The future of nickel production - the outlook for nickel sulphide and laterite resource development

Nickel Processing 2015
Falmouth, UK. May 2015

Agenda

1. Supply/Demand outlook
2. Dispelling some myths
3. So what's the problem with laterites?
4. Sulphides – “easier” now, but for how long?
5. Is Indonesia the key to the future?
6. The long term nickel price
7. Summary
Declining refined production is expected from 2015-2017
New projects needed through 2019 if supply is to keep pace with demand

- The global nickel market is expected to be in deficit between 2015 and 2019, after a near 50% cut in Chinese NPI production due to the Indonesian ore export ban
- Beyond 2019, even with the development of new projects, including a replacement NPI sector in Indonesia, world nickel demand will continue to outstrip the supply
- 775kt of new nickel is required by 2030 to maintain a reasonable market balance
Dispelling the myth
“low grade high cost laterite projects…”

Ore processed head grades

Operating costs pre by-product credits

Source: Wood Mackenzie

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While laterite and sulphide processes have similar costs, sulphide producers benefit from significantly higher by-product credits.

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Capex increases – on average 16% p.a. since 2005 through to 2013
No isolated to large scale laterite projects or indeed just nickel – commodity wide phenomenon

Capex increases from 2007

Source: Wood Mackenzie

N.B. VNC capital estimated; some sources suggest that true capital may be over $7bn

Recent projects highlight the tendency towards start-up delays and capital cost increases

Source: Wood Mackenzie
PAL ramp up is significantly lower than general industry expectations
A case of “over promise and under deliver”

FeNi is much more varied, however beyond initial ramp-up it maintains the trajectory towards nameplate capacity
In addition to quick ramp-up periods, FeNi is less capital intensive – but it is still not “cheap” and HPAL has greater potential upside if “done right”

<table>
<thead>
<tr>
<th>Process</th>
<th>Pros</th>
<th>Cons</th>
<th>Key Considerations</th>
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<tbody>
<tr>
<td>HPAL</td>
<td>• Significantly reduced net energy requirement due to power generation from sulphur burning, reducing opex • Ability to recover cobalt as a salable product • The process produces Class 1 nickel i.e. is LME deliverable</td>
<td>• Capital costs are significant, ca. US$90-100000/t Ni/a • Ramp-up to capacity potentially slow and/or problematic, due largely to process complexity • Industry and observer perception is poor – developer tendency to “over promise” but “under deliver” outcome</td>
<td>• Keep it simple and do not try and reinvent HPAL – Learn from the mistakes made previously BUT don’t believe you can do it better another way • Understand the orebody and its variability - Critical to understand not only nickel but also the other major components such as MgO, FeO, Al2O3, SiO2 as these control the ore behaviour in processing</td>
</tr>
<tr>
<td>FeNi</td>
<td>• Capital intensity of FeNi lower – particularly when compared to HPAL (ca. US$60000/t Ni/a) • Process “well understood” and less complex in comparison to HPAL • Ramp-up to capacity generally quicker than HPAL, ca. 4.5 years</td>
<td>• FeNi is a Class 2 nickel product i.e. not LME deliverable • Can only be used in stainless steel - limiting market for sale • Significant competition with NPI which currently limits access to main market of China for sale of product</td>
<td>• Limited market with significant risk of having to discount product – significant growth in production has increased competition for sales and puts pressure on sellers. In discount product, also issue of no market of last resort, limited end user markets and NPI competition • Lower capital for entry into production – but not “cheap” - relatively less complex than HPAL but potential for major issues e.g. furnace run outs at Barro Alto and Onca Puma</td>
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## New Technology

### New technologies and potential impacts

<table>
<thead>
<tr>
<th>Description</th>
<th>Opex Impact</th>
<th>Capex Impact</th>
<th>Stage</th>
<th>Summary</th>
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<tbody>
<tr>
<td>Nitric acid pressure leaching (NAPL) Direct nickel</td>
<td>Uses a nitric acid leach and is believed to be the first process capable of treating the full laterite profile using a single flowsheet</td>
<td>Potential to significantly decrease opex, as most of the nitric acid used can be recycled</td>
<td>Uses atmospheric pressure and a standard stainless rig so high potential to significantly decrease capex</td>
<td>Undergoing pilot plant trials</td>
</tr>
<tr>
<td>Heap leaching</td>
<td>Leaching with sulphuric acid, solution purification followed by roasting and cobalt recovery as a mixed hydroxide – potential to roast the ore prior to processing</td>
<td>Variable – dependant on sulphur price and labour costs</td>
<td>Relatively low in comparison to HPAL or FeNi</td>
<td>Small-scale commercial operations. Effect of pre-roasting ore being investigated</td>
</tr>
<tr>
<td>Atmospheric leaching</td>
<td>Leaching with sulphuric acid at atmospheric pressure</td>
<td>Higher than HPAL due to higher quantities of sulphuric acid necessary to obtain suitable quantities of nickel</td>
<td>Lower than HPAL as cheaper, more conventional structures and equipment can be used</td>
<td>Used on small scales as a secondary process</td>
</tr>
<tr>
<td>High pressure acid leaching</td>
<td>Uses a sulphuric acid leach under high temperatures and extremely high pressures</td>
<td>Opex largely influenced by sulphur price and capacity utilisation</td>
<td>High capex - uses a titanium rig to withstand high pressures and temperatures</td>
<td>Used extensively in nickel production. Undergoing studies to optimise production</td>
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</tbody>
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Sulphide deposit resource grades

Source: Company reports

Future of sulphide mine development – a low(er) grade story

Source: Wood Mackenzie

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Global nickel concentrate balance

- New base case and highly probable projects potentially leading to excess concentrate availability in near term
- Balance from 2016 dependent upon FQM’s Enterprise project and what level the mine produces at. Nominal rate 40kt Ni/a but FQM has stated that actual output will depend upon market demand at the time
- Vale Thompson smelter and refinery closure deferred to ca. 2019
- Boliden has stated its intention to continue to operate the Harjavalta smelter on a custom basis - now needs to secure offtake agreements for both concentrate purchases and subsequent matte sales
- Need for additional sulphide concentrate from 2018
- In order to meet this requirement need to see sulphide mine development either by existing producers or new players within the next two to three years

The custom concentrate market

- 186t Ni in concentrate custom production for 2014, forecast to increase to 197kt for 2015
- 5.9% increase on 2014. Production from Eagle in the USA offsetting decline in Australia and Botswana. Botswana decline due to Tati becoming integrated feed with BCL
- Australia remains the major producer of custom concentrates with 33% of custom production
- 124kt Ni in concentrate expected to be exported from country of origin in 2015
- Bulk of concentrate export market is to China and Canada and Finland.
- For 2015, there is presently a significant tonnage of nickel in concentrate for which the destination is unclear
There have been several nickel processing developments in China (1)

Tsingshan NPI production via nickel sulphide concentrate
- In March 2013, Canadian company Royal Nickel Corporation and Chinese group, Tsingshan Holding Group entered into a strategic alliance to work together on the downstream processing of nickel sulphide concentrate.
- The process is being trialled at present (ca. 200t/d conc) and is believed to be working well. Our view is that although this process may be suitable for atypical nickel concentrates (like that which could be produced by Royal Nickel’s Dumont project, i.e. no by-products and low in sulphur content due to the specific mineralogy) this is unlikely to find large scale application. Typically nickel sulphide concentrates will contain by-product metals such as copper, cobalt and precious metals and these are not recovered via the Tsingshan process. Thus the miner would not get paid for the these values and generate less revenue than if sold to conventional sulphide smelters.

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Impact of ban on NPI costs of production

Source: Wood Mackenzie

There are several Indonesian nickel project developments post the export ban

- In early 2014, the Government of Indonesia presented a list of some +60 proposed nickel smelter developments – almost solely from Chinese companies in partnership with Indonesian companies
- Of these, we believe that there are only 13 which could potentially be in production by the end of 2017
- 2 are already in production, a third will enter production this year, the balance are considered only probable projects at best currently

Source: Wood Mackenzie
There is significant nickel potential production from existing and new project developments

Proposed and existing smelters production forecast

- There are presently two producers that have commenced nickel production post the ban and a single project we consider definite to enter production in the next 2-3 years:
  - PT Indoferro – current capacity around 8kt Ni in 4-6% NPI using a blast furnace
  - Expanding to 20kt with the addition of an EAF (under construction) which should commission around 2016-2017
- CMMI entered production at the end of 2013 ca. 2kt Ni in low grade NPI using blast furnace
- Tsingshan Bintang Delapan – started construction in 2012. Phase I capacity of 30kt Ni in FeNi using RKEF. Commissioning Q2 2015

There have been several nickel processing developments in China (2)

Application of the Krupp-Renn process

- The Krupp-Renn process was developed in Germany in the 1930’s to recover iron from low-grade iron ores that could not be directly blast furnace smelted
- During WWII, Nippon Yakin built a plant at Miyazu to process nearby low grade nickel ore. In 1950, the company switched to utilising ore from New Caledonia. Presently it processes ore from New Caledonia and the Philippines but did take a large portion of its ore from Indonesia prior to the ore export ban.
- Essentially ore is mixed with anthracite and fluxes and formed into briquettes. These are into reduction kilns and travel counter currently to the combustion gases. Preheating, drying, reduction and metal formation all take place in the kiln. At the far end of the kiln the pasty slag is cooled rapidly in water and the solids crushed and screened to recover the nickel-iron-cobalt alloy (known as luppen), which at Yakin is then subsequently refined in an electric furnace to a finished FeNi. The luppen typically grades around 22% Ni+Co and therefore depending upon the other impurities could actually be used directly for stainless steel production as with NPI
- Clearly this relatively simple process could have wide ranging application to produce NPI both in China and Indonesia at a relatively low capital cost (in 2010 GITS Sintering Services Inc indicated capital costs of just $4M per 100kt/a production module, and an operating cost of around US$63/t of sintered product – ca. $0.70/lb for a 4% Ni luppen). Our estimate for Nippon Yakain, inclusive of ore purchasing, freight and the refining stage for 2014 is $6.60/lb Ni.
- We are aware that at least 3 companies in China have attempted to utilise the Krupp Renn process with apparently minimal success. Key is ensuring that the charge is fully homogenised and does not become too fluid. This results in the charge sticking to the kiln walls (ringing) which creates hot spots and all control is lost in the overall process and production has to be stopped and the kiln cleaned out and potentially relined.
There have been several nickel processing developments in China (3)

Application of the Krupp-Renn process continued

- The process can treat any lateritic ore but the nickel content of the product will depend upon the nickel and iron grade of feed – a high nickel, low iron laterite producing a higher grade nickel luppen than a low nickel high iron feed
- Not easy to swap between ore types as the control of the melting in the kiln will be governed by the overall ore, flux and coal mixture characteristics which needs to be consistent
- There is no doubt that such a process could readily be applied to Indonesian ores to produce a luppen which would be allowed for export. The product could then be further refined in China with existing furnace capacity if necessary. This would increase overall operating costs but would lower transportation costs or raw material feed

There have been several nickel processing developments in China (4)

Large hearth blast furnaces

- Typically blast furnaces have been used to process 1-1.5% Ni ore with high iron to produce a 3-5% Ni in NPI. For comparison, EAF’s typically utilise >1.5-2% Ni ore with low iron to produce 5-15% Ni in NPI.
- An option being suggested is to construct blast furnaces with a larger base area at the bottom of the furnace – providing a greater surface area for slag/metal separation and the possibility to utilise lower iron bearing ores in order to make a higher grade NPI. The capital costs of blast furnaces are lower than for EAK or RKEF and construction is quick and relatively simple. It is not clear whether this modification has been trialled

AlloyStream Process

- Potential to process 1-3% Ni ore to a 3-30+ Ni in NPI. The process has apparently been trialled in the production of ferromanganese but is untested in the nickel industry. A patented process owned by Exxaro – not on China’s radar as yet
Philippines ban possibility

The Philippines has proposed a ban on the export of unprocessed nickel ores akin to that implemented by Indonesia commencing January 1st 2021.

The implementation of such a ban, which appears very likely to happen, will result in the total cessation of NPI production in China as it is currently undertaken – the removal of some 260kt Ni from global supply from around 2021/2022 depending on what ore stocks are present when the ban is implemented.

Our present market adjustment for 2022 is a requirement for an additional 460kt of new nickel supply in order to meet our demand forecast. The ban on Filipino ore exports would push this to 720kt – 30% of the required global supply at that time.

Indonesian and Filipino nickel resources (2012 data)

- Philippines 716.8Mt grading 1.29%
- Of which +1.5% Ni around 111Mt
- Based on 2013 production of 25Mt ore in 2013 implies a resource life of ca. 27 years
- On same basis, "high grade" production in 2013 was around 13.8Mt implying just 7 years production capability from high grade ores
- Indonesian resources totalled 3020Mt grading 1.47% Ni, of which proven and probable was 1163Mt grading 1.85% Ni
- On the basis of tonnage and grade alone, Indonesia would be the country of choice to develop smelters
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Incentive price analysis for 2014

2014 Incentive price

775 kt Ni required to balance market by 2035. Assume China produces for her own needs, reducing the requirement from western developments to around 400kt Ni
Historically, the growth of the incentive price over time reflects the rise in capital intensity and operating costs in the industry.

The sharp decline in 2013 reflects our view that China will develop nickel projects to fulfill its own needs, the balance having to come from Western World developments.

Potential margin capture

**NOTE:** Ore mining costs assumed to be ca. $38/wmt, selling price based on Filipino ore into China FOB, 15% Ni concentrate, Intermediate NiFe selling price 75% of Ni price, nickel price $17637/t.

Pre Tax Cash Flow ($/lb Ni)
Summary and conclusions

- **We need to see nickel project development NOW if we are to meet our outlook for global nickel demand**
  - It is too late for the "west" to meet the challenge and much of new nickel production will have to be from Chinese investment in Indonesia
  - There is a distinct lack of what would historically have been considered "world class" projects in the pipeline
- **Costs of production and capital will remain challenging**
  - Although new process developments are being looked at, there has not been a game changing development arguably since HPAL
  - NPI was old technology which filled a requirement
- **Nickel prices need to be higher in order to see project development**
  - Our view is that there are limited number of projects which can generate a reasonable return on investment at nickel prices below $22,000/t
  - Ultimately, maybe it only needs to be a "perception" of higher nickel prices that will drive development
- **Nirvana would be realistic feasibility study capital estimates, opex estimates and views on ramp-up**
  - All too often the nickel industry has over promised and under delivered. If it is to regain credibility it needs to "get real" and manage expectation and deliver on promises
- **Opportunities exist for both sulphide and laterite developments**
  - Although the future of nickel will undoubtedly be dominated by laterite developments, new sulphide mines are needed in order to maintain existing smelter production rates
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