Brazilian Nickel Ltd

WHY HEAP LEACH NICKEL LATERITES ?

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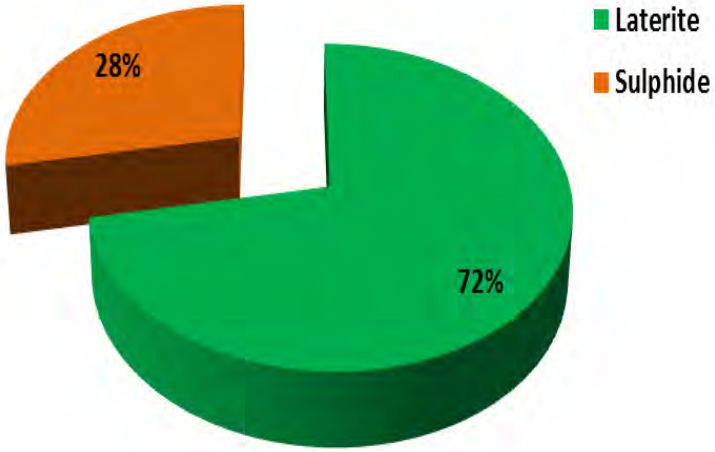
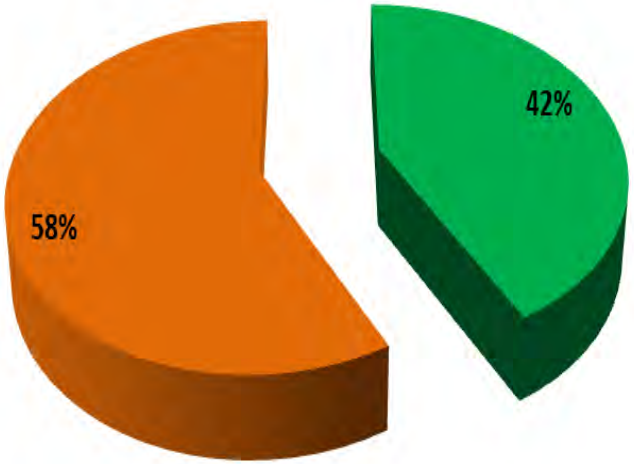
WHY HEAP LEACH NICKEL LATERITES

- 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



Primary Nickel Production

PROCESSING NICKEL LATERITES

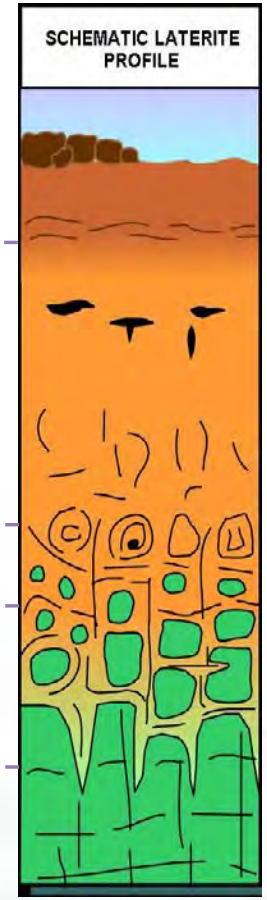
Current View On Processing Options For Nickel Laterites

Limonite

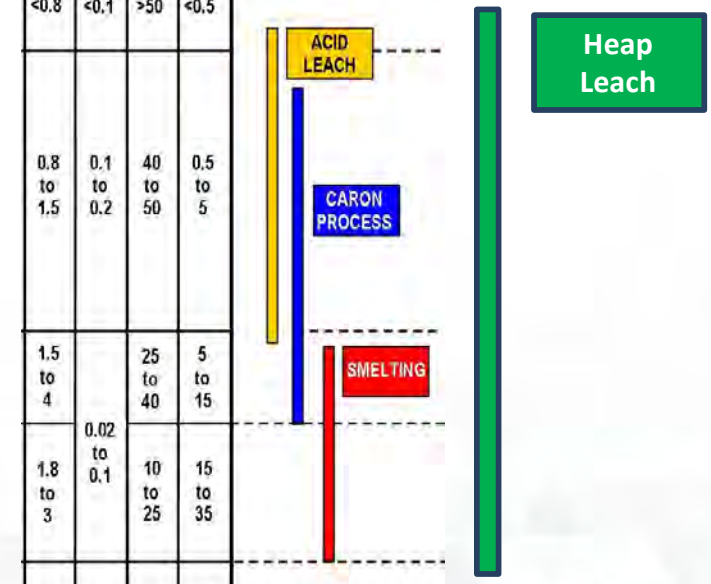
Transition

Saprolite

(after Elias 2001)



APPROXIMATE ANALYSIS (%)				EXTRACTION PROCESS
Ni	Co	Fe	MgO	
<0.8	<0.1	>50	<0.5	
0.8 to 1.5	0.1 to 0.2	40 to 50	0.5 to 5	
1.5 to 4	0.02 to 0.1	25 to 40	5 to 15	
1.8 to 3		10 to 25	15 to 35	
0.3	0.01	5	35 to 45	



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**

Onca Puma, Brazil

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 (<u>$204.17/lb</u>)
- 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)

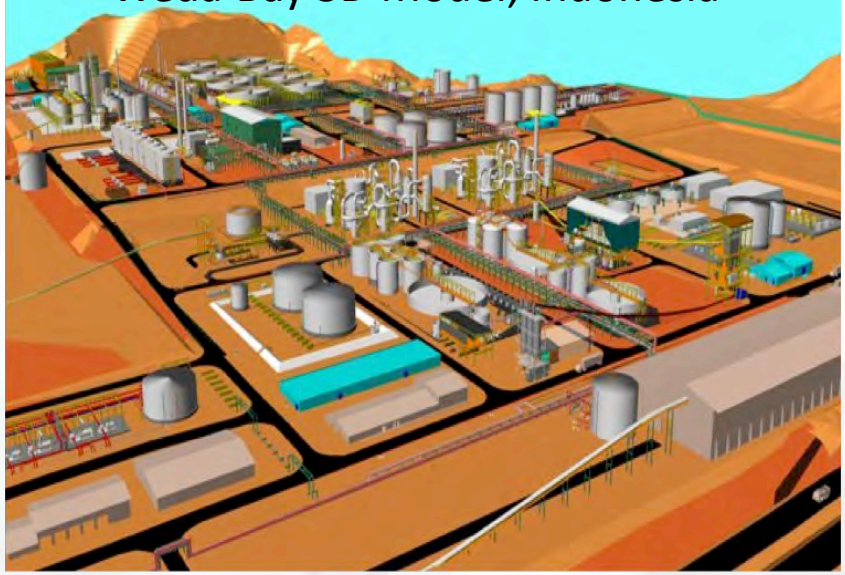
  Investment decision deferred to 2017 (high costs)
- Dutwa, Tanzania
  - >$2 billion (27ktpa; $33.61/lb)

  Company now in liquidation
- Acoje, Philippines

  Project suspended due to poor economics

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

Weda Bay 3D Model, Indonesia



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

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

** High Opex from HPALs like Ambatovy & Goro which are currently operating at much < nameplate capacity*

PROCESS INTEGRATION: HL + FeNi/HPAL

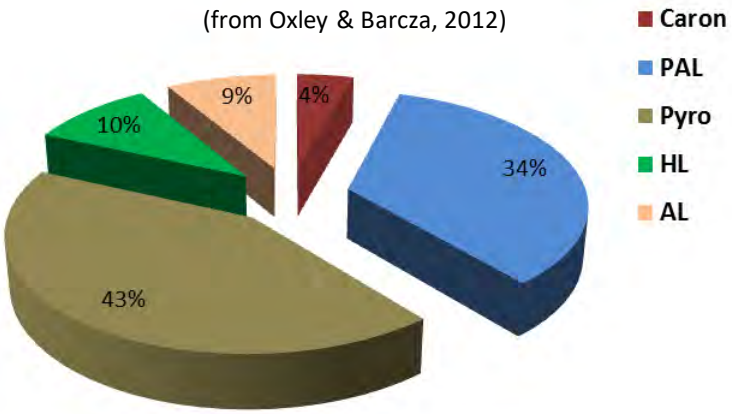
Commercial Operations:

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

Development Projects:

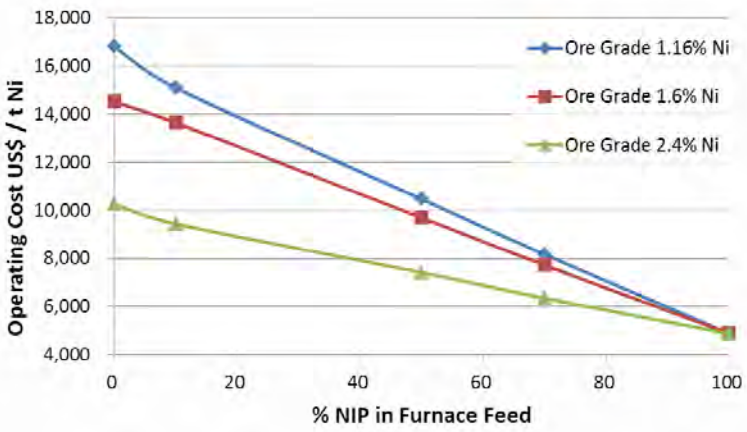
- Cerro Matoso, Colombia
  - Status: Operating Smelter, HL in development
- Guatemala
  - Status: FeNi/HL & HPAL/HL PFS completed
- Brazil
  - Status: FeNi/HL in early study

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

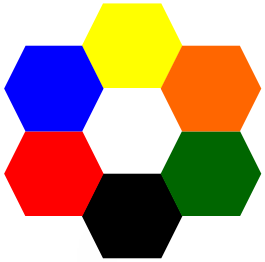


- **Circuit efficiency:**
  - Increased average grade to & recovery from FeNi or HPAL
    - Increased Ni production for existing plant
    - Reduced plant cost for greenfield project
  - HL product (NHP) can be added to FeNi furnace
    - Increases furnace efficiency
    - Increases NPV of HL circuit (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

KNOWLEDGE BASE?

Piauí Nickel Project

ENK at Çaldağ & Acoje

BHPB at Cerro Matoso

Worldwide Cu & Au Heap Leaching

Standard Equipment & Materials

Worldwide Ni Laterite Operations

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

Ore/Location (# of tests)	Ave Perm (cm/s)
Nickel: -37 samples from 5 sites	2x10-3
Copper (operating heaps): -Low quality ore, Peru (63) -Good quality ore, Peru (30)	6x10-4 2x10-2
Gold (operating heaps): -Central America, saprolite (10) -Brazil, saprolite (13)	7x10-4 9x10-3

LATERITES & CLAY

- Most Ni laterite ores have very low clay mineral content and are amenable to agglomeration

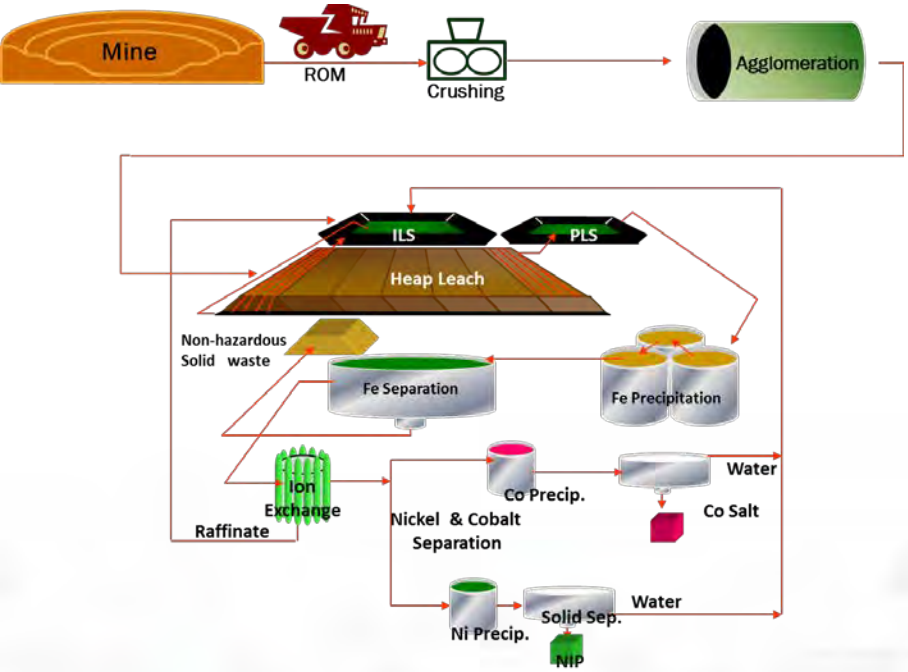
Australia, operating Ni heap

LOW RECOVERY?

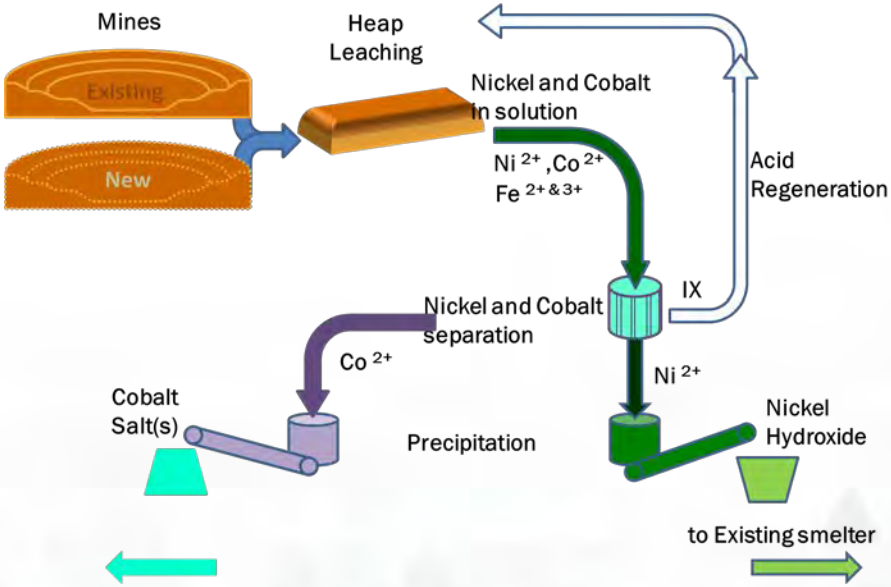
- Heap leaching treats the entire ore body
- No need for selective mining or blending
  - except in rare cases where permeability needs to be managed, such as with very high limonite ore bodies
- Overall resource recovery can be >80%, with 70 to 75% typical
- With Smelting, HPAL & AL:
  - recovery of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

TYPICAL Ni HL FLOWSHEETS

Stand alone Heap Leach:



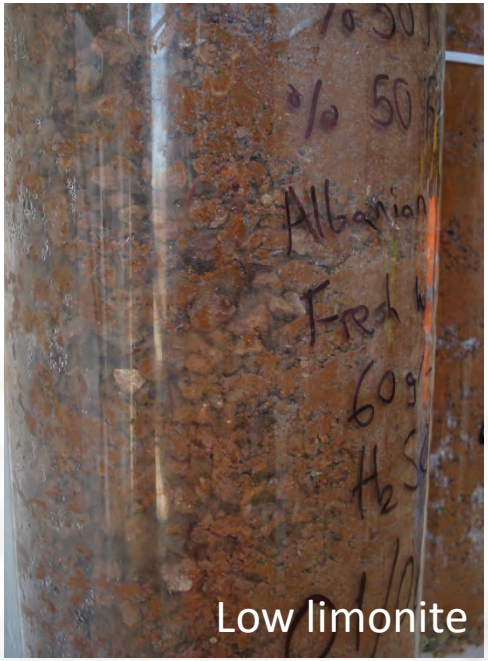
Heap Leach with FeNi plant:



THE IDEAL PROJECT

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

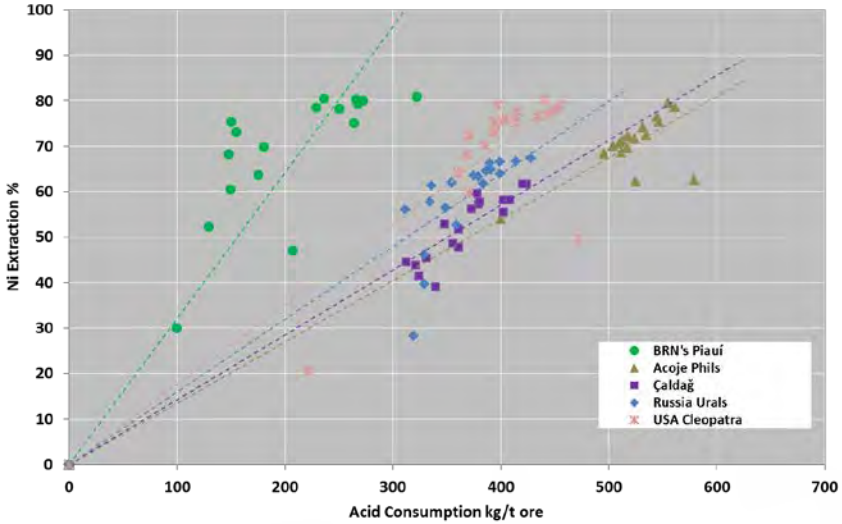

Rocky, high silica deposit

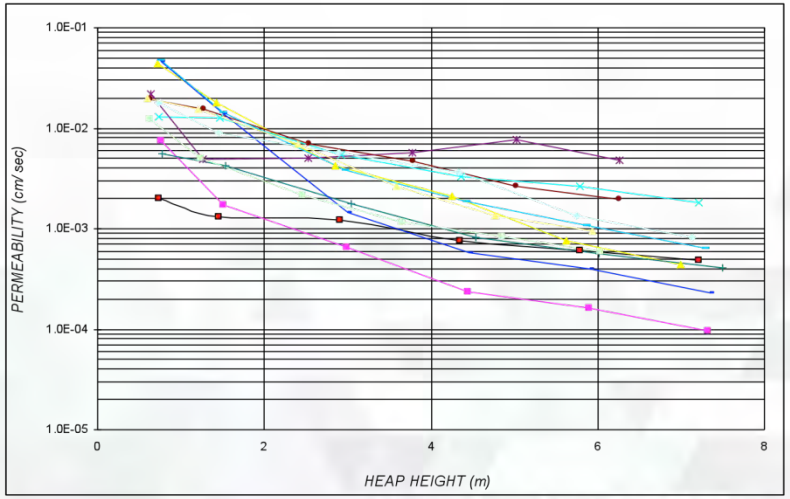

Low limonite


Very High limonite

THE IDEAL PROJECT

- 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

Heap Leaching of Ni Laterites

Stand-alone or integrated

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

Thank you

Questions