NICKEL SULFIDE VERSUS LATERITE : THE HARD SUSTAINABILITY CHALLENGE REMAINS

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ABSTRACT

There are widespread nickel resources around the world, but divided principally between nickel sulfide or laterite (oxide) resources. Historically production has been dominated by sulfide ores but future production is increasing shifting to laterite ores. The principal reason for this historically is that sulfide ores are easier to process, through conventional mining, smelting and refining, compared to laterite ores which require intensive hydrometallurgical processing (such as high pressure acid leaching or HPAL). This means that laterite ores typically require substantially more energy and chemicals to produce than sulfide nickel. Given that many major nickel companies report annually on their sustainability performance, such as Eramet, Inco (now Vale Inco), WMC Resources (now BHP Billiton), Norilsk Nickel, there is data available to examine in detail the differences in the environmental costs of nickel sulfide versus laterite. The paper compiles and analyses a range of data, showing the higher energy costs of laterite projects, but also the critical importance that energy sources can have on overall environmental costs. Given that the world is continuing to demand nickel, and most uses are somewhat dissipative which limit high rates of recycling, the progressive shift to nickel laterite projects in the global nickel industry is perhaps inevitable, but it will clearly come at higher environmental costs for nickel production. Based on present technology and research, there appears little hope for any alternatives which might significantly reduce the environmental costs of nickel laterite projects. The big sustainability challenges such as energy and greenhouse emissions therefore remain of paramount importance to the nickel sector.

Full Reference:

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INTRODUCTION

Nickel is an important metal in modern infrastructure, with major uses in stainless steel (~65%), metal alloys (~20%) and plating (~9%), as well as electric batteries and chemicals [1]. Economic resources of nickel are found in either sulfide or laterite-type ores. Globally, the bulk of historic production has been derived from sulfide ores, while the majority of nickel resources are contained in laterite ores. The difference between production and resources is due mainly to the difficulty associated with processing laterite compared to sulfide ores – leading to a historical preference for sulfide ores. To meet future demand for nickel, however, there is an increasing proportion of nickel being mined from laterite ores. This leads to an important issue in terms of the environmental costs of nickel – as laterite nickel increases, the footprint per tonne of nickel metal could be expected to increase.

This paper seeks to analyse and contrast the environmental sustainability metrics of existing nickel production from sulfide mines with more recent laterite projects, thereby leading to an important contribution on the environmental sustainability of a critical metal for modern infrastructure.

NICKEL RESOURCES AND MINING

Global nickel (Ni) production has increased significantly, including near exponential growth since 1950, from some 10,000 tonnes Ni (t Ni) in 1900 to about 1.6 million tonnes (Mt Ni) in 2007, shown in Figure 1 (including consumption). Based on the present global mining boom led by Chinese demand (amongst other factors), it is most likely that the increasing trend for nickel production and consumption, evident in Figure 1, will continue for a considerable period of time (despite the current global financial crisis). The principal issue associated with such a scenario is the environmental sustainability of this nickel production and consumption.

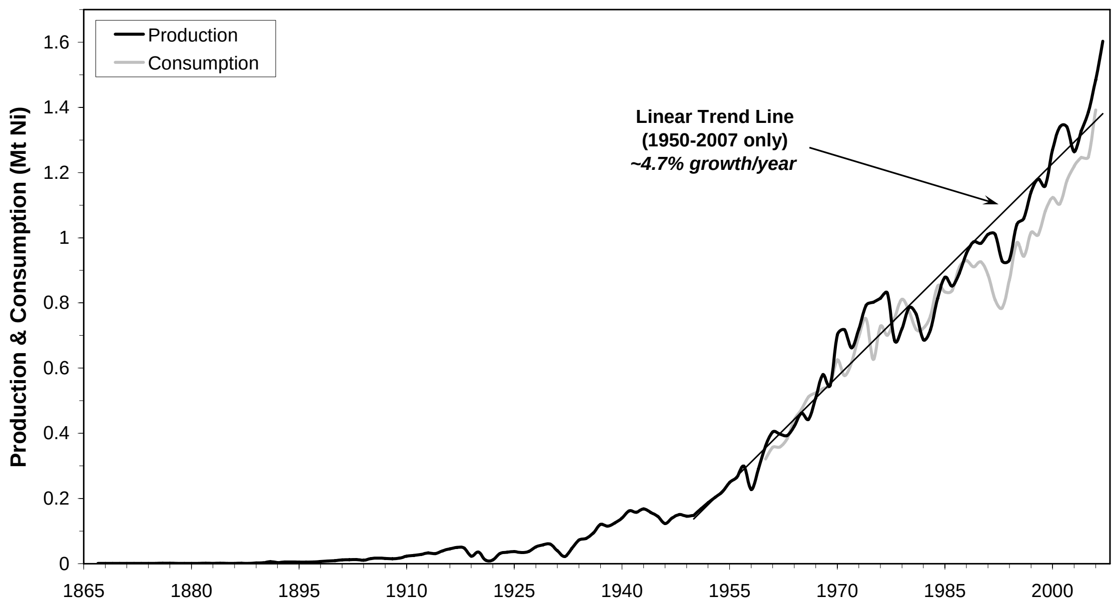

Figure 1 – Global nickel production and consumption, including linear trend line for production [2-4]

As a metal, nickel would commonly be considered a ‘finite’ resource and therefore mining is intrinsically unsustainable. However, there are still abundant nickel resources known around the world, principally in Australia, Canada, New Caledonia, Philippines, Indonesia and Russia, amongst others. According to the US Geological Survey, global economic and sub- economic resources in 2008 were estimated at 220 Mt Ni [5] – a figure whose magnitude has been similar for at least a decade, and even shows a gradual increase over this time (see earlier editions of [5]; e.g. resources in 1998 were 180 Mt Ni).

Nickel is commonly present in two principal ore types – sulfide or laterite ores. Sulfide ores are typically derived from volcanic or hydrothermal processes and usually include copper (Cu) and/or cobalt, and sometimes other precious metals such as gold or platinum and palladium (generally grouped as platinum group metals or PGMs). Laterite ores are formed near the surface following extensive weathering, and occur abundantly in tropical climates around the equator or arid regions of central Western Australia or southern Africa.

Historically, most nickel production has been derived from sulfide ores with laterite ores providing only a modest source. In terms of known nickel resources, approximately 60% is found in laterites while 40% is contained in sulfides [5] – the reverse of production. The major reason for this is the difficulty of processing nickel laterites compared to sulfides – laterite ores require extensive and complex treatment to extract nickel, and has historically been more expensive than sulfide ores. There have been very few mining projects extracting laterite ores, and these examples have had major technical and financial difficulties that took several years to resolve satisfactorily (e.g. Moa Bay in Cuba or Greenvale-Yabulu in Australia). The mining, processing and smelting of sulfide ores follows conventional pyrometallurgical technology and is well understood and implemented.

From the late 1990's, major new Ni laterite projects have been developed using improvements in materials and processing technology such as 'high pressure acid leaching' (HPAL). Although some were financial and technical failures (e.g. Cawse and Bulong, Western Australia), the Murrin Murrin (WA) project survived and is now producing near design capacity. At present several new nickel laterite projects are under development or recently entered production around the world, including Goro and Koniambo in New Caledonia, Ravensthorpe (WA) and Sorowako in Indonesia, with other projects being actively planned. As such, laterite-derived nickel will increase significantly in the near future.

In general, production of nickel from sulfide ores involves either open cut or underground mining, followed by concentration via flotation, smelting of concentrates to produce a nickel matte, finally leading to refining of matte to produce a pure metal. It is common for mines, smelters and refineries to be in different locations, depending on local geographic factors. The processing of sulfide ores in this manner is known as pyrometallurgy, with copper (Cu) either an important by-product or co-product (depending on ore grades).

Conversely, nickel production from laterite ores is relatively complex. Laterite mines are all open cut, due to the large area and shallow nature of the ores, and commonly apply a basic beneficiation to ore before processing (flotation is generally unsuitable). The next major step is high pressure acid leaching where the ore is leached with sulphuric acid at high pressures (up to 5.4 MPa) and temperatures (245 to 270°C) in a titanium-clad autoclave. Solid-solution separation is subsequently carried out through counter current decantation, and the metal-rich solutions fed to a solvent extraction (hydrometallurgical) facility. Recent laterite projects commonly vary at this stage, some operating a nickel refinery to produce pure metal, while some produce an intermediate nickel hydroxide (or even sulfide) product for export to a refinery. An alternative process for laterite ores is to use the Caron process, based on high temperature ammonia leaching and similar processing of metal-rich solutions. Cobalt is a valuable by-product metal from all Ni laterite projects (especially HPAL plants).

METHODS FOR ASSESSING ENVIRONMENTAL SUSTAINABILITY ASPECTS

A major concern with this increasing proportion of laterite nickel is that, although technology such as HPAL now exists to make processing of laterite ores more viable (technically and financially), it is widely perceived to be at a higher environmental cost.

When environmental costs are considered with continuing global growth in Ni consumption (e.g. using the trend line in Figure 1, Ni production in 2050 is predicted to reach ~2.3 Mt Ni), this leads to expectations of an increasing footprint from Ni production – that is, per tonne of Ni metal produced, environmental costs could increase compared to the current status.

There remains, however, relatively few analyses of the environmental costs of Ni production – especially with respect to the differences between sulfide and laterite ores. Given that major global Ni producers commonly release sustainability reports, often based on the Global Reporting Initiative [6], the pertinent data is becoming increasingly available to investigate these aspects in more detail. This paper achieves such a study by analysing data from various major Ni miners / producers, compiling data on basic mining production (ore processed, ore grades, metals produced) as well as critical environmental aspects such as direct plus indirect energy and water inputs and emissions outputs (especially greenhouse gases such as carbon dioxide). All data is then analysed with respect to ore type and other important factors (e.g. electricity source).

MAJOR GLOBAL NICKEL MINERS

The global Ni market is led by a number of major producers, namely (in order) Russia, Canada, Indonesia and Australia, as well as a range of moderate to minor producers; as shown in Table 1.

Table 1: 2008 Ni production and total reserves† by country (t Ni) [5]

Country	Production	Country	Total Reserves†
Russia	276,000	Australia	55,000,000
Canada	250,000	Cuba	28,600,000
Indonesia	211,000	New Caledonia	22,100,000
Australia	180,000	Canada	19,900,000
New Caledonia	92,600	Russia	15,800,000
Philippines	88,400	South Africa	15,700,000
China	85,000	Indonesia	15,200,000
Cuba	77,000	Brazil	12,800,000
Brazil	75,600	China	8,700,000
Colombia	74,900	Philippines	6,140,000
Dominican Republic	47,000	Colombia	3,100,000
South Africa	38,000	Dominican Republic	1,720,000
Botswana	36,000	Botswana	1,410,000
Greece	20,100	Greece	1,390,000
Venezuela	20,000	Venezuela	1,190,000
Zimbabwe	6,530	Zimbabwe	275,000
Other Countries	28,600	United States	150,000
Total	~1,610	Other countries	8,300,000

†Includes economic reserves and reserve base (see [5]).

A brief summary of important producers used in this study are (statistics given in Table 2):

- **Canada**: production was dominated by two companies – Inco Ltd and Falconbridge Ltd, taken over in 2006 by Vale Ltd (formerly CVRD Ltd) and Xstrata Ltd, respectively. Inco operated large Ni-Cu sulfide projects at Sudbury in northern Ontario and at Thompson in northern Manitoba (now Vale Inco). Falconbridge also operated in the Sudbury district of northern Ontario (now Xstrata Nickel), as well as at Raglan in northern Quebec. Inco also recently opened the Voiseys Bay project in Labrador/Newfoundland. All Canadian projects are based on Ni-Cu sulfide ores.

- **Indonesia**: production is entirely from Ni laterite ores, with most production historically associated with small scale mines (e.g. exporting ore to Yabulu, Queensland). Recently, Inco Ltd opened the Sorowako project in central Sulawesi Island based on pyrometallurgy. Other major projects are presently planned in various parts of Indonesia.

- **Russia**: production is pre-dominantly by JSC Norilsk Nickel Limited, from the Kola region of north-western Russia and the Taimyr Peninsula in north-central Russia (ie. Siberia), with all mines extracting Ni-Cu sulfide ores, often with rich palladium by-products.

- **Australia**: production was dominated by WMC Resources Ltd, taken over in 2005 by BHP Billiton Ltd (BHPB), who operated three major Ni sulfide mines at Mt Keith, Leinster and Kambalda as well as the Kalgoorlie Ni smelter in central Western Australia and Kwinana Ni refinery south of Perth. A range of smaller Ni sulfide mines in WA have also entered the sector since the mid-1990's. The Greenvale and Brolga Ni laterite mines in central Queensland (1974 to 1995) railed ore to the Yabulu refinery near Townsville (Yabulu is still operating based on imported Asia-Pacific ores, and is uniquely based on the Caron ammonia leach process; it is now owned by BHPB). Three new laterite mines were developed in WA in the late 1990's, at Cawse, Bulong and Murrin Murrin, all based on improvements in technology and high pressure acid leaching process design – only Murrin Murrin survived its respective major financial and technical problems (Cawse was re-opened and re-configured to produce Ni-Co carbonate but has recently been closed permanently). A new Ni laterite project has just been developed by BHP Billiton at Ravensthorpe (southern WA), producing an intermediate Ni hydroxide product which is shipped to Yabulu for refining, though Ravensthorpe was (unexpectedly) placed on care and maintenance in early 2009.
- **New Caledonia**: production is entirely from Ni laterite ores, with most production historically associated with small scale mines (e.g. exporting ore to Yabulu, Queensland), or major projects such as Doniambo owned by French company Eramet Group. Recently, Inco Ltd began construction of the large Goro project in the south-east, while the Koniambo project in the north-west is scheduled for production in the near future.
- **Columbia**: production is pre-dominantly by the Cerro Matoso Ni laterite project which produces ferronickel, now (99.9%) owned and operated by BHP Billiton Limited, from the Cordoba region of northern Columbia.

Many of the companies listed in the above descriptions publish annual sustainability reports (or corporate/financial reports), namely:

- Minara Resources Ltd – Murrin Murrin project (sparse site data, 1999 to 2008) [7];
- Eramet Group – Doniambo project (annual site data, 2002 to 2007) [8];
- Inco Ltd – Sorowako project (annual site data, 2002 to 2006) [9];
- Inco Ltd – Sudbury mines, smelter and refinery, Thompson mines and smelter (annual site data, 2001 to 2005) [9];
- Norilsk Nickel Ltd – Kola region (annual site data, 2003 to 2007) [10];
- WMC Resources Ltd – Mt Keith, Kambalda, Leinster mines, Kalgoorlie smelter, Kwinana refinery (annual site data, 1995 to 2004) [11];
- BHP Billiton Ltd – Yabulu refinery (sparse site data, 1999 to 2003) [12];
- BHP Billiton Ltd – Cerro Matoso (sparse site data, 2001 to 2003) [13].

For Australia, if data was not reported by a company or mine, some additional data for sulphur dioxide emissions was obtained from the National Pollutant Inventory [14].

As such, a range of Ni projects were able to be compiled and analysed, including such factors as laterite versus sulfide ores, pyrometallurgy versus HPAL, project scales, and located in regions varying from arid to arctic climates.

Table 2: Profile of major Ni mines / fields (average of recent years)

	Operation	Mt/yr	%Ni	%Cu	%Co	kt Ni	kt Cu	kt Co	Mine	Process
sulfides	Inco Sudbury, Canada[§]	7.69	1.40	1.51	~0.04	81.1	103.8	-	UG/OC	Pyro.
	Xstrata Sudbury, Canada	3.78	1.61	1.00	~0.07	51.3	33.2	~1.4	UG/OC	Pyro.
	Thompson, Canada	2.13	2.11	~0.13	-	46.6	~2.3	-	UG/OC	Pyro.
	Mt Keith[†], Australia	~10.9	0.62	-	-	45.0	-	-	OC	Conc.
	Leinster[†], Australia	2.6	2.08	-	-	40.4	-	-	OC/UG	Conc.
	Kambalda[†], Australia	~0.8	~3.4	~0.22	~0.05	~30	~2	~0.6	UG	Conc.
	Kalgoorlie[†], Australia	-	-	-	-	~92.6	-	-	Smelter	Pyro.
	Kwinana[†], Australia	-	-	-	-	~58.1	-	-	Refinery	Pyro.
	Taimyr, Russia[#]	13.49	1.66	3.02	-	124.3	356.9	-	UG/OC	Pyro.
laterites	Murrin Murrin, Aust.	2.69	1.32	-	0.09	28.9	-	1.94	OC	HPAL
	Sorowako, Indonesia	~5.1	1.88	-	-	70.0	-	-	OC	Pyro.
	Doniambo, New Cal.	~2.9	~2.6	-	-	59.7	-	-	OC	Pyro.
	Cerro Matoso, Columbia	NR	NR	-	NR	39.7[*]	-	-	OC	Pyro.[*]
	Yabulu, Australia	NR	NR	-	NR	~30[‡]	-	~1.8[‡]	-	Caron

[§]Platinum group metal grades ~1.51 g/t PGM. [#]~9.3 g/t PGM. [†]No production or environmental data reported by BHP Billiton since their takeover of WMC in August 2005. [‡]Approximate annual capacity before recent Ravensthorpe expansion. [*]Cerro Matoso produces ferronickel; exact smelter configuration unclear.

UG – underground, OC – open cut; Pyro – pyrometallurgical; HPAL – high pressure acid leach; Conc – concentrator; NR – not reported.

RESULTS AND DISCUSSION

The combined results for all companies and mines / fields are presented in Table 3, as well as Figures 2 and 3. The compiled data gives a valuable insight into the environmental aspects of the sustainability of nickel and associated production. There are, however, a range of issues which need to be highlighted and addressed.

Firstly, the reporting by the principal companies analysed is not consistent. Some use internal reporting protocols while others formal guidelines such as the Global Reporting Initiative (although the broad reporting focus is mostly very similar). Furthermore, some companies consistently fail to report on a key aspect such as water, energy or greenhouse emissions (each company tends to be different in this regard also). For example, Inco and Xstrata failed to report water consumption, Norilsk fails to report greenhouse emissions or Eramet fails to report energy consumption (although Eramet report energy for all other sites – just not for Doniambo). Falconbridge only reported global or Canadian data, which given their interests in copper, nickel, aluminium and zinc, does not facilitate accurate analysis of specific metals or mines. In contrast, WMC consistently reported almost all relevant data for each mine site. The inconsistency in data and reporting is a more strategic and widespread problem in sustainability reporting in the mining industry [15-17], and reflects the still evolving nature of this endeavour. The overall standard for sustainability reporting needs to improve significantly to ensure consistency across companies, countries and projects – and especially not leaving major gaps in key aspects of environmental sustainability such as energy, water or the like. In this fashion, a considerably improved data set can evolve over time to facilitate more thorough analyses in the future.

Table 3: Environmental sustainability metrics of major Ni mines / fields – average of recent years ± standard deviation (number of data points in brackets, v – variable)

Operation	%Ni±Cu±Co	GJ/t metal	kL/t metal	t CO_2/t metal	t SO_2/t metal
Inco Sudbury (5)	2.92±0.23	81.5±16	not reported	4.77±16[†]	1.13±0.08
Thompson (5)	2.11±0.29	82.8±3.9	not reported	0.86±0.14[†]	4.01±0.23
Xstrata Canada (4)	2.68±0.34	75.2±7.6	not reported	5.55±0.28	not reported
Mt Keith (9)	0.62±0.03	61.3±5.0	231±22	8.49±1.1	0.005±0.006
Leinster (9)	1.97±0.07	25.8±6.8	62.0±10 (13)	3.72±0.78 (10)	0.002±0.002
Kambalda[§] (5)	3.42±0.36	31.3±4.3	31.6±7.2	4.62±0.8	0.007±0.008
Kalgoorlie (v)	-	31.3±3.7 (10)	6.35±1.2 (14)	3.50±0.71 (13)	0.80±1.2 (9)
Kwinana (v)	-	62.0±11 (10)	12.9±4.4 (14)	5.56±1.2 (13)	0.004±0.006 (9)
Taimyr (v)	4.69±0.18 (8)	289±7.2 (5)	602±22 (4)	4.13±0.08 (5)	not reported
Murrin Murrin (v)	~1.34	~249 (3)	322±30 (5)	~25.5 (2)	0.21±0.26 (4)
Sorowako (v)	1.88 (3)	454±21 (5)	not reported	25.0±2.3 (5)	1.12±0.14 (5)[#]
Doniambo (v)	~2.6	not reported	22.7±1.0 (6)	30.7±2.2 (6)	0.36±0.07 (5)
Cerro Matoso (v)	not reported	290±35 (3)	1,308±54 (3)	~30±0.6 (2)	0.010±0.015 (2)
Yabulu (v)	not reported	572±42 (5)	215±13 (3)	45.8±1.4 (5)	not reported

[§]Only data up to 2000 is included since data from 2001 clearly shows effects of WMC selling mines and operating the Kambalda mill only. **[#]This value was corrected from the original paper.**

[†]Over 1998 to 2002, unit Inco's global unit CO_2 costs were 4.3 to 4.9 t CO_2/t metal.

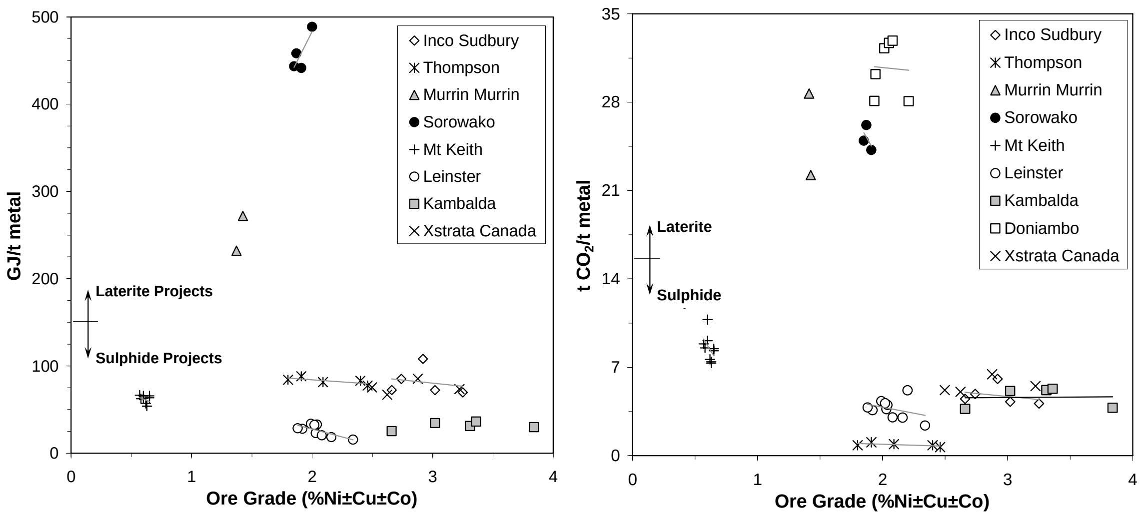

Figure 2 – Unit energy and carbon dioxide costs with respect to ore grade (%Ni±Cu±Co) (approximate linear trend lines include for some series)

With respect to energy, it is clear that laterite projects do require a higher intensity to produce nickel than their sulfide counterparts (with the exception of the Taimyr field, though this is dominantly a Cu producer with Ni-Pd co-products). For the major sulfide mines and fields operated by Inco and WMC, their unit energy cost is generally less than 100 GJ/t metal – compared to laterite projects with unit energy costs between 252 to 572 GJ/t metal. Although energy costs for Doniambo are not reported (curiously, Eramet do report for all of their other mine or smelter sites), unit energy consumption (kWh/kg Ni) is said to be generally stable, though it increased in 2005 due to plant disruptions [8]. Most projects analysed show variable energy performance over time, with many arguably even showing gradual increases in unit energy costs – only the Kwinana refinery shows a consistent long-term decline in unit energy costs.

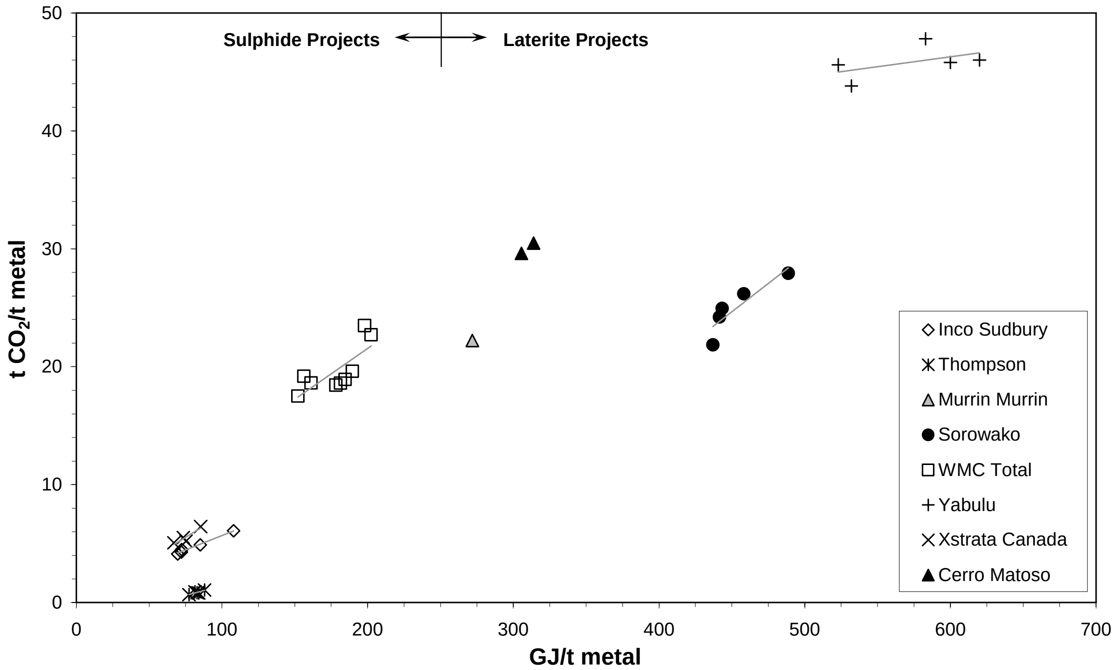

Figure 3 – Carbon dioxide versus energy costs per t metal (Ni±Cu±Co) production (approximate linear trend lines include for some series)

Water costs appear to be more variable, and are most likely related to local climate and geographic factors. A further issue with water cost is the degree of recycling incorporated at each site – with the data reported not able to differentiate such aspects.

The results for unit carbon dioxide or greenhouse costs of nickel production allow a clear distinction between laterite- and sulfide-derived Ni. All sulfide projects release less than 10 t CO_2/t metal compared to laterite projects which range from 25 to 46 t CO_2/t metal. An important aspect demonstrated in Figure 3 is the greenhouse costs of energy. Some projects have similar unit energy costs but are considerably in higher in unit greenhouse costs. For example, Inco's Sudbury operations has similar energy costs to their Thompson operations although Sudbury is some 5.5 times in unit greenhouse costs. Although both obtain the majority of their electricity from hydroelectric supply, the higher greenhouse cost for Subdury is most likely related to the larger proportion of open cut mining at Sudbury. The reported data remains insufficient to analyse the causes of the differences between various projects in detail. Similarly, although the energy cost for the Sorowako project is very high, its unit greenhouse cost is similar to Murrin Murrin – most likely to due Sorowako's use of hydroelectric supply compared to Murrin Murrin's gas-fired electricity.

The unit sulphur dioxide (SO_2) emissions vary significantly – with no clear relationship between ore type or process plant configuration. For example, although one could expect sulfide ores to lead to higher unit SO_2 emissions, a comparison of WMC operations (Mt Keith, Kambalda, Leinster, Kalgoorlie and Kwinana) to say the Murrin Murrin or Sorowako laterite projects shows that unit SO_2 emissions vary by several orders of magnitude, but with no clear association between ore type and unit SO_2 emissions. This suggests that the extent of pollution control, such as capture and conversion to sulphuric acid, is likely to be the major aspect controlling unit SO_2 emissions. For many projects, there is evidence of a decline in unit SO_2 emissions over time (data not shown), suggesting that efforts at reducing pollution are being effective.

(note: the blue text in the above paragraph has been edited after publication due to an error found in the original analyses).

CONCLUSIONS

This paper set out to compile and analyse the environmental sustainability of nickel production, with a particular focus on the comparison between sulfide and laterite nickel projects. In terms of sustainability reporting, there is a strong need for major improvement from most nickel miners, as many companies fail to report at least one key aspect such as energy, greenhouse emissions or water. Overall, there is sufficient data from several major global nickel miners to demonstrate that the production of nickel from laterite ores is clearly more energy intensive than sulfide ores, and this is closely associated with a higher greenhouse intensity. Greenhouse costs are also closely linked with electricity supply, such as gas or hydroelectricity. Water consumption is variable, and is likely to be influenced by accounting and reporting methodologies, local geographic and climatic aspects more than ore type or process plant configuration. With these various findings in mind, it is clear that the growing production of nickel from laterite ores will lead to a greater environmental footprint in the future – leading to a major sustainability challenge to continue to provide a critical metal in modern technology and infrastructure.

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