WHY HEAP LEACH NICKEL LATERITES?

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- Recent Nickel Laterite Projects
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WHY HEAP LEACH NICKEL LATERITES

- Nickel demand has been escalating faster than other metals
- Abundant, principally undeveloped but lower-grade nickel laterite sources
- Declining availability of high-grade sulphides
- Allows processing of entire laterite profile (increased resource utilization)
- Heap leaching has been successful on every other mineral attempted
- Lower Capital Cost, Lower Operating Cost, Lower Risk
WORLD RESOURCES OF NICKEL

World Resources on Land

- Laterite: 72%
- Sulphide: 28%

Primary Nickel Production

- Laterite: 42%
- Sulphide: 58%
PROCESSING NICKEL LATERITES

Current View On Processing Options For Nickel Laterites

- Limonite
- Transition
- Saprolite

(after Elias 2001)
RECENT NICKEL LATERITES PROJECTS

Ferro-nickel smelters

- **Barro Alto, Brazil**
  - $1.9 Billion (36ktpa; $23.90/annual lb of capacity)
  - Add $5.00/lb to account for refurbishing

- **Onca Puma, Brazil**
  - >$3 Billion (50ktpa; $27.17/lb)
  - Excludes refurbishing costs
  
  *Furnace failures on both of above projects → complete rebuilds required (>0.5B). Full operation not until mid 2016 for both projects.*

- **Koniambo, New Caledonia**
  - >$6 Billion (60 ktpa; $45.29/lb)
  
  *Very slow ramp up - H1 14 production 4.1kt ($332/lb)*
  *Full capacity expected 2015*

- **Few suitable resources remain**
- **High complexity**
- **High capital intensity**
- **Slow & problematic ramp ups**
RECENT NICKEL LATERITES PROJECTS

High Pressure Acid Leach

➤ VNC Goro, New Caledonia (2010)
  • >$6 billion (60ktpa; $45.29/annual lb of cap)
  
  *Highly Problematic ramp up. Total production < 40kt in 3 years ($204.17/lb)*

➤ Ambatovy, Madagascar (2011)
  • >$7 billion (60ktpa; $52.93/lb)
  
  *Slow ramp up. 2013 production 29.25kt ($108.59/lb)*

➤ Murrin Murrin, Australia (1999)
  • Australia $1.6 billion (40ktpa; $18.15/lb)
  
  *Slow ramp up, post ramp production ~29.3ktpa ($24.77/lb)*
  
  *Added heap leach circuit due to operating problems with HPAL plant*

➤ Ravensthorpe, Australia (2008)
  • $3.7 billion (50ktpa; $33.57/lb)
  
  *Only achieved 35% of capacity*
  
  *Shut down and sold for 10% of capital cost within months of commissioning*

➤ High complexity
➤ High Capital Intensity
➤ Slow problematic ramp ups
➤ Technical & environmental issues
RECENT NICKEL LATERITES PROJECTS

Atmospheric Leach

Forecast lower CapEx than HPAL, but higher than HL, but no successful projects (yet?)

- Weda Bay, Indonesia
  - >$6 billion (50ktpa; $54.44/annual lb of cap)
  - *Investment decision deferred to 2017 (high costs)*

- Dutwa, Tanzania
  - >$2 billion (27ktpa; $33.61/lb)
  - *Company now in liquidation*

- Acoje, Philippines
  - *Project suspended due to poor economics*

- High complexity
- High Capital Intensity (~80% of HPAL)
- Technical & environmental issues
Brazilian Nickel Ltd

**RECENT NICKEL LATERITES PROJECTS**

**Heap Leach**

**Commercial Operations:**
- **Murrin Murrin, Australia** $0.3 bn (9ktpa; $15.11/lb)
  *In operation since 2009, Leaching 1 mtpa of ore integrated with HPAL*
- **Yuanjiang, China**
  *Started heap leach production in 2007*

**Development Projects:**
- **Piauí, Brazil** $450M (22ktpa; $9.28/lb)
- **NiWest, Australia** $400M (14ktpa; $12.75/lb)
- **Colombia** $750M (20ktpa; $17.01/lb)
- **Çaldağ, Turkey** $450M (20ktpa; $10.30/lb)
- **Guatemala** $2,550M (79.5ktpa; $14.55/lb)
- **Pearl, Indonesia** $800M (32ktpa; $11.11/lb)
- **Gag Island, Ind** $800M (27.3ktpa; $13.47/lb)
- **Cleopatra, USA** $475M (21.5kpta; $10.02/lb)
- **Acoje, Philippines** $498M (24.5kpta; $9.22/lb)
- **NTUA, Greece**

**Comparison with FeNi, HPAL, AL:**
- **Low complexity, lower Capital Intensity**
- **Net power producer after ramp up**
- **Smaller carbon foot print**
## Nickel Production Technologies & Cost

<table>
<thead>
<tr>
<th>Process Technology</th>
<th>Typical Capacity ktpa of Ni</th>
<th>CapEx US $/lb annual Ni capacity</th>
<th>OpEx US $/lb Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smelting</td>
<td>18 to 60</td>
<td>24 to 45</td>
<td>2.20 to 4.00</td>
</tr>
<tr>
<td>HPAL / AL</td>
<td>10 to 60</td>
<td>21 to 70+</td>
<td>2.70 to 11.00*</td>
</tr>
<tr>
<td>Heap Leach</td>
<td>10 to 60</td>
<td>9 to 15</td>
<td>2.20 to 3.00</td>
</tr>
</tbody>
</table>

*High Opex from HPALs like Ambatovy & Goro which are currently operating at much < nameplate capacity*
PROCESS INTEGRATION: HL + FeNi/HPAL

Commercial Operations:
- Murrin Murrin, Australia
  - Status: Operating HPAL & HL
  - Added HL circuit to compensate for poor HPAL performance

Development Projects:
- Cerro Matoso, Colombia
  - Status: Operating Smelter, HL in development
- Guatemala
  - Status: FeNi/HL & HPAL/HL PFS completed
- Brazil
  - Status: FeNi/HL in early study

Possible Ni Laterite Production in 2020
(from Oxley & Barcza, 2012)
PROCESS INTEGRATION: HL + FeNi/HPAL

- **Increased resource utilization:**
  - FeNi or HPAL: 45% to 60% of total contained Ni
  - HL + FeNi/HPAL: 80% to 85% of total contained Ni

- **Circuit efficiency:**
  - Increased average grade to & recovery from FeNi or HPAL
    - Increased Ni production for existing plant
    - Reduced plant cost for greenfield project
  - HL product (NHP) can be added to FeNi furnace
    - Increases furnace efficiency
    - Increases NPV of HL circuit (no discount for selling intermediary product)

- **Economics**
  - Reduced operating cost & energy consumption per tonne of Ni produced
  - Increased cobalt production
  - Can reduce reliance on grid power
  - Can increase Ni grade in FeNi product, increasing market value
  - Reduced carbon emissions & reduced overall environmental impacts
  - Allows commercialization of otherwise uneconomic deposits
SCEPTIC’S PERCEIVED ISSUES

- New Technology
- No commercial operations
- Laterites don’t percolate
- Laterites & Clay
- Low recovery

Knowledge Base
Brazilian Nickel Ltd

KNO仟LEEDGE BASE?

- Piauí Nickel Project
- ENK at Çaldağ & Acoje
- BHPB at Cerro Matoso
- Worldwide Cu & Au Heap Leaching
- Worldwide Ni Laterite Operations
- Standard Equipment & Materials

Çaldağ pilot plant
NEW TECHNOLOGY?

- Used extensively in Au, Ag, Cu, U, Nitrates
- Tested on a demonstration scale by European Nickel, BHP Billiton, Metallica, Vale
- Technically & economically proven
- Successful with every other attempted mineral
NO COMMERCIAL OPERATIONS?

➢ Commercial production:
  ▪ Murrin Murrin (Minara, Australia)
  ▪ Yuanjiang (Yunnan, China)
  ▪ 200+ other minerals successfully operating
LATERITES DON’T PERCOLATE?

- All natural materials percolate
- Similar or better permeability than many copper projects:
  - Spence, El Tesoro, Ivan-Zar (Chile)
  - Tintaya, Cerro Verde (Peru)
- Agglomeration
  - Successfully used with Ni, Au laterites & poorer quality Cu ores
  - Limonite content is key

<table>
<thead>
<tr>
<th>Ore/Location (# of tests)</th>
<th>Ave Perm (cm/s)</th>
</tr>
</thead>
</table>
| **Nickel:**
  - 37 samples from 5 sites                   | 2x10-3          |
| **Copper (operating heaps):**
  - Low quality ore, Peru (63)                 | 6x10-4          |
  - Good quality ore, Peru (30)                 | 2x10-2          |
| **Gold (operating heaps):**
  - Central America, saprolite (10)            | 7x10-4          |
  - Brazil, saprolite (13)                      | 9x10-3          |
Most Ni laterite ores have very low clay mineral content and are amenable to agglomeration.

Australia, operating Ni heap
LOW RECOVERY?

- Heap leaching treats the entire ore body
- No need for selective mining or blending
  - except in rare cases where permeability needs to be managed, such as with very high limonite ore bodies
- Overall resource recovery can be >80%, with 70 to 75% typical
- With Smelting, HPAL & AL:
  - recovery of target ore zone = 85 to >90%
  - total resource recovery = 45 to 60%
TYPICAL Ni HL FLOWSHEETS

Stand alone Heap Leach:

Heap Leach with FeNi plant:
THE IDEAL PROJECT

- Target Resource:
  - Ore grade: >1.0% Ni, >0.05% Co
  - Resource size: >50M tonnes
  - In-hep recovery: >65%
  - Low ratio of limonite to saprolite
  - Local limestone supply

Rocky, high silica deposit
Low limonite
Very High limonite
Mineralogy:
- High SiO2
  - Better heap stability & equipment support
  - Better permeability, agglomerate quality
  - Faster leach kinetics
  - Lower acid consumption
- Low Fe, Mg
  - Lower acid consumption
  - Lower residue production
  - Better agglomerate durability
  - Smaller precipitation & filtration plant
- Clay & Limonite
  - Permeability, agglomerate quality
THE IDEAL PROJECT

Siting Factors:

- Similar criteria to copper heap leach facilities
  - Terrain, climate, water supply, access
  - Stakeholder & regulatory processes

- Transportation
  - In-coming tonnage exceeds out-going

- Power
  - Net producer after ramp-up
CONCLUSIONS

- Lowest Cost Option
- Lowest Risk Option
- Highest Resource Utilisation
- Increased Access to Raw Materials
- Environmental Improvements
Thank you

Questions