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# The Piauí Nickel heap leach project, Brazil

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## Abstract

The Piauí project in Northeast Brazil is a nickel laterite project in advanced development with measured and indicated resources totaling over 72 Mt containing 1.0% Ni and 0.05% Co (at a 0.6% Ni cut-off grade). Approximately 73% of this resource is in the measured category. Resources will be extracted using a simple open pit mining method (the deposit occurs as an isolated hill surrounded by flat land) with an estimated stripping ratio close to1.9:1 (tonnes waste:tonne ore).

The selected metallurgical process consists of two-stage crushing, agglomeration, conveying, stacking, and leaching as a dynamic heap (on/off pad). Heap leaching will use counter-current technology where the resultant pregnant leach solution (PLS) is treated in a downstream single-stage iron removal and two-stage nickel precipitation plant to produce nickel as a mixed hydroxide product (MHP).

Studies and test work completed to date include more than 76,000 m of drilling and sampling, small and large-scale column tests, pilot heaps, a demonstration nickel recovery plant, and a prefeasibility study. The column and heap tests demonstrate an extraction rate of greater than 80% Ni, with low acid consumption and short leach cycles. The project is currently finalizing the demonstration of the process and the feasibility study is expected to commence in 2016.

Target nickel production is 22,000 tpa as an MHP when in commercial operation.

## Introduction

The Piauí Nickel Project (PNP) located in the Municipality of Capitao Gervasio in the Piauí State of northeastern Brazil, was previously owned by Vale S.A. They spent over US$60M during the course of 9 years developing the project to a pre-feasibility level. The deposit has been extensively drilled. Almost 73% of the resource is classified as Measured with a combined Measured and Indicated resource of 72 million tonnes containing 1.0% Ni and 0.05% Co. The project also has adjacent exploration licenses which may provide a further upside resource potential. The geo-metallurgical characteristics of the deposit (high silica, low iron content, rocky in texture, low clay content, etc.) combined with the

climatic conditions (semi-arid), the site topography, and the available infrastructure all strongly support the decision to use heap leaching as the extractive technology.

The combined standard unitary processes of crushing, agglomeration, conveying, stacking, heap leaching, impurity removal and nickel precipitation constitute a low risk route to produce nickel as an intermediate product. This route provides a great degree of flexibility in terms of resource utilization, process capacity expandability, and product quality. In addition, this process exhibits well-documented lower capital and operating costs as compared to more intensive treatment options (i.e. rotary kiln/electric furnace, high pressure leaching, etc.)

The deposit occurs as an isolated hill surrounded by flat land. Mining will thus be a straightforward open pit process with no, or very limited, groundwater issues. Metallurgically, the ore exhibits fast leaching kinetics, high nickel extraction and, most importantly, low acid consumption. The project is close to road and rail infrastructure. These connect the project to a choice of ports. There is a large source of water nearby and the arid climate facilitates both the heap leaching process and to the availability of ample land for the heaps. The surrounding terrain is flat and currently used only for low productivity animal grazing.

In 2005, Vale commenced heap leach test work with positive results, which led to the construction of a demonstration plant on the site. Large-scale columns were operated from 2007-2009 and demonstrated excellent results with average nickel extractions exceeding 85%. In 2014, Brazilian Nickel (BRN) finalized an asset purchase agreement to acquire 100% of the project which encompassed all mineral rights, the demonstration plant, and the camp. After securing initial financing, BRN is now completing all the necessary steps to develop a test pit, refurbish and restart the demonstration plant, and operate said plant. This should provide the data required to complete a bankable feasibility study (BFS) and secure construction finance. During the course of preparing the BFS, BRN will also identify the most economically viable approach to project development. BRN will also complete environmental and social gap analyses and any further work needed to enable timely application for the environmental licenses.

Planned metallurgical test work includes several full-height heaps to confirm the process design criteria and a series of large columns to test ore variability and confirm the operating window.

## Project location

PNP is located in northeastern Brazil in the Municipality of Capitão Gervásio de Oliveira, in the state of Piauí. The municipality of Capitão Gervásio de Oliveira is located in the southwestern region of the state of Piauí some 46 km from the city of São João do Piauí and 545 km from Teresina, the capital of the state.

PNP site can be accessed:

- from São João do Piauí-PI on highways PI-459 and then PI-465; and,

- from the city of Afrânio-PE on PE-407 followed by PI-459 via Queimada Nova to the municipality of Campo Alegre Fidalgo, where it connects to PI-465.

Both of these routes are on modern, asphalt roads. From the PI-465 there is an 8 km long unpaved road to the project site. Figures 1 and 2 show the location maps.

The nearest commercial airport is Senador Nilo Coelho Airport at Petrolina (IATA Code: PNZ).


**Figure 1: Location map**

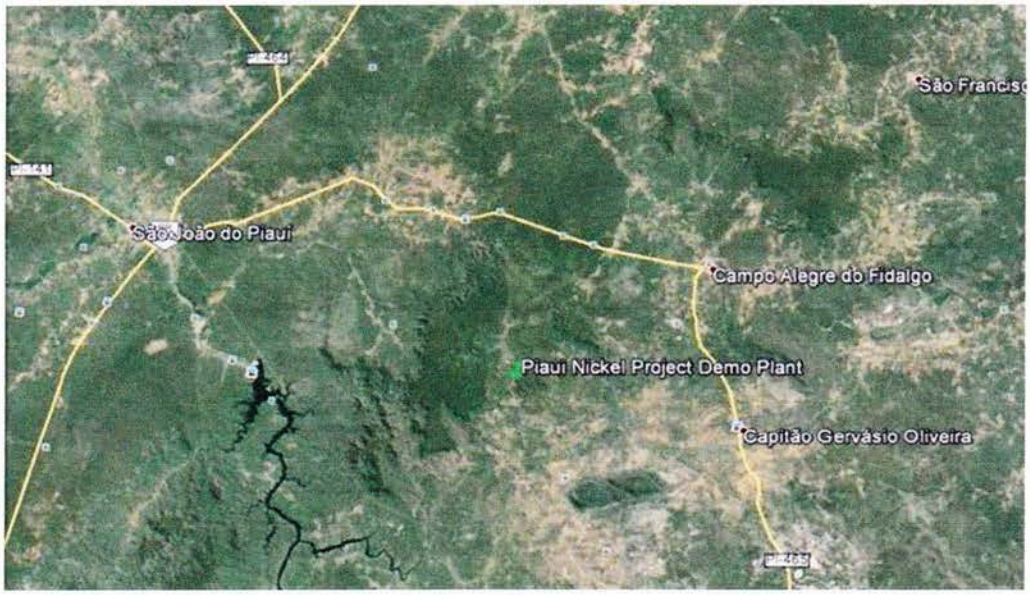


**Figure 2: Project site location (from Google Earth)**

The Piauí deposit lies atop a low-lying hill with elevations up to 500 m surrounded by a flat plain with elevations around 370 m above sea level. The hill itself is sparsely vegetated and the plain is cover with small trees and scrub.

The project is located in a semi-arid, tropical steppe region. It has a short wet season from December to May and a long dry period from June to November.

The average annual rainfall at the mine site ranges from 500 mm to 700 mm.

## Geology and resources

The geological setting of the Piauí deposit is within a terrain of intensely deformed volcanic, volcano-sedimentary and sedimentary rocks of Precambrian age which have been intruded by mafic-ultramafic bodies. The Piauí ultramafic comprises a massive body of serpentinised dunite and peridotite, grading to the south into a mafic complex of diorites, gabbros and troctolites. The ultramafic body as expressed by the lateritised hill is about 3 km long (E-W) by about 1.3 km wide (N-S). The hill rises about 100 m above the surrounding plain. The ultramafic body has been intensely and deeply lateritised forming the nickel deposit. The character of the nickeliferous laterite is typical of lateritised dunites, which are composed almost entirely of MgO and $SiO_2$ and are highly susceptible to breakdown in the weathering environment. Olivine breaks down as Mg is rapidly removed in solution, and the relatively small amount of Fe remains as limonite.

The total estimated resource are 298 million tonnes at 0.50% Ni. Table 1 shows a summary of the resource estimate without using a cut-off grade, and Table 2 presents measured and indicated resources at a cut-off grade of 0.6% nickel:

| Category | Tons ('000t) | Ni (%) | $Al_2O_3$ (%) | MgO (%) | $Fe_2O_3$ (%) | Cr (%) | MnO (%) | $SiO_2$ (%) | Co (%) |
|---|---|---|---|---|---|---|---|---|---|
| **Measure** | 165,835 | 0.55 | 3.90 | 6.24 | 17.07 | 0.70 | 0.24 | 60.81 | 0.032 |
| **Indicated** | 88,559 | 0.46 | 4.20 | 5.44 | 17.99 | 0.76 | 0.25 | 60.72 | 0.031 |
| **Inferred** | 43,218 | 0.40 | 7.80 | 8.73 | 13.59 | 0.54 | 0.23 | 54.73 | 0.024 |
| **Total** | **297,612** | **0.50** | **4.56** | **6.36** | **16.84** | **0.70** | **0.24** | **59.90** | **0.031** |

**Table 1: Piauí resource estimate without cut-off grade applied**

| Category | Tons ('000t) | Ni (%) | $Al_2O_3$ (%) | MgO (%) | $Fe_2O_3$ (%) | Cr (%) | MnO (%) | $SiO_2$ (%) | Co (%) |
|---|---|---|---|---|---|---|---|---|---|
| **Measure + Indicated** | 72,211 | 1.00 | 4.81 | 10.08 | 17.95 | 0.73 | 0.29 | 51.51 | 0.048 |

**Table 2: Piauí resource estimate @ cut-off grade 0.6% nickel**

## Process general description

### Mining

The Piauí deposit consists of a hill with relatively limited overburden. Conventional open pit methods will be used to recover the resource and because the deposit occurs as an isolated hill surrounded by flat land and the ore generally follows the ground contours, groundwater issues are limited.

The mine plan calls for an ore production capacity of 3 Mtpa (dry) over a 24 hours per day, 7 days per week operating schedule.

The mining equipment will consist of typical hydraulic excavators, rigid body rear dump heavy-duty 36 t trucks, rotary drills and dozers. Standard support equipment such as graders, explosives trucks, backhoe loaders, water trucks, service trucks and others will also be included.

Some of the criteria to be used to optimize the pit during the development of the BFS are:

- Annual ore production rate: 3 Mtpa
- Surface constraints: None
- Nominal cut-off grade: 0.6% Nickel
- Open pit slopes: 35 degrees
- Mining recovery: 98%
- Global nickel recovery: 76%

The current mineable portion of the measured and indicated resource is present in Table 3. The corresponding stripping ratio is 1.92:1.

| Category | Ore Tons ('000t) | Ni (%) | $Al_2O_3$ (%) | MgO (%) | $Fe_2O_3$ (%) | Cr (%) | MnO (%) | $SiO_2$ (%) | Co (%) |
|---|---|---|---|---|---|---|---|---|---|
| **Measure + Indicated** | 50,527 | 1.076 | 5.31 | 11.13 | 17.84 | 0.71 | 0.29 | 47.00 | 0.048 |

**Table 3: Piauí project mineable resource**

### Crushing

Run-of-mine (ROM) ore will be crushed in two stages prior to stacking. Ore will be hauled from the pit to either a course ore crusher-feed stockpile or directly to the crusher bin. ROM will be stored according to its lithological classification and the heap-stacking plan will determine the crusher feed sequence. Knowhow is directly transferable from both other laterite operations and copper heap leach operations.

### Agglomeration

This process is included to initiate nickel extraction and improve the homogenization of the particle size distribution within the heap, thereby improving heap percolation and permeability throughout the life cycle of the heap cell. Optimized agglomeration allows irrigation of the heap for the entire leach cycle and improves the initial leach response. Operational experience is transferable from heap leach operations for copper, gold and uranium. Specific methods used to agglomerate a variety of ore types with a wide range of characteristics (i.e. particle size distribution, raw moisture, clay content, etc.) are well known and documented through extended periods of demonstration test work undertaken by the BRN team over the past 16 years.

### Conveying and stacking

Standard conveying and stacking systems will transport the agglomerated ore from the agglomeration drum to the leach pad area. Design criteria and engineering methods target the preservation of the integrity of the agglomerated ore; a practice common in copper heap leaching operations.

### Heap leaching

The topography of the project location allows for the use of a dynamic leach pad. Maximum heap height is determined by the hydrodynamic characteristics of the ore, the metallurgical response, and slope stability. Leach pad size is calculated based on the estimated total leach cycle.

The engineering configuration of the leach pad (liner, overliner, collecting pipes, slope, etc.), the irrigation system (drippers, distribution pipes, control valves, etc.) and the solution management system (ponds, pumps, piping, control valves, etc.) are all in accordance with well-known industry practices. Heap operating philosophy (irrigation rate, irrigation solution chemistry, recirculation strategy, leaching stages, etc.) are the strength and the competitive advantage of the BRN team:

- Since 1999 the members of the BRN team have been studying heap leaching of nickel laterites. In this time, they have looked at over 35 deposits in 13 different countries. Considerable amounts of test work have been completed on these, from bottle roll scale up to demonstration heaps. All under direct supervision of the BRN team.
- The team began working with John Bartlett of Metsim in 2005 and has developed a state of the art dynamic metallurgical simulation model that will be used to predict and validate the data for the PNP.
- The team has developed data collection process and analysis techniques that allow for scale up assessment and general process optimization.
- They have an understanding of the impact that the geo-metallurgical, mineralogical, and hydrodynamic characteristics of the ore have on the metallurgical performance and vice versa.

- The team has developed an integrated economic model that combines all key inputs to assess conceptually the potential benefits of developing any given laterite deposit using this technology.
- And they understand the risk-management requirements of implementing heap leaching projects.

Although different for each deposit, the link between the ore characteristics and the approach to treatment is fundamental to optimize performance.

Spent ore will be removed from the pads and disposed of in a dedicated residue disposal facility. The equipment used will be selected from a variety of options based on both project site specifics and economic criteria.

### Impurity removal (PLS purification)

During this stage elements that precipitate at a lower pH than that at which nickel precipitates are removed in a standard precipitation circuit (agitated tanks, thickener and filter) with the aim of producing a purer nickel concentration product. Total residence time (and therefore the number and size of the tanks and thickeners) is defined by the PLS chemistry and the required amount of precipitant (limestone slurry). Standard equipment is used throughout the precipitation stage. Filters include two stage washing to minimize nickel losses in the filter cake moisture.

**Figure 3: Impurity removal filter cake**

The filter cake is a process plant residue that is co-disposed with the spent ore in the same contained area.

### Nickel precipitation

Using similar standard equipment to the impurity removal stage, the nickel is precipitated by further raising the pH with addition of the correct amount of precipitant (soda ash or magnesia). As before, solution chemistry and the precipitating agent define the equipment size. The filter cake produced during this stage is the nickel intermediate product. Filtered solution is returned to the process ponds for re-use. Filter washing is also planned here to improve the product quality.

### Reagents

The main reagents consumed in the process are sulfuric acid, limestone and soda ash. Sulfuric acid will be produced at a dedicated sulfur burning acid plant located at the project site. The sulfur to feed this plant and the soda ash will be imported through one of two selected ports, both of which are connected to the site via rail link.

The acid plant will generate enough electricity to run the entire plant once production has ramped up to full capacity. A connection to the national power grid will be used as back up and for the ramp-up period. At full production, there will also be excess power which will be sold to the market.

Different sources for limestone have been identified near the project site and final selection will be part of the BFS. The limestone trade-off study will include the location of the crushing plant and micronizing plant. Limestone will be crushed at the quarry and then micronized at the project process plant site (to optimize pumping requirements).

Soda ash (sodium carbonate) is employed to precipitate nickel and cobalt in the Nickel Precipitation circuit. Soda ash solution is prepared by mixing soda ash with filtered water in the soda ash preparation tank. Soda ash will be delivered in 1 t bulk bags to the reagent preparation area. After the soda ash is discharged into the soda ash mixing tanks, a predetermined volume of water is added and the mixture agitated until the soda ash is fully dissolved. The solution is then transferred by pump to the storage tank. Soda ash solution is delivered in a ring main to the nickel precipitation circuits.

**Figure 4: View from the mine to the future commercial plant area**

## Why heap leaching?

Low grade (1.5% Ni or less) laterite deposits require low capital and operating costs for an economically viable business case. Traditional smelters or high pressure leaching processes do not qualify as low cost

operations and, in addition, have a significant implementation risk due to the complexity of their flowsheets.

Heap leaching, on the other hand, involves the use of simple and well know unitary processes. The risks are therefore not technology based. They are instead based on the potential for an incomplete understanding of the link between the ore characteristics and the operating strategy, a risk borne by all process methods.

The commercial application of heap leaching technology to nickel laterites is still in its infancy, and even then only at a small scale (around 2,000 tpa of nickel contained in an intermediate product). Multiple test work campaigns and demonstration programs at different scales undertaken by several of the industry leaders have confirmed the amenability of nickel laterites to heap leaching. The development of larger commercial operations has been constrained by external economic factors.

A primary benefit of the use of heap leaching is its high degree of flexibility which allows multiple approaches to a business case based on project specifics. This flexibility allows the operator to:

- Use a staged approach (multiple expansions) to implement the project, which minimizes risk;
- Increase resource utilization, which results in less selective mining requirements;
- Expand the processing capacity without major disruptions in the installed capacity;
- Modularize the downstream plant to produce a variety of products using different refining technologies (i.e. ion exchange).

**Figure 5: View of the Piauí demonstration plant**

## Project upside potential

### Intermediate product quality

The base case examined for the Piauí project calls for a simple precipitation-based downstream plant; however, there has been much work done in recent years on ion exchange of leach liquors from nickel

laterites. Many companies including BHP Billiton, Vale and European Nickel have completed pilot test work with favorable results. The BRN Team has been directly involved in much of this work and the suitability of ion exchange to produce higher quality products will be assessed for the PNP.

### By-products

Ion Exchange (IX) technology will allow BRN to evaluate the associated economic benefits and process risks to decide if production of further products such as a Cobalt precipitate is both technically and financially feasible.

**Figure 6: Nickel intermediate product sample**

## Conclusions

BRN is developing the Piauí Nickel Project (PNP) using a series of conventional technologies sufficiently proven at commercial scale. PNP will rely upon a simple but robust process flow sheet to produce nickel from a very well characterized nickel laterite deposit. This deposit is found in an optimum location with enough space for all processing facilities and with access to all critical infrastructure (if heap leaching is used as the extractive technology). The proposed processing capacity for PNP means that common equipment sizes will be used. This minimizes the risk of installation, commissioning and operation.

The selected processing route does not require exotic materials of construction, which reduces the degree of specialization required for the construction and maintenance work force. That translates into lower capital expenditures and operating costs.

The risk of technology integration (such as the overall water balance, the impact of the ore variability in the process performance, the consistency of the characteristics of both the spent ore and PLS purification residue, etc.) will be managed through an extensive test work program, which will

include large test columns and demonstration heaps combined with a dynamic process model. This program will continue during the project execution and ramp-up stages.

It is time for the nickel industry to take advantage of heap leaching technology as the gold, silver, copper and uranium have been doing during the last decades, and the Piauí Nickel Project is set to be among the first to achieve that.

## Acknowledgements

To the Brazilian Nickel Ltd. Board of Directors for allowing the Piauí Nickel Project team to share this information to the nickel industry.