Overview of the Australian Nickel-Cobalt Industry

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INTRODUCTION

Australia continues to be a significant force in the global picture of the nickel-cobalt industry. The past 15 years have seen significant changes in the nickel sulfide industry, with new developments mainly in Western Australia and the growth of an entirely new nickel-cobalt industry based on application of new extractive technologies to Australia's vast lateritic resources, also mainly in Western Australia. This has taken place against a background of highly volatile commodity prices and fluctuating global demand.

THE GLOBAL CONTEXT

For some decades, the major use of nickel (approximately 65 per cent of new nickel produced) has been in the manufacture of stainless steel, a versatile material which resists corrosion, has strength at high and low temperatures and has a range of electrical and magnetic properties. These properties make it ideal for use in food preparation equipment, medical equipment, building and chemical processing amongst many other applications. As a consequence, its demand growth shows a strong correlation with industrial production indices, particularly in developing economies. Other uses for nickel are in a range of other steel and non-ferrous alloys, often with highly specialised applications (20 per cent) and plating (nine per cent) and six per cent in other uses such as batteries for hybrid cars.

The main uses for cobalt are in superalloys for the aerospace industry, steel alloys to make wear-resistant and hardened steels, in magnetic alloys and in the chemical industry (largely batteries). Slightly over half of the world's cobalt is derived as a by-product of the nickel industry, with the rest coming from the copper industry and from primary cobalt operations. Global annual production of cobalt in refined products is about 76 000 t.

Global nickel production from 2000 has shown a steady growth of about 2.5 per cent year-on-year until 2004, during a period when the nickel price hovered between US$6000 and US$9000/t (Figure 1). This was followed

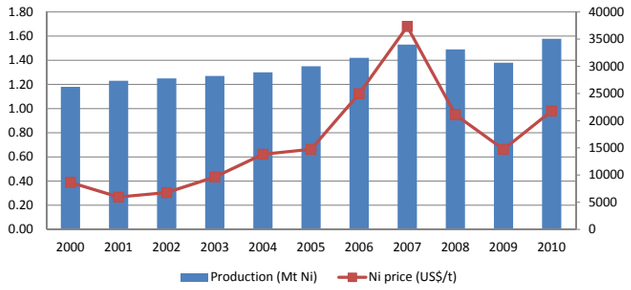

FIG 1 - Annual nickel production and annual average London Metal Exchange nickel price 2000 - 2010.

by a period of rapid growth (5.5 per cent year-on-year) through to 2007, when production peaked at slightly over 1.5 Mt nickel in ore or concentrates. The growth was driven by rapidly increasing nickel prices, which peaked at around US$54 000/t (US$24.50 per pound) in the first half of 2007. The onset of the global financial crisis brought about a collapse in the nickel price (as it did with most other metal commodities), which fell to a low of around US$9000 in early 2009, accompanied by two successive years of falling mine production in 2007 and 2008 due to a host of mine closures and temporary suspensions of operations and expansion plans. During 2009 and into 2010, mine production and nickel prices staged a strong comeback as economic conditions improved, and there was a return to strong demand from China.

China's demand for nickel has been the driving force behind the industry's expansion over the last decade, accounting for nearly its entire growth. It has been pointed out by one commentator (Lennon, 2011) that from 2001, when China's demand accounted for ten per cent of global demand, China has since overtaken the rest of the world in nickel demand in a period of only ten years.

The phenomenon of historically high nickel prices and strong Chinese demand has set the stage for the development in 2005 of a new industry in China based on producing nickel-bearing pig iron (NPI) in blast

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furnaces and electric furnaces using low-grade laterite ore imported mainly from Indonesia and the Philippines. This is a non-premium, low-grade product which finds its way mainly into the production of lower-ranked 200-series stainless steels. Its high unit cost economics means it is viable only in times of high nickel prices (generally greater than US$20 000 to US$22 000/t). The sector has shown extraordinary growth, accounting for up to 150 000 t/a of nickel or over ten per cent of world nickel production, when prices are favourable. However, when the nickel price falls, the NPI industry output contracts rapidly.

THE AUSTRALIAN SCENE

As described by Parbo and Elias (1993), nickel sulfide mining in the 1980s took place at a number of centres in Western Australia by various operators, but difficult financial conditions and limited reserves forced the closure of most of these, and their subsequent acquisition by Western Mining Corporation Limited (WMC). By the early 1990s, nickel production was almost entirely in the hands of WMC, with nickel sulfide mining and concentrating operations in the north-eastern and eastern goldfields of Western Australia, feeding the Kalgoorlie Nickel Smelter and the Kwinana Nickel Refinery. The only nickel mine production outside Western Australia took place in Queensland and Tasmania. In Queensland, the Greenvale lateritic nickel mine operated until its closure in 1993 due to exhaustion of reserves. Greenvale ore was processed at the Yabulu Nickel Refinery in Townsville. Since the mine's closure, the Yabulu plant has continued to operate, treating laterite ores imported mainly from New Caledonia, the Philippines and Indonesia. In Tasmania, the Avebury nickel sulfide mine near Zeehan operated for two years up to 2009 after its discovery in 1997.

Nickel sulfide operations

In the decade up to the early 1990s, annual production from nickel sulfide deposits ranged mostly between 45 000 t and 60 000 t Ni in ores and concentrates, all from Western Australia. The following decade saw a significant increase in annual nickel production in Western Australia, resulting from new mine developments, some from known deposits and some from new discoveries.

The Kambalda and Leinster nickel mines continued to be the mainstay of production for WMC (and, after its takeover of WMC in 2005, BHP Billiton [BHPB]). Two significant developments amongst the WMC/BHPB operations were:

1. the establishment in 1995 of a large, low-grade open cut mine at Mt Keith, north of Leinster; at the time, the Mount Keith Mine added about 28 000 t/a nickel to WMC's production capacity; subsequent expansions have increased its production to 43 000 t/a nickel
2. the dismantling of the previously integrated WMC Kambalda-Widgiemooltha mine assets and their sale to independent operators, in the period 2001 - 2003; the sales were made on the condition that WMC had first option to buy and toll treat ore from the mines, thereby ensuring continued access to production and feed for their downstream facilities; eight mining centres were involved, in the Kambalda and Widgiemooltha corridors.

Together these developments increased WMC's production to 100 000 - 120 000 t/a nickel in concentrate.

The Mount Windarra mine, subject of the infamous Poseidon nickel bubble in the early 1970s and acquired by WMC in 1983, ceased mining in 1991 due to exhaustion of economic reserves. In 2006, the project was acquired by a company which took on the original name of Poseidon Nickel Limited and commenced redeveloping the mine and exploring the tenements for new deposits.

A new wave of sulfide discoveries in Western Australia

The period from 1995 onward was notable for the discovery of a number of high-grade nickel deposits in Western Australia, with one exception by explorers other than WMC. The first discovery of the new wave was the Silver Swan deposit, found under and beside the minor Black Swan deposit, a low-grade disseminated deposit known since the early 1970s. Silver Swan was discovered in May 1995 by the MPI-Outokumpu joint venture (JV) with an initial resource before production of 440 000 t at 14 per cent Ni and a reserve of 640 000 t at 9.5 per cent Ni. The deposit is now owned by Norilsk Nickel Australia.

The next significant find, the Emily Ann deposit, was made in February 1997 by Forrestania Gold NL in the Lake Johnston belt 250 km south-west of Kalgoorlie. Located near the previously-discovered Maggie Hays nickel deposit, Emily Ann had a preproduction resource of 2.1 Mt at four per cent Ni. The deposits are now owned by Norilsk.

The next group of discoveries were made where there was no former surface expression or evidence of deposits, although they were in a familiar geological environment. These were Cosmos, found in September 1997 by Jubilee Mines NL (420 000 t at 7.25 per cent Ni in an open cut), Mount Goode (March 1998, Forsayth/Homestake) and Cosmos Deeps (February 2000, Jubilee Mines, 630 000 t at 6.6 per cent Ni underground) in a small area about 40 km north of Leinster. The Cosmos complex, now under the ownership of Xstrata PLC, has since revealed three additional high-grade underground positions (Alec Mairs, Prospero and Tapinos). Another deposit, Sinclair, located 100 km south of Cosmos, was discovered in 2005 and is operated by Xstrata.

In April 2000 WMC announced the discovery of nickel-copper mineralisation in the West Musgrave area in Central Australia, near the South Australian border.

In a geological setting akin to the world-class nickel-copper deposits of Norilsk-Talnakh in Russian Siberia, a drill intersection of 27 m at 2.45 per cent Ni, 1.8 per cent Cu and 0.7 g/t platinum group elements (PGE) was encountered at a shallow depth at the Nebo prospect. Subsequent exploration, however, failed to confirm early hopes of a major high-grade deposit.

Two further small, high-grade discoveries were made in 2002. These were the Waterloo and Amorac nickel deposits in the Wildara area, 45 km south-east of Leinster, found by the LionOre/Dalrymple JV. LionOre merged with Dalrymple and the entity was acquired by Norilsk in 2007.

Significant development has taken place in the Forrestania nickel belt, the site of discoveries originally made in the 1960s nickel boom. The Finnish company Outokumpu developed two underground nickel mines, one open cut and a nickel concentrator that operated from 1992 to 1999 before low nickel prices forced their closure. In 2001 their entire lease package was farmed out to Western Areas NL, a newly floated company with a nickel focus. Almost immediately, Western Areas discovered a new zone of nickel mineralisation near the existing New Morning deposit, which they called Daybreak. Since then, a number of new deposits and extensions to existing deposits were found. The most significant up to now have been depth extensions to the Flying Fox deposit, where new underground development started in 2005. Premining reserves for Flying Fox exceeded 2 Mt at 4.3 per cent Ni. A new deposit known as Spotted Quoll contains 1.7 Mt at 6.0 per cent Ni in open cut and underground reserves. Western Areas operates a concentrator with a capacity of 550 000 t/a ore.

A new mine was developed at the Savannah deposit operated by Panoramic Resources, located 240 km south of Kununurra in the East Kimberley district of Western Australia. Savannah (formerly known as Sally Malay) was discovered and explored by Anglo American in 1973, and passed to Normandy in 1989, which carried out further work before selling the deposit to Panoramic in 2001. Premining resources were estimated at 3.7 Mt at 1.74 per cent Ni and 0.72 per cent Cu. Open cut and subsequently underground mining commenced in 2004.

Nickel-cobalt laterites

Although the nickel industry in Western Australia was built almost entirely on nickel sulfide deposits, the potential of the vast nickel laterite resources was not clearly demonstrated until advances in hydrometallurgical technology made their commercial development possible.

The main commercial interest in nickel laterites in Western Australia occupied a concentrated period in the mid- to late-1990s, driven largely by a rejuvenation of interest in high-pressure sulfuric acid-leaching (HPAL) technology. This renewed interest was brought about by three main factors:

1. the opening up to the West in 1990 of the Moa Bay HPAL plant in Cuba, which had operated more or less successfully behind the Iron Curtain for 30 years
2. a significant drop in the price of sulfur, the main consumable used in the HPAL process
3. improvements in autoclave technology.

Exploration for nickel sulfides had shown that many ultramafic bodies in Western Australia and, to a lesser extent, Queensland are covered by a thick mantle of weathered material with elevated nickel and cobalt grades. These weathered ultramafic rocks, which are virtually all sulfide-free, are now known to collectively represent a significant nickel resource by global standards, having in excess of 25 Mt of contained Ni metal.

The Bulong ultramafic complex east of Kalgoorlie was the first laterite project to be investigated with HPAL technology in mind. Originally explored by WMC, the project was purchased by Resolute Resources, which carried out successful pressure leaching tests and embarked on a project feasibility study. Bulong, with a capacity of 9000 t/a Ni, was one of three HPAL nickel laterite operations to come on-stream in quick succession in 1998 and 1999. The others were Murrin Murrin (east of Leonora), operated by Anaconda Nickel Ltd (later renamed Minara Resources) and Cawse (40 km north of Kalgoorlie). An aerial view of the Murrin Murrin operation is shown in Figure 2. Cawse was developed by Centaur Mining and Exploration Ltd with a capacity of 9000 t/a Ni and up to 2000 t/a Co, the latter based on several high-grade cobalt pods. All three operations suffered major commissioning problems, and only Murrin Murrin continues to operate at about 30 000 t/a Ni and 2000 t/a Co. In addition to these three projects, large areas of ultramafic rocks in the Goldfields of Western Australia were drilled for laterite resource definition.

A fourth acid-leaching operation, Ravensthorpe, located on the south coast of Western Australia, was constructed by BHPB and operated for less than a year before being shut down in January 2009. Its capacity was to be 50 000 t/a Ni in Ni-Co hydroxide to be refined at the Yabulu nickel facility in Queensland, which had been expanded to 76 000 t/a Ni to accommodate the additional feed. The Ravensthorpe project was subsequently sold to Canadian-listed First Quantum Minerals, which has since brought the mine and plant back into production.

Outside Western Australia, two areas in Queensland have received attention in respect of their nickel laterite potential. One is located around the Greenvale area, where Metallica Minerals has delineated a number of nickel-cobalt resources with significant scandium credits in their Nornico project, with total resources of about 50 Mt at 0.8 per cent Ni and 0.09 per cent Co. Metallica

FIG 2 - Aerial view of the Murrin Murrin operation.

is planning an HPAL development based on these deposits. The other is in an area approximately 100 km north-west of Rockhampton, where the Marlborough laterite deposits contain resources totalling over 100 Mt at about one per cent Ni and 0.06 per cent Co. Operator Gladstone Pacific Nickel Ltd has announced plans to move slurried ore in a 200 km pipeline from the mine area to a HPAL plant and refinery to be built on the coast at Gladstone, to produce 50 000 t/a Ni and 2000 t/a Co. Ore from Marlborough is planned to be supplemented by ore imported from New Caledonia.

Two nickel-cobalt laterite deposits have been defined in central New South Wales. Jervois Mining Ltd has a resource of 167 Mt at 0.72 per cent Ni and 0.07 per cent Co at Young, and IvanPlat's Syerston deposit has a resource of 77 Mt at 0.73 per cent Ni and 0.13 per cent Co. In addition to nickel and cobalt at the Syerston project, there is also some 700 000 oz of platinum estimated in the resource.

Three significant Ni-Co laterite deposits have been defined in Papua New Guinea, of which one (Ramu River, near Madang) is undergoing commissioning and the other two are in exploration. Ramu River comprises an inland mine and a coastal HPAL plant connected by a 134 km slurry pipeline. The project, which is majority-owned by Chinese government companies, has a resource of about 140 Mt at one per cent Ni and 0.1 per cent Co and will produce 31 000 t/a Ni and 3300 t/a Co.

Wowo Gap, owned by Resource Mining Corporation, is an exploration prospect located 200 km east of Port Moresby. Wide-spaced drilling programs from 1999 to 2007 have delineated a global resource estimated at 125 Mt at 1.1 per cent Ni and 0.07 per cent Co.

The Mambare project comprises a laterite blanket overlying a plateau just north of Kokoda. The resource has undergone several phases of drilling, mostly in 2006 to 2008, and is currently being drilled by a JV of Regency Mines PLC and extractive technology company Direct Nickel Pty Ltd.

Metal production

Mine production data for the years 2000 to 2010 are shown in Table 1, in terms of contained nickel and cobalt in ores and concentrates.

TABLE 1
Nickel and cobalt mine production 2000 - 2010 (source: DMP Western Australia).

Year	Mine production Western Australia (contained metal)	
	Ni (kt)	Co (t)
2000	153.51	3599
2001	181.79	4265
2002	183.00	4698
2003	187.74	5165
2004	174.70	4552
2005	191.71	4593
2006	176.64	5129
2007	161.01	4734
2008	187.79	4785
2009	171.97	4345
2010	185.74	3852

As mentioned, production by WMC in the 1990s increased rapidly from 50 000 t/a Ni to over 100 000 t/a Ni due to the development of the Mount Keith open cut and expansions at the Leinster nickel operations. Further increases in nickel production occurred in the late 1990s with the new nickel-cobalt laterite operations coming on-stream. Although two of these faltered (Bulong and Cawse), development of the new sulfide discoveries set the state on a firm footing to maintaining the current production levels of 160 000 -180 000 t/a.

COMMODITY OUTLOOK

Global demand and supply

The demand for nickel is driven largely by industrial expansion in the developing economies, mainly China, and its consequent effect on stainless steel production. While China has enjoyed phenomenal growth over the past decade, there are signs of a softening in the rate of expansion, but to levels that are still well in excess

of those of Western economies. Added to China's demand growth, India is showing early signs of taking a similar trajectory, so it appears that continued growth in demand for nickel is assured, at least at the current rates. Threats which could disrupt the growth trend include the possibility of further recession in the western world economies such as occurred in 2008/2009, and nickel price peaks which might bring on excess new production, such as Chinese NPI.

Trend nickel prices over the last decade have increased from a range of US$6000 to US$9000/t at the beginning of the period to around US$20 000/t currently. Except for the unusual peaks in 2006 and 2007, the trend appears to have been firmly established. However, the production of Chinese NPI, which appears on the market when the nickel price exceeds US$22 000/t, tends to act as an impediment to nickel prices increasing much beyond this level. It therefore appears that nickel prices are likely to range between US$15 000/t and US$20 000/t in the foreseeable future.

Fortunately, prices at this level are generally sufficient to allow economic return on capital investment in new production capacity, which is essential to satisfy growing demand. The bulk of new production capacity will come from nickel laterite projects. A huge laterite resource base and the refinement of processing technologies are expected to overcome the challenges of capital intensity and engineering risk. A lack of new nickel sulfide discoveries and the increasing difficulties of deeper underground mining will mean that growth in this sector is limited.

Because cobalt is essentially a by-product metal in primary nickel and copper operations, the price of cobalt is usually of limited relevance to the viability of a project. While volatile, the cobalt price seems to return to a trend price of around US$45 000/t. The anticipated development of new nickel capacity from laterites will increase the amount of by-product cobalt being produced. The main end-use applications for cobalt are in superalloys and batteries, both applications which appear to be showing continued growth.

Australasian outlook for nickel and cobalt

Future growth in the nickel sulfide sector in Australasia will require successful development of a number of existing projects and further discoveries in brownfield and greenfield locations. Current resources would seem to indicate a long-lived future for the nickel industry in Australia, and in particular in Western Australia (Table 2). However, a large proportion of the sulfide resources (about 65 per cent) are held in four large, low-grade deposits in the Northeastern Goldfields, of which two are currently undeveloped. Yakabindie (BHPB) and Honeymoon Well (Norilsk Nickel Australia) in the Northeastern Goldfields have been known about since the late 1960s and require the right combination of supporting infrastructure and nickel price to justify their development. Exploration success by Western Areas NL at Forrestania since that company's entry into the project has allowed production to far exceed initial expectations, and further expansions are likely. Western Areas is currently producing over 30 000 t/a Ni in ore.

TABLE 2
Publicly reported nickel resources by mineralisation style, Western Australia (source: DMP Western Australia).

Mineralisation style	Current Resources (kt Ni)	Percentage of total
Sulfide	11 750	30.9
Laterite	26 306	69.1
Total	38 056	

While the nickel-cobalt laterite resources in Western Australia are vast (Table 2), their development is hampered by location, lack of infrastructure and limited access to process water. Existing operations (Murrin Murrin and Ravensthorpe) have to a large extent overcome these challenges, but it is unlikely that significant expansion in the laterite sector will take place. An added disadvantage is that the Western Australian laterite deposits do not share the high-grade characteristics of deposits in the tropical environments of Indonesia and New Caledonia. Most Australian nickel-cobalt laterite deposits comprise average grades of no more than 1.2 per cent Ni and 0.06 per cent Co, whereas the tropical laterites contain grades in excess of 1.8 per cent Ni. Demonstrated economic resources of Ni and Co in Australia and globally are given in Table 3.

TABLE 3
Economic demonstrated Resources of Ni and Co in Australia and globally (source: BREE for Australian figures and USGS Minerals Commodities Summaries for global figures).

Area	Ni (Mt)	Co (kt)
Western Australia	18.8	N/A
New South Wales	1.0	N/A
Queensland	0.8	N/A
Tasmania	0.1	N/A
Total Australia	20.7	1191
World	75.6	7259
Australia % of world	28.4	16.4

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