) batteries, phosphors, optical glass and ceramics.

The Chinese Government has imposed production and export restrictions, adding upward pressure on prices for rare earths and contributing to incentives for the development of rare earth resources outside China. Lynas Corporation Ltd reported in its June 2010 quarterly report that export restrictions by the Chinese Ministry of Commerce resulted in a 40% decrease in available export quota for rare earths in 2010 compared with 2009. This decrease coincided with the launch of a nationwide crackdown on illegal mining of rare earths in China. Lynas also reported in May 2011<sup>39</sup>, that demand for rare earths of 127 000 tonnes in 2010 is set to increase to about 177 200 tonnes in 2014.

## World Ranking

China holds 55Mt (48.3%) of the world's economic reserves for REO, followed by the Commonwealth of Independent States with 19Mt (16.7%) REO and the USA with 13Mt (11.4%). Australia's EDR accounts for 1.61% of world's economic reserves with 1.83Mt REO.

The main types of REE deposits worldwide include the Bayan Obo deposit in China, which is predominantly REE-iron ores with bastnasite and monazite as the main REEs bearing minerals. The only production of REOs from a carbonatite has been the Mountain Pass deposit in California, which has total resources of 1.8Mt REO at an

<sup>37</sup> Barrie, J., 1965. Rare Earths, *In*: McLeod, I.R. (editor), Australian Mineral Industry: The Mineral Deposits. Bureau of Mineral Resources, Australia, Bulletin 72, 515–521.

<sup>38</sup> <http://www.roskill.com/reports/minor-and-light-metals/rare-earth> (accessed November 2011)

<sup>39</sup> Lynas Corporation Limited, 2011. Investor presentation May 2011. 38 pp.

average grade of about 9% REO. Deposits associated with carbonatite laterites include Araxa in Brazil with 8.1Mt REO at 1.8% and Mount Weld in WA with 1.42Mt REO at 8.1%. Other deposit categories with significant REO resources include a vein type at Nolans Bore in the Northern Territory (NT) and an alkaline trachyte deposit at Toongi in NSW, along with a peralkaline syenite deposit at Lovozero in Russia. Table 7 shows the distribution of types of rare earth elements at selected deposits.

**Table 7.** Distribution of types of rare earth elements in selected deposits (Arafura Resources Ltd).

Rare Earth Oxide	Application	Nolans Bore %	Mount Weld %	Mountain Pass USA %	Baiyunebo China %
Lanthanum	Petroleum cracking catalysts, batteries (NiMH)	19.74	25.6	33.2	27.1
Cerium	Autocatalyst, glass, polishing	47.53	45.74	49.1	49.86
Praseodymium	Magnets, glass	5.82	5.42	4.34	5.15
Neodymium	Magnets (NdFeB)	21.2	18.62	12.0	15.4
Samarium	Magnets, (SmCo)	2.37	2.44	0.8	1.15
Europium	Phosphors, nuclear control applications	0.4	0.55	0.12	0.19
Gadolinium	Intravenous contrast agents, phosphors	1.0	0.97	0.17	0.4
Terbium	Phosphors	0.08	0.09		
Dysprosium	Magnets (NdFeB), lasers	0.33	0.16		0.3
Other Rare Earths (Ho, Er, Tm, Yb, Lu)		0.21	0.04	0.16	0.03
<b>Other Elements</b>					
Yttrium	Phosphors, metal alloys	1.32	0.37	0.1	0.2

## Industry Developments

**Lynas Corporation Ltd:** The Mount Weld deposit in WA is within the lateritic profile over an alkaline carbonatite complex. In September 2010, Lynas announced new resource figures for the Central Lanthanide deposit of Measured, Indicated and Inferred Resources of 9.88Mt with total lanthanide oxides (TLnO) at 10.6% and 990ppm  $Y_2O_3$  (heavy REO) and the newly named Duncan heavy REO deposit with Measured, Indicated and Inferred resources totalling 7.62Mt at 4.5% TLnO and 2570ppm  $Y_2O_3$ . In another part of the carbonatite complex, the Crown Polymetallic deposit, there are Indicated (1.5Mt) and Inferred (36.2Mt) Resources totalling 37.7Mt, which include total lanthanides at 1.16% and 0.09%  $Y_2O_3$ . The company completed the first stage of mining activities in 2008 and commenced construction of a concentration plant at Mount Weld and an advanced materials plant in Malaysia.

The concentration plant was commissioned in May 2011 and by the end of October, Lynas Corporation reported that the plant achieved a concentrate grade of 36.8% REO and a recovery of 64%. In Malaysia, construction of the company's advanced materials plant was 78% complete at the end of September 2011 and its September 2011 quarterly reported that the first feed to kiln was expected to occur in the first quarter of 2012. Subject to receipt of a pre-operational licence, the company anticipates the plant will reach commercial scale supply during the first half of 2012.

**Arafura Resources Ltd:** Nolans Bore rare earth-phosphate-uranium-thorium deposit is located 135km northwest of Alice Springs in the NT. It has Measured, Indicated and Inferred Resources totalling 30.3Mt to a depth of 130 metres which grades at 2.8% REO, 12.9%  $P_2O_5$ , 0.44 pounds per tonne  $U_3O_8$ , and 0.27% Th. According to Arafura, the distribution of the light REEs currently being considered for extraction, (La, Ce, Pr, and Nd)

amount to 95%, whereas the heavy REEs (Sm, Eu, Gd, Tb, Dy) amount to 4.23%. Arafura reported<sup>40</sup> that it is planning to release a revised resource statement by the end of 2011. The company is planning to process the rare earth-phosphate-uranium-thorium ore concentrate from the Nolans Bore deposit at Whyalla in SA. Environmental studies are being conducted at Nolans Bore and at the proposed rare earths processing plant at Whyalla. Arafura have engaged AMEC Minproc to carry out preliminary engineering studies for the Whyalla processing plant. A sulphation plant and REO separation plant are being constructed at the Australian Nuclear Science and Technology Organisation (ANSTO) for demonstration trials to produce customer scale samples.

A prefeasibility study of the project was completed by Bateman, Sinclair Knight Mertz (SKM) and GHD Australia in October 2007 and a bankable feasibility study is planned for completion in 2012.

**Alkane Resources Ltd:** The company's Dubbo Zirconia Project located 30km south of Dubbo in NSW has a reported 35.7Mt of Measured Resource and 37.5Mt of Inferred Resources grading 1.96% ZrO<sub>2</sub>, 0.04% HfO<sub>2</sub>, 0.46% Nb<sub>2</sub>O<sub>5</sub>, 0.03% Ta<sub>2</sub>O<sub>5</sub>, 0.14% Y<sub>2</sub>O<sub>3</sub>, 0.745% total REO, 0.014% U<sub>3</sub>O<sub>8</sub>, and 0.0478% Th. On 16 November 2011, Alkane Resources announced a Proved and Probable Reserve for the deposit of 35.93Mt grading 1.93% ZrO<sub>2</sub>, 0.04% HfO<sub>2</sub>, 0.46% Nb<sub>2</sub>O<sub>5</sub>, 0.03% Ta<sub>2</sub>O<sub>5</sub>, 0.14% Y<sub>2</sub>O<sub>3</sub>, and 0.74% total REO. On 19 September 2011, the company released results of a definitive feasibility study which indicated a nett present value for the project of \$181 million at a processing rate of 400 kilotonnes per annum (ktpa) and \$1.207 billion at a processing rate of 1000ktpa.

The Australian Nuclear and Science and Technology Organisation (ANSTO) has been operating a demonstration pilot plant (DPP) for Alkane Resources at laboratory facilities of ANSTO Minerals at Lucas Heights south of Sydney NSW since May 2008 and to date has recovered substantial quantities of zirconium products and niobium concentrate. The DPP has continued to operate for short periods to trial engineering and processing innovations, and has demonstrated recovery of an yttrium-rich heavy rare earth concentrate and a light rare earth concentrate.

**Navigator Resources Ltd:** The company's Cummins Range carbonatite deposit occurs in the southeast part of the Kimberley region in WA. In September 2009, it reported Inferred Resources of 4.17Mt at 1.72% total REO, 11.0% P<sub>2</sub>O<sub>5</sub>, 187ppm U<sub>3</sub>O<sub>8</sub> and 41ppm Th at a cut-off grade of 1% total REO. The total REO was subdivided into 95.6% light REO (La, Ce, Pr, Nd), 4.1% middle REO (Sm, Eu, Gd, Tb, Dy) and 0.3% heavy REO (Ho, Er, Tm, Yb, Lu). A mineralogical investigation of the Cummins Range deposit by the CSIRO Minerals Down Under Flagship was completed during the March 2010 quarter with the principal rare earth bearing minerals being primary apatite and monazite and only subordinate amounts of secondary rare earth bearing minerals are present. A rotary drilling program commenced on the deposit in September 2011.

**Capital Mining Limited:** The peralkaline granitic intrusions of the Narraburra Complex 177km northwest of Canberra contain anomalous amounts of zirconium, REO and low concentrations of Th (73.2Mt at 1250 grams per tonne (g/t) ZrO<sub>2</sub>, 146g/t Y<sub>2</sub>O<sub>3</sub>, 327g/t REO, 45g/t HfO<sub>2</sub>, 126g/t NbO<sub>2</sub>, 54g/t Ga<sub>2</sub>O<sub>3</sub>, 118g/t Li<sub>2</sub>O and 61g/t ThO<sub>2</sub>, Capital Mining Limited<sup>41</sup>). In the March 2010 quarterly report Capital Mining Limited reported that it was conducting metallurgical test to recover hafnium (Hf), Th, tantalum (Ta), Nb, Nd and Ce.

**Hastings Rare Metals Limited:** Historic exploration records reported that the Yangibana ferrocarnatite-magnetite-rare earth-bearing dykes (ironstones) form part of the Gifford Creek Complex in WA. The dykes occur as lenses and pods and are typically the last stage of carbonatite fractionation and are enriched in REE fluorite and uranium-thorium mineralisation. The Yangibana prospect has a recorded historic resource of 3.5Mt at 1.7% REO. The rare earths are in coarse grained monazite containing up to 20% Nd<sub>2</sub>O<sub>5</sub> and 1600ppm Eu<sub>2</sub>O<sub>3</sub>.

**Marathon Resources Limited:** In August 2005, the company reported that an Inferred Resource of 51 800 tonnes lanthanum- cerium is associated with the uranium deposit at Mount Gee, about 520km north northeast of Adelaide in SA.

**BHP Billiton Limited:** About 53Mt of the Submarginal and Inferred Resources are in the Olympic Dam iron oxide-copper-gold deposit in SA (predominantly 0.2% La and 0.3% Ce) and are not currently economic.

<sup>40</sup> Arafura Resources Ltd, 2011. Quarterly activities report and appendix 5B for the period ending 30 September 2011.

<sup>41</sup> Capital Mining Limited, 2011. ASX announcement, 9 November 2011.

The historic uranium mine of Mary Kathleen in northwest Qld is essentially a uranium-rare earths skarn deposit which has a remnant resource in tailings of about 5.5Mt at 6.4% REO +Y. Commonly occurring REE minerals in the original deposit were stillwellite and allanite while other REE-bearing minerals included apatite, titanite and garnet.

**Metallica Minerals Limited:** During 2010, Metallica Minerals Limited announced scandium resources within its Kokomo and Lucknow lateritic nickle-cobalt (Ni-Co) deposits in Qld. The Kokomo deposit is 50km north northeast of Greenvale and the Lucknow deposit is 2km south of Greenvale which is about 190km west-north-west of Townsville. On 19 January 2011<sup>42</sup>, the company reported Indicated and Inferred Resources for the Lucknow deposit totalling 6.24Mt grading at 169g/t Sc, 0.2% Ni and 0.04% Co delineated at a cut-off-grade of 70g/t Sc. The company's Measured, Indicated and Inferred Resource for the Kokomo deposit total 9Mt grading 109g/t Sc, 0.24% Ni and 0.03% Co associated with a lateritic Ni-Co deposit of 16.3Mt at 0.67% Ni, 0.12% Co and 36g/t Sc. The total Sc resource for the two deposits amounts to 15.1Mt at 133g/t Sc, 0.22% Ni, 0.04% Co. The contained scandium metal in the two deposits amounts to approximately 2000 tonnes Sc<sup>43</sup>.

The Lucknow deposit includes a high grade zone at a cut-off-grade of 120g/t Sc, the Red Fort, measuring 4.12Mt of Indicated and Inferred Resources at 206g/t Sc, 0.21% Ni and 0.05% Co.

Metallica Minerals Limited also announced in September 2011 that it had entered a 12–15 month period of detailed feasibility and environmental studies for its nickle-cobalt and nickle-cobalt-scandium .

**Jervois Mining Ltd:** In June 2005 the company reported that its Nyngan lateritic nickel-cobalt-scandium-platinum deposit in NSW had a resource of 16Mt at 0.87% Ni and 0.06% Co. A scandium-rich portion of this deposit was updated in June 2009 as Measured Resources of 2.718Mt at 274ppm Sc and Indicated Resources of 9.294Mt at 258ppm Sc. Jervois formed a joint venture agreement with EMC Metals Corporation of Canada which is conducting a three phased test-work to study the recovery of scandium from lateritic ores at Nyngan.

**Krucible Metals Ltd:** For its Korella phosphate-yttrium deposit south of Mount Isa in northwest Qld, the company has published Inferred phosphate and REE resources of 13.72Mt at 0.70k/t Y<sub>2</sub>O<sub>3</sub> and Nd and, although dysprosium are reported to be present, the resources have not been estimated (Krucible Metals Ltd, 2011<sup>44</sup>). The Korella deposit also has an Inferred Resource of 8.3 Mt at 27.36% P<sub>2</sub>O<sub>5</sub> at a cut-off grade of 20% P<sub>2</sub>O<sub>5</sub> (Krucible Metals Ltd, 2010). The anomalous zone of yttrium enrichment at Korella appears to remain open towards the Duchess deposit to the north. There is little published data in regard to REE resources in phosphorite in Australia. Total phosphate resources in the Georgina Basin are considered to be of the order of 4 billion tonnes (Lottermoser, 1991<sup>45</sup>), but total rare earth elements contained in the phosphorites are generally much less than 1000ppm.

## Shale Oil

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Oil shale is organic-rich shale, which yields substantial quantities of oil (normally referred to as shale oil) and combustible gas by heating (retorting) and distillation. The organic material in oil shale is called kerogen, which under appropriate conditions in the Earth's crust can be a precursor to conventional oil reservoirs. One tonne of commercial grade oil shale may yield from about 100 to 200 litres of oil.

<sup>42</sup> Metallica Minerals Limited, 2011. Major resource upgrade as Queensland tri-metal project celebrates milestone. ASX Release, 19 January 2011.

<sup>43</sup> Metallica Minerals Limited, 2011. Quarterly report to 30 Sept 2011.

<sup>44</sup> Krucible Metals Ltd, 2011. ASX announcement, 10<sup>th</sup> October 2011. Inferred Resource update for Korella yttrium deposit. Announcement to the Australian Securities Exchange, 13 pp.

<sup>45</sup> Lottermoser, B.G., 1991. Rare earth element resources and exploration in Australia. The Australasian Institute of Mining and Metallurgy, Proceedings 296, Number 2, November 1991, 49–56.

## Resources

The majority of oil shale resources of commercial interest are located in a series of narrow and deep extensional-basins near Gladstone and Mackay, and further north near Proserpine in central Queensland (Qld). These are thick Cenozoic lacustrine (lake-formed) deposits which are relatively easy to mine and process compared to carbonate-rich oil shales (marls) elsewhere in the world. The Permian Galilee and Bowen Basins in Qld contain oil shale associated with coal measures. Oil shales occur in the Cretaceous Toolebuc Formation of the Eromanga Basin in northwest Qld. Oil shale deposits of varying quality are located in the Sydney Basin, New South Wales (NSW), northern Tasmania (Tas) (Latrobe tasmanite deposit), Eyre Peninsular in South Australia (SA) and an oil shale – heavy mineral sand deposit in southern Western Australia (WA).

Resource estimates were reviewed to take into account the historic nature of the estimates and losses resulting from processing. Australia's shale oil resources estimates are for **recoverable** shale oil. Paramarginal and Submarginal Demonstrated Resources of shale oil are 213 gegalitres (GL) (about 1340 million barrels) and 2074GL (about 13 050 million barrels) respectively.

An Inferred Resource is estimated to be 1272GL (about 8000 million barrels). This figure excludes the total potential shale oil resources of the Toolebuc Formation (Qld) of around 245 000 GL which was an estimate made by Geoscience Australia's predecessor, the Bureau of Mineral Resources, and the CSIRO in 1983<sup>46</sup>. The research project undertook detailed geological, petrophysical and geochemical examination of the oil shales of the Toolebuc Formation. The project was aimed at investigating and developing methods to assist government and industry to assess the potential of the sedimentary sequence as a possible future source of oil shale and developing an understanding of geological controls and the distribution of oil shale within the Toolebuc Formation. A resource assessment of around 245 000GL was based on productive oil shale covering an area of 484 000 square kilometres and ranging from 6.5 to 7 metres (m) thick with a specific gravity of 1.9 and yielding an average 37 litres of oil per tonne oil shale.

## Exploration

In Queensland, the majority of exploration activity has been in care and maintenance since the Queensland Government announced a two year review into the oil shale industry and a 20-year moratorium on oil shale development in the Whitsunday region around Proserpine. Previously, exploration was predominantly focused near Gladstone and Mackay in central Qld and in northwest Qld. In Tasmania, Boss Energy Ltd is continuing to undertake exploration work southeast of Devonport at the Latrobe oil shale deposit and Eagle Nickel Ltd is assessing exploration tenements adjacent to the Latrobe project. Data associated with shale oil exploration are not available.

## Production

In September 2011, Queensland Energy Resources Ltd (QER) produced its first crude oil from its demonstration Paraho IITM vertical shaft kiln processing plant at the Stuart deposit near Gladstone, central Qld. The oil is being stored in secure tanks on-site, awaiting commissioning of the oil upgrading unit (refinery).

There was no oil being extracted from oil shale in Australia between 2004 and September 2011. From 2000 to 2004, the previous demonstration processing plant at the Stuart deposit (Qld) produced more than 1.5 million barrels of oil using a horizontal rotating kiln process (Alberta Taciuk Process). The facility has been dismantled and the site remediated.

The demonstration plant achieved stable production capacity of 6000 tonne of shale per day and oil yield totalling 4500 barrels per stream day while maintaining product quality and adhering to Environment Protection Authority emissions limits. The oil products from the demonstration plant were Ultra Low Sulphur Naphtha (ULSN) 55% to 60% and Light Fuel Oil (LFO) 40% to 45%. The ULSN, which can be used to make petrol, diesel and jet fuel, has a sulphur content of less than one part per million (ppm). To put this into perspective, from January 1, 2008, the Fuel Standard (Petrol) Determination regulated that the maximum content of sulphur is 50ppm in premium unleaded petrol.

<sup>46</sup> Ozimic, S. and Saxby, J.D., 1983. Oil Shale Methodology: An examination of the Toolebuc Formation and the laterally contiguous time equivalent units, Eromanga and Carpentaria Basins. Bureau of Mineral Resources and CSIRO research project.

## World Ranking

The 2010 Survey of Energy Resources by the World Energy Council (WEC) reported that total world **in-place** resources of shale oil are estimated to be 4.8 trillion barrels. The largest known deposit is in the western USA (3 trillion barrels in-place resource), with other important deposits in China, the Russian Federation, the Democratic Republic of the Congo, Brazil, Italy, Morocco, Jordan and Estonia, as well as Australia. Only Estonia, China and Brazil produce shale oil. The WEC survey reported that total oil production at the end of 2008 was about 1165ML, with Estonia producing 445ML, China 470ML and Brazil 250ML.

## Industry Developments

In August 2008, the Queensland Premier announced a review into whether oil shale deposits can be developed in an environmentally acceptable way. The review report is to be prepared no earlier than two years from the commencement of operation of the QER Stuart facilities in order to allow that research to come to fruition. QER produced its first crude oil in September 2011.

In November 2008, Queensland Government amendments to the *Mineral Resources Act 1989 (Qld)* placed a 20-year moratorium on oil shale mining in the Whitsunday region around Proserpine. The granting of new tenures and variation of existing entitlements relating to oil shale were suspended until the Queensland Government considers the report on an oil shale review.

In mid 2011, QER (**Stuart Project**, Qld) commissioned a small-scale technology demonstration Paraho IITM oil shale processing retort. The company anticipates that it will produce small amounts of finished products such as ultra low sulphur diesel and aviation fuel in late 2011. These fuels will be used in further testing and certification trials over the next one to three years.

In Queensland, several companies have either scaled back investment or revised projects. These companies include:

- Australian Thermal Solution Pty Ltd, a subsidiary of Blue Ensign Technologies Ltd (**Julia Creek Project (south)**, northwest Qld), which, in June 2009, was planning to build a demonstration plant to test the thermal solution technology (Rendall Process), a thermal conversion and hydrogenation, followed by supercritical solvent extraction.
- Greenvale Mining NL (**Alpha Project**, Qld), which continues to review the viability of Vertical Retort Torbanite (VRT) processing technology being developed by a South African based company. Samples from the Alpha project continued to be tested in South Africa.
- Xtract Energy Plc (**Julia Creek Project (north)**, northwest Qld) which continues to maintain its tenements, but has scaled back investment in the development of the Xtract technology, a hydrogen and supercritical solvent extraction process.

In Tasmania, Boss Energy Ltd has engaged the Chinese company, Fushun Mining Group, to carry out tests on tasmanite oil shale samples from the **Latrobe Project** using Fushun vertical retort technology to determine physical and chemical properties and key operating parameters.

## Tantalum

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The main use of tantalum (Ta) is in the manufacture of capacitors required for the electronics and telecommunications industries. Because they are small and have high reliability, these capacitors are used in miniaturised electronic circuits, mainly in mobile phones. Because of its anti-corrosive properties tantalum metal is used in the chemical industry in applications such as tantalum carbide in tools for metal cutting and machining as well as in metal alloys in the aerospace and electricity-generating industries. Overall, approximately 60% of annual world consumption of tantalum is used in the electronics industry, with more than half of this currently used in the manufacture of mobile phones.

Tantalum minerals have more than 70 different chemical compositions, of which tantalite, microlite, and wodginite are of greatest economic importance. It is common practice to name any mineral concentrate containing tantalum as tantalite.

Australia, through the mining operations at Greenbushes 250 kilometres south of Perth, Western Australia (WA) and at Wodgina 100 kilometres south of Port Hedland, WA, has historically been the world's largest producer of tantalum (as tantalite concentrates), providing approximately half of the world's mine output.

## Resources

In WA, granitic rare-metal pegmatites are the dominant host rock for primary tantalum mineralisation. The only exceptions are the carbonatite type deposit at Mount Weld in the eastern goldfields of WA and an unusual form of subalkaline granite–syenite mineralisation at the Brockman deposit, southeast of Halls Creek, WA.

Australia's Economic Demonstrated Resources (EDR) are estimated to be 53 kilotonnes (kt) of tantalum in 2010, a 4% increase on 2009 resource of 51kt. All of the EDR are in WA with more than 92% associated with Global Advanced Metals' (formerly Talison Tantalum) Greenbushes and Wodgina deposits. The remaining EDR occur at Mt Cattlin, Mt Deans and the Hastings Rare Metals (formerly known as Brockman) deposit.

The Hastings Rare Metals deposit, owned by Augustus Minerals Limited is located 18 kilometres southeast of Halls Creek, WA. It is hosted by a fine-grained volcanoclastic unit (informally known as the Niobium Tuff) within a sequence of thick volcano-sedimentary rocks. The Niobium Tuff can be traced over a strike length of 3.5 kilometres and varies in width up to 35 metres. The deposit has a Joint Ore Reserve Committee (JORC) Code compliant resource of 22.08 million tonnes (Mt) grading 0.79% ZrO<sub>2</sub>, 0.31% Nb<sub>2</sub>O<sub>5</sub>, 0.023% Ta<sub>2</sub>O<sub>5</sub> and 0.1% Y<sub>2</sub>O<sub>3</sub> comprising an Indicated Resource of 8.83Mt grading 0.022% Ta<sub>2</sub>O<sub>5</sub> from the surface to 100 metres depth and an Inferred Resource of 13.25Mt grading 0.024% Ta<sub>2</sub>O<sub>5</sub> from 100 to 250 metres depth.

Subeconomic Demonstrated Resources account for about 23% of total Demonstrated Resources. The Paramarginal and Submarginal Resources amount to 15kt and 0.2kt, respectively which is unchanged from 2009. New South Wales (NSW) is the largest holder of Paramarginal Resources with 57% followed by WA with 43%. All the Submarginal Resources occur in WA.

Inferred Resources totalled 30kt compared to 39kt in 2009, which results from upgrading the resources at Hastings Rare Metals deposit and the removal from the national inventory of historical estimates which pre-date the JORC Code and so do not comply with the requirements of the Code. WA and NSW account for 69% and 31% of Inferred Resources respectively.

## Accessible EDR

All of Australia's EDR of tantalum is accessible.

## JORC Reserves

The Joint Ore Reserve Committee (JORC) Code reserves comprise total tantalum in Proved and Probable Ore Reserves as defined in the JORC Code. In 2010, JORC Code reserves of 19kt accounted for approximately 36% of Accessible Economic Demonstrated Resources (AEDR).

## Exploration

Data on exploration expenditure for tantalum are not available.

## Production

According to the Western Australian Department of Mines and Petroleum, no tantalite concentrate was produced in 2010 which was a contrast to 2009 when 105 tonnes for approximately 22 tonnes of contained tantalum was produced.

## World Ranking

Based on estimates published by the United States Geological Survey (USGS) and Geoscience Australia, the world resources of tantalum in 2010 totalled 121kt, although this figure is not complete for 2010. The world's largest holder of tantalum resource is Brazil with an estimated 65kt, followed by Australia with 53kt.

Using Western Australian Department of Mines and Petroleum and USGS data, Geoscience Australia estimated world production of tantalum in 2010 to be 590 tonnes (606 tonnes in 2009). Production in 2010 was dominated by Brazil, with 180 tonnes, which amounted to about 30% of world output, although this figure is not complete for 2009. According to the USGS, other main producers were Mozambique with 110 tonnes, Rwanda with 100 tonnes and Canada with 25 tonnes.

## Industry Developments

Global Advanced Metals' (GAM) recommenced mining in January 2011 at its **Wodgina** mine which had been on care and maintenance since December 2008 in response to the impact of the Global Financial Crisis (GFC). Throughout 2009 and 2010, the company continued to process tantalum pentoxide from its pre-GFC ore stockpiles. Although the initial recommencement mining rate will be at 700 000 pounds a year, the Wodgina mine has a capacity to produce 1.4 million pounds a year of tantalum pentoxide ( $Ta_2O_5$ ) from tantalum-bearing pegmatite ores at the **Mount Cassiterite** and **South Tinstone** open cut mines. The ores are crushed, milled and fed into the advanced gravity separation plant. The Wodgina plant produces primary tantalum concentrate, grading between 8% and 10%  $Ta_2O_5$  which is transported by road to the Greenbushes plant for secondary processing to produce saleable tantalum products.

GAM's **Greenbushes** operations in WA, consist of open cut and underground mines, primary and secondary tantalum processing plants, a tin smelter and a lithium plant. The company's primary tantalum plant remains on care and maintenance. Its secondary processing plant treats stockpiles of primary tantalum concentrates from the Wodgina mine. Processing of newly mined Wodgina ore is expected to commence in mid 2011. The company's Greenbushes tin smelter is closed and its lithium operation produces various grades of spodumene products (see Lithium Chapter).

In early 2011, Traxys Tantalum LP, a member of the Traxys Group, agreed to acquire a 20% interest in Global Advanced Metals subject to approval by the Australian Foreign Investment Review Board.

During the December quarter 2010, Galaxy Resources Limited commenced production from the Dowling Pit at its **Mount Cattlin** lithium tantalum project (hard-rock spodumene) north-north-east of Ravensthorpe, WA. At full production, the project is expected to produce 137 000 tonnes a year of spodumene concentrate grading 6% lithium oxide ( $Li_2O$ ) and 56 000 pounds a year of contained  $Ta_2O_5$  in concentrate. In December 2010, Galaxy Resources entered an agreement with GAM to supply 200 000 pounds of its Mt Cattlin  $Ta_2O_5$  ore over 5 years to GAM, which will upgrade the material at its Greenbushes plant. The Mount Cattlin deposit has a reported JORC Code compliant resource of 18.188Mt with an average grade of 1.08%  $Li_2O$  and 156 parts per million of  $Ta_2O_5$  containing an estimated 197 000 tonnes of  $Li_2O$  and 6.26 million pounds of  $Ta_2O_5$  above a cut-off grade of 0.4%  $Li_2O$ .

The Alkane Resources Ltd's demonstration pilot plant at ANSTO Minerals Lucas Heights operation in Sydney, NSW, has recovered several tonnes of zirconia concentrate, niobium-tantalum concentrate and yttrium-rare-earth concentrate. The source material has come from Alkane Resources' Dubbo Zirconia Project based on the **Toongi** deposit 20 kilometres south of Dubbo, NSW. The company is in advanced process of developing a Memorandum of Understanding with a niobium consumer to form a joint venture to produce ferro-niobium from niobium concentrate for specialised alloy markets.

# Thorium

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Thorium oxide (ThO<sub>2</sub>) has one of the highest melting points of all oxides (3300°C) and has been used in light bulb elements, lantern mantles, arc-light lamps and welding electrodes, as well as in heat resistant ceramics.

Currently, there is no large scale demand for thorium resources. Thorium can be used as a nuclear fuel through breeding to <sup>233</sup>U and any large-scale commercial demand for thorium is expected to be dependant on the future development of thorium fuelled nuclear reactors. Several reactor concepts based on thorium fuel cycles are under consideration, but a considerable amount of development work is required before it can be commercialised.

India has been developing a long-term three stage nuclear fuel cycle to utilise its abundant thorium resources. The construction of a 500 megawatt electric (MWe) prototype fast breeder reactor at Kalpakkam, near Madras, was about 66% complete in early 2011. It will have a blanket with thorium and uranium to breed fissile <sup>233</sup>U and plutonium respectively. This project will take India's thorium program to stage 2.

In stage 3 Advanced Heavy Water Reactors (AHWRs) burn <sup>233</sup>U and plutonium with thorium to derive about 75% of the power from thorium. For each unit of energy produced, the amount of long-lived minor actinides generated is nearly half of that produced in current generation Light Water Reactors. Importantly, a high level of radioactivity in the fissile and fertile materials recovered from the used fuel of AHWR, and their isotopic composition, preclude the use of these materials for nuclear weapons. In mid 2010 a pre-licensing safety appraisal had been completed by the Atomic Energy Regulatory Board (AERB) and site selection was in progress. The AHWR can be configured to accept a range of fuel types including enriched U, U-Pu MOX, Th-Pu MOX, and <sup>233</sup>U-Th MOX in full core.

However, full commercialisation of the AHWR is not expected before 2030.

In September 2009, India announced an export version of the AHWR – the AHWR- Low Enriched Uranium (LEU) version. This design will use LEU plus thorium as a fuel, dispensing with the plutonium input. About 39% of the power will come from thorium (via in situ conversion to <sup>233</sup>U). This version can meet the requirement also of medium sized reactors in countries with small grids along with the requirements of next generation systems (World Nuclear Association 2011<sup>47</sup>; Kakodkar 2009)<sup>48</sup>.

The China Academy of Sciences, in January 2011, launched a research and development program on Liquid Fluoride TR, known at the academy as the thorium-breeding molten-salt reactor (Th-MSR or TMSR).

A 5 MWe MSR is apparently under construction at Shanghai, with a target of being operational by 2015.

Atomic Energy of Canada Ltd (AECL) has reported that some countries are assessing the use of thorium fuels in existing CANDU 6 (700MWe class) reactors. In July 2009, AECL signed a second phase agreement with four Chinese entities to develop and demonstrate the full-scale use of thorium fuel in the CANDU 6 reactors at Qinshan in China<sup>49</sup>.

A company in the USA, Lightbridge Corporation, is developing thorium-uranium fuel for the existing Russian Vodo-Vodyanoi Energeticheskyy reactors (VVER-1000) and for use in existing Pressurised Light Water Reactors (PWR).

The thorium fuel design program for the VVER-1000 reactors is aimed primarily at the Indian market, which has two VVER-1000s under construction, with four more planned and another four having received environmental approval.

On 24 July 2009 it was reported in World Nuclear News (<http://www.world-nuclear-news.org/newsarticle.aspx?id=25688> accessed on 26 July 2009) that the French public multinational industrial conglomerate, Areva, and Thorium Power (now Lightbridge Corporation) signed an initial collaborative agreement on 23 July to investigate the potential use of thorium in Areva's Evolutionary Power Reactor (EPR). This was followed by a five year consulting agreement signed on 3 August 2009 (Lightbridge Corporation presentation to Deutsche Bank Conference 11 May 2010 <http://ir.ltbridge.com/phoenix.zhtml?c=121550&p=irol-irhome>).

<sup>47</sup> World Nuclear Association 2011, Nuclear Power in India. Country briefings, September 2011, 31pp.

<sup>48</sup> Kakodkar A, 2009, Statement by Dr Anil Kakodkar, Chairman of the Atomic Energy Commission and leader of the Indian delegation, IAEA 53rd General Conference, Vienna, 16 September 2009.

<sup>49</sup> World Nuclear Association 2011, Nuclear Power in China. Country briefings, September 2011, 12pp

## Resources

Australia's total indicated and inferred in-situ resources of thorium amounts to about 527 000 tonnes. Because there is no publicly available data on mining and processing losses for extraction of thorium from these resources, the recoverable resource of thorium is not known. However, assuming an arbitrary figure of 10% for mining and processing losses in the extraction of thorium, the recoverable resources of Australia's thorium could amount to about 470 000 tonnes.

Because there is no established large scale demand and associated costing information, there is insufficient information to determine how much of Australia's thorium resources are economically viable for electricity generation in thorium nuclear reactors.

There are no comprehensive detailed records on Australia's thorium resources because of the lack of large-scale commercial demand and a paucity of the required data.

### Thorium resources in heavy mineral sand deposits

Most of the known thorium resources in Australia are in the rare earth-thorium phosphate mineral monazite within heavy mineral sand deposits, which are mined for their ilmenite, rutile, leucoxene and zircon content. Prior to 1996, monazite was being produced from heavy mineral sand operations and exported for extraction of rare earths. However, in current heavy mineral sand operations, the monazite is generally returned to the pit in dispersed form, as stipulated in mining conditions, to avoid the concentration of radioactivity when returning the mine site to an agreed land use. In doing so, the rare earths and thorium present in the monazite are negated as a resource because it would not be economic to recover the dispersed monazite for its rare earth and thorium content. The monazite content of heavy mineral resources is seldom recorded by mining companies in published reports.

Most of the known resources of monazite are in Victoria and Western Australia (WA). Heavy mineral sands are being mined in the Murray basin deposits at Ginkgo and Snapper in New South Wales (NSW) and at Douglas in Victoria. In WA, mining of heavy minerals is taking place at Eneabba, Cooljarloo, Dardanup and Gwindinup.

Using available data, Geoscience Australia estimates Australia's monazite resources in the heavy mineral deposits to be around 6.1 million tonnes (Mt). The data on monazite and the thorium content in the monazite in the mineral sand resources is very variable, but the available sources include:

- Analyses for monazite and thorium in published and unpublished reports;
- Published and unpublished analyses of thorium content in exported monazite concentrates; and
- Monazite and thorium analyses on heavy mineral sand deposits in company reports on open file available at some State Geological Surveys.

Information from these sources was applied to resource data on individual heavy mineral sand deposits to estimate the thorium resources in these deposits. Where local data on the monazite and thorium was not available, regional data were applied to individual deposits to estimate their monazite and thorium resources. Using this information, Australia's inferred thorium resources in the mineral sands were estimated to be around 372 000 tonnes.

Apart from heavy mineral sand deposits, thorium can be present in other geological settings such as alkaline intrusions and complexes, including carbonatites, and in veins and dykes. In these deposits, thorium is usually associated with other commodities such as rare earths, zirconium, niobium, tantalum and other elements. The more significant deposits are described in the following paragraphs.

### Thorium resources in vein-type deposits

**Arafura Resources Ltd:** Nolans Bore rare earth-phosphate-uranium-thorium deposit is located 135 kilometres (km) northwest of Alice Springs in the Northern Territory (NT). The mineralisation is hosted in fluorapatite veins and dykes. This deposit contains about 81 810 tonnes of Th in 30.3Mt of Measured, Indicated and Inferred Resources grading 2.8% rare earth oxides (REO), 12.9% P<sub>2</sub>O<sub>5</sub>, 0.02% U<sub>3</sub>O<sub>8</sub> and 0.27% Th. Arafura is currently considering processing the rare earth-phosphate-uranium-thorium ore concentrate from the Nolans Bore deposit at Whyalla in South Australia. The thorium content in the concentrate will be separated as an iron thorium precipitate and transported back to the Nolans Bore mine site in NT for long-term storage as a possible future energy source.

### Thorium resources in alkaline rock complexes

**Alkane Resources Ltd:** The Toongi zirconium-niobium-rare earth deposit occurs within an alkaline trachyte plug about 30km south of Dubbo in NSW. The deposit has a Measured Resource of 35.7Mt and 37.5Mt of Inferred Resources grading 1.96% ZrO<sub>2</sub>, 0.04% HfO<sub>2</sub>, 0.46% Nb<sub>2</sub>O<sub>5</sub>, 0.03% Ta<sub>2</sub>O<sub>5</sub>, 0.14% Y<sub>2</sub>O<sub>3</sub>, 0.745% total REO, 0.014% U<sub>3</sub>O<sub>8</sub>, and 0.0478% Th, giving a total of about 35 000 tonnes contained Th. A demonstration pilot plant (DPP) was constructed and commissioned in May 2008 at the **Australian Nuclear Science and Technology Organisation** (ANSTO, <http://www.ansto.gov.au>) in the Sydney suburb of Lucas Heights. The DPP is designed to test the flowsheet for ore from Toongi and provide the various products for distribution to potential end users. Alkane reported that two trial runs of the DPP were completed in 2008 and one more in the first quarter of 2009. The plant operated efficiently during this period with no significant issues and in the latter half of the run produced high quality zirconium and niobium products. On 19 September 2011, Alkane announced a Proved Reserve for the deposit of 8.07Mt grading 1.91% ZrO<sub>2</sub>, 0.04% HfO<sub>2</sub>, 0.46% Nb<sub>2</sub>O<sub>5</sub>, 0.03% Ta<sub>2</sub>O<sub>5</sub>, 0.14% Y<sub>2</sub>O<sub>3</sub>, and 0.75% total REO. At the same time the company released results of a definitive feasibility study for the project that excluded the production of thorium. The financial analysis indicated a nett present value for the project of \$181 million at a processing rate of 400 kilotonnes per annum (ktpa) and \$1.207 million at a processing rate of 1000ktpa.

**Hastings Rare Metals Limited:** Other alkaline complexes with known rare earth and thorium mineralisation include Brockman in WA. It is a large low-grade zirconium-niobium-rare earth element (Zr-Nb-REE) deposit hosted in altered trachytic tuff of Paleoproterozoic age. On 8 September 2011, Hastings reported 36.2Mt of Indicated and Inferred Resources grading 8.86 parts per million (ppm) ZrO<sub>2</sub>, 3.55ppm Nb<sub>2</sub>O<sub>5</sub>, 182ppm Ta<sub>2</sub>O<sub>5</sub>, 110ppm Ga<sub>2</sub>O<sub>5</sub>, 318ppm HfO<sub>2</sub>, 186ppm Dy<sub>2</sub>O<sub>5</sub>, 1120ppm Y<sub>2</sub>O<sub>3</sub>, 2102ppm total REO and 1802ppm heavy REO. Historic company reports on open file on the Geological Survey of Western Australia WAMEX database show analyses for thorium in six separate drill hole intersections (in tuffs) of 16 metres (m) to 28m averaging from 259-371ppm Th (Western Australia Geological Survey WAMEX database report A 40991).

**Capital Mining Limited:** The peralkaline granitic intrusions of the Narraburra Complex 177km northwest of Canberra contain anomalous amounts of zirconium, REO and low concentrations of Th (55Mt at 1000 grams per tonne (g/t) ZrO<sub>2</sub>, 60g/t Y<sub>2</sub>O<sub>3</sub>, 300g/t REO, 40g/t HfO<sub>2</sub>, 80g/t NbO<sub>2</sub>, and 50g/t ThO<sub>2</sub>, Capital Mining Limited Prospectus 2006). The thorium oxide (ThO<sub>2</sub>) content amounts to 2750 tonnes (2420 tonnes Th). In the March quarterly report in 2010, the owners of the project, Capital Mining Limited, reported that it was conducting metallurgical test to recover hafnium (Hf), Th, tantalum (Ta), Nb, Nd and Ce.

### Thorium resources associated with carbonatite intrusions

Data on the thorium content of carbonatite intrusions in Australia is sparse. Mount Weld and Cummins Range in WA have the most significant rare earth resources reported for carbonatites in Australia to date, with both having some thorium content.

**Lynas Corporation Ltd:** The Mount Weld deposit in WA occurs within a lateritic profile developed over an alkaline carbonatite complex. On 6 September 2010 Lynas reported Measured, Indicated and Inferred REO resources for the Central Lanthanide Deposit at a cut-off of 2.5% REO of 9.88Mt at 10.7% REO including 990ppm Y<sub>2</sub>O<sub>3</sub>. The ThO<sub>2</sub> content of the deposit is estimated to be 712ppm which equates to 626ppm Th (personal communication B Shand, Lynas Corporation Ltd (Lynas) 17 June 2009).

On 6 September 2010, Lynas also announced additional REO resources in the Duncan Deposit, of the carbonatite complex of 7.620Mt of Measured, Indicated and Inferred Resources at 4.8% REO including 2570ppm Y<sub>2</sub>O<sub>3</sub>. The ThO<sub>2</sub> content is estimated to be 441ppm (388ppm Th). In another part of the carbonatite complex there are 37.7Mt of mostly Inferred Resources grading 1.07% Nb<sub>2</sub>O<sub>5</sub>, total lanthanides at 1.16% and 0.09% Y<sub>2</sub>O<sub>3</sub>, 0.3% ZrO<sub>2</sub>, 0.024% Ta<sub>2</sub>O<sub>5</sub>, 7.99% P<sub>2</sub>O<sub>5</sub> and a ThO<sub>2</sub> content of 479ppm (421ppm Th).

**Navigator Resources Ltd:** In their annual report for 2010, Navigator Resources reported Inferred Resources for Cummins Range in WA carbonatite deposit of 4.17Mt at 1.72% REO, 11.0% P<sub>2</sub>O<sub>5</sub> 187ppm U<sub>3</sub>O<sub>8</sub> and 41ppm Th. In other parts of the deposit however, sample analyses recorded in open file report A16613 in the Geological Survey of Western Australia WAMEX database averaged about 500ppm Th in the top 48m of weathered zone in one drill hole. Thorium-rich zones of 200–400ppm Th were intersected in two drill holes in fresh carbonatite and carbonated magnetite amphibolite to depths of 400m.

**Artemis Resources Ltd:** The Yangibana ferrocarbonatite-magnetite-rare earth bearing dykes in WA (termed ironstones) crop out over an area of 500 square kilometres and form part of the Gifford Creek Complex. The dykes are part of a carbonatitic episode which intrudes the Proterozoic Bangemall Group. The ferrocarbonatite-magnetite-rare earth bearing dykes occur as lenses and pods and are typically the last stage of carbonatite fractionation and are enriched in REEs, fluorite and uranium-thorium mineralisation. The Yangibana prospect has a recorded resource of 3.5Mt at 1.7% REO. The rare earths are in coarse grained monazite containing up to 20% Nd<sub>2</sub>O<sub>5</sub> and 1600ppm Eu<sub>2</sub>O<sub>3</sub>. Whole rock chemical analyses of 21 ironstone samples collected from five prospects in the Yangibana area recorded more than 1000ppm Th for 10 of the samples (1062ppm to 5230ppm Th).

**Capital Mining Limited:** Similarly the peralkaline granitic intrusions of the Narraburra Complex 177km northwest of Canberra contain anomalous amounts of zirconium, REO and low concentrations of Th (55Mt at 1000g/t ZrO<sub>2</sub>, 60g/t Y<sub>2</sub>O<sub>3</sub>, 300g/t REO, 40g/t HfO<sub>2</sub>, 80g/t NbO<sub>2</sub>, and 50g/t ThO<sub>2</sub>; Capital Mining Limited Prospectus 2006). The ThO<sub>2</sub> content amounts to 2750 tonnes (2420 tonnes Th). In the March quarterly report in 2010, the owners of the project, Capital Mining Limited, reported that it was conducting metallurgical test to recover hafnium (Hf), Th, tantalum (Ta), Nb, Nd and Ce.

## Exploration

There has been no widespread exploration for thorium in Australia. However thorium is a significant component of some deposits being explored for other commodities. Thorium is present in the Nolans Bore deposit in the NT and in the Toongi intrusives complex in NSW. Heavy mineral concentrations within the King Leopold Sandstone and the Warton Sandstone, which constitute the Durack Range uranium project in WA, also contain up to 2% thorium in the heavy mineral concentrate (**Northern Mining Ltd**—announcement to the Australian Securities Exchange, 21 March 2007). **Western Desert Resources Ltd** reported that thorium was one of the commodities being explored for at Blueys and Cloughs Dam prospects near Alice Springs in the NT with 599-1400ppm Th being reported in rock chip samples from the Blueys rare earth, zirconium, thorium prospect. In April 2011 Centius Gold reported low altitude airborne thorium and uranium anomalies over the northern rim of its Bethungra Caldera prospect which was claimed to resemble similar airborne radiometric anomalies over Alkane's Dubbo (Toongi) zirconium-rare earth project to the north.

## Production

There is no production of thorium in Australia, but it is present in monazite currently being mined with other minerals in heavy mineral beach sand deposits.

Between 1952 and 1995, Australia exported 265 kilotonne (kt) of monazite with a real export value (2008 dollars) of \$284 million (Australian Bureau of Statistics 2009). Most of the monazite was exported to France for extraction of REE, but the monazite plant in France was closed because its operators were unable to obtain a permit for the toxic and radioactive disposal site.

In current heavy mineral sand operations, the monazite fraction is returned to mine site and dispersed to reduce radiation as stipulated in mining conditions.

## World Ranking

The Organisation for Economic Cooperation and Development/Nuclear Energy Agency OECD/NEA & International Atomic Energy Agency (IAEA) (2009) have compiled estimates of thorium resources on a country-by-country basis. The OECD/NEA report notes that the estimates are subjective as a result of the variability in the quality of the data, a lot of which is old and incomplete. Table 8 has been derived by Geoscience Australia from information presented in the OECD/NEA analysis. The total identified resources refer to Reasonably Assured Resources (RAR) plus Inferred Resources recoverable at less than US\$80/kilogram Th. With increasing cost of production, the upper limit for these costs categories may have to be raised to US\$130/kilogram. See Uranium chapter for definitions of resource categories.

OECD/NEA & IAEA (2009) have grouped thorium resources according to four main types of deposits as shown in Table 9. Thorium resources worldwide appear to be moderately concentrated in the carbonatite type deposits, accounting for about 30% of the world total. The remaining thorium resources are more evenly spread across the other three deposit types in decreasing order of abundance in the placers, vein type deposits and alkaline rocks. In Australia, a larger proportion of resources are located in placers where the heavy mineral sand deposits account for about 70% of the known thorium resources.

**Table 8.** Estimated thorium resources by country.

Country	Total Identified Thorium Resources (Reasonably Assured + Inferred Resources)* <USD 80/kg Th (’000 tonne Th)
Australia	474
United States of America	400
Turkey	Not available
India	319
Brazil	302
Venezuela	300
Norway	132
Egypt	100
Russian Federation	75
Greenland	54
Canada	44
South Africa	18
Others	33
<b>Total</b>	<b>2251</b>

\*Sources: Data for Australia compiled by Geoscience Australia; estimates for all other countries are from: OECD/NEA & IAEA, 2009: Resources, Production and Demand. OECD Nuclear Energy Agency & International Atomic Energy Agency.

**Table 9.** World and Australia’s thorium resources according to deposit type (modified after OECD/NEA and IAEA, 2009). Australia’s thorium resources are expressed as recoverable resources after an overall reduction of 10% for mining and milling losses.

Major deposit type	World Deposits (Includes Australia)		Australian Deposits	
	Resources (’000 tonne Th)	Percentage	Resources (’000 tonne Th)	Percentage
Carbonatite	1900	31.3	24	5.1
Placer deposits	1500	24.7	333	70.2
Vein-type deposits	1300	21.4	73	15.4
Alkaline rocks	1120	18.4	42	8.9
Other	258	4.2	2	0.4
<b>Total</b>	<b>6078</b>	<b>100.0</b>	<b>474</b>	<b>100.0</b>

# Tin

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Tin (Sn) is used in solders for joining metals and pipes, as a coating for steel cans and in metal alloys. The largest single application for tin is in solders, which accounts for about half of current world consumption. Solders are used in light engineering applications such as plumbing and sheet metal work, in the motor vehicle industry and in cans for various uses. Another major application for tin is coating steel sheet in the manufacture of tinsplate, which accounts for about 16% of world tin consumption. Tinsplate is used for containers in the form of tin cans for food products, drinks, oils, paints, disinfectants and chemicals.

## Resources

Australia's Economic Demonstrated Resources (EDR) of tin increased by 203% to 358 kilotonnes (kt) at December 2010, up from 176kt in 2009. This primarily resulted from a large increase in tin resources at Renison Bell in Tasmania (Tas), including a doubling of the resource at Rentails. There was an increase also of about 40% or around 10 kilotonne (kt) in resources in Queensland (Qld) at Gillian, Collingwood and Deadmans Gully.

Australia's EDR are in the deposits at Renison Bell and Mount Bischoff in western Tas, alluvial deposits in northeast Tas, and at Gillian, Baal Gammon and Collingwood in north Qld.

## Accessible EDR

All of Australia's EDR for tin are accessible.

## JORC Reserves

Joint Ore Reserve Committee (JORC) Code reserves comprise total tin in Proved and Probable Ore Reserves as defined in the JORC Code. In 2010, JORC Code reserves of 141kt accounted for approximately 39% of Accessible Economic Demonstrated Resources (AEDR).

## Exploration

Exploration continued in the historic tin mining areas of Herberton-Mount Garnet in far north Qld, in the northern New England, Bourke and Broken Hill regions of New South Wales (NSW), and at several prospects in western Tas. Data on tin exploration expenditures are not compiled by the Australian Bureau of Agricultural and Resource Economics and Sciences.

Venture Minerals Limited announced a significant JORC-compliant resource upgrade for the **Mount Lindsay** tin-tungsten deposit in northwest Tas, with revised combined resources of 43 million tonnes (Mt) at 0.4% Sn equivalent (with a 0.2% cut-off) or 10Mt at 0.7% Sn equivalent (at 0.45% cut-off). The latter figure includes Indicated Resources of 6.2Mt at 0.4% Sn and 0.3% tungsten oxide (WO<sub>3</sub>). The deposit also includes an iron resource. The Mount Lindsay prospect is located 15 kilometres (km) northwest of Renison Bell tin mine and 20km west of Rosebery in western Tas. The prospect is in magnetite (Fe<sub>3</sub>O<sub>4</sub>) rich skarns within the contact aureole of the Meredith granite, which is part of a suite of Devonian granites that are the source rocks for a number of large tin, tungsten and magnetite deposits in western Tas and on King Island in Bass Strait. The company completed a successful prefeasibility study for Mount Lindsay in March, 2011 that confirmed the economics of the project. The company is undertaking a bankable feasibility study which is expected to be completed in 2012. Ongoing regional and infill drilling has been undertaken during the past year in association with the feasibility study. Infill drilling in the McDonald Tin Zone (Main Skarn) returned results of 26 metres (m) at 2.7% Sn, and 10m at 1.9% Sn. Broad zones of tungsten mineralisation were also identified, including 30m at 0.35% WO<sub>3</sub>, and 44m at 0.24% WO<sub>3</sub>. Results at the Reward prospect 3.5km from Mount Lindsay comprised 28m at 0.89% Sn, including 7.5m at 1.74% Sn, 18m at 0.69% Sn, including 8m at 0.94% Sn, 31m at 0.45% Sn, including 11m at 0.87% Sn and 6m at 1.4% Sn, and 27m at 0.52% Sn, including 6m at 1.29% Sn. Venture Minerals Limited submitted a Mining Lease Application for the Company's Mount Lindsay Tin/Tungsten Project on 15 September 2011.

Malachite Resources continued exploration at a number of historic tin deposits in the Inverell district in northern NSW—mainly the **Karaula** alluvial-tin-tungsten deposit at Newstead, the **Sheep Station Hill** greisen deposit and the **Standon** vein prospect. Further exploration at Standon was terminated because grades proved to be subeconomic. Similarly, Malachite Resources indicated that greisen-hosted hard rock tin occurrences, such as Sheep Station Hill, were unlikely to be economic for mining. Some bulk sampling continued at the Karaula Lead alluvial-tin prospect to assist with determination of bulk mineable tin grades. The Karaula alluvial deposit occurs as flat-lying paleoalluvial material partly draped around Bruce's Hill at Newstead. Tin grades are variable; commonly in the 0.5 to 1.0 kilogram (kg) per cubic metre range, but up to 3.5kg of contained tin (as cassiterite) per cubic metre. Malachite Resources also continued work on its Conrad Project investigating polymetallic silver deposits, which also contain tin (stannite and cassiterite).

YTC Resources report no activities over the past year at the **Giants Den** alluvial deposits near Bendemeer in northern NSW. Previously, the company reported that overall results from its 72 hole drilling program were disappointing.

Within YTC Resources' **Doradilla** project 55km southeast of Bourke, NSW, the Doradilla-Midway-3KEL tin deposits occur within a linear skarn unit which can be traced for more than 17km along strike. The top 40–60m of the skarn is highly weathered. The resource is limited to the weathered zone (laterite) where tin is hosted in stanniferous goethite, garnets, secondary cassiterite and minor primary cassiterite. The company has announced a combined Inferred Resource for the tin laterite (oxide) mineralisation of 7.81Mt averaging 0.28% Sn (at a cut-off grade of 0.1% Sn) for 22.3kt of contained tin. Exploration within the Doradilla Project in 2010 and early 2011 has concentrated on other commodities (bismuth, silver, gold, copper), with minimal exploration for tin.

At its **Tallebung** tin-tungsten deposit, 70km northwest of Condobolin in central NSW, YTC Resources re-sampled an historic drill hole generating new reported intersections of 14m averaging 29 parts per million (ppm) silver (Ag), 0.15% lead (Pb), 0.25% Sn and 322 ppm tungsten (W). They also undertook a resistivity survey to test for the mineralising granite at depth. The company is currently seeking access to the historic Tallebung Mine site to undertake two deep drill holes aimed at testing targets from the resistivity survey (below outcropping mineralisation) and to assist in scoping of the Tallebung system for a potential large tonnage low grade tin deposit.

In October 2010, YTC Resources reached agreement to sell its New England tin projects, Pound Flat and Torrington, to Taronga Mines Limited. The latter company also controls the adjacent lease over the large, low-grade Taronga tin deposit.

Carpentaria Exploration Ltd continued work at the **Euriowie** project, 60km north of Broken Hill, NSW, undertaking limited exploratory drilling of a pegmatite dyke testing continuity of tin mineralisation at depth. Results included 4m at 0.38% Sn. The company followed this with mapping and surface rock channel sampling of pegmatite bodies in the lease. Fifteen of the pegmatites were sampled. Best results included 3m at 0.21% Sn and 1m at 0.77% Sn from the Trident Pegmatite. In late 2010, the company purchased from Wolf Minerals Limited the Yanco Glen Exploration Licence Application (ELA) located 30 km north of Broken Hill, NSW. The ELA covers the Waukeroo Pegmatite Tin Field and includes the Yanco Glen scheelite (tungsten) deposit with an Inferred Resource of 0.83Mt of 0.21% WO<sub>3</sub>. The company also undertook preliminary rock sampling of previously unexplored pegmatite at two locations in its Apollyon tenement, 20km northwest of Broken Hill, returning four anomalous results ranging from 0.27% to 3.2% Sn.

In the Mount Garnet tin field 200km southwest of Cairns, Qld, Consolidated Tin Mine Ltd (CTM) in July 2011 completed 8148m of drilling at the **Gillian** (5km southwest of Mount Garnet), and Windemere (25km north-east of Mount Garnet) tin deposits, and the Coolgarra (15km northeast of Mount Garnet) Project. The Gillian and Windemere deposits are in iron-rich skarns adjacent to granitic intrusions, while the Coolgarra Project area contains sediment-hosted and granite greisen mineralisation. Preliminary results for the Windemere deposit include intersections of 2m at 2.7% Sn, 4m at 1.16% Sn, and 15m at 0.63% Sn. In September 2010, the company announced a revised total JORC Code resource of 7.38Mt at 0.6% Sn, 5.27Mt at 25.78% Fe and 0.96Mt at 15.25% fluorine (F) for its Mount Garnet project, reflecting the inclusion of resources at the Windemere deposit. Included within the total resource, is a JORC Code Measured Resource at the Gillian deposit of 1.2Mt at 0.82% Sn. The company continued metallurgical test work to separate the fine cassiterite from the ironstone skarn material, and sent an 80 tonne sample from the Gillian Project for processing at Greenbushes in WA. The company also initiated a prefeasibility study at the Mount Garnet Project. The company entered into an Indigenous Land Use Agreement (ILUA) with the Bar-Barrum Aboriginal Corporation and the Bar-Barrum People on 25 March 2011.

In March 2011, Stellar Resources Limited and Gippsland Limited announced a combined Mineral Resource of 4.4Mt at 1.1% Sn for their Heemskirk Tin Project (**Queen Hill, Montana** and **Severn** deposits). The resource includes Indicated Mineral Resources of 1.6Mt at 1.2% tin at the Queen Hill deposit. Stellar Resources Limited has recently completed a scoping study and is undertaking further drilling at Severn, Montana and Stormsdown. Recent intersections include 2m at 1.57% Sn, 2.3% Pb, 9.0% zinc (Zn), 62g/t Ag and 0.17% WO<sub>3</sub> at the Montana deposit. The company is also undertaking metallurgical testing.

MGT Resources acquired 75% subsidiary MGT Mining Limited (formerly Xtreme Resources Limited) and continued limited exploration around their historic tin mines, including **Dalcouth, Summer Hill, Extended, Tom Hood** and **Smiths Creek** in the immediate proximity of the Mount Veteran tin plant and smelter. All are located in the Mount Garnet District, north Qld. Drilling in mid-2010 included intersections at Summer Hill of 4m at 1.2% Sn, 2m at 8% Sn and 3m at 1.6% Sn.

Outback Metals continued resource estimation of its **Mount Wells** tin-copper deposit 200km southeast of Darwin in the Northern Territory (NT).

## Production

Australia's mine production in 2010 was 6600<sup>50</sup> tonnes of tin in concentrates, a 17% increase from the 2009 production of 5660 tonnes. There has been no production of refined tin in Australia since 2007 when the Greenbushes (WA) tin smelter closed. Total exports of tin for 2010 were 6011 tonnes valued at \$116 million. This compares with 6086 tonnes valued at \$97 million exported in 2009.

## World Ranking

Australia's EDR for tin was ranked eighth in the world with the major economic resources in China, Indonesia, Peru, Brazil, Bolivia, Russia, and Malaysia.

## Industry Developments

The price of tin on the London Metal Exchange had recovered significantly from the late 2008–early 2009 low point in the global financial crisis (US\$10 000 a tonne or A\$14 400) to reach new highs (US\$33 000 or around A\$33 000) in the second half of the 2010/11 financial year. The price has receded since then (about US\$20 000 or around A\$19 600) reflecting the Eurozone and other debt crises.

In March 2010, Metals X Limited completed the sale of a 50% interest in its Tasmanian Tin assets to the world's largest tin producer, China's Yunnan Tin—Parkson Group (YTG). The Tasmanian Tin assets include the Renison Bell Mine, the Renison Tin Concentrator, the Renison Expansion Project, Rentails, and the Mt Bischoff Tin Project. A new joint venture company Bluestone Mines Tasmania Joint Venture Pty Ltd (BMTJV) was established by Metals X through its wholly owned subsidiary Bluestone Mines Tasmania Pty Ltd, and YTG Parkson Australia Holding Pty Ltd which will manage the assets.

BMTJV current operations are in western Tas at the **Renison Bell** underground mine near Zeehan. Current production is from the South Renison area, with North Renison production expected in late 2011. Ore from the mine is treated at the Renison concentrator. Once mining from both North and South Renison begins in early 2012, production rates are expected to reach 8000 tonnes of tin in concentrates per year. A copper circuit was commissioned in December 2010, with a current production of around 500 tonnes per year of copper in concentrate. Mining ceased at **Mount Bischoff** in July 2010 and the last ore was treated in late 2010. The company is actively exploring around the deposit. Resources at Renison Bell have increased to 8.35Mt grading 1.63% Sn, representing about 136 000 tonnes of contained tin.

In 2009, Metals X Limited completed a feasibility study on proposals to recover tin from tailings produced by historic processing of tin ores at Renison Bell mine. Resources in the tailings dam are estimated to be 18.95Mt averaging 0.44% Sn and 0.20% copper (Cu), which represents 83 380 tonnes of contained tin and 37 900 tonnes of contained copper. The recovery project proposes reclaiming tailings at a rate of 2Mt a year to produce about

<sup>50</sup> Excluding production in Western Australia (for which no definitive figures are available).

5300 tonnes of tin and 2000 tonnes of copper contained in concentrates a year. The company reported that a combination of sulphide flotation and tin flotation techniques would produce a 10% tin concentrate which could be smelted to produce a tin fume product assaying in excess of 68% tin.

Metals X's **Collingwood** mine, about 30km south of Cooktown in north Qld, has been under care and maintenance since its closure in mid-2008. The company has decided to dispose of the property.

In February 2009, Van Dieman Mines (VDM) went into administration as a result of start-up problems at its **Scotia** and **Endurance** alluvial tin and sapphire deposits in northeast Tas. The Scotia and Endurance projects had a planned capacity of 1300 tonnes per year of tin-in-concentrates and were expected to generate by-product revenues from sales of sapphires. However, tin grades were lower than expected and very few sapphires were recovered during trial mining. In mid 2010, expressions of interest were sought for the purchase of alluvial tin resources and for associated mineral processing infrastructure located near Gladstone, Tas.

In February and September 2011, TNT Mines Limited (demerged from Minemakers Limited) applied for offshore exploration tenements in Ringarooma Bay, part of its Ringarooma Bay alluvial tin project. The tenements cover parts of the old Ringarooma River channel. The project has an historic Indicated Resource of 16 million cubic meters at 227 grams of tin per cubic meter.

At **Greenbushes** mine, in southwest WA, production of tin ceased in 2007 with the closure of the smelter. Tin resources for Greenbushes operations have not been publicly reported for more than a decade. Historical estimates of tin resources for Greenbushes have not been included in Australia's EDR since 2008.

## Tungsten

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Tungsten (W) metal and its alloys are amongst the hardest of all metals. It occurs as wolframite, (Fe, Mn) WO<sub>4</sub>, which is an iron manganese tungstate mineral, and scheelite, CaWO<sub>4</sub>. Tungsten carbide has a hardness approaching that of diamond and is used for cutting and wear-resistant materials, primarily in the metalworking, mining, oil drilling and construction industries. Tungsten alloys are used also in electrodes, filaments (light bulbs), wires and components for electrical, heating, lighting and welding applications.

Ferrotungsten (FeW) is a high value-added intermediate product and is used in steels and alloys where hardness and heat resistance is required.

### Resources

Australia's total Economic Demonstrated Resources (EDR) of tungsten at December 2010 was 403 kilotonnes (kt), more than double the resources in 2009 (196kt). The majority of the increase was in Western Australia (WA) where resources were more than 16 times or about 211 kt up on 2009, primarily at O'Callaghans with about 186kt and Big Hill with 29.5kt.

Australia's EDR are in deposits at Dolphin and Bold Head on King Island in Bass Strait off Tasmania (Tas), Kara and Mount Lindsay (Tas), at Watershed in Queensland (Qld), O'Callaghans, Big Hill and Mount Mulgine in Western Australia (WA) and Molyhil in the Northern Territory (NT).

The bulk of Australia's EDR of tungsten are in WA with 56%, followed by Tas with 29% and Qld with 13%. The WA share is up from 7% in 2009.

In 2010, Subeconomic Demonstrated Resources (comprising Paramarginal and Submarginal Resources), which account for about 0.5% of the total Demonstrated Resources, remained essentially unchanged from 2009. Queensland accounts for 46% of Subeconomic Demonstrated Resources followed by Tas with 37%.

Inferred Resources decreased by about 53% from 204kt in 2009 to 110kt in 2010. Queensland accounts for 51%, followed by WA with 27%, Tas with 18% and NSW with 13%.

## Accessible EDR

All of Australia's EDR for tungsten are unencumbered.

## JORC Reserves

Joint Ore Reserve Committee (JORC) Code reserves comprise total tungsten in Proved and Probable Ore Reserves as defined in the JORC Code. In 2010, JORC Code reserves of 217kt accounted for approximately 54% of Accessible Economic Demonstrated Resources (AEDR).

## Exploration

Increase in the demand for tungsten, together with restrictions on exports of tungsten concentrates from China, has led to an increase in exploration and re-evaluation of tungsten mines and deposits, mainly in north Qld, Tas and WA. Data on exploration expenditure for tungsten are not reported by the Australian Bureau of Statistics.

Following release of a resource estimate in April 2008 for the **Attunga** deposit 20 kilometres (km) north of Tamworth in New South Wales (NSW), Peel Exploration Ltd undertook additional drilling in 2009. Results include 27 metres (m) grading 0.54% WO<sub>3</sub>, 0.06% molybdenum (Mo) from 19m, including 2m grading 3.38% WO<sub>3</sub> and 0.27% Mo from 22m and 2m grading 0.59% WO<sub>3</sub> and 0.03% Mo from 58m. Mineralisation at the deposit occurs within skarns developed at the contact of a lime-rich sequence with the Inlet Monzonite. In 2010/11 the company undertook a study investigating development options, which showed that conditions were favourable for a low capital expenditure operation. In 2010, the company undertook drilling at the nearby Kensington gold prospect, 5km north of the Attunga tungsten deposit, targeting tungsten and gold mineralisation, on the basis of historic data, which suggested the presence of a shallow large low-grade tungsten resource. Although drilling returned favourable gold intercepts the drilling did not show tungsten mineralisation.

Frontier Resources Ltd continued exploration of their **Moina** Project area, including the stratiform gold-base metal Narrawa deposit 40km southwest of Devonport, Tas and gold-bismuth Stormont skarn deposits 190km northwest of Hobart. This exploration targeted mineralisation, including tungsten and tin, associated with the Dolcoath Granite. The company recently completed a detailed soil geochemical program over 4km<sup>2</sup> encompassing the Narrawa deposit, identifying zones anomalous in tungsten, tin, molybdenum, copper and bismuth as well as gold. The company has previously undertaken a positive Conceptual Mining Study (completed 2009) investigating possible mining and processing of the gold and base metal mineralisation at the Narrawa and Stormont deposits.

Hazelwood Resources Ltd released an initial ore reserve estimate at a cut off grade of 0.05% WO<sub>3</sub> for the **Big Hill** deposit of Proven Reserves of 18.78 million tonnes (Mt) averaging 0.11% WO<sub>3</sub> and Probable Reserves of 6.43Mt averaging 0.11% WO<sub>3</sub>. This forms part of the overall resource estimate at a cut-off grade of 0.05% WO<sub>3</sub> of Measured Resources of 22.94Mt averaging 0.11% WO<sub>3</sub>, Indicated Resources of 11.95Mt grading 0.1% WO<sub>3</sub>, and Inferred Resources of 12.54Mt grading 0.08% WO<sub>3</sub> for a total resource of 47.43Mt averaging 0.1% WO<sub>3</sub>. The deposit is part of the **Cookes Creek** tungsten project located 70km from Nullagine, WA. Hazelwood Resources Ltd also undertook diamond drilling (five holes) at the **Mulgine Hill** deposit, Mount Mulgine tungsten project (70% Hazelwood, 30% Gindalbie Metals Limited), about 300km east-south-east of Geraldton, confirming the presence of near-surface high grade tungsten mineralisation. Drill intersections include 2m at 3.17% WO<sub>3</sub>, 34m at 0.20% WO<sub>3</sub>, and 15m at 0.16% WO<sub>3</sub>. This followed release of new resource figures for the deposit in March 2011, comprising Indicated Resources, at a cut off grade of 0.1% WO<sub>3</sub>, of 5.87Mt averaging 0.22% WO<sub>3</sub>, for a contained 13 000 tonnes of WO<sub>3</sub>. The company also indicated that 95% of the resource is within 100m of the surface. Hazelwood acquired its 70% share of Mount Mulgine from Vital Metals Ltd in 2010.

Newcrest Mining Ltd released a maiden ore reserve and revised resource figures for its **O'Callaghans** polymetallic (tungsten-copper-zinc-lead) skarn deposit about 10km south of Telfer, WA, with Probable Reserves of 51Mt grading 0.34% WO<sub>3</sub>, Indicated Resources of 69Mt grading 0.34% WO<sub>3</sub> and Inferred Resources of 9Mt grading 0.25% WO<sub>3</sub>. On current figures the O'Callaghans deposit represents about 44% of Australia's EDR of tungsten. Mineralisation occurs within a sub-horizontal skarn at the contact between a large granite body and overlying limestone.

YTC Resources undertook reconnaissance rock chip sampling over the historic **Marobee** tungsten field, located about 25km north of the Tallebung tin field northwest of Condoblin in NSW. A number of the collected samples returned good results of up to 3.9% W, up to 3.7 grams per tonne (g/t) Au and up to 0.8% Sn.

## Production

During 2010, 28 tonnes of high-grade scheelite concentrates averaging 75% WO<sub>3</sub> together with magnetite was produced at the Kara scheelite mine near Hampshire in northwest Tas, representing 17.9 tonnes of contained tungsten. The scheelite and magnetite were produced from skarn within Ordovician limestone adjacent to the contact with Devonian granite.

## World Ranking

In 2010, world economic resources of tungsten are estimated to be 2900kt based on United States Geological Survey (USGS) data and updated by Geoscience Australia for Australia's resources. According to the USGS, China holds approximately 65% of the resources followed by Russia 8.6% and the USA 4.8%. Australia has a 14.5% share of world resources, based on the USGS figures for world economic resources of tungsten and Australia's 2010 figures presented here.

The USGS estimates that world production of tungsten in 2010 amounted to 61kt compared with 58kt in 2009. China was the major producer with 85% of world production, followed by Russia with 4%. USA production was not recorded for confidential reasons. Over the past few years, the Chinese Government has restricted the amount of its tungsten ores which can be offered on the world market, favouring instead the export of value-added downstream tungsten materials and products.

## Industry Developments

The price of tungsten has risen dramatically over the past 18 months from a low of less than US\$200 per metric tonne unit (MTU = 10kg) of ammonium paratungstate (APT) in late 2008 to early-mid 2009, following the global financial crisis, to reach new highs of US\$480 per MTU in mid 2011. This price increase reflected the tightening of supply by China and increased demand. Prices have eased since to around US\$460-440 per MTU, reflecting the Eurozone and other debt crises. The rise of tungsten prices has seen an increased interest in tungsten and renewed activity at a number of projects.

Metallic Minerals Limited's **Wolfram Camp** tungsten-molybdenum project, 90km west of Cairns in Qld, has been under care and maintenance since late 2008. In May, 2010 the company's 76% owned-subsi-diary, Planet Metals Limited released a revised total resource estimate of 1.42Mt grading 0.6% WO<sub>3</sub> and 0.12% Mo comprising 0.78Mt grading 0.56% WO<sub>3</sub> and 0.13% Mo in Indicated Resources and 0.64Mt grading 0.65% WO<sub>3</sub> and 0.11% Mo in Inferred Resources. Planet Metals Limited also undertook studies into enhancing the run of mine pre-concentrate in order to improve the mill-feed grade. In May 2011, Planet Metals Limited announced it had successfully undertaken a Share Sale Agreement with Deutsche Rohstoff AG to sell its 100% owned subsidiary, Wolfram Camp Mining Pty Ltd, which holds an 85% stake in the Wolfram Camp tungsten-molybdenum project.

Vital Metals Limited's 100% owned **Watershed** scheelite project, 150km northwest of Cairns, Qld, has an Indicated Resource of 15.1Mt at an average grade of 0.46% WO<sub>3</sub> using a cut-off grade of 0.10% WO<sub>3</sub>, for 69 300 tonnes of contained WO<sub>3</sub>. The company has completed a pre-feasibility study, including a full Environmental Impact Study, which has been accepted by the Queensland Environmental Protection Agency. However, the 2008-09 decline in tungsten prices had an adverse impact on the project's economic viability. The subsequent price increase in late 2010 resulted in Vital Metals Limited undertaking a review of the pre-feasibility study. In May 2011 Vital Metals Limited announced it had entered into an earn-in agreement with Japan Oil, Gas and Metals National Corporation (JOGMEC) for 30% of the Watershed project by funding completion of a bankable feasibility study for the project. JOGMEC confirmed the farm-in in August 2011.

In July 2011, Icon Resources approved the purchase and relocation of a second hand plant and equipment for the reprocessing of tailings at the **Mount Carbine** mine, about 130km northwest of Cairns, Qld. Production from the 2Mt of tailings is envisaged to commence in late 2011. It has an anticipated project life of about two years, expected to be producing around 5000 metric tonne units (mtu, 1 mtu = 10kg) of WO<sub>3</sub> in concentrate a month.

The company is undertaking feasibility studies into the viability of processing low grade stockpiles from late 2012, with a project life of around five years producing about 10 000 mtu of  $WO_3$  in concentrate a month. The company is also planning to commence production from the hard rock resource in the medium term with an anticipated project life, based on current resource estimates of more than 10 years, producing around 20 000 mtu of  $WO_3$  in concentrate a month. The Mount Carbine project has Inferred Resources for the hard rock mineralisation of 113.6Mt grading 0.06%  $WO_3$ . This includes an Inferred Resources of 39.8Mt at 0.14%  $WO_3$  at a 0.05%  $WO_3$  cut-off beneath and adjacent to the old Mount Carbine open-cut mine, which closed down in 1987. The company plans to undertake further drilling in 2011/12 of the hard rock resource and extensions as well as in the neighbouring Iron Duke tungsten and Mount Holmes tungsten-tin prospects.

The Dolphin Joint Venture between King Island Scheelite (KIS) and Chinese Hunan Nonferrous Metals Corporation (HNC) to redevelop the former **King Island** scheelite mine on southeast King Island off Tas was terminated mid December 2010. HNC transferred its 50% interest in the joint venture assets to KIS's wholly owned subsidiary Australian Tungsten Pty Ltd (ATPL). HNC has a royalty of 2% on future project revenue from the project, capped at \$3.9 million. KIS is currently undertaking a feasibility study investigating both retreatment of tailings and re-opening the underground mine. The current development plan is to produce 1000 tonnes of  $WO_3$  per annum from tailings from late 2012, increasing to 3500 tonnes of  $WO_3$  concentrate with commencement of underground operations in late 2014. King Island Scheelite reported Indicated Resources for the Dolphin Mine and Bold Head Mine at a cut-off grade of 0.25%  $WO_3$ , as 8.42Mt averaging 0.95%  $WO_3$ , and 2.3Mt averaging 0.73%  $WO_3$ , respectively, for a combined total of 96 780 tonnes of contained  $WO_3$ . Estimates of Probable Reserves were upgraded in August 2011 to 2.69Mt averaging 1.04%  $WO_3$ , and containing 27 940 tonnes of  $WO_3$ . In June 2011, the company also reported Measured Resources for the tailings at the Dolphin Mine at a cut-off grade of 0.08%  $WO_3$  as 2.7Mt averaging 0.17%  $WO_3$ , containing 459 000 tonnes of contained 4590 tonnes of  $WO_3$ .

Venture Minerals Limited announced a JORC-compliant resource upgrade for the Mount Lindsay tin-tungsten deposit in western Tas, with revised combined resources of 43Mt at 0.4% Sn equivalent at 0.2% cut-off) or 10Mt at 0.7% Sn equivalent at 0.45% cut-off. The latter figure includes Indicated Resources of 6.2Mt at 0.4% Sn and 0.3%  $WO_3$ . The deposit also includes an iron ore resource. The Mount Lindsay prospect is located 15km northwest of Renison Bell tin mine and 20km west of Rosebery in western Tas. The prospect is in magnetite ( $Fe_3O_4$ ) rich skarns within the contact aureole of the Meredith granite, which is part of a suite of Devonian granites that are the source rocks for a number of large tin, tungsten and magnetite deposits in western Tas and on King Island in Bass Strait off Tas. The company completed a successful prefeasibility study for Mount Lindsay in March 2011 that confirmed the economics of the project. The company is undertaking a bankable feasibility study which is expected to be completed in 2012. Ongoing regional and infill drilling has been undertaken during the past year in association with the feasibility study. Infill drilling in the McDonald tin zone (Main Skarn) returned favourable tin results and identified broad zones of tungsten mineralisation, including 30m at 0.35%  $WO_3$ , and 44m at 0.24%  $WO_3$ . Venture Minerals Limited submitted a Mining Lease Application for the company's Mount Lindsay project on 15 September 2011.

Thor Mining PLC has reported total Proved and Probable Reserves of 2.21Mt grading 0.47%  $WO_3$  and 0.21% molybdenum disulphide ( $MoS_2$ ) for its **Molyhil** tungsten-molybdenum project, 250km northeast of Alice Springs, NT. Potential development of the project has been hampered by the global financial crisis and decline in international metal prices, resulting in the company subsequently scaling back activities. The company had signed an off-take agreement with CITIC Australia Trading Limited, one of China's largest State-owned companies, committing CITIC to take all of the molybdenum and tungsten concentrates produced from the project. The agreement has now lapsed. The recent increase in tungsten prices has resulted in renewed interest and Thor Mining initiated a definitive feasibility study of the deposit in June 2011. Initial findings were favourable with capital and operating cost estimates for the first phase of production of 1.4 million tonnes of ore to be \$66 million and \$79 per tonne, respectively with an annual throughput of 400 000 tonnes of ore. The company also undertook drilling in mid 2011 to test extensions of the resource and to better define the known resource. Initial results indicate existence of mineralisation outside the existing resource. Best results include 16m at 0.81%  $WO_3$  and 0.44%  $MoS_2$  from 189m and 13m at 0.38%  $WO_3$  and 0.13%  $MoS_2$  from 290m.

Hazelwood Resources Ltd has completed an integrated pre-feasibility study incorporating its **Big Hill** tungsten deposit, about 220km northwest of Newman, WA, and a ferrotungsten (FeW) project in Vietnam. Asia Tungsten Products Company Ltd (60%-owned by Hazelwood Resources Ltd) is constructing a FeW plant in the Vihn

Bao district near the Port of Haiphong in northern Vietnam. The company is currently undertaking a definitive feasibility study for the Big Hill deposit, including further metallurgical test work. Stage 1 of the Vietnam ferrotungsten plant was finalising practical completion in June 2011, with cold commissioning expected August, 2011 and hot commission and trial production some time later. Stage 1 of the plant is expected to have a capacity of approximately 3000 tonnes of contained tungsten in the form of 75% grade ferrotungsten per annum. A decision on stage two, involving the construction of a second furnace, is yet to be made. If undertaken this would increase capacity to around 6000 tonnes of contained tungsten, enough to supply 25% of projected global demand. The company indicates it plans to develop the Big Hill project and begin production from by 2013 with the deposit providing most of the feedstock for the Vietnam ferrotungsten project.

## Uranium

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Major uses for uranium (U) are as fuel in nuclear power reactors for electricity generation, in the manufacture of radioisotopes for medical applications and in nuclear science research using neutron fluxes.

On March 11, 2011, Japan suffered a devastating earthquake and tsunami. This natural disaster resulted in human tragedy and widespread damage to infrastructure. Damage to the Fukushima Daiichi nuclear power plant, caused by the tsunami led to a loss of emergency cooling systems and subsequently a substantial radiological release to the atmosphere in a nuclear incident involving four of the six units at the site (WNA<sup>51</sup>, 2011).

In the wake of the incident, there have been a range of political responses issued by governments in countries around the world. Many countries with long established nuclear power industries such as the USA, France, the Russian Federation, China, the European Union, South Korea and others have completed comprehensive safety reviews of all their nuclear reactors and upgraded safety standards as required in the light of findings from the Fukushima incident. These countries have voiced support for their existing reactors and their nuclear electricity industries. Other countries, notably Germany and Switzerland, have decided to shut down their oldest reactors and plan to gradually phase out other nuclear power plants. Several countries (eg Italy) have formally decided not to proceed with nuclear power programs while others which have been considering introducing nuclear power have delayed plans at least until safety lessons from the Fukushima event have been learnt.

In Japan a number of its nuclear power plants have been shut down and a review of the pre-existing energy policy will be undertaken with a view to possibly reducing future dependence on nuclear power (WNA, 2011).

The number of nuclear power plants operating worldwide has fallen from 442 at December 2010 (in 30 countries) to 432 in October 2011 and their share of world electricity generation fell from 14% to 13.8% over the same period. The number of plants under construction worldwide has remained unchanged at 63. The World Nuclear Association reported that there was a short term decline in world uranium requirements for electricity generation between December 2010 and October 2011 (WNA<sup>52</sup>, 2011). The Organisation for Economic Cooperation and Development Nuclear Energy Agency (OECD/NEA) (Cameron, 2011<sup>53</sup>) considers that enhanced safety measures will be implemented from the results of safety reviews on existing reactors and that the lessons from the Fukushima event will be integrated into the design and location of new and existing plants. Overall nuclear electricity generation (and uranium demand) are forecast to increase into the future.

Uranium spot market prices rose from US\$45 a pound (lb) of uranium oxide (U<sub>3</sub>O<sub>8</sub>) in January 2010 to US\$62.50 a lb by the end of 2010, but by October 2011 prices had fallen to US\$52 a lb.

<sup>51</sup> WNA, 2011: Policy Responses to the Fukushima Accident. World Nuclear Association. [http://world-nuclear.org/briefings/policy\\_responses\\_fukushima\\_accident.html](http://world-nuclear.org/briefings/policy_responses_fukushima_accident.html)

<sup>52</sup> WNA, 2011: World Nuclear Power Reactors and Uranium Requirements. <http://world-nuclear.org/info/reactors.html>

<sup>53</sup> Cameron, R. 2011: Nuclear Development in the aftermath of Fukushima Dai-ichi Accident. Australian Nuclear Association Conference. Sydney, October 2011.

## Resources

Geoscience Australia prepares estimates of Australia's uranium resources within categories defined by the OECD/NEA and the International Atomic Energy Agency (IAEA). The resource categories within this NEA/IAEA scheme reflect total costs of mining and milling ore.

In recent years, the cost of mining and milling uranium ores has increased in Australia. Prior to 2010, economic uranium resources were confined to the cost category of less than US\$80 per kilogram (kg) U, however increasing costs of uranium mining and milling, and increases in market prices, have extended economic uranium resources up to the category of less than US\$130/kg U.

The estimates in each category are for resources of recoverable uranium after losses resulting from mining and milling have been deducted (Tables 10 & 11).

**Table 10.** Australia's uranium resources at December 2010 (reported under corresponding categories of NEA/IAEA and Australian national schemes).

National Scheme	NEA/IAEA Scheme	Tonnes U Recoverable
Economic Demonstrated Resources (EDR)	Reasonably Assured Resources (RAR) recoverable at less than US\$130/kilogram (kg) U	1 158 000
Paramarginal Demonstrated Resources	RAR recoverable at US\$130–260/kg U	22 000
Submarginal Demonstrated Resources	RAR recoverable at greater than US\$260/kg U	0
Economic Inferred Resources	Inferred Resources recoverable at less than US\$130/kg U	504 000
Paramarginal Inferred Resources	Inferred Resources recoverable at US\$130–260/kg U	55 000
Submarginal Inferred Resources	Inferred Resources recoverable at greater than US\$260/kg U	0

Australia's RAR of uranium which can be produced at costs of less than US\$130/kg at December 2010 were estimated to be 1.158 million tonnes (Mt), which was a decrease of 6% on the estimates for December 2009 resulting from the impacts of increasing mining and milling costs. As a result, resources in some uranium mines and deposits are now assigned to higher cost categories compared with the estimates for 2009. Australia had an additional 504 000 tonnes of uranium in Inferred Resources recoverable at costs of less than US\$130/kg. These Inferred Resources are mainly in the southeast area of the Olympic Dam deposit.

Although there are more than 35 deposits with RAR of uranium recoverable at costs of less than US\$130/kg, the vast majority of these resources are within the following five deposits:

- Olympic Dam, which is the world's largest uranium deposit,
- Ranger and Jabiluka, in the Alligator Rivers region of the Northern Territory (NT),
- Kintyre and Yeelirrie in Western Australia (WA).

**Table 11.** Uranium resources in States and the Northern Territory at December 2010.

	RAR Recoverable at <US\$130/kg U Tonnes U	Inferred Resources Recoverable at <US\$130/kg U Tonnes U	Total Resources Tonnes U	Percentage of Australia's Total Resources
South Australia	930 300	411 500	1 341 800	81%
Northern Territory	124 000	49 400	173 400	11%
Western Australia	72 100	34 300	106 400	6%
Queensland	31 600	8 400	40 000	2%
New South Wales	0	0	0	-
Victoria	0	0	0	-
Tasmania	0	0	0	-
<b>Australia Total (Rounded)</b>	<b>1 158 000</b>	<b>503 600 (504 000)</b>	<b>1 661 600</b>	<b>100%</b>

## Accessible EDR

Approximately 10% of uranium in Economic Demonstrated Resources (equates with RAR at less than US\$130/kg) is inaccessible for mining. All uranium deposits in Queensland (Qld) remain inaccessible because current State Government policy prohibits uranium mining. Applications for new mine developments in the NT are subject to approval by the Commonwealth Government Minister for Resources, Energy and Tourism, the Hon. Martin Ferguson. In the NT, inaccessible resources include the Jabiluka deposit, where the traditional Aboriginal land owners have not granted approval to mine the deposit, and the Koongarra deposit, which was added to the Kakadu World Heritage Area by the World Heritage Committee on 27 June 2011. In South Australia (SA), the Mount Gee deposit is within the Arkaroola Protection Area, which was established by the SA Government in July 2011. Exploration and mining titles will not be granted in this area.

## JORC Reserves

Joint Ore Reserve Committee (JORC) Reserves comprise total uranium in Proved and Probable Ore Reserves as defined in the JORC Code. At December 2010, JORC Reserves of 391 000 tonnes recoverable uranium account for approximately 37% of accessible Economic Demonstrated Resources.

## World Ranking

Australia has the world's largest resources of uranium with an estimated 1.158 million Mt in RAR recoverable at costs of less than US\$130/kg. Based on the latest estimates<sup>54</sup> for other countries, this represents approximately 33% of world resources in this category. Other countries with large resources in RAR recoverable at costs of less than US\$130/kg include Canada with 10%, Kazakhstan 10%, Niger 7% and the United States 6%.

Australia's Inferred Resources of uranium recoverable at costs of less than US\$130/kg are the world's largest resources in this category.

## Exploration

Uranium exploration expenditure in 2010 was \$190.0 million<sup>55</sup> which was an increase of 6% on expenditure in 2009 (\$179.6 million). The majority of expenditure was in WA (44%), followed by SA (25%), the NT (20%) and Qld (11%). Uranium exploration expenditure in Australia increased progressively from 2003 to reach a peak level in 2008. This was in response to the significant increases in spot market uranium prices, which peaked in July 2007 but declined through 2008 and 2009.

<sup>54</sup> latest estimates for other countries as reported in 'Uranium 2009: Resources Production and Demand'.  
OECD Nuclear Energy Agency and International Atomic Energy Agency, Paris.

<sup>55</sup> ABS Mineral and Petroleum Exploration, December quarter 2010.

## South Australia

Exploration drilling continued at Carrapateena deposit, 100 kilometres (km) southeast of Olympic Dam. It is a hematite breccia complex deposit hosted by brecciated granites (similar to Olympic Dam). The deposit is known over a vertical height of 1000 metres with the top of the deposit 470 metres below the surface. Total Inferred Resources are 203Mt averaging 1.31% Cu, 0.56 g/t Au, 6 g/t Ag, 270ppm U. Metallurgical testwork to date has achieved uranium recoveries of approximately 75%. The average uranium grade of Carrapateena is the same as the average grade of total resources at Olympic Dam, although Olympic Dam ore reserves are higher grade, averaging 500ppm U.

Quasar Resources continued exploration for sandstone deposits in the Frome Embayment to north of the **Beverley Mine** east of Olympic Dam. Additional zones of mineralisation were intersected in Eyre Formation sands at **Pepegoona** and **Pannikan** deposits, which respectively are 10km north and 8km north of Beverley mine.

## Northern Territory

The **Thunderball** deposit, near Hayes Creek, 140km southeast of Darwin, occurs as disseminated to massive uraninite in sheared carbonaceous shales, cherts and tuffaceous siltstones of the Pine Creek Orogen. In February 2011, Thundelarra Exploration Ltd released initial resource estimate of 829 000 tonnes of Inferred Resources averaging 924ppm U<sub>3</sub>O<sub>8</sub>, which represents 766 tonnes of contained U<sub>3</sub>O<sub>8</sub>. Further drilling is planned to explore for other mineralised zones at depth and along strike from the known deposit.

Exploration drilling by Energy Resources of Australia in the **Georgetown** area, east of the **Ranger 3** open cut, intersected 14 metres averaging 0.35% U<sub>3</sub>O<sub>8</sub> from a depth of 403 metres. The company plans to conduct a major exploration drilling program in the Ranger 3 Deeps and Georgetown areas over the period 2012 to 2014 for a total expenditure of \$40 million.

**Ngalia Basin**—Several companies explored the northern margins of the Ngalia Basin (Mount Eclipse Sandstone). Energy Metals in a joint venture with Paladin Energy continued regional exploration in the northern portion of the Basin between 180km and 350km northwest of Alice Springs. **Bigrlyi** is the main deposit in this area and other zones of mineralisation include Walbiri, Malawiri, Anomalies 4 and 15. Drilling intersected continuations of the mineralised zones at Anomaly 15 and Anomaly 4. High grade mineralisation was intersected at the Camel Flat prospect, in Mount Eclipse Sandstone 35km southeast of Bigrlyi.

Exploration drilling continued at **Cappers** deposit where mineralisation is associated with calcareous alluvium. Toro Energy continued exploration at the **Napperby** deposit which is in calcrete on the northeast part of the basin.

Energy Metals commenced a pre-feasibility study at the **Bigrlyi** deposit 300km northwest of Alice Springs. Metallurgical test work on large diameter drill core samples achieved good recoveries using acid leach techniques.

Cameco Australia Pty Ltd in a joint venture with Paladin Energy continued exploration drilling to locate extensions of the **Angela-Pamela** deposits, 25km south of Alice Springs. In November 2010, the joint venture announced that the project would have a reduced program and budget for the rest of 2010 and 2011. The announcement took into account the uncertainty created by a policy statement made the previous month by the NT government that it would not allow any uranium mine to be built in proximity to Alice Springs.

Toro Energy commenced exploration for sandstone hosted uranium mineralisation in the Wiso Basin.

## Queensland

Paladin Energy Ltd continued exploration drilling in an area extending from 10km to 110km north of the city of Mount Isa in northwest Qld. Exploration tenements are held in joint venture with Summit Resources Ltd and Fusion Mineral Resources. There are more than 14 uranium deposits within these tenements eight of which have significant resources. They are the Valhalla, Skal, Oldin, Bikini, Andersons, Watta, Duke-Batman and Honey Pot deposits. The total uranium resources in the Mount Isa region which are managed by Paladin and its subsidiary Summit Resources Ltd amount to 34 800 tonnes of U<sub>3</sub>O<sub>8</sub> Measured+Indicated Resources and 23 900 tonnes of U<sub>3</sub>O<sub>8</sub> Inferred Resources<sup>56</sup>. Latest resource estimates for these deposits can be viewed in the Paladin Energy Ltd annual report. ([http://media.corporate-ir.net/media\\_files/IROL/17/176316/2011\\_Annual\\_Report.pdf](http://media.corporate-ir.net/media_files/IROL/17/176316/2011_Annual_Report.pdf)).

<sup>56</sup> Paladin Energy Ltd Annual Report 2011

Drilling to extend the known resources was carried out at these deposits during the year and exploration work aimed at locating new deposits continued over part of the area of the tenements.

### Western Australia

Several companies explored for sandstone hosted uranium deposits in Cenozoic (Eocene) sands and lignite of the Gunbarrel Basin overlying the eastern margins of the Yilgarn Craton. Energy and Minerals Australia Ltd continued exploration in areas adjacent to its **Mulga Rock** deposit, 250km east-north-east of Kalgoorlie. The company also released the finding of its scoping study, which investigated production by open pit mining and resin-in-pulp of the lignite hosted deposit, concurrent with in situ recovery of adjacent sandstone hosted deposits. The company reported that the project is expected to be a long term, low cost producer of uranium. Mulga Rock deposit has Inferred Resources of 24 250 tonnes contained  $U_3O_8$ .

Manhattan Corporation continued drilling into paleochannel sands at its Ponton project 180km northeast of Kalgoorlie (40km southwest of Mulga Rock). The **Double 8** deposit and the Stallion South, Highway South and Ponton prospects are within exploration licence applications in the Queen Victoria Spring Nature Reserve (QVSNR). Granting these tenements requires consent of the WA Minister for Mines and Petroleum and the Minister for the Environment. Manhattan is seeking these approvals.

The paleochannel drilling undertaken by Manhattan Corporation was north of the QVSNR. Historic drilling (by PNC Exploration) at the Double 8 deposit was compiled and the company has reported Inferred Resources of 26Mt averaging 300ppm  $U_3O_8$  (7800 tonnes contained  $U_3O_8$ ). Mineralisation is at depths ranging from 40 metres to 70 metres below surface.

Toro Energy explored in several areas of eastern WA and the NT. At the company's Lake Mackay project adjacent to the border with NT in central eastern WA, drilling intersected mineralisation in Cainozoic paleochannel sands adjacent to uranium rich rocks of the Amadeus Basin.

Energy Metals continued exploration for calcrete hosted deposit at the Anketell and Lake Mason deposits southwest of Wiluna north of Kalgoorlie.

### Production

Australia's mine production for 2010 was 5899 tonnes of U (6957 tonnes  $U_3O_8$ ), which was 26% less than for 2009. Production declined at all three operating mines. Ranger, which produced 3792 tonnes  $U_3O_8$  was disrupted by heavy rainfall, Olympic Dam with 2747 tonnes  $U_3O_8$  was disrupted by damage to the main haulage shaft and Beverley with 418 tonnes  $U_3O_8$  was lower because of limited resources remaining at the main Beverley deposit. Mine production has decreased progressively at all three mines since 2007. For the calendar year 2010, Australia, with 11% of world production, was the third largest after Kazakhstan and Canada.

Total world production in 2010 was 53 663 tonnes of U (63 282 tonnes  $U_3O_8$ ), an increase of 6% compared with 2009. Most of the increased production is attributable to significant growth in Kazakhstan's output, which rose 27% to 17 803 tonnes U in 2010, and Niger which rose 29% to 4198 tonnes U in 2010. Uranium requirements in 2010 exceeded production by more than 8900 tonnes U.

### Exports

Exports in 2010 were 6219 tonnes U (7334 tonnes  $U_3O_8$ ) valued at \$755 million. Exports of Australian uranium are controlled by stringent safeguards conditions which ensure that it is used only for peaceful purposes and does not enhance, or contribute to, any military applications. Australian mining companies supply uranium under long-term contracts to electricity utilities in the USA, Japan, China, South Korea and Canada as well as members of the European Union including the United Kingdom, France, Germany, Spain, Sweden, Belgium and Finland.

### Industry Developments

During 2010 and 2011 there were four uranium projects undergoing Australian/State Government environmental approval processes. They were the Olympic Dam Expansion in SA (BHP Billiton) and the Yeelirrie (BHP Billiton), Wiluna (Toro Energy) and Lake Maitland (Mega Uranium) projects in WA.



Olympic Dam, South Australia, is a multi-mineral orebody producing copper, uranium, gold and silver. It is the world's largest uranium deposit (BHP Billiton).

**Olympic Dam (SA):** BHP Billiton proposed a major expansion of the Olympic Dam operation based on a large open pit to mine the southeast portion of the deposit. At full production the open cut and underground operations will mine a total of 80 million tonnes per annum (Mtpa) of ore with annual production estimated to reach 750 000 tonnes of refined copper, 19 000 tonnes of  $U_3O_8$ , 800 000 ounces of gold and 2.9 million ounces of silver. The capacity of the existing underground mine will be increased to approximately 20Mtpa by 2015. The company proposes to expand all four major components of the existing metallurgical processing plant (concentrator, hydrometallurgical plant, smelter and refinery). A further expansion of the concentrator is proposed, which will produce an additional 1.6Mtpa copper concentrates for export and further processing overseas.

BHP Billiton released the Supplement to the Environmental Impact Statement (EIS) on 13 May 2011, triggering the formal assessment process. Geoscience Australia provided advice to Commonwealth Department of Resources, Energy and Tourism and Department of Sustainability, Environment, Water, Population and Communities (SEWPaC). That advice centred on groundwater and tailings storage issues throughout the assessment of the EIS and Supplementary EIS. On 10 October 2011 the Australian and South Australian Governments formally approved the expansion project and imposed a comprehensive range of environmental conditions as part of the approval process.

BHP Billiton's estimates of ore reserves and mineral resources are shown in Table 12.

**Table 12.** Olympic Dam Mineral Resources and Ore Reserves (JORC Code) at June 2011 (Source: BHP Billiton Annual Report 2011).

	Million Tonnes	Copper %	U <sub>3</sub> O <sub>8</sub> Kg/Tonne	Gold Grams/Tonne	Silver Grams/Tonne
Total Mineral Resources <sup>(1)</sup> Measured+Indicated+Inferred	9129	0.86	0.27	0.32	1.48
Total Ore Reserves	552	1.84	0.57	0.76	3.41

1. Mineral Resources includes Ore Reserves

Mine production for 2010 was reduced following damage to the haulage system in the Clark Shaft on 6 October 2009, which reduced the mine's ore hoisting capacity. Following repairs, ore hoisting from the shaft resumed during the June quarter 2010 and the mine returned to full production.

**Ranger mine (NT):** As a result of near record rainfall in latter part of 2010 and early 2011 the level of water in the tailings storage facility (TSF) rose to almost the maximum operating limit. Because there was a large volume of water in Pit 3, mining operations ceased in January and the company suspended metallurgical processing operations to ensure water levels in the TSF remain below the authorised limit. Mining operations recommenced in April 2011 and milling operations resumed in June. Uranium oxide production during 2010 and early 2011 has been adversely impacted.

Energy Resources of Australia Ltd (ERA) carried out detailed feasibility studies into the construction of an exploration decline for underground drilling to further evaluate the extent of the Ranger 3 Deeps ore zone (immediately east of No. 3 orebody open pit). In August 2011, the Board of ERA approved construction of the decline after receiving notification of approval from the NT Government. Work to prepare the site is underway with construction of the box cut scheduled to commence in May 2012. The exploration decline will allow ERA to conduct close spaced underground exploration drilling and explore areas adjacent to the Ranger 3 Deeps resource. The current Ranger 3 Deeps mineral resource contains an estimated 34 000 tonnes of uranium oxide (10Mt averaging 0.34% U<sub>3</sub>O<sub>8</sub>).

ERA completed the feasibility study of a proposed heap leach facility for extraction of U<sub>3</sub>O<sub>8</sub> contained in low grade mineralised material, both in situ and in stockpiles. In August 2011, the company announced that the study demonstrated that this facility was technically feasible, but the high capital costs and present economic assumptions limit its value. There was uncertainty also surrounding stakeholder support so the ERA Board decided not to proceed with the proposed heap leach facility.

**Beverly in situ recovery (ISR) mine (SA):** Heathgate Resources operates the Beverly mine between the North Flinders Ranges and Lake Frome, approximately 300km northeast of Port Augusta. Uranium production has declined in recent years as the company mines the remaining resources within the Beverly mining lease. By 2010, the deposit had been completely mined and production was mainly from old wellfields, some of which closed several years ago. The company re-activated these old wellfields from where additional uranium was produced.

**Beverly North ISR mine (SA):** Beverly North comprises the Pepegooona deposit, 12km north of Beverly mine and the Pannikan deposit, 10km northwest of Beverly. Field leach trials were completed in late 2010 at the Pepegooona deposit. Following assessment of the environmental impacts under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) in 2010 formal approval by the Australian and South Australian Governments was granted in February 2011 and ISR operations commenced in the same month. Total time from discovery in late 2009 to full operations was 16 months.

Beverly North is mined by a satellite ISR operation. Although commonly used in the USA and Kazakhstan, this is the first time the technique has been used in Australia. The satellite operation comprises wellfields, pumps, pipelines and facilities for circulation of the mining (leach) solutions, and ion exchange columns. Uranium is captured on resins within the ion exchange columns and when the resin is completely loaded with uranium, it is transferred into a road tanker and transported to the Beverly plant for metallurgical processing to recover the uranium. After the uranium has been removed, the clean resin is transported back to Beverly North for reuse in the ion exchange columns.

During the first quarter of 2011, combined production at Beverly plant was 30% from old re-activated wellfields at Beverly deposit and 70% from Beverly North.

**Four Mile ISR project (SA):** Four Mile comprises two large sandstone-hosted uranium deposits, Four Mile West and Four Mile East and is 75% owned by Quasar Resources (affiliate of Heathgate Resources) and 25% owned by Alliance Resources. It is proposed to construct a satellite ion exchange plant at Four Mile East. Loaded resin will be transported to the Beverly plant where uranium will be stripped from the resin and processed to produce uranium hydroxide concentrates. The clean resin will be returned to the Four Mile satellite plant for reuse.

In October 2009, Alliance Craton Explorer Pty Ltd, which is owned by Alliance Resources, issued legal proceedings against Quasar Resources. As a result, issues surrounding the registration of a Native Title Mining Agreement have not been resolved and the SA government is unable to issue a mining lease for the project until these legal issues are resolved. Development of the project has been delayed pending resolution of litigation.

**Honeymoon ISR mine (SA):** Honeymoon mine is located 75km northwest of Broken Hill. Construction of the solvent extraction plant, pulse columns and water treatment facilities for the ISR operations continued. Commissioning of the ground water treatment plant and operation of the calcium sulphate removal circuit commenced in the latter part of 2010 and early 2011. The South Australian Environmental Protection Authority and Primary Industry and Resources SA have granted authorisation to begin wellfield acidification. Production commenced in late 2011 at 400 tonnes  $U_3O_8$  a year.

**Oban ISR project (SA):** Curnamona Energy carried out field leach trials at the Oban deposit, about 100km northwest of Broken Hill. Acid leach solutions and an oxidant were used in the trials. A five well pattern, comprising four injection and one central extraction well was used, which is analogous to in situ recovery operations at Beverley and Honeymoon.

The trials continued for several months and the company reported that plant and wellfield worked according to design but only low levels of uranium were detected in leach solutions. Commenting on the results, Curnamona Energy reported<sup>57</sup>:

*"The reasons are not entirely clear but it is most likely that the bulk of the uranium minerals are contained in thin (5–20mm) bands of clay which occur in the sand bands that we are attempting to leach. These thin bands are not detected in the gamma and Prompt Fission Neutron logging and only show up in the core samples which are very difficult and expensive to obtain. Experiments with alternative lixivants have dissolved some uranium in solution but the rates of dissolution are low and not acceptable. We suspect that this is due to the impervious nature of the clay bands."*

Work on the field leach trial will continue. Further sonic drilling is planned in new areas where further leach tests are proposed.

**Yeelirrie project (WA):** BHP Billiton plans to mine the Yeelirrie deposit, 70km southwest of Wiluna. Uranium mineralisation occurs in calcretes within a paleochannel and the deposit is at shallow depths down to 15 metres below the surface. Yeelirrie currently has total resources of 52 500 tonnes  $U_3O_8$  and is Australia's second largest undeveloped uranium deposit. BHP Billiton produced an environmental scoping document for the Yeelirrie EIS and the environmental impacts will be assessed by the WA Government under a bilateral agreement with the Australian Government. In mid 2011, BHP Billiton placed the Yeelirrie project on hold until further notice.

**Wiluna project (WA):** Operated by Toro Energy Limited the project comprises two shallow (less than 8 metres deep) calcrete hosted deposits, Lake Way and Centipede, which are 15km south and 30km south of Wiluna respectively. Lake Way has Inferred Resources of 10.53Mt averaging 543ppm  $U_3O_8$  (5714 tonne contained  $U_3O_8$ ) and Centipede has total Measured+Indicated+Inferred Resources of 9.7Mt averaging 553ppm  $U_3O_8$  (5355 tonne contained  $U_3O_8$ ). In mid 2010, the company mined an evaluation pit (45 000 tonne) at the Centipede deposit to increase confidence in the resource estimates and in the proposed mining method. Mining was carried out using a surface miner together with excavators and trucks. Bulk samples were collected for metallurgical test work. Two options for processing the calcrete ores were investigated, alkaline heap leaching and agitated alkaline leaching in tanks. Optimisation studies showed that alkaline agitated leaching in tanks at elevated temperatures to be the preferred process option. It is proposed to produce uranium concentrates containing approximately 1000 tonnes  $U_3O_8$  per annum.

In March 2011, Toro Energy Ltd submitted a draft Environmental Review and Management Program which will be the basis for environmental assessment of the project by both the Australian and Western Australian Governments.

**Lake Maitland project (WA):** is a calcrete hosted uranium deposit 100km south east of Wiluna which occurs as a single horizontal layer 1 metre to 3 metres thick and the top of the mineralised zone is 1 metre to 2 metres below the surface. In 2010, Mega Uranium Ltd commenced feasibility studies on developing an open cut operation and focused on various processing, engineering and infrastructure options. In late 2010 two test pits, approximately 34 metres long by 19 metres wide and 5metres deep were mined as part of the feasibility study. The objectives of the test pits were to:

- Validate the geological model interpreted from drilling data and costean programme;
- Demonstrate that a truck and excavator mining method is viable and that the ore and overburden can be excavated without blasting; and
- Demonstrate that selective mining is achievable using high precision GPS equipment on an excavator.

<sup>57</sup> Curnamona Energy Ltd, 2011. Annual report to Australian Securities Exchange, October 2011.

In October 2010, Mega Uranium Ltd received approval from the Environmental Protection Authority of Western Australia for the Environmental Scoping Document (ESD) for the project.

The ESD identified the key potential environmental impacts in connection with the project and defined the scope of the environmental investigations and studies which are being carried out to complete the environmental review and management program, which is the next stage in the assessment and approval process.

**Kintyre project WA:** Cameco completed a mineral resource estimate on 31 March 2011 which had Indicated Resources of 25 583 tonnes contained  $U_3O_8$  at an average grade of 0.49%  $U_3O_8$  and Inferred Resources of 2404 tonnes contained  $U_3O_8$  at an average grade of 0.47%  $U_3O_8$ . Further drilling was aimed at testing the depth extensions of the deposits. The company submitted an Environmental Scoping Document to the Australian and Western Australian Governments in November 2010. It is proposed to mine the deposit by open cut with planned production in the range 2700 tonnes to 3500 tonnes  $U_3O_8$  per annum.

## Other Developments

In recognition of its important natural and cultural values, the **Koongarra** area, along with its contained uranium deposit was added to the Kakadu World Heritage Area by the World Heritage Committee on 27 June 2011. The inclusion of Koongarra into the Kakadu World Heritage Area means that it will have protection under the EPBC Act.

On 22 July 2011, the Premier of SA announced the establishment of the Arkaroola Protection Area which will, as a first step, be reserved from operation as a result of the Mining (Reservation from Act) Proclamation 2011 under section 8 of the SA Mining Act. It is proposed ultimately to enact legislation protecting the area and follow that with an application for World Heritage Listing. As a result, future exploration and mining titles will not be granted in the designated Area.

The Four Mile (both East and West) deposits, the Four Mile South prospect and the area of the mining lease application (MLA) are outside the Arkaroola Protection Area and are not affected by this announcement. However it does cover approximately 38% of exploration licence (EL) 3666 in which Alliance Resources has a 25% interest. Based on the announcement, that area will not be available when application for a subsequent licence is lodged later this year. This will prevent mining on the area covered by Marathon Resources' Mount Gee exploration licence (EL4355).

## Vanadium

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Vanadium (V) is used in metal alloys with iron to produce high strength steel which has a range of uses. These include structural applications such as gas and oil pipelines, tool steel, the manufacture of axles and crankshafts for the motor vehicle industry and in jet engines for the aircraft industry as well as for reinforcing bars in building and construction.

Non-steel uses include welding and in alloys used in nuclear engineering and superconductors. Vanadium chemicals and catalysts are used in the manufacture of sulphuric acid, the desulphurisation of sour gas and oil and in the development of fuel cells and low charge time, light weight batteries.

Vanadium is sold as vanadium pentoxide ( $V_2O_5$ ), or less commonly as vanadium trioxide ( $V_2O_3$ ) and as an alloy of iron and vanadium, most commonly as FeV80 which has 80% contained vanadium, or as FeV50.

Primary production of vanadium from mining and processing of magnetite ores accounts for only 29% of annual world production of vanadium. The majority of world production of vanadium (56%) is recovered from slag produced as a by-product of steel making, while the remaining world production (15%) is recovered from wastes, including fly ash and oil residues.

Vanadium prices have fluctuated during the past decade, with sharp rises and equally sharp declines over short periods. Historically, prices have ranged from US\$1.30 a pound  $V_2O_5$  to more than US\$20 a pound. Average prices fell from US\$14.75 a pound  $V_2O_5$  in 2008 to US\$4.00 a pound in 2009 in response to the impacts of the global financial crisis and the decreased demand for vanadium from the steel industry in many countries. During 2010, prices for  $V_2O_5$  slowly increased to US\$7.50 a pound by May but decreased again in the second half of the year to US\$7.41 early in 2011.

## Resources

Australia's Economic Demonstrated Resources (EDR) of vanadium decreased by 34% in 2010 to 1762 kilotonne (kt) as a result of a reassignment of resources for some deposits to the paramarginal category.

Historically, Australia's EDR have fluctuated because of the economic impacts of volatile prices and the nature of the vanadium market, which is supplied largely from secondary sources, including reprocessing of slags from iron smelting. These secondary sources are able to rapidly increase or decrease output in response to price trends.

## JORC Reserves

About 67% of Accessible Economic Demonstrated Resources (AEDR) is made up of Joint Ore Reserve Committee (JORC) Code Reserve. The remaining 33% of AEDR represents resources assessed by Geoscience Australia from the Measured and Indicated categories of industry reported mineral resources, as defined under the JORC Code.

## World Ranking

Based on the US Geological Survey Mineral Commodity Summary for 2010 the world's largest economic resources of vanadium are in China which has around 5100 kt followed by the Russian Federation with 5000 kt and South Africa with around 3500 kt. It is not possible to determine definitively Australia's ranking, but Geoscience Australia data indicates that Australia has the world's fourth largest resources.

## Exploration

Data on exploration expenditure for vanadium are not available in published statistics. However, during 2010 exploration or resource drilling was undertaken at Lilyvale in Queensland (Qld) by Intermin Resources Ltd, at Hawkwood (Qld) by Eastern Iron Ltd, at Biglyi in the Northern Territory (NT) by Southern Cross Exploration NL, at Analy Hill in Western Australia (WA) by Black Ridge Mining NL and at Windimurra (WA) by Atlantic Ltd.

## Production

There was no production of vanadium in Australia during 2010. Although there are a number of vanadium deposits in Australia, Windimurra, has been the only deposit mined in recent years. Most of the world's mine production of vanadium during 2010 was in China (38%), South Africa (33%) and Russia (26%).

## Industry Developments

During 2010, vanadium resource figures were updated by Intermin Resources Ltd for its **Julia Creek** project (Qld), TNG Ltd for its **Mount Peake** (NT), NiPlats Australia Ltd for the **Speewah** project (WA) and Yellow Rock Resources Ltd for its **Gabanintha** project (WA). In contrast, Atlas Iron announced marginally reduced resources for the **Balla Balla** deposit (WA) as a result a feasibility study and re-estimation of resources. Several companies undertook metallurgical studies on samples, including material from the Hawkwood deposit (Qld) operated by Eastern Iron Ltd, Mount Peake (NT) operated by TNG Ltd and the Speewah project (WA) operated by NiPlats Australia Ltd. Atlantic Ltd successfully acquired the **Windimurra** project and commenced planning reconstruction of the plant and mine for resumption of operations in 2011/12.

For further information on industry developments please refer to vanadium chapter in AIMR2010:  
[http://www.ga.gov.au/image\\_cache/GA19253.pdf](http://www.ga.gov.au/image_cache/GA19253.pdf)

## Zinc, Lead, Silver

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**Zinc** (Zn) is the 23rd most abundant element in the Earth's crust and the 4th most common metal in use after iron, aluminium and copper. The construction, transport and appliance manufacturing industries use large amounts of zinc, mainly as anti-corrosion coatings (galvanizing) on sheet steel, steel beams, vehicle panels, chain-link fencing, guard rails and light posts. World-wide, around four million tonnes (Mt) of zinc is used annually to protect around 100Mt of steel, representing almost half of the world's total consumption of zinc. The widespread use of zinc as a protective coating is due mainly to its resistance to normal weathering. This is an electrochemical reaction known as galvanic action. Zinc is more reactive than iron or steel and consequently attracts almost all local oxidation. A protective surface layer of oxide and carbonate forms as the zinc corrodes. Zinc is used also in brass (almost 20% zinc), alloys (16%) such as for die cast precision components, pigments, salts, as oxide additives to rubber and for agricultural chemicals as well as for wrought or rolled products. Zinc metal is produced in Australia at Sun Metals' Townsville refinery in Queensland (Qld) and at Nyrstar NV's Hobart refinery in Tasmania (Tas).

The widespread occurrence of **lead** (Pb), its relatively simple extraction and a combination of desirable properties have made it useful to humans since at least 5000 BC. In deposits mined today, lead, mainly in the form of galena (PbS), is usually associated with zinc, silver (Ag) and sometimes copper (Cu) and is extracted as a co-product of those metals. The largest use is in batteries for vehicles, which accounts for 80% of modern lead usage. The remaining 20% of applications include underwater cable sheathing, solder, casting alloys, chemical compounds, ammunition, glassware and radiation protection. Uses for lead could increase in the future in large storage batteries used for load-levelling of electrical power and in electric vehicles. The growing popularity of electric bikes, particularly in China, has led to the e-bike now consuming more than 8% of world lead production. More than half of the lead currently used is from recycling rather than from mining. Lead recycling plants jointly owned by Nyrstar NV and the Sims Group are in Melbourne, Victoria (Vic) and in Sydney, New South Wales (NSW). Nyrstar NV's Port Pirie smelter in South Australia (SA) is the world's largest primary lead smelting facility and a leading global silver producer.

The relative scarcity, attractive appearance and malleability of **silver** make it suitable for use in jewellery, ornaments and household silverware. Its extensive use in coins throughout history has declined over the past 50 years. In Australia, the 1966 50 cent piece was the last coin in general use to contain silver (80% Ag, 20% Cu). Silver is mined and produced mainly as a co-product of lead, zinc, copper and, to a lesser extent, gold (Au). Currently, jewellery, photographic paper and film, followed by electronics and tableware, are the most important users of silver. Other applications include coatings for mirrors, for biocide and bacteriostatic activity in plastic and textiles formulations and as an anti-bacterial agent in areas such as water treatment including, for example, as an ioniser with copper in domestic swimming pools.

### Resources

Australia's total resources of zinc, lead and silver rose significantly in 2010. Total identified resources of zinc rose by 9Mt to 94Mt in 2010, lead by 6Mt to 60Mt and silver by 7 kilotonne (kt) to 126kt.

#### Zinc

Australia's Economic Demonstrated Resources (EDR) of zinc increased by 7Mt to 65Mt and accounts for around 25% of world economic resources and is the world's largest holding. Queensland continued to hold the largest resource with 35Mt, or 54% of national EDR, predominantly at the George Fisher, Mount Isa, Century and Dugald River deposits. The Northern Territory (NT) had the second largest EDR with 19Mt, or 29% of national EDR, all at the McArthur River deposit. Following was NSW with 5Mt EDR, up from 4Mt in 2009 and mostly at the Broken Hill and Endeavor deposits, and then, Western Australia (WA) with 3Mt, mostly at the Golden Grove, Sulphur Springs and Jaguar-Bentley deposits. Total inferred zinc resources increased to 24Mt in 2010.

#### Lead

Australia's EDR of lead increased by 4Mt in 2009 to 35Mt of contained lead and constituted 57% of Australia's total identified lead resources. Australia also accounts for the largest share of world economic resources for lead at 39%. Queensland retained the top ranking with its EDR increasing from 18Mt in 2009 to 19Mt in 2010, which

represents a 56% share of national EDR. The NT lead EDR ranks second with 8Mt or 24% of the national total, almost all of which is at the McArthur River mine. New South Wales recorded an increase in EDR from 3Mt in 2009 to 4Mt. Australia's Paramarginal Demonstrated Resources of lead decreased by 1Mt to 4Mt, which is 7% of total Identified Resources, as more of the older resources are re-drilled and re-estimated under the Joint Ore Reserve Committee (JORC) Code. Total Inferred Resources of lead increased slightly in 2010 to 21Mt.

### Silver

EDR for silver is 77kt which is 15% of world economic resources. Queensland has 44kt or 57% of Australian EDR, mainly in the Cannington, Mount Isa, George Fisher, Dugald River and Century deposits. Most other silver EDR occurs in SA (11kt), the NT (8kt), NSW (8kt), WA (3kt) and Tas (3kt). In SA, most silver EDR is at Olympic Dam with some at Prominent Hill, while in the NT silver EDR is nearly all at McArthur River. In NSW it is mostly at Broken Hill and Endeavor, while in WA it is predominantly at Golden Grove, Spinifex Ridge and Jaguar-Bentley.

### Accessible EDR

All zinc, lead and silver EDR is accessible.

### JORC Reserves

Of Australia's EDR of zinc, 33% occurs in the JORC Code ore reserves categories. The remaining EDR is made up of those measured and indicated resources as reported by mining companies and which Geoscience Australia considers will be economic over the long term. The zinc resource life using national EDR divided by annual production is 44 years, but using the ore reserve and dividing by annual production gives a resource life of only 14 years.

Of Australia's EDR of lead, 34% occurs in the JORC Code ore reserves categories. For lead, the national EDR/production ratio is 49 years, but if the ore reserve/production ratio is used it is 17 years. For silver, JORC Code reserves account for around 36% of EDR and resource life is 41 years for EDR or 15 years for JORC Code reserves.

### Exploration

In 2010, exploration spending on zinc, lead and silver was \$67 million, 39% higher than in 2009. The 2010 expenditure was 12% of the total base metal expenditure of \$563 million compared to 13% in 2009. Expenditure on exploration for the three commodities made up only 2.7% of all mineral exploration of \$2.49 billion (excluding petroleum), and compared to 2% in 2009.

### Production

According to the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), 2010 Australian mine production of zinc, lead and silver was 1.48Mt, 0.712Mt and 1.88kt, respectively. Compared to 2009, production in 2010 increased by 15%, 26% and 15% for zinc, lead and silver respectively. The majority of production was from Qld which contributed 994kt, or 67% to national zinc production during 2010 (up 179kt on 2009) along with 474kt or 67% of lead (up 66kt) and 1.60kt or 85% of silver. Western Australia produced 99kt of zinc and 31kt of lead with both increasing over the 2009 production levels. The large increase in lead production in WA resulted from reopening of the Magellan mine (see below). Elsewhere, NSW produced 102kt zinc and 75kt lead, the NT 180kt zinc and 31kt lead and Tas 86kt zinc and 28kt lead. In all of these states production of zinc and lead was similar to that in 2009.

The Century zinc mine, which is located close to the Gulf of Carpentaria about 250 kilometres (km) north of Mount Isa in northwest Qld, ranks in the top few globally in zinc production. Century produced 511kt of zinc and 38.7kt of lead as metal-in-concentrate in 2010. The Cannington mine, also located in northwest Qld, is the world's largest and lowest cost single mine producer of both silver and lead as well as a significant producer of zinc. Cannington produced 256kt of lead, 1.2kt of silver and 59.7kt of zinc in 2010. Also in Qld are Xstrata's Mount Isa operations which produced 355kt of zinc, 144kt of lead and 211t of silver (including 50t in silver from purchased concentrate) in 2010.

The value of Australia's exports of zinc concentrates and refined zinc in 2010 totalled \$2376 million, 32% more than the \$1804 million in 2009 and 1% of the value of total merchandise exports. The amount of zinc exports

increased by 5% to 1.5Mt in 2010. The average price for zinc in 2010 was \$2419 a tonne, 8% higher than the average of \$2233 a tonne in 2009. The 2010 December quarter average price was slightly higher than for the December quarter in 2009.

Exports of lead totalled 661kt in 2010, up 2% on 2009. The value of the 2010 exports was 17% higher at \$1938 million compared to \$1651 million in 2009. The average price for lead was 10% higher at \$2631 a tonne compared to the average of \$2376 a tonne in 2009. However, lead prices were 5% lower when comparing December quarters. For silver, the average price was 18% higher at \$695 a kilogram (kg) compared to the average of \$589/kg in 2009 with a 39% December on December increase. The value of Australia's mine production of silver was \$1311 million in 2010, up 36% on 2009.

## World Ranking

Based on United States Geological Survey (USGS) data for other countries, Australia has the world's largest economic resources of zinc (25%), lead (39%) and silver (15%). In terms of production, Australia ranks third for zinc after China and Peru, second for lead after China and fourth for silver after Peru, Mexico, and China.

## Industry Developments

**Mount Isa (Qld):** Mount Isa zinc-lead operations commenced production in 1931 and were acquired by Xstrata Plc in 2003. Operations currently comprise the George Fisher underground mine, the open cut mines of Black Star and Handlebar Hill, an eight million tonnes per annum (Mtpa) capacity zinc-lead concentrator, a lead smelter and a zinc filter plant. During 2009 there was extensive restructuring of Mount Isa operations, resulting in a 40% reduction in costs. This restructuring flowed on to major increases in production in the Mount Isa operations. Ore treated increased by 15%, from 7.42Mt in 2009 to 8.57Mt in 2010. Underground production at George Fisher was at record levels at 3.3Mt, while production at the Black Star open cut was 4.5Mt, 32% higher than in 2009. However, the head grades were slightly lower. Overall this resulted in increases in zinc and lead in concentrate of 10% and 14%, respectively. Together, the cost savings and increased zinc and lead volumes contributed to a profit of \$270 million for Xstrata's Australian zinc operations, including McArthur River (see below), compared to \$192 million in 2009. Smelter production of lead in bullion of 140kt was 4% lower than in 2009, mainly as a result of a decrease in third-party concentrate supply.

During 2010 and the 2011, a number of announcements were made by Xstrata regarding expansion of the Mount Isa operations. Expansions of the Black Star open cut and the George Fisher underground mines were made in March and September 2010 respectively. The Black Star Deeps development will extend its life to 2015, and the George Fisher development will increase production 28% by 2013. In addition, a pre-feasibility study was commissioned in the latter half of 2011 into the development of a large open cut zinc-lead-copper mine at Mount Isa. If developed, this project will extend the life of the combined zinc-lead and copper operations until 2060. Finally, following purchase of the remaining 25% stake in the Lady Loretta deposit from Cape Lambert Resources in February, Xstrata approved a \$246 million development in July 2011, with immediate development of a decline. The ore will be trucked 140km to the Mount Isa milling operations.

**McArthur River (NT):** Underground mining at McArthur River began in 1995, with open cut mining beginning in 2009. The conversion to open cut mining combined with a concentrator expansion increased production capacity to 2.5Mtpa in 2009. Actual ore treated increased slightly (3%) to 2.23Mt in 2010. Higher zinc grades resulted in an increase in zinc in concentrate of 10% to 184kt, but lower lead grades resulted in a decrease in lead in concentrate of 15% to 31.6kt. In March 2011 Xstrata announced a \$270 million plan to more than double concentrate production from McArthur River. The increase in production is seen as critical for the viability of the mine by decreasing unit production costs. However, this development necessitates the installation of proprietary hydrometallurgy technology in company smelters in Europe and improvements to the Brunswick smelter in North America to allow processing of the bulk zinc-lead concentrates produced from McArthur River. If the development plan is successful, mine life will be extended by six years to 2033.

**Century (Qld):** The Century mine is one of the world's three largest zinc mines, producing 4% of global production. Minerals and Metals Group (MMG), a Chinese-owned corporation, acquired the Century, Rosebery and Golden Grove mines, amongst others, in early 2009. During 2010, production of zinc in concentrate from the Century operation increased by 42% over 2009, and lead in concentrates increased by 138%. Total silver production was 95.5 tonnes, an

increase of 222% over 2009. The increase in production was due to resolution of the failure of the zinc-transporting pipeline to port at Karumba and the lack of the major rain events which disrupted production in 2009. The much higher relative increases in lead and silver production is the result of mining ore with twice the grades of lead and silver as that mined in 2009. At current rates of production, mine life extends to 2015. An 18-month exploration program in 2009–10 failed to identify new resources at the mine, or in adjacent exploration leases.

**Cannington (Qld):** The Cannington deposit in northwest Qld was discovered in 1990 by BHP-Billiton, with mining operations commencing in 1997. Production in 2010 increased on that achieved during 2009 by 14% and 13% for silver and lead respectively. This increase in production was the result largely of higher silver and lead grades (up 11.7% and 10.2%, respectively) and a small (2.8%) increase in ore milled. A slight decrease in zinc grades offset the increase in ore milled so that 2010 zinc production was similar to that of 2009.

**Rosebery (Tas):** In 2010, metal in concentrate produced at the Rosebery operations of MMG was 86.2kt of zinc, 27.0kt of lead, 2.3kt of copper, 1.09t of gold and 78.3t of silver. This production is broadly similar to that achieved in 2009. Ore from the nearby South Hercules mines is expected to be delivered to the Rosebery mill on a trial basis in the 2011 December quarter. Near-mine exploration is targeting deep targets below the Rosebery orebody and a new mineralised horizon identified to the north of the mine at the Jupiter prospect. Rosebery currently has a mine life beyond 2020.

**Golden Grove (WA):** MMG's Golden Grove operation consists of the Scuddles and Gossan Hill underground mines and the Scuddles processing plant. In 2010, a greater emphasis was placed on zinc production, with a commensurate increase in zinc-in-concentrate and lead-in-concentrate production of 29% to 73.3kt and 78% to 7.75kt. Silver-in-concentrate and gold-in-concentrate production also increased substantially by 38% to 59.2 tonnes and by 25% to 1.13 tonnes, respectively. Copper-in-concentrate production increased marginally to 33.3kt. These increases in production were on the basis of a 46% increase in the tonnage of zinc ore milled to 580kt, although at lower grades (13.9% in 2010 compared with 16.8% in 2009). The amount of copper ore milled, 1017kt, was similar to 2009, but at a slightly higher grade (3.9% in 2010 compared with 3.4% in 2009). The Scuddles mine was on care and maintenance through 2010, re-opening in April 2011. In the first half of 2011, approval was granted for development of a shallow copper resource at Gossan Hill. Near-mine exploration targeted down-plunge extensions of the Scuddles and Gossan Hill ore bodies and testing of near-mine prospects south of Golden Grove. Work on an additional tailings storage facility with a 15-year life was completed in September. At current production rates, the Golden Grove reserves will support mining operations until 2016.

**Broken Hill (NSW):** In 2010 Perilya Limited increased ore production from their Southern Operations at Broken Hill, treating a total of 1.64Mt, compared with 1.4Mt in 2009. However, the processing of lower grade ore resulted in decreased production of metal-in-concentrate. Relative to 2009, zinc production, at 63.6kt, and lead production, at 51.2kt, each decreased 10%. Silver production was 44.7 tonnes, down from 56 tonnes in 2009. In December Perilya reported an 18% increase in ore reserves for its Southern Operation to 15.26Mt at 5.3% Zn, 4.0% Pb and 42 grams per tonne (g/t) Ag and a 13% increase in total mineral resources to 23.7Mt at 9.4% Zn, 7.3% Pb and 89g/t Ag. These reserves provide for at least 10 years of production at the Southern Operations. Perilya's three other developments, North Mine, North Mine Deeps and the Potosi project remained on care and maintenance throughout 2010.

In 2010, CBH Resources Limited continued to push towards production at its Rasp development, which had been placed on care and maintenance in June 2008. Approval from the New South Wales Department of Planning for development was gained in January 2011 and development was approved by the Toho Board (see below) in February. Full scale production is now expected in mid 2012. Current mineral resources stand at 16.5Mt at 6.6% Zn, 5.1% Pb and 89g/t Ag (reported on 1 July 2009). At an annual production of 0.75Mt, annual production would be 48kt of zinc, 39kt of lead and 72 tonnes of silver over 15 years. In September 2010, CBH Resources was taken over by Toho Zinc Company Limited of Japan.

**Endeavor (NSW):** Because of the takeover of CBH Resources by Toho Zinc in September 2010, production figures for zinc and lead at the Endeavor mine near Cobar in NSW are available for the March and June quarters only. Production during this period was 14.8kt of zinc and 9.0kt of lead, which was 11.3% and 6.2%, respectively, lower than the corresponding period in 2009. Silver production at Endeavor during 2010 was reported by Couer d'Alene Mines Corporation, which owns silver production, at 18.2 tonnes (566134 ounces).

**Angas (SA):** Operations began at Terramin Australia Ltd's underground Angas mine in July 2008 at a setup cost of \$71 million. The mine reached nameplate production capacity of 0.4Mtpa in the second half of 2009. Production for 2010 was 19.3kt of zinc, 8.4kt of lead, 145 tonnes of copper, 7.7 tonnes of silver and 0.108 tonnes of gold, all as metal in concentrate. Production of all metals in 2010 exceeded production in 2009. On 31 December 2010, Angas had reserves of 1.69Mt at 6.95% Zn and 2.80% Pb, which are sufficient for a further four year operation at current production rates. Terramin is undertaking both near-mine and regional exploration, including at many nearby historic mine sites which have not been the subject of modern exploration. More regionally, successful exploration at the Meninnie zinc prospect (SA), 450km northwest of Adelaide, has doubled the resource, which now stands at 7.7Mt grading 3.1% Zn, 2.6% Pb and 27 g/t Ag.

**Mungana (Qld):** Kagara Limited's zinc interests are centred on the Mount Garnet-Chillagoe region of north Qld and include mines at Mungana, Mount Garnet and Balcooma and ore processing facilities at Mount Garnet (separate facilities for copper and polymetallic ores) and Thalanga. The Thalanga facility was refurbished in 2010, converting it from a copper-only circuit to a polymetallic facility with a capacity for oxide ores. This facility was commissioned in October using ores from the Vomacka deposit. Zinc in concentrate production in 2010 across Kagara's north Qld operations was 38kt, similar to that in 2009, but copper and lead production decreased by 26% and 10% to 17.8kt and 1.2kt respectively. Silver and gold production was 15.8t and 106kg respectively. Production was impacted by a prolonged wet season, delays in mining of the Vomacka deposit, road closures and plant down time.

**Jaguar—Bentley (WA):** The Jaguar project consists of three high grade deposits, Jaguar, Teutonic Bore, and Bentley, located approximately 300km north of Kalgoorlie. Perth-based Jabiru Metals Limited began operations at Jaguar in 2007 and production in 2010 was 20.2kt of zinc and 9.66kt of copper from 0.362Mt of ore. Although copper production was similar to 2009, zinc production was 39% lower because of lower grades. In late 2008, Jabiru discovered the Bentley deposit, 4km to the south and of a similar size to Jaguar. The total pre-mining mineral resource at Bentley stood at 3.038Mt grading 9.8% Zn, 2.7% copper, 139 g/t Ag and 0.7 g/t Au (including ore reserves of 2.45Mt grading 8.6% Zn, 1.5% Cu and 106 g/t Ag). Production began in June 2011, with ore being processed through the Jaguar concentrator. Jabiru Metals Ltd was taken over by Independence Group in February 2011.

**Que River and Hellyer—Fossey (Tas):** Following cessation of Bass Metals mining activities at the Que River mine in September, the last shipment of ore was made in October to the MMG Rosebery mill. A total of 31.4kt of ore grading 14.7% Zn, 8.2% Pb, 0.3% Cu, 261g/t Ag and 3.9g/t Au was mined during 2010. Metals-in-concentrate from the Que River ore are included in the Rosebery operations described above.

During 2010, most of Bass Metals activities were directed towards starting the Hellyer Mining Project, which includes development of the Fossey and Fossey East deposits, discovered in 2007 and 2010 respectively, along with extraction of remnant ore and resuming re-treatment of tailings from the historical Hellyer Mine. The last activity involves developing methods of extracting metallurgically refractory gold from the Hellyer tailings. Work to develop a decline to access the Fossey deposit and refurbish the Hellyer mill began in January. First ore production from Fossey was achieved in March 2011. Under an off-take agreement Bass has committed 100% of zinc and lead concentrate to Nyrstar NV.

**Magellan (WA):** Magellan Metals Pty Ltd, which is a wholly owned subsidiary of Toronto-listed Ivernia Inc, totally owns the Magellan deposit, 30km west of Wiluna. Lead production at this deposit, which is the largest known carbonate lead deposit in the world, began in October 2005, with concentrates sold overseas and shipped initially from the Port of Esperance. However, because of lead contamination at the port, shipping was suspended and the mine was placed on care and maintenance in April 2007. Mine production re-commenced in February 2010 following revision of concentrate transport procedures with the concentrate being shipped through the Port of Freemantle. However, production ceased again in early January 2011 following a stop order on the transportation of lead carbonate and the mine was placed on care and maintenance. Total production at Magellan in 2010 was 44.1kt of lead-in-concentrate, but no zinc or silver were produced.

**Other zinc-lead-silver developments:** There are several zinc-lead-silver prospects at various stages of development which could come on line in the next decade. The most significant of the zinc-lead projects is the **Dugald River** deposit (Qld), which is owned by MMG. This deposit, the first zinc deposit discovered in the Mount Isa region, was the subject of a feasibility study in 2008, which was updated in 2010. The feasibility study indicated a mine life of 23 years based on a resource of 53Mt grading 12.5% Zn, 1.9% Pb and 36g/t Ag. Progress on this project is continuing, with an environmental impact statement released in March 2011 for public comment and a decision to proceed expected in the latter part of 2011.

After Dugald River, the most advanced project is the Independence Group's Stockman project (Vic) which includes the **Wilga** and **Currawong** volcanic-hosted massive deposits with a combined resource of 12.69Mt grading 4.4% Zn, 0.7% Pb, 2.1% Cu, 39g/t Ag and 1.0g/t Au. At the time of writing this report, a defensible feasibility study and an environmental effects statement for this project were being prepared. Another project for which a defensible feasibility study was completed is YTC Resource's **Hera** project near Cobar in NSW. Based on a global resource of 2.44Mt grading 3.8% Zn, 2.8% Pb, 0.2% Cu, 16.7g/t Ag and 4.1g/t Au, the feasibility study indicated a financially and technically robust project with a minimum 7.3 year mine life. This result would be enhanced by a significant resource at the nearby **Nymagee** prospect.

Venturex Pt Ltd has consolidated many of the zinc-lead resources in the Pilbara region (WA) into its Pilbara VMS Copper-Zinc Project. The project includes the **Whim Creek**, **Mons Cupri**, **Salt Creek**, **Evelyn** and **Sulphur Springs** deposits. Current resources for the consolidated project total 26.274Mt grading 3.0% Zn, 0.3% Pb, 1.2% Cu, 19.8 g/t Ag and 0.1 g/t Au. The company is conducting a bankable feasibility study, which began in February 2011.

The **Myrtle** project (NT) is located about 40km south of the MacArthur River deposit in the same host succession. The owner of this project, Rox Resources, has attracted Teck Australia as a joint venture partner. This project is still at the exploration stage, but has a total resource of 43.6Mt grading 4.09% Zn and 0.95% Pb, with a higher-grade resource of 15.3Mt grading 5.45% Zn and 1.40% Pb.

At Kagara's **Admirals Bay** deposit in the Canning Basin (WA), a pre-feasibility study identified mineral resources of 72Mt grading 3.1% Zn, 2.9% Pb, 18 g/t Ag and 20% barite. However, this deposit is located more than a kilometre below the surface and requires a large injection of money to bring the project to bankable feasibility status.

**Silver:** One of the more interesting developments over the past few years in the zinc-lead-silver sector has been the interest in projects in which silver is the main commodity, with zinc and lead as by-products or co-products. This activity is occurring in NSW and Qld, particularly in the New England and Lachlan Orogens, and includes a producing mine at **Twin Hills** (Qld), an advanced project at **Wonawinta** (NSW) and several other projects at various stages of development. At its Texas Project, Alcyone Resources Ltd began re-commissioning the Twin Hills mine in February this year, with irrigation of historic heap leach stockpiles beginning in April and the first silver production in June. At the time of writing this report, mining had not commenced, but Alcyone has identified mineral resources at Twin Hills deposit of 3.642Mt grading 83g/t Ag and 0.08g/t Au and 2.347Mt at the nearby **Mount Gunyan** grading 77g/t Ag and 0.09g/t Au.

At the Wontawinta deposit, in the Cobar mineral field, Cobar Consolidated Resources Ltd completed a bankable feasibility study in December 2010, with a decision to mine taken in June 2011. At present the project is based on an ore reserve of 4.6Mt grading 97g/t Ag and 1.4% Pb within a mineral resource of 21.9Mt grading 72g/t Ag and 1.0% Pb. A small resource has also been identified at the nearby **De Nardi** deposit. First production in the Wonawinta project is expected in December 2011.

Other silver projects in early stages of development include Argent Mineral's Kempfield project (NSW), Kingsgate Consolidated **Bowdens** project (NSW), which are the subject of feasibility studies due in early 2012. At Kempfield, oxide/mixed and sulphide resources of 5.8Mt grading 58g/t Ag and 0.1g/t Au and 14.4Mt grading 49g/t Ag, 0.1g/t Au, 1.2% Zn and 0.6% Pb, respectively. In addition, the deposit contains large amounts of barite. At Bowdens, a total resource of 58.2Mt grading 52.9g/t Ag, 0.40% Zn and 0.30% Pb has been defined. Other less advanced silver projects include Silver Mines Ltd's **Webbs** project (NSW) and White Rock Minerals' **Mount Carrington** project (Qld). In addition, silver is a significant component of polymetallic projects at **Mount Carlton** (Qld; Conquest Mining) and **Kangiara** (NSW; Paradigm Metals).

**Takeovers and mergers:** A final trend in the zinc-lead-silver sector during the past few years is the number of takeovers and mergers. Although in several cases this involved the takeover of a junior to mid-sized Australian company by a major Chinese company, other takeovers and mergers involved Japanese and other Australian companies. The most significant Chinese takeovers include Abra Mining by Hunan Nonferrous Metals, and Meridian Metals by Northwest Nonferrous International Investment Company. CBH Resources was taken over by Japanese zinc and lead smelting company, Toho Zinc. Jabiru Mining was taken over by the Australian company, Independence Group, while Conquest Mining and Catalpa Resources merged into Evolution Mining.

## RESOURCES TO PRODUCTION RATIOS



Coal reclaimers and loaders working at the coal shipping terminal in Mackay, Queensland.

## Resources to Production Ratios

The continuing contribution of mineral resources to Australia's economic performance in the medium and longer term will depend on the discovery and development of new, good quality resources. To assist with an assessment of the future supply capability of identified resources, an indicator of resource life using ratios of Accessible Economic Demonstrated Resources (AEDR) to current mine production are provided in the commodity review chapters. Ratios of ore reserves to production are a much more conservative indicator of what is likely to be available for mining in the foreseeable future. It is important to note that these duration indicators can change rapidly with significant variations to rates of production and/or major changes to resources.

Table 13 presents a comparison of the AEDR/production ratios from 1998 to 2010. During this 13 year period there has been a persistent long term decline in the AEDR/production ratio for black coal, iron ore and rutile, which was the nett result of major increases in production and reassessment of resources. The decline in iron ore has been offset in the past few years by the development of large magnetite iron ore deposits in the Pilbara and mid-west regions of Western Australia. These magnetite resources, which were previously considered to be subeconomic, have been re-assessed as economic.

**Table 13.** Years of Accessible Economic Demonstrated Resources (AEDR) at the production level for each year (rounded to nearest 5 years).

Commodity	1998	2003	2008	2009	2010
Bauxite	70	90	85	85	80
Black Coal	180	110	90	100	90
Brown Coal	630	440	490	470	495
Copper	40	50	85	95	100
Diamond	3	5	10	20	30
Gold	15	20	30	30	30*
Iron Ore	100	60	70	70	80
Lead	30	30	40	55	50
Manganese Ore**			20	20	15
Mineral Sands					
Ilmenite	70	85	85	110	125
Rutile	75	90	55	70	45
Zircon	60	50	55	70	60
Nickel	65	120	130	145	120
Silver	30	25	30	45	40
Uranium	105	80	125	140	175
Zinc	30	25	35	45	45

\* Average AEDR/production ratio for gold (30 years) is strongly influenced by low grade copper-gold deposits with ratio of 90 at current rates of mine production, whereas lode gold deposits have AEDR/production ratio of only 14 years.

\*\* AEDR/production ratios allows for losses which occur in beneficiating (upgrading) manganese ores.

Commodities with a resource life of less than 50 years are manganese ore (about 15 years at current rates of production), diamonds and gold (30 years), silver (40 years), zinc and rutile (45 years). There is a need for ongoing successful exploration in the short and medium term to ensure sufficient available resources to maintain Australia's levels of exports of these commodities.

Increases in the AEDR/production ratios during 2010 were recorded for brown coal, copper, diamond, iron ore, ilmenite and uranium, with reduced production (rather than increases in resources) accounting for increases in the AEDR/production ratios for ilmenite and uranium.

At the same time, reductions in AEDR/production ratios during 2010 were recorded for bauxite, black coal, lead, manganese ore, rutile, zircon, nickel and silver with recoveries in production levels for some commodities being partly responsible for a reduction in AEDR/production ratios.

It is important to note that a long resource life for a particular commodity is not a guarantee that such resources will continue to be exploited in Australia. In an increasingly globalised and competitive commodity market, multinational mining companies are continuously searching for mineral deposits which offer the most attractive returns on investment. Such returns are influenced not only by the quality of the resources (grade and tonnage) but also by the environmental, social and political factors, land access, infrastructure and the location and scale of the existing mining operations owned by the company.

The world financial crisis in 2008 exacerbated these factors and forced many companies to reassess their options for both existing and planned operations in Australia. In the case of black coal and iron ore, the initial impact of the world financial crisis caused some mining operations to scale back production while others delayed plans for expansion and some mines closed at the end of 2008. However, by mid 2009, recovery in mining operations and development plans were well under way for the affected commodities and this trend continued in 2010.

During 2009 and 2010, some multinational companies closed sulphide and lateritic nickel mines in Western Australia and Tasmania and consolidated their operations at larger low cost mining operations, although not necessarily in Australia. This is a consequence of the dominance of large multinational mining companies in the world mining industry. A number of these nickel mines resumed production by 2011 and the large Ravensthorpe lateritic nickel mine was refurbished during 2010/11 followed by restart of operations during the second half of 2011.

AEDR/production ratios for copper have increased progressively over the past 13 years. During this period, annual mine production of copper and resources have increased, mainly at the Mount Isa and Olympic Dam deposits.

AEDR/production ratios for lead and zinc have increased slowly over the past 13 years. Mine production and resources of lead and zinc also have increased over this period.

During 2010, the assessment of gold deposits, many with historic production, led to several feasibility studies, the purchase and upgrading of processing plants and widespread drilling programs. Many operating mines commenced enlarging open pits (referred to as cutbacks) or accessing panels in underground operations to extract material which previously was deemed uneconomic. These activities led to a substantial increase in the EDR for gold and are leading to expanding production capacity. While domestic mine production increased to 260 tonnes in 2010, around 37 tonnes higher than 2009, it was still less than production highs of about 310 tonnes achieved in the late 1990s. Gold was a primary output of about 70 operations but several mines also produced gold as a by-product of processing other commodities such as at the polymetallic base metal deposits of Rosebery, Olympic Dam and Prominent Hill.

For gold, the average resource life of 30 years is strongly influenced by large resources and the relatively low production rate of the copper-gold deposits (including iron oxide copper-gold deposits, e.g. Olympic Dam and Prominent Hill, and porphyry copper-gold deposits e.g., Northparkes and Cadia). These deposits have an average resource life based on EDR of about 90 years. In contrast, lode gold deposits (all types) produce about 75% of Australian mine production but have a resource life of only 14 years (Table 3).

For heavy mineral sands operations, some producers closed down low grade ilmenite deposits in 2008 to concentrate on deposits which are more readily amenable to beneficiation, or have a higher zircon content. However, sharply lower levels of production of ilmenite, rutile and zircon in 2009 resulting from the flow-on effects of the global financial crisis in late 2008 and early 2009, led to increases in resource life. In 2010, Australia produced 1.313Mt of ilmenite, 430 000 tonnes of rutile, 160 000 tonnes of leucoxene and 540 000 tonnes of zircon compared with 1.534Mt of ilmenite, 280 000 tonnes of rutile, 166 000 tonnes of leucoxene and 476 000 tonnes of zircon in 2009 resulting in further increase in AEDR/production ratios for ilmenite, but reductions for rutile and zircon.

For Australia to maintain its position as a premier mineral producer and compete in the world market, it will require continuing investment in exploration to locate good quality resources and to upgrade known deposits. It will also require investment in metallurgical beneficiation processes to improve ore recovery levels.

# Appendix 1

## Abbreviations and Acronyms

**ABARE** Australian Bureau of Agricultural and Resource Economics

**ABARES** Australian Bureau of Agricultural and Resource Economics and Sciences

**ABS** Australian Bureau of Statistics

**A\$** Australian dollar (where not stated, assume Australian currency)

**AEDR** Accessible Economic Demonstrated Resources

**BRS** Bureau of Resource Sciences

**c** carat

**cpht** carats per hundred tonnes

**CSIRO** Commonwealth Scientific and Industrial Research Organisation

**EDR** Economic Demonstrated Resources

**GIS** geographical information system

**g** grams

**g/t** grams per tonne

**GL** gigalitre

**Gt** gigatonne

**IAEA** International Atomic Energy Agency

**JORC** Joint Ore Reserve Committee – Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves

**kg** kilogram

**km** kilometre

**kt** kilotonne (thousand tonnes)

**ktpa** kilotonne per annum

**LNG** liquefied natural gas

**m** metre

**Mc** million carats

**MEL** mineral exploration licence

**ML** million litres

**Mozs** million ounces

**Mt** million tonnes

**Mtpa** million tonnes per annum

**MW** megawatt

**MWe** megawatt electric

**NSW** New South Wales

**NT** Northern Territory

**OECD/NEA** Organisation for Economic Cooperation and Development/Nuclear Energy Agency

**ozs** ounces

**PDR** Paramarginal Demonstrated Resources

**PGE** platinum-group elements

**PJ** petajoules

**ppm** parts per million

**Qld** Queensland

**RAR** Reasonably Assured Resources

**REO** rare earth oxide

**REE** rare earth element

**SA** South Australia

**SDR** Subeconomic Demonstrated Resources

**Tas** Tasmania

**tpa** tonnes per annum

**U** uranium

**U<sub>3</sub>O<sub>8</sub>** uranium oxide

**USA** United States of America

**USGS** United States Geological Survey

**US\$** United States of America dollar

**Vic** Victoria

**WA** Western Australia

**\$1M** million dollars

## Appendix 2

### Australia's National Classification System for Identified Mineral Resources (2009 edition)

#### Introduction

Australia's mineral resources are an important component of its wealth, and a long-term perspective of what is likely to be available for mining is a prerequisite for formulating sound policies on resources and land access.

In 1975, Australia (through the Bureau of Mineral Resources, which has evolved to become Geoscience Australia) adopted, with minor changes, the McKelvey resource classification system used in the USA by the then Bureau of Mines and the United States Geological Survey (USGS). Australia's national system remains comparable with the current USGS system, as published in its Mineral Commodity Summaries.

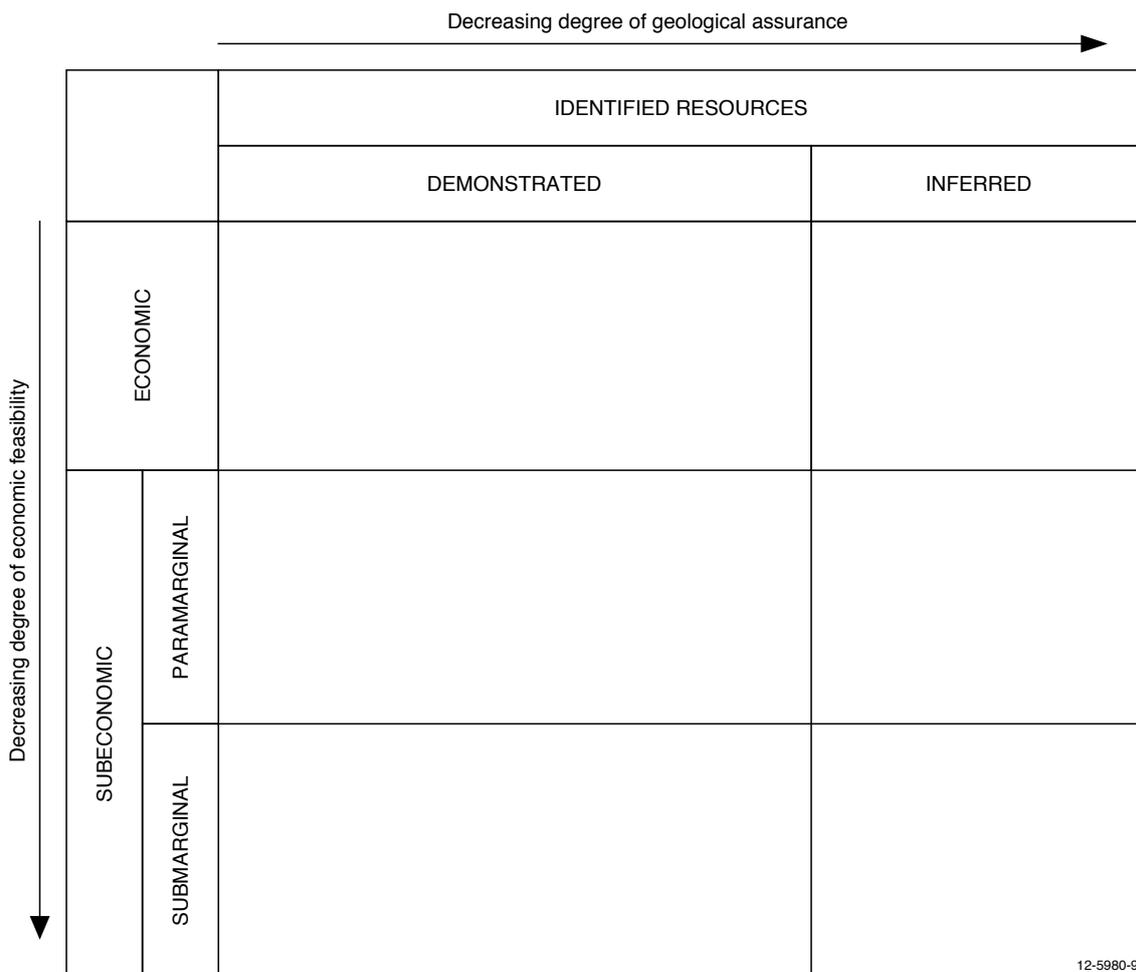
Companies listed on the Australian Securities Exchange are required to report publicly on ore reserves and mineral resources under their control, using the Joint Ore Reserves Committee (JORC) Code (see <http://www.jorc.org/>). This has also evolved from the McKelvey system, so the national system and JORC Code are compatible. Data reported for individual deposits by mining companies are compiled in Geoscience Australia's national mineral resources database and used in the preparation of the annual national assessments of Australia's mineral resources.

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

- JORC Code Reserves will all be mined, but they only provide a short term view of what is likely to be available for mining.
- Most current JORC Code Measured and Indicated Resources are also likely to be mined.
- Some current JORC Code Inferred Resources will also be transferred to Measured Resources and Indicated Resources and Reserves.
- New discoveries will add to the resource inventory.

#### Classification principles

The national system for classification of Australia's identified mineral resources is illustrated in Figure A1. It classifies Identified (known) Mineral Resources according to two parameters, the degree of geological assurance and the degree of economic feasibility of exploitation. The former takes account of information on quantity (tonnage) and grade while the latter takes account of economic factors such as commodity prices, operating costs, capital costs, and discount rates.



**Figure A1.** Australia’s national classification system for mineral resources.

Resources are classified in accordance with economic circumstances at the time of estimation. Resources that are not available for development at the time of classification because of legal and/or land access factors are classified without regard to such factors, because circumstances could change in the future. However, wherever possible, the amount of resource affected by these factors is stated.

Because of its specific use in the JORC Code, the term ‘Reserve’ is not used in the national inventory, where the highest category is ‘Economic Demonstrated Resources’ (EDR, Figure A1). In essence, EDR combines the JORC Code categories ‘Proved Reserves’, Probable Reserves’, plus ‘Measured Resources’ and ‘Indicated Resources’ as shown in Figure A2. This is considered to provide a reasonable and objective estimate of what is likely to be available for mining in the long term.

**Terminology and definitions for Australia’s national system**

**‘Resource’:** A concentration of naturally occurring solid, liquid or gaseous material in or on the Earth’s crust in such form and amount that economic extraction of a commodity from the concentration is currently or potentially (within a 20–25 year timeframe) feasible.

The definition does not intend to imply that exploitation of any such material will take place within that time span, but that exploitation might reasonably be considered. It should be applied also on a commodity by commodity basis to take account of prevailing and prospective technologies. The term includes, where appropriate, material such as tailings and slags. Mineralisation falling outside the definition of ‘Resource’ is referred to as an ‘occurrence’ and is not included in the national inventory.

**‘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 feasible.

### Categories based on degree of geological assurance of occurrence

To reflect degrees of geological assurance, Identified Resources are divided into Demonstrated Resources and Inferred Resources:

- 1) **'Demonstrated Resource'**: A collective term used in the national inventory for the sum of 'Measured Mineral Resources', 'Indicated Mineral Resources', 'Proved Ore Reserves' and 'Probable Ore Reserves' (see Figure A2), which are all defined according to the JORC Code:
  - A **'Measured Mineral Resource'** is that part of a Mineral Resource for which tonnage, densities, shape, physical characteristics, grade and mineral content can be estimated with a high level of confidence. It is based on detailed and reliable exploration, sampling and testing information gathered through appropriate techniques from locations such as outcrops, trenches, pits, workings and drill holes. The locations are spaced closely enough to confirm geological and grade continuity.
  - An **'Indicated Mineral Resource'** is that part of a Mineral Resource for which tonnage, densities, shape, physical characteristics, grade and mineral content can be estimated with a reasonable level of confidence. It is based on exploration, sampling and testing information gathered through appropriate techniques from locations such as outcrops, trenches, pits, workings and drill holes. The locations are too widely or inappropriately spaced to confirm geological and/or grade continuity but are spaced closely enough for continuity to be assumed.
  - A **'Proved Ore Reserve'** is the economically mineable part of a Measured Mineral Resource. It includes diluting materials and allowances for losses which may occur when the material is mined. Appropriate assessments and studies have been carried out, and include consideration of and modification by realistically assumed mining, metallurgical, economic, marketing, legal, environmental, social and governmental factors. These assessments demonstrate at the time of reporting that extraction could reasonably be justified.
  - A **'Probable Ore Reserve'** is the economically mineable part of an Indicated, and in some circumstances, a Measured Mineral Resource. It includes diluting materials and allowances for losses which may occur when the material is mined. Appropriate assessments and studies have been carried out, and include consideration of and modification by realistically assumed mining, metallurgical, economic, marketing, legal, environmental, social and governmental factors. These assessments demonstrate at the time of reporting that extraction could reasonably be justified.
- 2) An **'Inferred Mineral Resource'** is that part of a Mineral Resource for which tonnage, grade and mineral content can be estimated with a low level of confidence. It is inferred from geological evidence and assumed but not verified geological and/or grade continuity. It is based on information gathered through appropriate techniques from locations such as outcrops, trenches, pits, workings and drill holes which may be limited or of uncertain quality and reliability.

By definition, Inferred Resources are classified as such for want of adequate knowledge and therefore it may not be feasible to differentiate between economic and Subeconomic Inferred Resources. Where the economics cannot be determined, these Inferred Resources are shown as 'undifferentiated'.

### Categories based on economic feasibility

Identified resources include economic and subeconomic components.

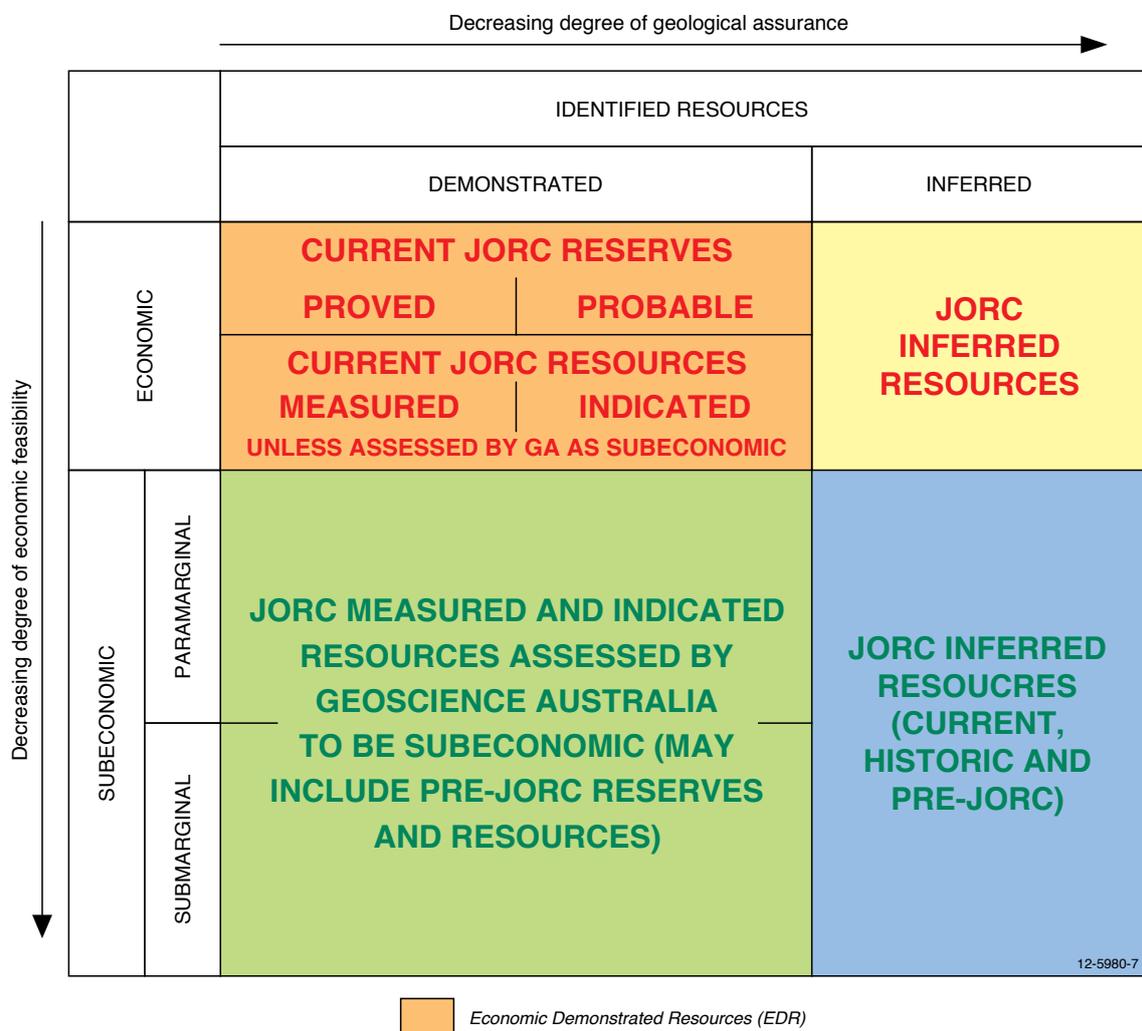
- 1) **'Economic'**: Implies that, at the time of determination, profitable extraction or production under defined investment assumptions has been established, analytically demonstrated, or assumed with reasonable certainty.
- 2) **'Subeconomic'**: Refers to those resources which do not meet the criteria of economic; 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 for 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.

The definition of 'economic' is based on the important assumption that markets exist for the commodity concerned. All deposits that are judged to be exploitable economically at the time of assessment are included in the economic resources category irrespective of whether or not exploitation is commercially practical. It is also assumed that producers or potential producers will receive the 'going market price' for their production.

The information required to make assessments of the economic viability of a particular deposit is commercially sensitive. Geoscience Australia's assessment of what is likely to be economic over the long term must take account of postulated price and cost variations. Economic resources include resources in enterprises that are operating or are committed, plus undeveloped resources that are judged to be economic on the basis of a realistic financial analysis, or compare with similar types of deposits in operating mines.

**How is the national inventory compiled?**

Virtually all of the mineral resource estimates compiled by Geoscience Australia's commodity specialists, including Subeconomic Resources, originate from published mining company sources reporting under the JORC Code. Given the common resource categories and definitions, the transfer of mineral resources from company reports into Australia's national mineral resource categories is quite straightforward, as summarised in Figure A2.



**Figure A2.** Correlation of JORC Code mineral resource categories with Australia's national mineral resource classification system.

**Notes:**

- i) EDR comprise mainly current JORC Code reserves and resources, but minor proportions of EDR come from selected historic JORC Code and pre-JORC Code reserves and resources;

- ii) In some instances, where a deposit is reported as having Measured and/or Indicated Resources, particularly where there are no Reserves reported, a professional judgement is made by Geoscience Australia as to whether all or part of the reported Resources are included in EDR, or assessed as subeconomic; and
- iii) Subeconomic Resources are largely from historic company reports but are still the most recent estimates, and it also includes proportions of resources from current company reports which are JORC Code compliant but have been assessed by Geoscience Australia as subeconomic.

In essence, for the reasons outlined above, the national inventory is compiled by:

- Incorporating the JORC Code Proved and Probable Ore Reserves and Measured and Indicated Mineral Resources into EDR.
- Transferring JORC Code Inferred Resources to the national Inferred Resources category. There is commonly insufficient information to determine whether or not Inferred Resources are economic.

In addition, Geoscience Australia makes decisions on the transfer of historic JORC Code and pre-JORC Code estimates of ore reserves and mineral resources. Some of these old estimates are economically less attractive under current conditions, usually due to lower commodity prices and/or unforeseen technical problems. Some of these resources may be removed from EDR and transferred to Paramarginal or Submarginal Resources. However, if such resources cannot be reasonably expected to become economic within a time frame of 20 to 25 years, they are removed from the national mineral resources database.

Companies report grade and tonnage data for individual deposits. However, it is not meaningful to add up grades and tonnages from different deposits, so the national inventory reports only the aggregated total tonnage for each commodity—that is, the sum of the contained metal in individual deposits for each resource category, which has been derived from company reports.

#### Allowances for losses

Loss of resources resulting from mining and milling (metallurgical processing) are given for the reserve and resource categories of the JORC Code. The allowances for losses, which apply to all minerals except coal, uranium, thorium and oil shale, are summarised as follows:

National System	JORC Code System	Mining Losses	Milling (Metallurgical) Losses
Demonstrated Resources	Proved Ore Reserves	Deducted	Not deducted—but are considered in assessing economic viability
	Probable Ore Reserves	Deducted	Not deducted—but are considered in assessing economic viability
	Measured Mineral Resources	Not deducted	Not deducted
	Indicated Mineral Resources	Not deducted	Not deducted
Inferred Resources	Inferred Resources	Not deducted	Not deducted

#### Exceptions:

- i) For coal, the following resource categories are used—'Recoverable coal resources' makes allowance for mining losses only. 'Saleable coal' makes allowance for mining as well as processing losses.
- ii) Uranium and thorium resources are reported with losses resulting from mining and milling deducted from all categories, consistent with the international uranium resource classification system of the OECD Nuclear Energy Agency and International Atomic Energy Agency.
- iii) Oil Shale resources are reported as recoverable oil.

### Correlation of Australia's national classification system for mineral resources with United Nations Framework Classification system

In order to compare Australia's national inventory of mineral resources with those of other countries and estimate total global stocks, it is useful to map different systems onto a common international classification template.

The United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC 2009) is an internationally applicable generic principle-based system in which mineral resource categories are classified on the basis of the three fundamental criteria of:

- Economic and social viability (E),
- Project status and feasibility (F), and
- Geological knowledge (G).
- Mineral resource 'classes' are defined by using a numerical coding system ordered in a three-dimensional system along the three axes of E, F and G with '1' being the highest category in terms of quality and knowledge and 4 the lowest.
- A mineral resource class is defined by selecting from each of the three criteria a particular combination of a category or a sub-category.
- The codes are always quoted in the same sequence (e.g., E1; F1; G1),
  - The letters may be dropped and just the numbers retained, for example 111 at class level or 3.2; 2.2; 1,2 at sub-class level; and
  - These criteria may be further subdivided.

A full description of the UNFC system can be accessed at <http://www.unece.org/energy/se/reserves.html>

UNFC Classes defined by categories and sub-categories							
Total commodity initially in place	Extracted	Sales production					
		Non-sales production					
	Class	Sub-class	Categories				
			E	F	G		
Known deposit	Commercial projects	On production	1	1.1	1	2	3
		Approved for development	1	1.2	1	2	3
		Justified for development	1	1.3	1	2	3
	Potentially commercial projects	Development pending	2	2.1	1	2	3
		Development on hold	2	2.2	1	2	3
	Non-commercial projects	Development unclarified	3.2	2.2	1	2	3
		Development not viable*	3.3	2.3	1	2	3
	Additional quantities in place		3.3	4	1	2	3
Potential deposit	Exploration projects	(No sub-classes defined)	3.2	3			4
	Additional quantities in place		3.3	4			4

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Australia's National Resource System



**Figure A3** Correlation of Australia's national mineral resource classification system with United Nations Framework Classification (UNFC) system.

As discussed previously (Figure A2), Geoscience Australia's EDR comprises JORC Reserves and JORC Resources where:

- The JORC Reserves component of EDR correlates with the UNFC's class of 'Commercial Projects' (as defined by mineral resource categories 111 and 112 in Figure A3); and
- The JORC Resources component correlates with 'Potentially Commercial Projects' (as defined by categories 221 and 222).
- Geoscience Australia's Subeconomic Resources (Paramarginal and Submarginal) correlate with a subclass of UNFC's 'Non-Commercial Projects' (categories 3.2; 2.3; 1,2).
- Geoscience Australia's Inferred Resources are identified by the UNFC geological criterion G3 and could be defined by:
  - 113 in cases where there is sufficient information to decide that an Inferred Resource is economic; and
  - 223 where the economic status of an Inferred Resource is not defined.

UNFC's mineral resource classes under 'Potential Deposits' comprise Exploration Results under the JORC Code and various types of quantitative estimates of undiscovered mineral resources which are not currently assessed under Geoscience Australia's national mineral resource system.

## Appendix 3

### Mineral Resources and Advice Project: Staff, Contacts and Credits

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Mike Huleatt	+ 61 2 6249 9087	mike.huleatt@ga.gov.au	Black coal, brown coal
Yanis Mieзитis	+ 61 2 6249 9523	yanis.mieзитis@ga.gov.au	Nickel, PGE, mineral sands, rare earths, potash, thorium, chromium
Keith Porritt	+ 61 2 6249 9479	keith.porritt@ga.gov.au	Copper, zinc, lead, silver
Daisy Summerfield	+ 61 2 6249 9357	daisy.summerfield@ga.gov.au	Iron ore
Alan Whitaker	+ 61 2 6249 9702	alan.whitaker@ga.gov.au	Gold, vanadium
Paul Kay	+ 61 2 6249 5829	paul.kay@ga.gov.au	Bauxite-alumina-aluminium
Roy Towner	+61 2 6249 5828	roy.towner@ga.gov.au	Lithium, magnesite, molybdenum, niobium, phosphate, tantalum, tin, tungsten.
Michael Sexton	+ 61 2 6249 9262	michael.sexton@ga.gov.au	Manganese ore, Information management and project data support
David Champion	+ 61 2 6249 9215	david.champion@ga.gov.au	Tin, tungsten
David Huston	+ 61 2 6249 9577	david.huston@ga.gov.au	Zinc, lead, silver
Anthony Schofield	+ 61 2 6249 9833	anthony.schofield@ga.gov.au	Diamonds
Dean Hoatson	+ 61 2 6249 9593	dean.hoatson@ga.gov.au	Rare earths

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