# TECHNICAL ASSISTANCE ON BRAZIL MINERAL RESOURCES

# Nickel – Market Analysis and Competitiveness Report

**Prepared for:**
Office of Energy Programs
Bureau of Energy Resources
U.S. Department of State

**Prepared by:**
Deloitte Financial Advisory Services, LLP
1919 N. Lynn Street
Arlington, VA 22209

**June 2, 2022 (Updated on December 5, 2022)**

This work was funded by the U.S. Department of State, Bureau of Energy Resources, Energy and Mineral Governance Program (EMGP)

## DISCLAIMER

This document has been prepared by Deloitte Financial Advisory Services LLP ("Deloitte FAS") for the U.S. Department of State ("DOS") under a contract between Deloitte FAS and the DOS. This document does not necessarily reflect the views of the Department of State or the United States government. Information provided by the DOS and third parties may have been used in the preparation of this document but was not independently verified by Deloitte FAS. The document may be provided to third parties for informational purposes only and shall not be relied upon by third parties as a specific professional advice or recommendation. Neither Deloitte FAS nor its affiliates or related entities shall be responsible for any loss whatsoever sustained by any party who relies on any information included in this document.

# TABLE OF CONTENTS

EXECUTIVE SUMMARY 1

KEY FINDINGS ........ 1

KEY RECOMMENDATIONS ........ 4

1. INTRODUCTION 6

1.1 PURPOSE OF THIS REPORT ........ 6

1.2 ORGANIZATION OF THIS REPORT ........ 6

1.3 BACKGROUND AND CONTEXT ........ 7

1.4 SUMMARY OF MARKET TRENDS AND OUTLOOK FOR NICKEL ........ 8

2. NICKEL PHYSICAL CHARACTERISTICS 11

2.1 NICKEL COMES IN MANY FORMS ........ 11

3. NICKEL RESOURCES 13

3.1 NICKEL RESOURCES ........ 14

3.2 BRAZILIAN NICKEL RESOURCES ........ 15

4. NICKEL SUPPLY 17

4.1 NICKEL MINING ........ 17

4.2 NICKEL-PRODUCING COMPANIES ........ 19

4.3 THE RISE OF NICKEL PIG IRON (NPI) ........ 21

4.4 CHALLENGES WITH HPAL PRODUCTION ........ 22

4.5 MIDSTREAM PROCESSING OF NICKEL ........ 23

4.6 RECYCLING AND SUBSTITUTION ........ 24

4.7 CURRENT NICKEL PRODUCTION IN BRAZIL ........ 26

5. NICKEL DEMAND 28

5.1 NICKEL USES AND APPLICATIONS ........ 28

5.2 BRAZILIAN CONSUMPTION AND EXPORTS OF NICKEL ........ 31

6. NICKEL TRADE AND PRICES 33

7. OUTLOOK FOR NICKEL DEMAND 36

7.1 NICKEL DEMAND GROWTH FOR STAINLESS STEEL ........ 36

7.2 NICKEL DEMAND FOR BATTERIES ........ 38

7.3 NICKEL DEMAND FOR OTHER USES ........ 39

7.4 OVERALL DEMAND FORECASTS FOR 2030 ........ 40

8. OUTLOOK FOR NICKEL SUPPLY 41

8.1 EXPANSION OF EXISTING PRODUCERS ........ 41

8.2 NEW NICKEL MINE SUPPLY ........ 41

8.3 NICKEL PROJECTS IN BRAZIL ........ 44

9. MARKET BALANCE AND PRICE OUTLOOK 46

9.1 NICKEL MARKET BALANCE ........ 46

9.2 THE TSINGSHAN EFFECT ........ 47

9.3 PRICING ........ 48
**10. ECONOMIC COMPETITIVENESS 49**
10.1 COMPARISON OF CURRENT NICKEL MINING OPERATIONS ........ 49
10.2 COMPARISON OF PROJECT FEASIBILITY STUDIES ........ 51
**11. CONCLUSIONS AND KEY RECOMMENDATIONS 57**
11.1 NICKEL MARKET CAPACITY ........ 57
11.2 NICKEL MARKET STRUCTURE ........ 57
11.3 THE RUSSIAN WAR WITH UKRAINE ........ 58
11.4 BRAZILIAN NICKEL OPPORTUNITIES ........ 58
11.5 KEY RECOMMENDATIONS ........ 58
**ANNEX 1 – NICKEL ORES AND RESOURCES 60**
NICKEL SULFIDE DEPOSITS ........ 60
NICKEL LATERITE DEPOSITS ........ 61
DEEP-SEA MANGANESE NODULES ........ 61
**ANNEX 2 – MINING AND PROCESSING OF NICKEL ORES 63**
MINERAL EXTRACTION AND PROCESSING OF NICKEL ........ 63
REFINING OF NICKEL INTERMEDIARIES ........ 70
**ANNEX 3 – NICKEL USES 72**
STAINLESS STEEL ........ 72
NICKEL ALLOYS ........ 73
BASE METAL ALLOYS ........ 73
NICKEL ELECTROPLATING ........ 74
BATTERIES ........ 74
NICKEL COMPOUNDS ........ 76
**ANNEX 4 – LIST OF NICKEL PROJECTS 77**

# LIST OF FIGURES


Figure 1: Simplified Flow Sheet for Primary Nickel Processing ... 11
Figure 2: Global Reserves and Resources of Nickel ... 13
Figure 3: Location of Significant Sulfide and Laterite Nickel Operations ... 14
Figure 4: Global Production of Nickel by Process Route 2009-2020 ... 17
Figure 5: Mine Production by Ore Type and Primary Nickel Products[1] ... 18
Figure 6: Global Mine Production of Nickel ... 18
Figure 7: Nickel Pig Iron (NPI) Production ... 21
Figure 8: Global $CO_2$/t Ni Equivalent Comparison ... 23
Figure 9: Simplified Flow Sheet for Nickel Mining & Processing ... 24
Figure 10: Brazilian Nickel Production by State 2010-2020 (kt nickel) ... 26
Figure 11: Global Nickel Demand 2020 ... 28
Figure 12: Global Stainless Steel Production 2014-2020 (kt) ... 29
Figure 13: Global Stainless Steel Production and Consumption 2020 ... 30
Figure 14: Stainless Steel Production and Nickel Consumption in Brazil 2010-2020 (kt) ... 31
Figure 15: LME Nickel Price and Warehouse Stocks ... 33
Figure 16: Nickel Exchange Inventories (Days of Consumption) ... 34
Figure 17: Forecast Primary Nickel Demand 2020-2030 (kt) ... 36
Figure 18: Stainless Steel Production 2020-2030 (Mt Stainless Steel) ... 37
Figure 19: Chinese Stainless Steel Production Forecast by Nickel Type 2020-2025 (kt nickel) ... 38
Figure 20: Nickel Consumed in EV batteries 2020-2030 (kt nickel) ... 39
Figure 21: Potential New Nickel Supply 2020-2030 ... 42
Figure 22: The Balance Between Demand Growth and Supply Growth (kt) ... 46
Figure 23: Consensus Price Forecast for Nickel ($/t) ... 48
Figure 24: Nickel C1 Cash Cost Curve US$/t ... 49
Figure 25: Nickel Production Ranked on Total Cash Cost ($/t) ... 50
Figure 26: Cost Curve for Nickel Sulphate by Feedstock Type ($/t contained nickel) ... 51
Figure 27: Nickel Projects: Resources (Mt) and grade (% Ni) ... 52
Figure 28: Nickel Projects: Production Capacity (t/y) and Mine Life (years) ... 52
Figure 29: Nickel Projects: Production Capacity (t/y) and Operating Costs ($/t) ... 53
Figure 30: Nickel Projects: LOM Capital Expenditure ... 53
Figure 31: Nickel Projects: Capital Intensity – Total Capex per Tonne Annual Production Ni (US$/t) ... 54
Figure 32: Nickel Projects: NPV versus IRR ... 54
Figure 33: Nickel Projects: Capital Efficiency (NPV/CAPEX) ... 55
Figure 34: Nickel Projects: Nickel Projects NPV versus IRR ... 55
Figure 35: Schematic of Nickel Laterite and Processing Methods ... 61
Figure 36: Simplified Flow Sheet for Nickel Mining & Processing ... 63
Figure 37: HPAL Process Flowsheet and MHP ... 66
Figure 38: Ferronickel Process Flowsheet and Product ... 67
Figure 39: Nickel Pig Iron Flowsheet and Product ... 69
Figure 40: Four Main Nickel Refining Methods ... 70
Figure 41: Nickel Market Flowchart ... 73
Figure 42: GWh in EVs Deployed on Roads by Nickel Cell Chemistry 2021 ... 75
Figure 43: Main Uses of Nickel Compounds ... 75

# LIST OF TABLES

Table 1: Global Nickel Reserves and Resources (Mt nickel) ........ 15
Table 2: Reported Brazilian Nickel Reserves and Resources ........ 16
Table 3: Global Nickel Mine Production by Country (kt nickel) ........ 19
Table 4: Largest Nickel Mining Companies Attributable Production (kt nickel) ........ 20
Table 5: Largest Nickel Mine Operations ........ 20
Table 6: Brazilian Nickel Producers (Nickel Production tonnes) ........ 26
Table 7: Nickel Consumption Outlook to 2030 (kt nickel) ........ 40
Table 8: Potential New Nickel Capacity Growth 2020-2030 ........ 43
Table 9: Brazilian Nickel Exploration Projects ........ 44
Table 10: Brazilian Nickel Mine Total Cash Costs ($/t) ........ 49
Table 11: Typical Processing Factors for Sulfides and Laterites ........ 64
Table 12: Existing HPAL Plants ........ 65
Table 13: Metal Content of Different Battery Cathodes kg/kWh ........ 74
Table 14: Potential New Sulphide Projects 2020-2030 ........ 77
Table 15: Potential New Indonesian Smelter Capacity 2020-2030 ........ 77
Table 16: Potential Other New Laterite Projects 2020-2030 ........ 78

# Acronyms

| | |
|---|---|
| ANM | Agência Nacional de Mineração |
| BFS | Bankable Feasibility Study |
| BMI | Benchmark Minerals Intelligence |
| CAGR | Compound Annual Growth Rate |
| CAPEX | Capital Expenditure |
| CCZ | Clarion-Clipperton Zone |
| CPRM | Geological Survey of Brazil |
| DERA | German Mineral Resources Agency |
| DOS | Department of State |
| DSO | Direct Shipping Ore |
| DSTP | Deep-Sea Tailings Placement |
| EMGP | Energy and Mineral Governance Program |
| ENR | Bureau of Energy Resources |
| ESG | Environment, Social, and Governance |
| ESS | Energy Storage Systems |
| EEZ | Exclusive Economic Zone |
| EU | European Union |
| EV | Electric Vehicle |
| FID | Final Investment Decision |
| HPAL | High Pressure Acid Leaching |
| IRR | Internal Rate of Return |
| ISA | International Seabed Authority |
| LME | London Metal Exchange |
| LOM | Life of Mine |
| MHP | Mixed Hydroxide Product/Precipitate |
| MME | Ministry of Mines and Energy |
| MSP | Mixed Sulfide Product/Precipitate |
| MW | Megawatt |
| NATO | North Atlantic Treaty Organization |
| NCA | Nickel-Cobalt-Aluminum |
| NCM | Nickel-Cobalt-Manganese |
| NPI | Nickel Pig Iron |
| NPV | Net Present Value |
| OEM | Original Equipment Manufacturer |
| PGM | Platinum-Group Metals |
| PNM | National Plan for the Brazilian Mineral Sector |
| REE | Rare Earth Elements |

| | |
|---|---|
| RKEF | Rotary Kiln-Electric Furnace |
| SHFE | Shanghai Futures Exchange |
| SMP | São Miguel Paulista |
| TMC | The Metals Company |
| USGS | U.S. Geological Survey |

# EXECUTIVE SUMMARY

Deloitte is implementing the *Government of Brazil Mining Sector Technical Support and Cooperation* Task Order (the Project) under Deloitte's Blanket Purchase Agreement (BPA) with the U.S. Department of State (DOS) in support of the Bureau of Energy Resources' (ENR) Energy and Minerals Governance Program (EMGP). The Deloitte team is providing technical assistance to support the Government of Brazil's Ministry of Mines and Energy (MME) and the Geological Survey of Brazil (CPRM) as they seek to improve their ability to:

- Develop safe, sustainable, and effective mine closure procedures and use of tailings, including methods of tailings sampling and characterization, based on international leading practices. This will assist Brazil to protect and improve the legacy of ongoing and future projects, thereby realizing sustainable benefits from the extractives industry;
- Manage a growing mineral sector and compete effectively in the global market, given the growing market and accelerating demand for critical minerals, which are essential to the development of innovative technologies to advance the global clean energy transition (electric vehicles [EVs]), batteries, and battery storage systems, etc.); and
- Streamline the structure of Brazil's Ni-Co data inventory, so the country can improve its understanding and maximize development of critical minerals.

Under *Task 2A: Economic Viability and Global Market Competitiveness of Specific Minerals*, the Deloitte team will develop a series of Reports focused on (i) a high-level analysis of nine minerals including graphite, lithium, nickel, cobalt, rare earth elements (REEs), titanium, vanadium, tantalum, and copper; and (ii) a deep-dive analysis of four minerals identified by MME and CPRM, including graphite, lithium, nickel, and REEs. The purpose of these Reports is to provide recommendations to the Government of Brazil on where and how Brazil could compete most effectively, and to inform its long-term strategic planning for mineral commercialization based on global market trends and challenges to mineral resource development that may inhibit Brazil's overall market competitiveness. Deloitte's recommendations will also inform the National Plan for the Brazilian Mineral Sector (PNM 2050) and future policy actions for the Government of Brazil. This Report*,* focuses on nickel, one of the four minerals selected by the Government of Brazil for a deep-dive market analysis.

## Key Findings

**Brazil has significant reserves and resources of nickel and it is a top 10 global nickel producer.** Brazil has nearly 17 percent of reserves and almost 6 percent of resources of nickel in the world. The country also produces 3.6 percent of the world's nickel.[1] Brazil has five nickel mining operations (Barro Alto, Onça Puma, Santa Rita, Codemin, and Americano do Brasil – see Table 6) that produced over 85 kt of nickel in 2021, three advanced stage development projects (Araguaia, Piauí, and Jaguar – see Table 9), and four promising earlier stage exploration projects (Itapitanga, Vermelho, Jacaré, Morro Sem Bone - see Table 9). In Brazil, nickel mining takes place from both sulfide and laterite projects. Global growth in nickel mine supply in recent years has primarily come from laterite ore sources, particularly from Indonesia (see Section 4.3), which has recently grown over the last decade to account for over a third of global production capacity.[2]

---

[1] U.S. Geological Survey (USGS) and Nickel Institute.

[2] Estimates for global nickel reserves and resources are substantial, with Australia, Indonesia, South Africa, Russia, and Canada accounting for more than 50 percent globally.

The second largest producer is the Philippines (13 percent), followed by Russia (9 percent), and New Caledonia (7 percent).[3] Nickel mines in Brazil produce Class II nickel (74 percent) or concentrate that is exported to be processed into Class I nickel (26 percent).[4] Figure 1 provides a simplified view of the processing routes used to make final-use nickel products. Also, *Annex 1 contains more detail on nickel ores, Annex 2 contains more detail on nickel mining and processing, and Annex 3 contains detailed information on nickel end-use consumption.*

- **The nickel market has the potential to be balanced out until 2030, with a slight deficit expected in 2029 and 2030[5] (excluding any impacts created by the Russian invasion of Ukraine).** Deloitte analysis shows that demand for nickel is expected to increase from 2.4 Mt/y in 2020 to 3.8 Mt/y – 4.5 Mt/y by 2030 due to its rising use in lithium-ion batteries in EVs. At the same time, new capacity coming online could increase supply to approximately 4.5 Mt/y by 2030, potentially balancing the market. The large increase in supply would mostly come from nickel pig iron (NPI) and high-pressure acid leach (HPAL) projects in Indonesia processing large resources of local laterite ores. In addition, the nickel market could also be affected by Russia's invasion of Ukraine. Although the scale of possible sanctions to this output are not yet fully clear, they have the potential to result in major supply disruptions (see Section 1.3). As noted above, Russia is major producer of nickel, accounting for 9 percent of global production in 2021. The Russian invasion of Ukraine caused the international nickel price to rise. This resulted in the covering of short positions by a Chinese nickel company Tsingshan, due to margin calls, and in March 2022 the price briefly spiked to over $100,000/t, which resulted in a halt in trading on the London Metal Exchange (LME).[6] The price remains elevated, but is gradually declining.
- **Brazil is mainly an exporter of commodity nickel.** Brazil exports 85 percent of its nickel production—with China being its largest market (45 percent of exports)—and consumes just 13 kt/y of nickel for domestic stainless-steel production.[7] If Brazil decides to develop downstream battery facilities, it is likely that battery grade nickel would be available, or could potentially be produced, by Brazil's nickel industry. Piauí and Jaguar, Brazil's late-stage nickel development projects are both planning to produce Class I nickel, with domestic conversion facilities for battery-grade nickel sulphate.

---

[3] Additional information on the scale of possible sanctions in Russia (as a result of Ukraine invasion) are discussed in Section 1.3 and Section 11 of this Report.

[4] Globally, there are two main types of nickel produced, Class I and Class II. Class I nickel generally describes a group of nickel products including nickel metal, powders, and briquettes. These nickel products are mainly used to make metal alloys and nickel sulphate for batteries. The majority of nickel produced from nickel laterites is Class II nickel and is mixed with iron (ferronickel and nickel pig iron - NPI) and is mainly used to make stainless steel.

[5] Roskill forecast

[6] LME. https://www.lme.com/en/metals/non-ferrous/lme-nickel

[7] Inseego Corp (INSG) Insight No.35.

- **Brazil has competitive advantages over Indonesia in producing nickel.** Growth in global mine supply in recent years has principally come from laterite ore sources, particularly from Indonesia (using HPAL, ferronickel, and NPI processing methods). Meanwhile, there has essentially been no growth in mine supply from sulfide deposits. As noted above, Brazil has a robust nickel industry, with five mining operations (Barro Alto, Onça Puma, Santa Rita, Codemin, and Americano do Brasil – see Table 6), three advanced stage development projects (Araguaia, Piauí, and Jaguar – see Table 9), and four promising earlier stage exploration projects (Itapitanga, Vermelho, Jacaré, Morro Sem Bone - see Table 9). Three of the five mining operations ( Barro Alto, Codemin, and Santa Rita) have operating costs below the market average (Table 10), partly due to favorable labor and energy costs in Brazil.[8] The use of hydroelectricity in Brazil compared with the use of coal in Indonesia to supply energy to the nickel market, also means that Brazil has a competitive advantage in terms of carbon footprint (Figure 8). This is becoming increasingly important to manufacturers of lithium-ion batteries and original equipment manufacturers (OEMs) when sourcing raw materials.
- **New processing routes could ease the projected deficit of Class I nickel:** Until recently, analysts expected an oversupply of Class II nickel, due to the forthcoming development of large new nickel laterite projects in Indonesia, and a shortage of Class I nickel due to strong demand from the battery industry. However, this outlook changed in March 2021 when Chinese producer Tsingshan announced plans to convert NPI into a nickel matte that can be refined to produce Class I nickel for battery grade chemicals.[9] Conversion of NPI to nickel matte could satisfy marginal demand for Class I nickel. A stable market provides opportunities for nickel producers in the long-term, including mines and projects in Brazil.

**Summary: Global Nickel Demand and Potential for Development in Brazil**

- ***Green Uses of Nickel**: Required for EV battery development, and battery storage systems. Demand for both applications is set to rise through 2030.*
- ***Market Demand for Nickel**: Nickel demand and prices dropped during the COVID-19 pandemic, but production has increased since late 2020. While known global nickel deposits (both lateritic and sulfide) are sufficient to meet demand in the medium-term, increased consumption (especially for green technologies) will necessitate new resources or the identification of mineral/metal substitutes for existing applications. Nickel demand is expected to increase from 2.4 Mt/y in 2020 to 3.8 Mt/y – 4.5 Mt/y by 2030 due to its rising use in lithium-ion batteries in EVs. At the same time, new capacity coming online could increase supply to approximately 4.5 Mt/y by 2030, indicating that the market has the potential to be balanced in 2030. The large increase in supply would primarily come from Indonesian NPI and HPAL projects processing large resources of local laterite ores.*
- ***Opportunities in Brazil**: Nickel is considered a strategic mineral under Brazil's Pro-Strategic Minerals Policy, which is designed to streamline environmental approvals and permitting procedures to accelerate production.*[10]

---

[8] The data for the other two mining operations, Onça Puma and Americano do Brasil is not available.

[9] https://www.spglobal.com/marketintelligence/en/news-insights/blog/profit-margins-key-to-tsingshans-battery-nickel-supply-plans

[10] Through the Pro-Strategic Minerals policy, the Government of Brazil has issued a list of specific critical minerals it aims to boost production of, and that are deemed of special interest to the country. Resolution

| Summary: Global Nickel Demand and Potential for Development in Brazil |
| --- |
| ***Opportunities in Brazil Cont'd:*** *Brazil has five mining operations, three late-stage projects, and four promising exploration projects. Mining takes place from both sulfide and laterite projects, and the operations produce both class I and Class II nickel. Piauí and Jaguar, Brazil's late-stage nickel development projects are both planning to produce Class I nickel, with domestic conversion facilities for battery-grade nickel sulphate. The three advanced stage projects comprise two laterite projects and a sulfide project. The sulfide project is planning to process the ore through to battery-grade nickel sulfate while the laterite projects are for ferronickel and a heap leach operation to produce nickel hydroxide. Brazil consumes around 13 kt/y (17 percent) of its nickel production in domestic stainless steel, but the remainder of it is exported, with China importing 45 percent of exports. If Brazil decides to develop downstream battery facilities, it is likely that battery grade nickel would be available, or could potentially be produced, by Brazil's nickel industry.* |

## Key Recommendations

The nickel market will likely remain balanced through 2030, with the possibility of a slight deficit in 2029 and 2030, excluding any impacts created by the Russian invasion of Ukraine. This offers opportunities for continued supply growth to mines and projects, including those operating and planned in Brazil. The Government of Brazil should continue to further develop its resources to meet global demand and encourage investment in the longer term by:

- **Streamlining access to, and circulation of, up-to-date domestic nickel resource data to domestic and international exploration companies to encourage exploitation and to promote nickel development in Brazil.** This may require gathering and distributing more extensive information for those regions considered to have significant nickel potential, including Goiás, Pará, Bahia, and Minas Gerais. Legacy CPRM geological data, reports, and studies should be broadly published online and in multiple languages. Brazil should also actively 'market' these documents to expand their circulation, use, and impact.
- **Providing nickel producers with access to Brazil's low-cost and low-emissions hydroelectric power.** In 2020, 66 percent of Brazil's electricity generation came from hydropower. Access to low-cost and low-emissions hydroelectricity in Brazil gives nickel producers a competitive advantage in their operating costs and carbon footprint. The nickel market is increasingly focused on the carbon footprint of nickel producers, feeding into the lithium-ion battery market, particularly given the high carbon footprint of Indonesian nickel producers. Figure 8 shows a global comparison of nickel production carbon footprints based on tonnes of $CO_2$ per tonne of nickel production, with Brazil having a low to medium carbon footprint, and Indonesia showing the highest carbon footprint. Addressing environmental, social, and governance (ESG) challenges related to mining, smelting, refining, and tailings management in nickel production is becoming increasingly important to OEMs. Tesla has reportedly signed contracts with Vale in Canada, BHP in Australia, and Talon Metals in the United States for the supply of low-carbon footprint nickel. It is critical for nickel producers in Brazil to demonstrate to OEMs that these challenges are being addressed successfully throughout the value chain.

No. 2 of June 18, 2021, defines the list of strategic minerals for the country. https://www.in.gov.br/web/dou/-/resolucao-n-2-de-18-de-junho-de-2021-327352416. Through the Pro-Strategic Minerals policy, the Government of Brazil is focusing on easing the environmental licensing process by facilitating, for example, the dialogue between the environmental agency responsible for conducting the environmental licensing process and authorities such as the managing bodies of Conservation Units, the National Indian Foundation (Funai), the National Institute for Colonization and Agrarian Reform (Incra) and the National Institute of Historic and Artistic Heritage (Iphan).

- **Ensuring Brazilian nickel projects achieve timely production by 2030 to capture potential higher returns of the forecast tight market.** Deloitte anticipates that three of the late-stage development projects (Araguaia, Piauí, and Jaguar) could come into production by 2030. If this is the case, these projects will likely benefit from the forecast tight nickel markets and the likely higher prices anticipated by the end of 2030. To ensure that these four projects come into production by 2030, the Government of Brazil should encourage these companies to apply for assistance under the Policy for Supporting the Environmental Licensing of Investment Projects for the Production of Strategic Minerals (Decree No. 10,657 of March 24, 2021)[11]. For example, the Government of Brazil recently selected three mining projects to receive accelerated environmental licensing support. Jaguar, was one of projects selected by the government.[12]
- **Developing downstream processing facilities to capture more of the nickel value chain domestically.** A portion of Brazil's nickel production could be refocused from direct exports towards the downstream development of domestic cathode-manufacturing and lithium-ion battery production. Proactive marketing by the Government of Brazil with existing global lithium-ion battery companies about investment and construction of battery Gigafactories in the country, may help to increase the consumption of domestic nickel production. The 'Colossus Cluster Minas Gerais', which aims to build a 35 GWh battery Gigafactory, an initiative between the Minas Gerais Investment and Trade Promotion Agency and US-based Bravo Motor Company, is the first such project under way.

[11] The Pro-Strategic Minerals Policy has been qualified under the Investment Partnerships Program (PPI), which is a government entity dedicated to expanding and accelerating the implementation of projects with the participation of the private sector in Brazil. Accordingly, if it meets specific criteria, the company that has a project of a mineral deemed strategic, may request that their project be qualified as a PPI project.

[12] The projects, all in northern Pará state, are considered by the Government of Brazil as strategic for the expansion of aluminum, nickel, and copper production. The selected projects include: Novas Minas, owned by Mineração Rio do Norte (aluminum), Centauros Níquel's Jaguar (nickel), and Pantera of Avanco Resources Mineração (copper).

# 1. INTRODUCTION

## 1.1 Purpose of this Report

This Report provides a detailed analysis of the global nickel market, the current and future dynamics of the industry, plus potential opportunities and possible risks associated with nickel development. The Report analyzes global nickel resources, supply and demand dynamics, technological and industrial drivers, current and future mineral producers and processors, and nickel market economics. The Report also examines Brazil's position within the current nickel market, and its potential positioning in the future, thereby enabling MME and CPRM to make informed decisions about future policy actions for Brazil's nickel industry and resources.

## 1.2 Organization of this Report

This Report is organized into 11 main sections and four annexes:

- **Section 1: Introduction** – Presents the purpose of this Report, background and context on nickel, and a summary of market trends and outlook for nickel.
- **Section 2: Nickel Physical Characteristics** – Provides information on nickel uses and applications and various nickel types.
- **Section 3: Nickel Resources** – Provides information on global nickel resources and reserves.
- **Section 4: Nickel Supply** – Gives an overview of the global production of nickel ores and nickel products and recent supply trends.
- **Section 5: Nickel Demand** – Explains global nickel demand trends based on end-user markets.
- **Section 6: Nickel Trade and Prices** – Provides information on the main features of global nickel trade and presents historical pricing data.
- **Section 7: Outlook for Nickel Demand** – Outlines expectations for future changes in global nickel demand, given growing consumption trends in relevant end-use industries, particularly lithium-ion batteries.
- **Section 8: Outlook for Nickel Supply** – Presents how the global nickel supply should increase to meet rising demand and consumption trends. This section also examines potential production increases from existing producers and other mining projects that could potentially come on stream by 2030.
- **Section 9: Market Balance and Price Outlook** – Examines whether there is sufficient nickel supply to match scenarios for future nickel demand by 2030 and provides insights on price forecasts for trade in the future.
- **Section 10: Economic Competitiveness** – Summarizes production and cost information of existing mines and 17 mining projects to benchmark and assess the economic competitiveness of the sector and other mines and exploration projects in Brazil.
- **Section 11: Conclusions and Key Recommendations** – Summarizes the Deloitte team's analysis of the nickel market, including project financing and potential global opportunities. This section also presents key recommendations for the Government of Brazil to inform its future policy actions for the nickel industry.
- **Annex 1** – Provides a description of nickel ores and resources.

- **Annex 2** – Provides a description of mining and processing of nickel ores.
- **Annex 3** – Provides a description of nickel uses.
- **Annex 4** – Provides a list of nickel projects.

## 1.3 Background and Context

Brazil has some of the largest and most diverse mineral deposits in the world, yet most of its mining sector activities and revenues focus on core commodities such as iron ore, gold, copper, and bauxite. While the production of these resources will remain valuable to global industries and markets, there is growing demand and new opportunities for nickel and other critical minerals and metals found in Brazil.

Nickel is a key component of lithium-ion batteries, which are the preferred technology for almost all EVs on the market today and will likely continue to be for the foreseeable future. Brazil currently produces approximately 3.6 percent of the world's nickel. The USGS estimates that Brazil holds nearly 17 percent of the world's global reserves, defined as the amount of nickel that can be economically extracted or produced at the time of determination, as supported by detailed mineral exploration and analysis. In addition, the Nickel Institute estimates that the country has nearly 6 percent of global resources, which is the amount of nickel in or on the earth's crust that could *potentially* be economically extracted based on geological evidence but have a lower level of exploration.

Brazil has a vibrant nickel industry, with five mining operations (Barro Alto, Onça Puma, Santa Rita, Codemin, and Americano do Brasil – see Table 6), three advanced stage development projects (Araguaia, Piauí, and Jaguar – see Table 9), and four promising earlier stage exploration projects (Itapitanga, Vermelho, Jacaré, Morro Sem Bone - see Table 9). Mining takes place from both sulfide and laterite projects and the operations produce both Class I and Class II nickel. Three of the five mining operations (Barro Alto, Codemin, and Santa Rita) operate in the lower half of the cost curve, meaning they have lower operating cost than the average nickel operation partly due to favorable labor and energy costs in Brazil.[13]

The Deloitte team drafted this Report following the Russian invasion of Ukraine. Russia is a major producer of nickel, accounting for 9 percent of global production in 2021, and although the scale of possible sanctions to this output are not yet fully clear, they have the potential to result in major supply disruptions. The Russian invasion of Ukraine caused the international nickel price to rise, which then resulted in the covering of short positions by a Chinese nickel company Tsingshan, due to margin calls, and in March 2022 the price spiked to over $100,000/t, which resulted in a halt in trading on the LME.[14] The price remains elevated, but is gradually declining. This has raised questions about the actions of the LME, particularly given LME's ownership by Hong Kong Exchanges and Clearing. This Report does not comprehensively analyze the possible consequences of these events, but discusses some of the risks in Section 11.[15]

---

[13] The data for the other two mining operations, Onça Puma and Americano do Brasil is not available.

[14] London Metal Exchange (LME)

[15] In developing this Report, Deloitte extracted data from publicly available sources including: (i) company reports (including regular market analysis from Norilsk Nickel); (ii) industry sources such as Wood Mackenzie, Benchmark Minerals Intelligence (BMI), Macquarie, and Roskill; (iii) government and other public institutions, including the USGS, British Geological Survey (BGS), International Nickel Study Group (INSG), Nickel Institute, International Stainless Steel Forum (ISSF), and the European Union (EU); and (iv) industry conferences and webinars.

## 1.4 Summary of Market Trends and Outlook for Nickel

### 1.4.1 Nickel Resources

Australia (15 percent), Indonesia (12 percent), South Africa (11 percent), Russia (8 percent), and Canada (7 percent) account for more than 50 percent of the global nickel resources, based on data from the Nickel Institute. The next four largest producers, Philippines (6 percent), Brazil (6 percent), Cuba (6 percent), and New Caledonia (5 percent), account for a further 22 percent. There are three principal types of nickel resources in the world: nickel sulfide deposits (contained in igneous rocks), nickel laterite deposits (formed from weathering of the igneous rocks), and accumulations found in manganese crusts and nodules on the ocean floor.

At present, countries mine nickel from either sulfide or laterite ores on land, given that nickel recovery from deep-sea sources is not yet economic.

### 1.4.2 Nickel Supply and Demand

The USGS estimates that mined nickel production worldwide totaled approximately 2.75 Mt in 2021. Growth in mined supply in recent years has principally come from laterite ore sources, with processing occurring through HPAL, ferronickel, and NPI methods. Conversely, there has been essentially no growth in mined supply from sulfide deposits. In 2020, sulfide sources generated 27 percent of global nickel production, while laterite sources generated 73 percent.

The nickel industry is relatively competitive, with multiple companies operating mines in a variety of countries around the world. Brazil currently has five nickel mining operations, and produced over 85 kt of nickel in 2021. Indonesia is the world's largest producer of nickel ore, accounting for over a third of global production capacity. Indonesia's nickel is produced from laterite ores and the country is expected to continue to drive nickel supply growth for the foreseeable future. The next largest producer is the Philippines (13 percent), followed by Russia (9 percent), and New Caledonia (7 percent). Brazil accounts for about 3.6 percent of global production.

Primary nickel consumption totaled 2.85 Mt in 2021, causing a slight deficit in the market. The stainless-steel industry is the main driver of global nickel demand, accounting for 72 percent of primary nickel consumption in 2020. Other demand drivers for nickel include alloy steels and castings, plating, and non-ferrous alloys, which each account for 6 to 7 percent of primary nickel consumption. The battery sector accounted for only 7 percent of primary nickel consumption in 2020; however, this sector has the strongest potential for growth of all the first uses of nickel and it is expected to generate 26 percent of demand within a significantly expanded market (see Section 1.4.4, below) by 2030.

### 1.4.3 Nickel Trade and Prices

Nickel metal is an exchange-traded commodity and can be traded in futures and options contracts. The price of nickel has been volatile, escalating dramatically through 2006 to reach a prior historical peak of $52,179/t in May 2007 due to supply problems (caused by strikes at Sudbury, a major nickel mine operation in Canada, and delays to new mines), strong demand for stainless steel from China, and low inventories. As noted above, in March 2022, the LME nickel price briefly rose to over $100,000/t following Russia's invasion of Ukraine, but due to short position covering (by a Chinese nickel company Tsingshan) and margin calls, authorities halted trading on metal exchanges. The price remains elevated, but is gradually declining (see Section 1.3).

### 1.4.4 Market Outlook

Deloitte analysis shows that nickel demand is expected to increase from 2.4 Mt/y in 2020 to 3.8-4.5 Mt/y by 2030 due to its rising use in lithium-ion batteries in EVs. At the same time, new capacity coming online could increase supply to approximately 4.5 Mt/y by 2030, indicating that the market has the potential to be balanced in 2030. The large increase in supply would primarily come from Indonesian NPI and HPAL projects processing large resources of local laterite ores. Roskill has a similar forecast and expects the nickel market to be broadly balanced out to 2028, but expects the market to move into a small deficit in 2029 and 2030[16].

While the overall market will likely remain balanced, markets for the two types of nickel—Class I, which is mainly used for alloys and battery markets (and 26 percent of Class I nickel is used for high quality stainless steel), and Class II, which is just used for stainless steel— will differ. Until recently, analysts expected Class II nickel to move into oversupply, as large new laterite projects are developed in Indonesia. Analysts also expected Class I nickel to be in supply shortage due to strong demand from the battery industry. These expectations were based on the historical assumption that Class II nickel was not a viable source for batteries, due to the high cost of refining Class II into Class I nickel.

However, in March 2021, Chinese steel and nickel producer Tsingshan announced plans to convert NPI into a nickel matte, which can be further refined to produce Class I nickel for battery-grade chemicals. Converting NPI to nickel matte, instead of Class II nickel now, creates an opportunity for NPI producers to diversify their production and take advantage of potential premiums in Class I nickel. Although this is not new technology, the economics remain unclear, and the recently announced NPI-to-nickel matte capacity conversions are not yet sufficient to close the supply gap between Class I and Class II nickel. Nevertheless, this conversion provides a potential route for excess Class II nickel production to satisfy demand for Class I nickel. More NPI nickel capacity needs to be converted to matte, but there is also potential to help the markets balance through a reduction in Class I nickel that flows to stainless steel.

### 1.4.5 Economic Competitiveness

Deloitte has evaluated data from existing nickel mines and from 17 companies that have produced recent feasibility, pre-feasibility, and scoping study reports for the market (which are typically done as part of the process of developing projects). Twelve of these pre-production projects are sulfide and five are laterite projects. These twelve projects represent only a portion of the nickel market projects, because most new production is coming from Indonesian NPI and HPAL projects being developed principally by Chinese companies for which project feasibility data is unavailable.

Brazil has five mining operations (Barro Alto, Onça Puma, Santa Rita, Codemin and Americano do Brasil) and three late stage/feasibility stage projects (Araguaia, Piauí, and Jaguar). Mining takes place from both sulfide and laterite projects and the operations produce both Class I and Class II nickel. Project data is available for three of the seven Brazilian exploration projects; Jaguar (late stage), Araguaia (late stage), and Vermelho (earlier stage). These projects were among the 17 projects that Deloitte evaluated and benchmarked against global competitors.

Of the three late stage/feasibility stage projects listed above, Vermelho and Jaguar are mid-size projects and Araguaia is a smaller development. However, both Vermelho and Araguaia are scheduled to be relatively long-life operations. The three Brazilian projects have higher-than-average financial returns of between 20 and 52 percent, versus 21 percent Internal Rate of Return (IRR) of the group of 17 projects.

---

[16] Roskill forecast

Jaguar and Araguaia have particularly strong returns of 52 percent and 26 percent, respectively. Jaguar and Vermelho also have relatively favorable capital efficiency ratios (Net Present Value [NPV]/Capital Expenditure [CAPEX]) of 1.7 and 1.5, in comparison to 0.9 for the group of 17 projects as a whole.

Brazil consumes around 13 kt/y (17 percent) of its nickel production in domestic stainless steel, but the remainder of it is exported, with China importing 45 percent of exports. Brazilian producers could probably shift to making battery-grade nickel if the country builds downstream battery facilities. Proactive marketing by the Government of Brazil, with existing global lithium-ion battery companies about investment and construction of battery Gigafactories in Brazil, may help to increase the consumption of domestic nickel production. The ‘Colossus Cluster Minas Gerais’, which aims to build a 35 GWh battery Gigafactory, an initiative between the Minas Gerais Investment and Trade Promotion Agency and US-based Bravo Motor Company, is the first such project under way.

# 2. NICKEL PHYSICAL CHARACTERISTICS

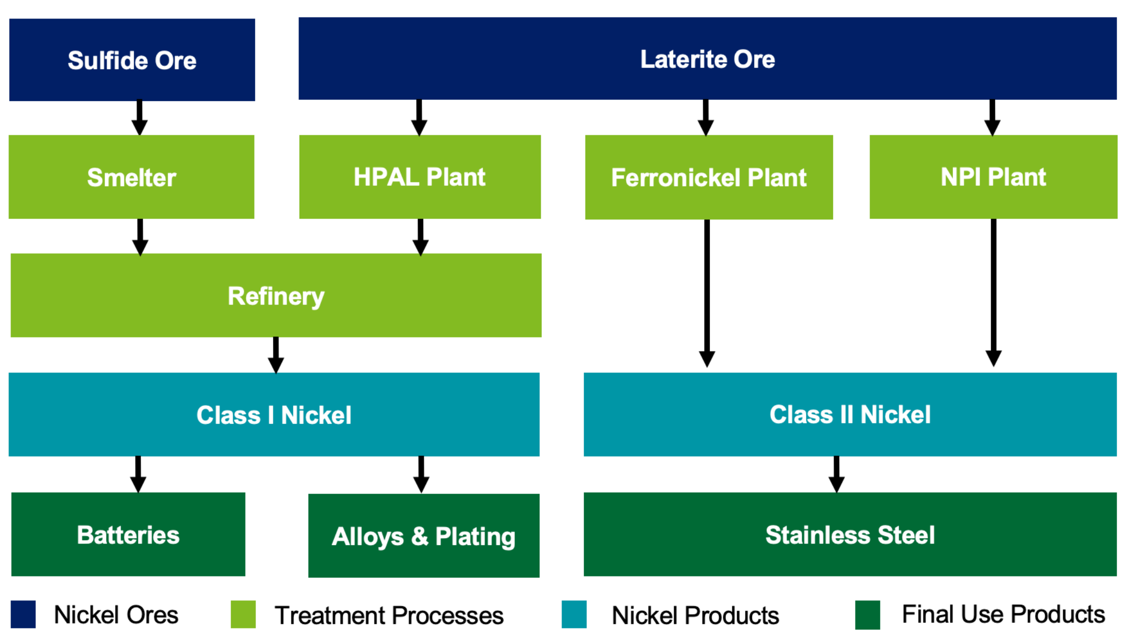
Nickel is a silvery-white metal which has fairly low thermal and electrical conductivity and can be magnetized. It has properties that are important to industrial applications, including its resistance to oxidation and corrosion by alkalis, its strength at high temperatures, and its ability to form alloys with many other metals. Economic concentrations of nickel-bearing minerals occur only in sulfide or laterite deposits (see Section 3). These deposits typically have different processing routes and generally produce three types of nickel products with different end uses.

## 2.1 Nickel Comes in Many Forms

Refined nickel products are subdivided into three groups: Class I nickel products with a content of more than 99.8 percent nickel, Class II products with a content of less than 99.8 percent nickel (ferronickel and NPI), and nickel chemicals. Class II nickel products accounted for approximately 61 percent of global nickel supply in 2021, while Class I products represented approximately 38 percent and other nickel chemicals about 1 percent.

Class I nickel generally describes a group of nickel products including electrolytic nickel metal, powders, and briquettes. These nickel products are principally used to make metal alloys and nickel sulphate for batteries (although 26 percent of Class I nickel is used in high grade stainless steels). Class II nickel includes output from laterites mixed with iron (ferronickel and NPI), and is principally used to make stainless steel. Stainless steel producers take advantage of the iron content contained in the ferronickel and NPI in the manufacturing. Nevertheless, some nickel laterites can also be processed (using HPAL) to produce Class I nickel (see Figure 1).

**Figure 1: Simplified Flow Sheet for Primary Nickel Processing**




Source: Deloitte.

Figure 1 provides a simplified view of the processing routes used to make final-use nickel products. However, in practice, the market is more complicated because there are several nickel intermediary products and processes, and some material flows between Class I and Class II products. In addition to this primary supply, about one-third of global nickel supply is currently derived from secondary sources (principally recycled stainless steel).

A lot of moving parts exist in the nickel supply chain and it is important to understand the different types of nickel ores, processing routes, intermediaries, end products, and nickel end markets to understand the industry's market dynamics. Figure 9 in Section 4.5 shows a more detailed flow sheet that highlights the complexities of these intermediaries and product flows. In addition, Figure 41 in Annex 3 displays a Sankey chart showing nickel material flows. *Annex 1 provides more details on nickel ores, Annex 2 provides more details on nickel mining and processing, and Annex 3 provides detailed information on nickel end-use consumption.*

Market demand also varies depending on the final-use product. The stainless-steel industry is the main driver of global nickel demand, accounting for 72 percent of primary nickel consumption in 2020. Other demand drivers for nickel include alloy steels and castings, plating, and non-ferrous alloys, which each account for 6 to 7 percent of primary nickel consumption. The battery sector accounted for only 7 percent of primary nickel consumption in 2020; however, this sector has the strongest potential for growth of all the first uses of nickel and it is expected to generate 26 percent of demand within a significantly expanded market by 2030.

Significant new nickel laterite capacity is coming on stream, particularly in Indonesia, which could enable supply to meet future demand for nickel use in batteries through 2030. However, Roskill expects insufficient supply to potentially cause a slight deficit post 2028. Much will depend on the continued growth of supply in Indonesia (much of which is largely financed by Chinese steel and battery companies) and whether efforts to produce nickel sulfate[17] for batteries from Class II nickel are successful.

[17] The process to manufacture nickel for us in batteries: Class 2 → Nickel matte → Nickel sulfate → Batteries. Nickel sulfate is the key battery intermediary.

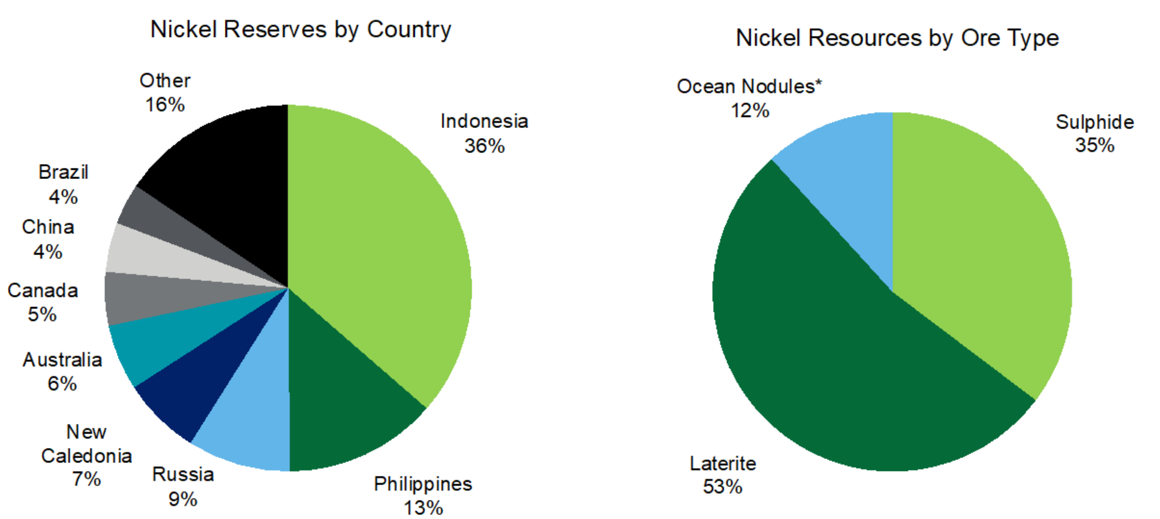
## 3. NICKEL RESOURCES

There are three principal types of nickel resources in the world:

- Nickel sulfide deposits (typically grading 0.2 to 2.0 percent nickel) contained in mafic and ultramafic (iron- and magnesium-rich) igneous rocks where nickel-sulfide minerals are concentrated by magmatic-hydrothermal processes;
- Nickel laterite deposits (grading 0.8 to 3.0 percent nickel), which represent residual concentrations of nickel resulting from the weathering of ultramafic rocks; and
- Deep-sea iron-manganese nodules (typically grading >1.0 percent nickel), related to ocean-floor volcanic activity.

Nickel recovery from deep-sea sources is not yet economical and nickel is mined either from sulfide or laterite ores that exist around the world. In some deposits, the nickel is also associated with concentrations of platinum-group elements, as well as copper and cobalt, which increases the value of the nickel ore deposits (which is the case at Norilsk in Russia). Figure 2 shows a breakdown of the nickel reserves by country as well as a breakdown of nickel resources by ore type.

**Figure 2: Global Reserves and Resources of Nickel**




Source: USGS 2022. *Inferred resource of CCZ only (see Annex 1).

The map in Figure 3 shows that the equatorial belt contains most of the nickel laterite deposits, dominated by Indonesia, the Philippines, and Cuba. Laterite resources outside this belt (Australia, Brazil, and Madagascar) are generally much older in geological terms. The map also shows locations with major resources of nickel sulfide deposits, including Australia, Canada, and Russia. *Annex 1 has further information on nickel ores.*

**Figure 3: Location of Significant Sulfide and Laterite Nickel Operations**


Source: Deloitte, company data.

The sections that follow will provide more information on nickel resources and reserves around the world, with special emphasis given to those found in Brazil.

## 3.1 Nickel Resources

Table 1 presents a breakdown by country of the USGS' estimates for 95 Mt of nickel reserves[18] and the Nickel Institute's estimates for 296 Mt of resources (see Table 1).[19] The USGS further reports that identified land-based resources averaging approximately 0.5 percent nickel or greater contain at least 300 Mt of nickel, with about 60 percent in laterites and 40 percent in sulfide deposits. Australia, Indonesia, South Africa, Russia, and Canada account for more than 50 percent of global nickel resources. The next four largest producers, Philippines, Brazil, Cuba, and New Caledonia, account for a further 22 percent.

[18] The USGS derives national information on reserves from a variety of sources. These sources include comprehensive evaluations, as well as national reserves estimates compiled by countries, academic articles, company reports, presentations by company representatives, and trade journal articles.

[19] Reserves and resources are defined terms in mineral deposits classification and are based on their geologic certainty and economic value. Reserves are defined as being valuable and economically, legally, and technically feasible to be extracted (defined by a high level of mineral exploration). Resources are potentially valuable and for which reasonable prospects exist for eventual extraction (defined by a lower level of exploration).

**Table 1: Global Nickel Reserves and Resources (Mt nickel)**

| Country | Reserves† | Sulphide Resources* | Laterite Resources* | Total Resources* |
|---|---|---|---|---|
| Australia | 21.00 | 12.0 | 32.0 | 43.0 |
| Indonesia | 21.00 | 0.0 | 33.0 | 33.0 |
| South Africa | N/A | 33.0 | 0.0 | 33.0 |
| Brazil | 16.00 | 2.0 | 15.0 | 17.0 |
| Russia | 7.50 | 21.0 | 4.0 | 25.0 |
| Philippines | 4.80 | 0.0 | 18.0 | 18.0 |
| China | 2.80 | 6.0 | 0.0 | 6.0 |
| Canada | 2.00 | 22.0 | 0.0 | 22.0 |
| Cuba | N/A | 0.0 | 16.0 | 16.0 |
| New Caledonia | N/A | 0.0 | 15.0 | 15.0 |
| United States | 0.34 | N/A | N/A | N/A |
| Other | 20.00 | 23.0 | 46.0 | 69.0 |
| **Total** | **95.44** | **118.0** | **178.0** | **296.0** |

Source: †USGS. *Nickel Institute.

Manganese nodules, which are found on the deep-sea floor, contain significant amounts of various metals, including nickel. According to estimates, there are more than 290 million tons of nickel contained in such deposits.[20] The development of deep-sea mining technologies is expected to facilitate access to these resources in the future, although it raises many environmental concerns. *See Annex 1 for more information on manganese nodules.*

## 3.2 Brazilian Nickel Resources

Brazil hosts both sulfide and laterite nickel deposits. According to the USGS, Brazil had 16 Mt of nickel reserves and 17 Mt of resources in 2020, of which 15 Mt were laterite and 2 Mt sulfide. Lateritic nickel deposits are scattered throughout Brazil and most of the deposits are lateritic weathering products of ultramafic rocks. Typically, there are three areas with higher concentrations of ultramafic rocks: central (the largest)—from north to south in Goiás and Pará; northeast—Bahia; and southeast—Minas Gerais. Table 2 provides more information on where nickel is found in the country.

The main nickel-bearing minerals are serpentine, smectite, garnierite, and goethite. The alteration profiles in the Brazilian lateritic nickel deposits are broadly similar to those described elsewhere in the world, but have two characteristic features: the silicate ore prevails over the oxidized ore, and a silicified layer covers the profiles developed on the highlands. For mining, the silcrete at the top of the profile is poor in nickel and considered barren. Each resource would have its own characteristics and profile, but generally a high silicified layer would require more waste removal and increased mining costs.

[20] Nickel Institute.

**Table 2: Reported Brazilian Nickel Reserves and Resources**

| Mine/Project | State | Owner | Dev. Stage | Status | Grade Ni% | Nickel Tonnes |
|---|---|---|---|---|---|---|
| Jacare | Pará | Anglo American | Res. Dev. | Active | 1.28 | 3,913,000 |
| Araguaia | Pará | Horizonte Minerals | Construction | Active | 1.25 | 2,570,926 |
| Onca Puma | Pará | Vale | Operating | Active | 1.51 | 1,584,000 |
| Vermelho | Pará | Horizonte Minerals | Scoping | Active | 1.05 | 1,555,000 |
| Barro Alto | Goiás | Anglo American | Operating | Active | 1.28 | 1,331,000 |
| Norwest (Morro Sem Boné e Morro do Leme) | Mato Gr. | Mineracao Tanagra | Target Outline | Active | 1.77 | 1,029,140 |
| Jaguar | Pará | Centaurus Metals | Feasibility | Active | 0.91 | 730,700 |
| Piaui | Piauí | Brazilian Nickel | Limited Prod. | Active | 1.00 | 723,000 |
| Tocantins | Goiás | Cia Bras. de Alumínio | Operating | On hold | 1.30 | 390,000 |
| Santa Rita | Bahia | Appian Capital | Operating | Active | 0.33 | 193,100 |
| Codemin | Goiás | Anglo American | Operating | Active | 1.24 | 160,000 |
| Vila Oito | Pará | Horizonte Minerals | Feasibility | Active | 1.36 | 141,000 |
| Americano dB | Goiás | Prometalica Mineracao | Operating | Active | N/A | N/A |
| **Total** | | | | | **1.20** | **14,320,866** |

Source: S&P Global Intelligence.

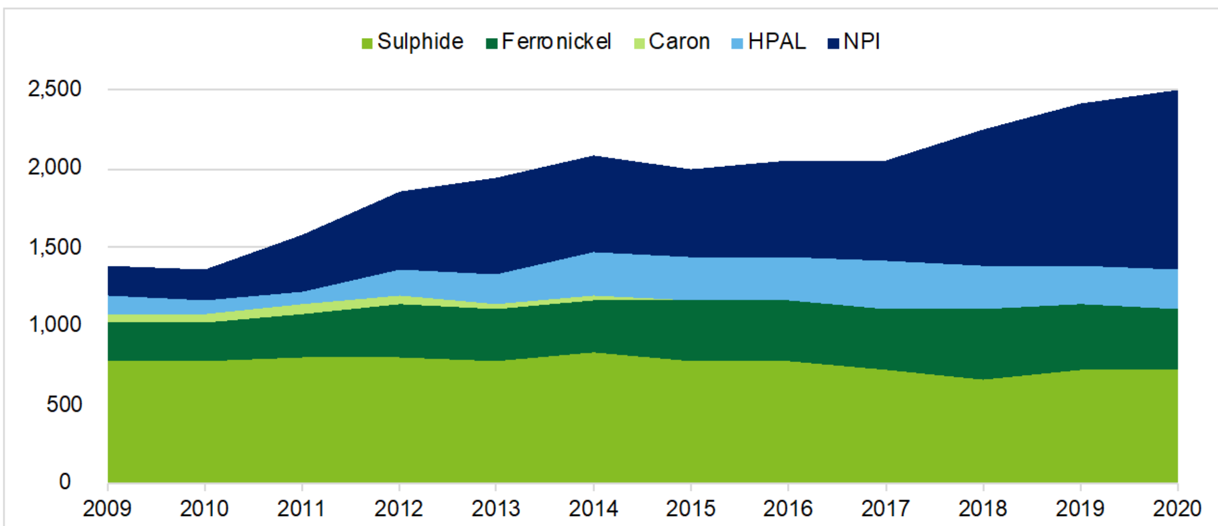
# 4. NICKEL SUPPLY

According to USGS estimates, total mined nickel production was approximately 2.75 Mt in 2021, an increase of 8.9 percent over 2020. This was lower than the market originally anticipated due to the slower-than-expected commissioning of new NPI operations in Indonesia affected by COVID-19 impacts. Nevertheless, the nickel industry remains relatively competitive, with numerous companies operating mines around the world (and in Brazil specifically) and numerous intermediary and final products being produced. The sections that follow provide more information on nickel mining, nickel production companies, NPI and HPAL production, midstream processing, recycling and substitution, and nickel production in Brazil.

## 4.1 Nickel Mining

Nickel ore is mined from either sulfide or laterite deposits, although a small amount is also produced as a by-product of copper and platinum-group metals (PGM) refining. Figure 4 shows that growth in mine supply in recent years has principally come from laterite ore sources (HPAL, ferronickel, and NPI), while there has been no growth in mine supply from sulfide deposits.

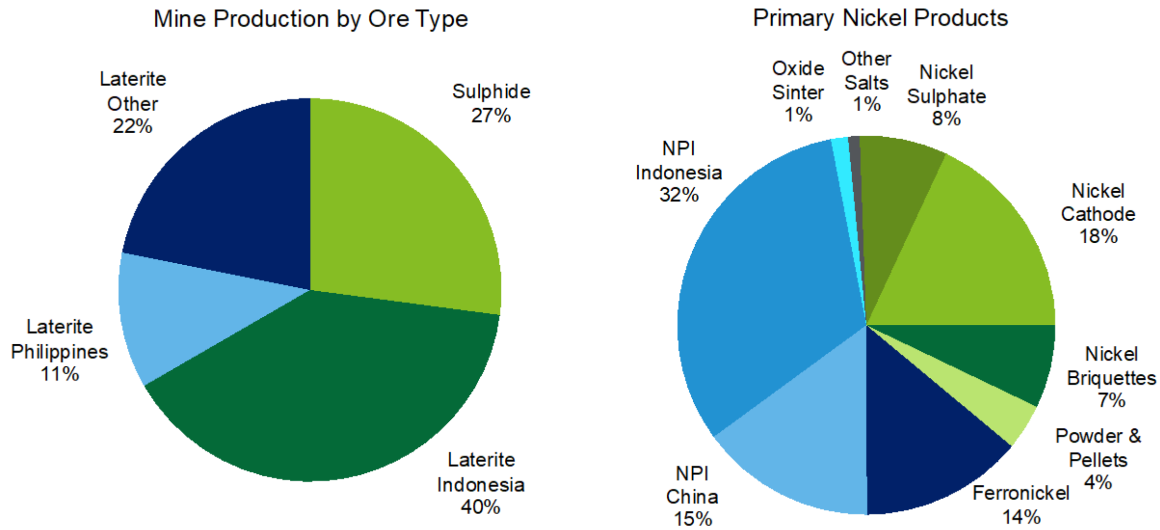
**Figure 4: Global Production of Nickel by Process Route 2009-2020**




Source: Macquarie 2021.

Nickel sulfide deposits tend to be relatively small or low grade, and the size and frequency of new discoveries have been declining. The last large discoveries were Voisey's Bay in Canada in 1994 and Nova Bollinger in Australia in 2012. Most new nickel sulfide deposits that were brought onstream in recent years have been necessary to replace the depletion of existing nickel sulfide mines. Figure 5, which displays the breakdown of production by ore types for 2020, shows that 27 percent of global nickel production was from sulfide sources, while 73 percent was from laterite sources.

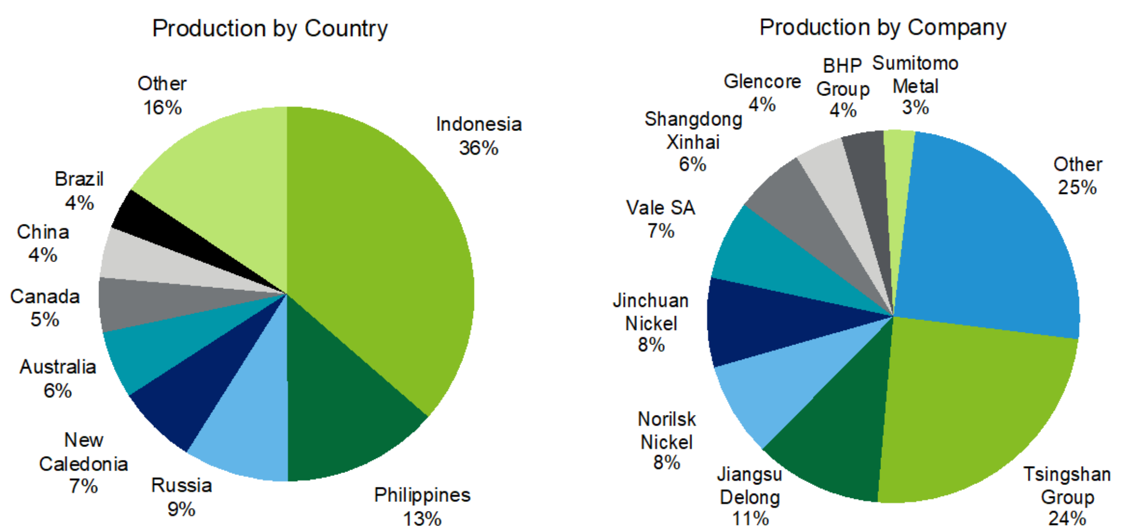
**Figure 5: Mine Production by Ore Type and Primary Nickel Products[1]**




Source: Norilsk 2021.[1.] Primary nickel products refer to production of any finished nickel products, suitable for use in first-use applications. Green shade denotes Class I and blue shade denotes Class II.

There are two distinct types of laterite ore that are mined—limonite and saprolite—which are found in sub-tropical to tropical regions. Limonite is typically more suited to HPAL processing to produce Class I metal and battery-grade nickel intermediates. Both limonite and saprolite can be processed into NPI, although saprolite is almost exclusively used in the production of ferronickel (ferronickel and NPI are principally Class II nickel and used in stainless steel). *See Annex 1 for more information on nickel ores and Annex 2 for more information on nickel mining and processing.*

**Figure 6: Global Mine Production of Nickel**




Source: S&P Global, company data.

Indonesia is the world's largest producer of nickel ore, accounting for over a third of global production capacity (see Figure 6, which also shows the production breakdown of the major nickel producing companies). Indonesia's nickel production comes from laterite ores, and the country has quintupled its production over the past five years. Indonesia is expected to remain the driver of nickel supply growth for the foreseeable future. The next largest producer is the Philippines (13 percent), followed by Russia (9 percent), and New Caledonia (7 percent). Brazil accounts for about 3.6 percent of global production. Table 3 shows how global nickel mine production has varied by country from 2016 onward. Production in Brazil declined in 2017 due to the closure of the Acampamento Macedo mine in 2016.

**Table 3: Global Nickel Mine Production by Country (kt nickel)**

| Country | 2016 | 2017 | 2018 | 2019 | 2020 | 2021e |
|---|---|---|---|---|---|---|
| Indonesia | 199 | 345 | 606 | 853 | 771 | 1,000 |
| Philippines | 347 | 366 | 345 | 323 | 334 | 370 |
| Russia | 222 | 214 | 272 | 279 | 283 | 250 |
| New Caledonia | 207 | 215 | 216 | 208 | 200 | 190 |
| Australia | 204 | 179 | 170 | 159 | 169 | 160 |
| Canada | 236 | 214 | 176 | 181 | 167 | 130 |
| China | 98 | 46 | 110 | 120 | 120 | 120 |
| Brazil | 160 | 79 | 74 | 61 | 77 | 100 |
| Cuba | 52 | 53 | 51 | 49 | 49 | * |
| Dominican Republic | * | * | * | 57 | 47 | * |
| Guatemala | 54 | 54 | 49 | * | * | * |
| Finland | * | 35 | 46 | * | * | * |
| South Africa | 49 | 48 | 44 | * | * | * |
| Colombia | 42 | 46 | 43 | * | * | * |
| Madagascar | 49 | 42 | 39 | * | * | * |
| United States | 24 | 22 | 18 | 14 | 17 | 18 |
| Other | 150 | 146 | 180 | 310 | 290 | 410 |
| **Total** | **2,093** | **2,104** | **2,439** | **2,614** | **2,524** | **2,748** |

Source: USGS 2021, *included in Other.

## 4.2 Nickel-Producing Companies

The nickel industry is relatively competitive, with numerous companies operating mines around the world. Table 4 shows the largest nickel producing companies, which account for approximately 83 percent of total global production. Over 40 companies worldwide produce more than 10 kt of nickel annually.

China-based Tsingshan Group is the world's largest stainless steel producer and the largest nickel producer, accounting for 16 percent of global nickel production. The company rose to the top of the nickel market in relatively few years through its exposure to several nickel smelter projects in China and Indonesia via joint ventures with other companies. Tsingshan Group was also the pioneer and global leader in the field of processing technology to produce NPI from nickel laterite ores. Chinese stainless steel producer Jiangsu Delong, now the second largest producer of nickel, and Shangdong Xinhai, now the sixth largest producer, have followed a similar path of developing their own nickel smelters to feed into their stainless steel operations.

Russian producer Norilsk Nickel is the third largest company, accounting for 10 percent of global production. Most of its assets are in Russia, unlike Glencore (8 percent) and Vale (6 percent), which have a diversified portfolio of global nickel assets.

**Table 4: Largest Nickel Mining Companies Attributable Production (kt nickel)**

| | Company | Domicile | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|---|
| 1 | Tsingshan Group | China | 110.0 | 330.0 | 395.0 | 596.0 |
| 2 | Jiangsu Delong Nickel | China | 30.0 | 175.0 | 180.0 | 269.0 |
| 3 | Norilsk Nickel | Russia | 217.0 | 225.0 | 221.0 | 200.0 |
| 4 | Jinchuan Nickel | China | 67.9 | 75.6 | 77.2 | 190.0 |
| 5 | Vale SA | Brazil | 140.0 | 116.5 | 183.7 | 168.0 |
| 6 | Shangdong Xinhai | China | N/A | N/A | 122.0 | 148.0 |
| 7 | Glencore | United Kingdom | 123.8 | 120.6 | 110.2 | 102.3 |
| 8 | BHP Group | Australia | 90.6 | 87.4 | 80.1 | 89.0 |
| 9 | Sumitomo Metal | Japan | 69.0 | 72.0 | 68.9 | 67.0 |
| 10 | PT Vale Indonesia* | Indonesia | 74.8 | 71.0 | 72.2 | 65.4 |
| 11 | Eramet | France | 30.4 | 26.5 | 35.9 | 48.8 |
| 12 | Anglo American | United Kingdom | 42.3 | 42.6 | 43.5 | 41.7 |
| 13 | South32 | Australia | 43.8 | 41.1 | 40.6 | 34.1 |

Source: Company reports, Wood Mackenzie, Deloitte estimates. *Vale owns 43.8 percent.

Table 5 provides a list of the top 15 global nickel mine operations that accounted for approximately 36 percent of global production in 2020. Norilsk's Kola Division in Russia is the largest standalone nickel producer, followed by Glencore's Sudbury operations in Canada and the Jinchuan operation in China.

**Table 5: Largest Nickel Mine Operations**

| | Mine | Country | Owner | Production 2020 kt Ni |
|---|---|---|---|---|
| 1 | Kola Division | Russia | Norilsk | 172.4 |
| 2 | Sudbury Operations† | Canada | Glencore | 91.5 |
| 3 | Jinchuan | China | Jinchuan Group | 77.2 |
| 4 | Sorowako | Indonesia | PT Vale Indonesia | 72.2 |

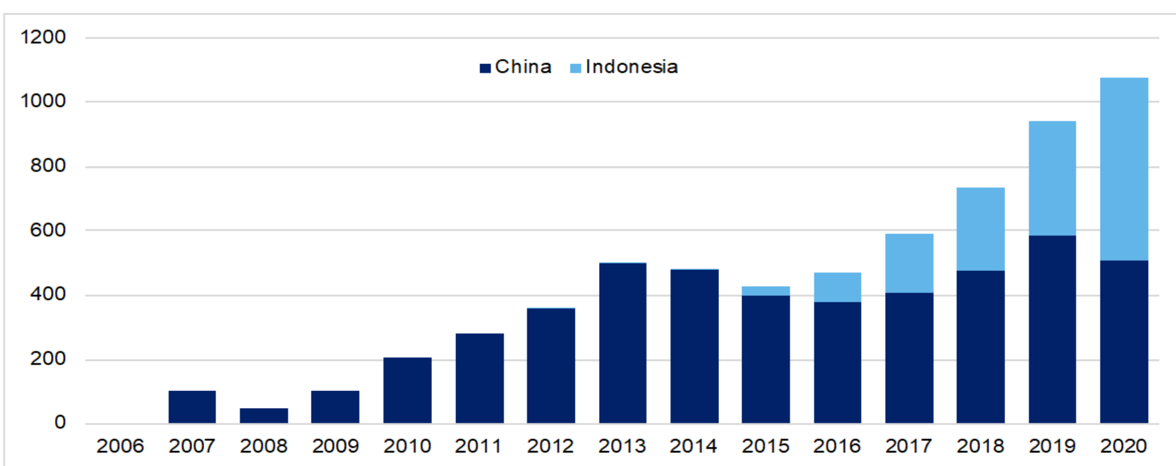
| | Mine | Country | Owner | Production 2020 kt Ni |
|---|---|---|---|---|
| 5 | Nickel West | Australia | BHP Group | 60.9 |
| 6 | Polar Division | Russia | Norilsk | 60.7 |
| 7 | SLN | New Caledonia | Eramet | 47.8 |
| 8 | Ontario Division | Canada | Vale | 43.2 |
| 9 | Murrin | Australia | Glencore | 40.8 |
| 10 | Cerro Matoso | Colombia | South32 | 36.1 |
| 11 | Voisey's Bay | Canada | Vale | 35.7 |
| 12 | Barro Alto | Brazil | Anglo American | 34.9 |
| 13 | Koniambo | New Caledonia | SMSP/Glencore | 34.5 |
| 14 | Ramu | PNG | Metallurgical Corp. | 33.7 |
| 15 | Moa Bay | Cuba | Sherritt International | 31.5 |

Source: S&P Global Intelligence, Company data. † Includes Raglan, Sudbury, and Nikkelverk.

## 4.3 The Rise of Nickel Pig Iron (NPI)

NPI is a relatively new nickel product that has changed the business model of nickel production. It was first produced in 2005 and it is now the dominant product in the nickel market (see Figure 7). NPI is a low-grade ferronickel that was developed in China as a cheaper alternative to Class I nickel, which could be used to produce stainless steel at a time when nickel prices were high. NPI comprises laterite nickel ore, coking coal, and a mixture of gravel and sand as an aggregate. This mixture is heated in either a blast furnace or electric arc furnace depending on the desired grade. Impurities are then removed via smelting and sintering processes and the resulting NPI contains 4 to 13 percent nickel and the balance iron.

**Figure 7: Nickel Pig Iron (NPI) Production**




Source: Deloitte.

NPI was initially processed in Chinese blast furnaces by stainless steel companies importing direct shipping ore (DSO) from Indonesia and the Philippines. Through 2013, Indonesia was the leading exporter of nickel ore to China, but production decreased dramatically in 2014 when the Indonesian government began to enforce its ban on the export of key unprocessed metalliferous ores. The regulations, originally enacted as Law No. 4 in 2009, effectively halted all sales of Indonesian nickeliferous DSO to overseas producers of ferronickel and NPI. The ban's intent was to stimulate development of domestic processing facilities that would produce higher-valued products within Indonesia. As a result, Chinese imports of lower grade nickel ore from the Philippines replaced ore imports from Indonesia.

In January 2017, Indonesia eased export restrictions on unprocessed ore following significant investment in new Indonesian nickel smelters. More than $9 billion had been invested in processing facilities in Indonesia, which resulted in the commissioning of 13 processing plants in 2017, with an additional 14 facilities planned or under construction. While some of these NPI processing plants were used to expand the domestic stainless steel industry in Indonesia, much of the investment came from Chinese steel companies who exported some of the NPI back to China. The nickel ore export restrictions in Indonesia were reimposed from the start of 2020 to slow the depletion of nickel ore reserves and promote investment in processing facilities. This resulted in increased exports of nickel ore from the Philippines to China. In addition to the development of NPI, there has been a revival in HPAL technology in Indonesia, also led by Chinese companies, reflecting a process route that can produce nickel for batteries.

## 4.4 Challenges with HPAL Production

HPAL treatment plants generally have high capital costs and a poor reputation. Although the technology works, facilities often do not reach nameplate capacity. Ramp-up projections are often protracted, and projects only achieve 80 percent of capacity on average, significantly increasing operating costs. Failed projects in recent years include Bulong and Murrin in Australia, and Goro in New Caledonia.

The Goro operation in New Caledonia, owned by Vale, had CAPEX that was originally budgeted at $1.5 billion but surged to $4.5 billion to support a 60 kt/y nickel-oxide and mixed-hydroxide product/precipitate (MHP) operation. Nameplate capacity was hardly reached after a ramp-up that took two years longer than expected due to the complexity of the HPAL facility. Vale sold the operation to Prony Resources in March 2021.

Additionally, other operators have already delayed some new HPAL plants in Indonesia, partly due to COVID-19, but also due to tailings disposal problems, according to press reports.

### 4.4.1 Environment, Social, and Governance Considerations for NPI

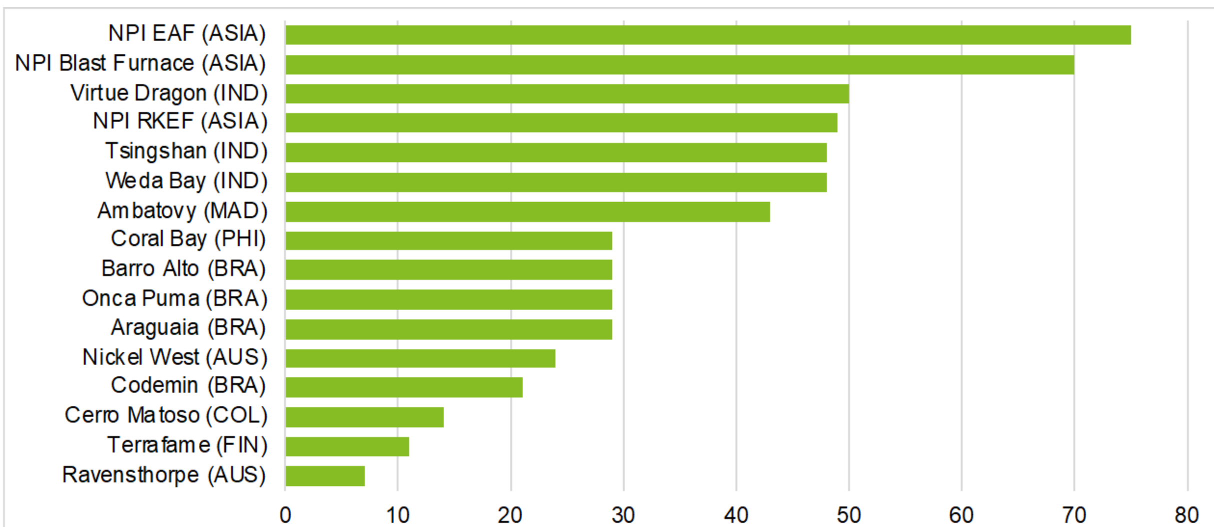
Despite the positive outlook for the nickel industry in Indonesia, ESG concerns remain a risk to investment. The first major ESG issue in Indonesia involved deep-sea tailings placement (DSTP) off the coast of Morowali. The operator abandoned these plans after the Government of Indonesia stopped issuing new permits for DSTP in an effort to respond to concerns about the environmental impact of new nickel processing facilities. Because of the limited suitable land available for onshore tailings ponds, high rainfall, and tectonic issues, dry tailings stacking is being used. This is a more environmentally friendly way to store tailings.

Other major ESG issues include land clearance and habitat loss resulting from nickel mining (particularly given the high levels of biodiversity in the Indonesian rainforests), as well as high energy consumption required for nickel smelting. Nickel smelting in Indonesia is based on coal-fired power stations, which have a large $CO_2$ footprint.

Some smelter operators are looking to resolve this in the medium to long term through renewable energy sources. For example, Tsingshan announced plans to build a 2,000 megawatt (MW) renewable energy plant using wind and solar power to support its Morowali Industrial Park and Weda Bay Industrial Park in Indonesia. The company is also looking at investment in a hydroelectric facility.

Figure 8 shows a global comparison of nickel production carbon footprints based on tonnes of $CO_2$ per tonne of nickel production. Indonesian production has one the highest carbon footprints.

**Figure 8: Global $CO_2$/t Ni Equivalent Comparison**




Source: Horizonte Minerals, Wood Mackenzie. NB Asia principally China and Indonesia.

## 4.5 Midstream Processing of Nickel

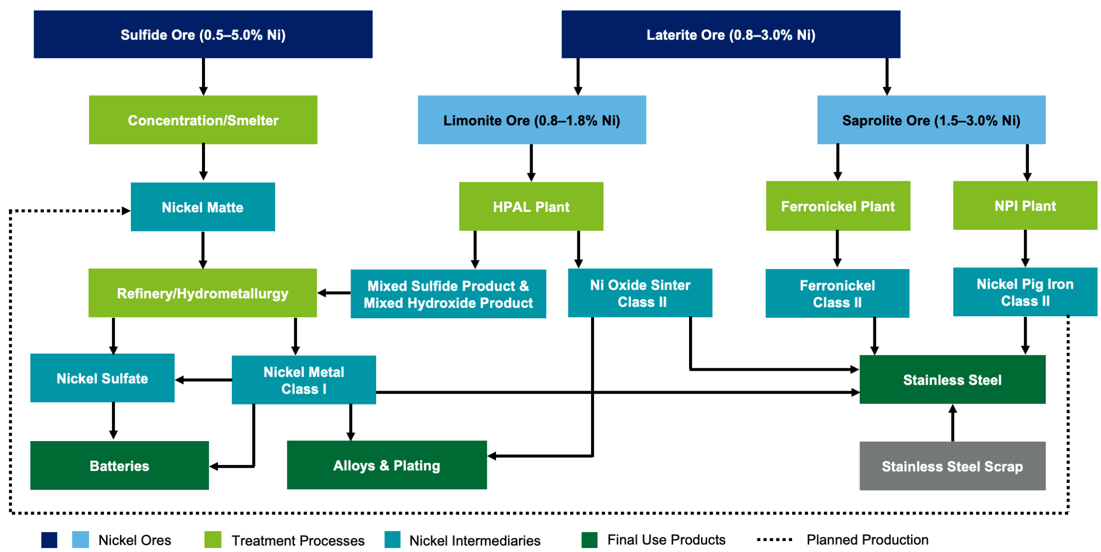
The previous sections explained the locations of nickel production, the companies involved and their different levels of nickel output, the different types of ore treated, and the processing route broadly used, dictated by the ore type mined. At midstream, however, the processing supply chain becomes more complicated as there is a broad mixture of intermediary and final products that can be produced, in part related to the initial processing route, but also related to the required final end-use.

Figure 9 illustrates the breakdown of primary nickel products produced. Nickel Class I products are shown in green shades and represent the different forms of nickel metal produced. Nickel Class II products are shown in shades of blue and are principally produced in combination with iron and fed directly into stainless steel furnaces. The figure also illustrates the different intermediary products that are produced from various processes and how they feed into the final-use products.

In addition, Figure 9 shows how sulfide ore processing entails the concentration of the nickel minerals through flotation and then smelting to produce a concentrate. This produces a nickel matte which is then sent to a nickel refinery where Class I nickel metal and nickel sulphate are produced. This process from mining to finished product is generally performed by the same company.

With nickel laterite ores, the ore can be processed on-site or transported to another location to produce NPI and ferronickel. The NPI and ferronickel produced is fed directly to the stainless steel industry, often as part of an integrated process. Nickel intermediaries from HPAL treatment of laterite ores are usually processed at the mine site to produce a mixed sulfide product/precipitate (MSP) or MHP, which are then fed principally to refineries to produce Class I nickel. *Annex 2 provides more detail of nickel mining and processing.*

**Figure 9: Simplified Flow Sheet for Nickel Mining & Processing**




Source: Deloitte.

Over time, the production ratios of the different types of nickel products have changed, not only to meet demand but also as a result of the types of orebodies being exploited. Electrolytic, high-purity nickel cathode metal (Class I metal) has long been the most common nickel product, as it has wide-ranging applications. However, the market has seen annual declines of refined nickel (nickel metal or nickel sulfate) supply due to capacity closures, short-term production outages, and general variability of supply from sulfide and HPAL operations. The market has adapted through the development of Class II stainless steel feedstocks from the abundant laterite ore resources.

## 4.6 Recycling and Substitution

Producers can recycle nickel without losing quality and can source it as secondary raw material to use in many applications. Producers currently use large tonnages of secondary or scrap nickel to supplement newly mined ores. Major recycling activities of nickel take place in the value chain, particularly in stainless steel mills, given that approximately 70 percent of nickel first uses are related to being used as an alloying element in stainless steel and other nickel-containing alloys.

Nickel is one of the most valuable common non-ferrous metals, along with aluminum, copper, lead, and zinc. Given its value as a commodity, governments and public sector are motivated to use nickel effectively. There is a similarly compelling incentive for recovering and recycling nickel effectively at all stages of the production and use cycle.

Since nickel-containing products have value, infrastructure exists for gathering and processing these materials. According to the Nickel Institute, in most countries the economics of gathering, sorting, preparing, transporting, and using scrap metal employs more people and is of greater economic importance than the mining and refining of ores.

The global efficiency of recycling nickel from end-of-life products is estimated at some 65 to 70 percent, although nickel-recycling efficiencies can vary greatly depending on the region and specific end uses. Losses that occur after use mainly relate to nickel-containing materials ending up in landfills. In the case of nickel-containing stainless steel, recycling can be done very efficiently.

### 4.6.1 Stainless Steel Scrap

Secondary sources of nickel are a key feedstock in the production of stainless steel. Stainless steel scrap is generated by recovering the material from the stainless steel production process itself from obsolete products and demolished buildings. Secondary nickel units coming from stainless steel scrap are extremely important when analyzing the global nickel market as they have been equivalent to around one third of primary nickel production in recent years. The international trade in stainless steel scrap is a very relevant part of the whole nickel market because a considerable part of the material available in some countries is exported and used elsewhere. The top three net exporting countries of stainless steel scrap are Germany, Netherlands, and Japan. The top three net importers are India, Belgium, and Finland.

Scrap plays a key role in determining how much demand for Class I metal the stainless steel sector requires. About 26 percent of Class I nickel is currently consumed in stainless steel, but higher uses of scrap and/or Class II material results in a lower volume of Class I demanded for stainless steel. Although secondary supply of nickel from stainless steel recycling provides significant quantities of nickel for re-use, these units are locked into the stainless steel circular economy.

Nickel units contained in stainless steel scrap are therefore unavailable or attainable for any future use other than stainless steel production. Nevertheless, the use of scrap by mills is of key importance for nickel availability by other primary nickel-consuming sectors. This is because any increase in remelt scrap use by stainless steel mills lowers the requirements for primary material, thus making more primary units available to other sectors. Such dynamics render stainless steel mills an important factor in determining future availability of Class I units.

Many stainless steel producers obtain most of their nickel units from stainless steel scrap rather than from primary sources. However, swings in the nickel price can affect scrap availability. For example, a period of low nickel prices acts as a disincentive for scrap collectors and processors to gather, sort, and sell stainless steel scrap, which in turn forces mills to obtain a greater quantity of their nickel units from primary sources.

### 4.6.2 Substitution

Substitutes are possible for nickel used in metal products such as plates, tubes, and beams with other steel alloy materials such as titanium, chromium, manganese, and cobalt. However, those alternatives usually have a higher cost or adverse impacts on performance. When international nickel prices are high, thrifting occurs in higher-quality stainless steel, as well as increased consumption of lower nickel-bearing stainless steels. *See Annex 3 for further information on stainless steel.* The opposite is happening in lithium-ion batteries. Several lithium-ion battery chemistries contain nickel, and different formulations contain different quantities of nickel. The trend, however, is to use increased quantities of nickel and lower quantities of other commodities such as cobalt and manganese in batteries.

## 4.7 Current Nickel Production in Brazil

There are currently five significant nickel mines operating in Brazil that produced over 85 kt of nickel in 2021. Barro Alto and Onça Puma are mid-sized operations, while Santa Rita, Codemin, and American do Brasil are small operations. Santa Rita and Americano do Brasil are sulfide projects while the other three are laterite operations (see Table 6 for more information on these nickel operations).

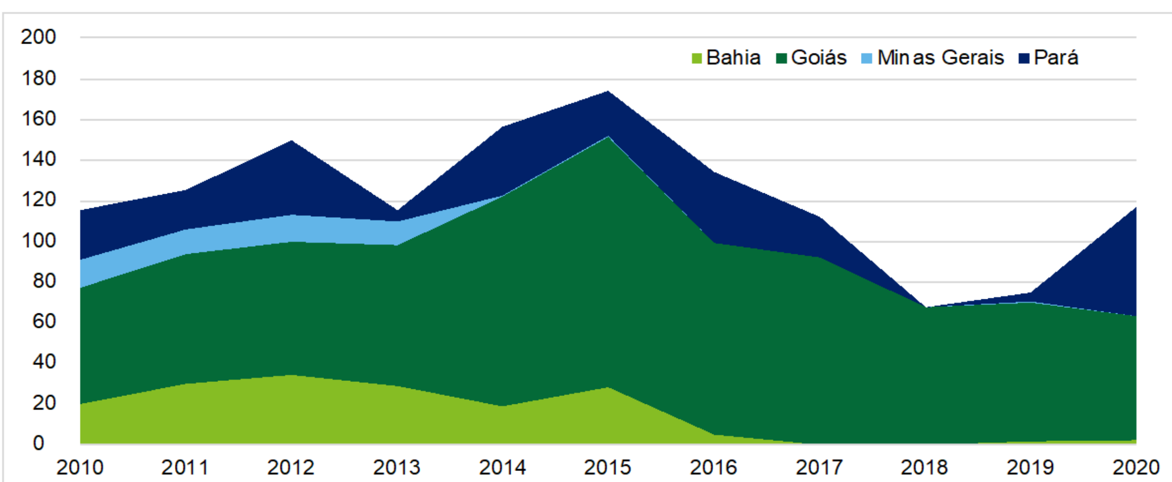
**Table 6: Brazilian Nickel Producers (Nickel Production tonnes)**

| Mine | State | Owner | Production 2019 | 2020 | 2021 |
|---|---|---|---|---|---|
| Barro Alto | Goiás | Anglo American | 33,900 | 34,900 | 33,900 |
| Onça Puma | Pará | Vale | 11,600 | 16,000 | 21,429 |
| Santa Rita | Bahia | Appian Capital | 0 | 9,159 | 16,087 |
| Codemin | Goiás | Anglo American | 8,700 | 8,600 | 7,800 |
| Americano do Brasil | Goiás | Prometálica Mineração | 6,000 | 6,000 | 6,000 |
| **Total** | | | **60,200** | **74,659** | **85,216** |

Source: S&P Global Intelligence.

**Anglo American** [LSE: AAL] operates Codemin and Barro Alto, which are two ferronickel mines in Goiás, the state with the most nickel production in the country (see Figure 10). Barro Alto nickel laterite ore was initially mined and transported to the Codemin plant (150 km away) beginning in 2004. Anglo then commissioned the Barro Alto processing plant in 2011, constructing it at a capital cost of $1.9 billion. The Barro Alto facility comprises an ore-crushing and processing plant with related infrastructure, including two identical rotary kiln-electric furnace (RKEF) pyrometallurgical process streams that can each treat 1.28 Mt/y of ore. The process involves crushing, drying, calcining, smelting, refining, and granulating. Codemin has been operating since 1982 and produces nickel in low-carbon ferronickel. The main market for Codemin's and Barro Alto's ferronickel product is within Brazil, primarily to local stainless steel producers.

**Figure 10: Brazilian Nickel Production by State 2010-2020 (kt nickel)**




Source: Agência Nacional de Mineração (ANM).

**Vale** [BOV: VALE3] operates the Onça Puma laterite mine in Pará State. The operation started in 2011 and involves a two-line RKEF plant with nominal capacity of 50 kt/y of ferronickel. The project has had a difficult history with technical issues due to furnace failures and socio-environmental issues with the local community. Production has been increasing but the mine still operates below its 50 kt/y nickel capacity. Mine production was halted temporarily in 2021 because of alleged non-compliance with local regulations.

The Santa Rita nickel-copper-cobalt project was acquired out of bankruptcy by Atlantic Nickel (which was then purchased by **Appian Capital Advisory**) for $68 million in 2018. The former operation located in Bahia State had suffered from poor operational performance, high debt, and declining nickel prices. Drilling by Appian expanded ore reserves and the 6.5 Mt/y plant was recommissioned, with the first concentrate shipment taking place in January 2020. In October 2021, Sibanye-Stillwater [JSE: SSW] announced that it planned to acquire Atlantic Nickel from Appian, but it withdrew in January 2022 after a geotechnical event occurred at Santa Rita. Sibanye-Stillwater stated that it assessed the event and its effect and concluded that it was material and adverse to the business, financial condition, results of operations, properties, assets, liabilities, or operations of Santa Rita.

**Prometálica Mineração** operates the American do Brasil mine and processing plant in Goiás State. The nickel-copper sulfide underground mine is a small operation that produces approximately 6.0 kt of nickel annually.

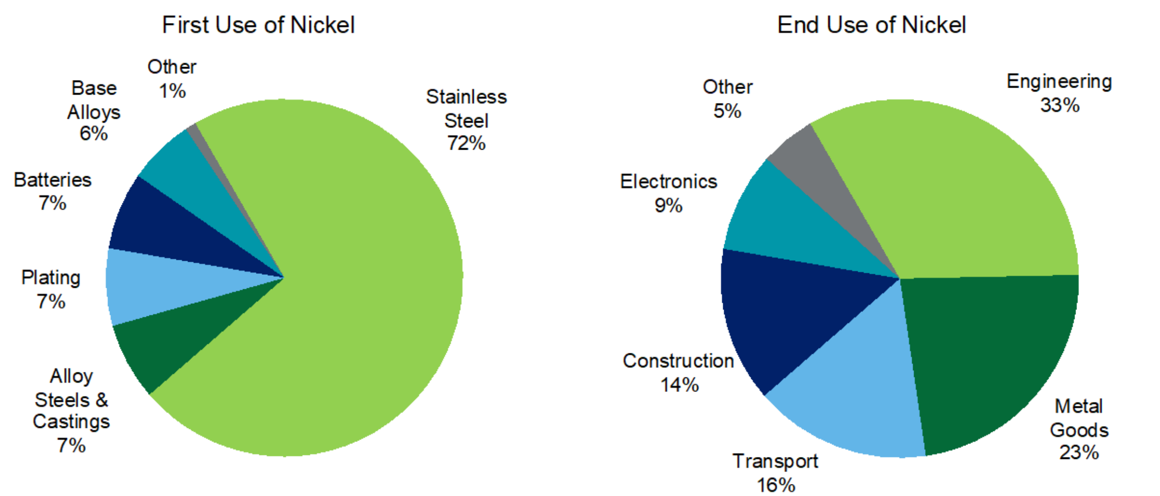
Brazil had another nickel mine and refinery until recently. In the State of Goiás, the Acampamento Macedo mine, owned by **Companhia Brasileira do Alumínio** (a subsidiary of Votorantim) ceased production in 2016. The lateritic ore near the mine had a grade of 1.45 percent nickel. Votorantim also ceased nickel-cathode production at its 25 kt/y capacity nickel refinery at São Miguel Paulista (SMP).

However, **Jervois Mining** [ASX: JRV] is acquiring SMP and looking to re-start the refinery. The company has completed a bankable feasibility study (BFS) and is also planning to construct a pressure-oxidation autoclave in front of the existing circuit to allow the processing of sulfides in addition to the hydroxide and carbonate feeds the refinery can already accommodate. This will allow the refinery to also process material from recycled lithium-ion batteries. Jervois Mining expects start-up to take place in 2024 with capacity of 25 kt/y nickel and 2.5 kt/y cobalt.

# 5. NICKEL DEMAND

In 2021, primary nickel consumption was 2.85 Mt, a 17 percent increase over 2020 levels.[21] This demand exceeded supply and there was a significant drawdown of the exchange inventories during the year. Currently, the stainless steel industry is what predominantly drives global nickel demand, accounting for 72 percent of total primary nickel consumption in 2020.[22] Other demand drivers for nickel include alloy steels and castings, plating, and non-ferrous alloys, which each accounted for only 6 to 7 percent of primary nickel consumption in 2020. That year, the battery sector accounted for only 7 percent of primary nickel consumption, but it has the strongest growth potential of all the first uses of nickel. It is expected to account for 26 percent of demand by 2030.[23]

**Figure 11: Global Nickel Demand 2020**




Source: Nickel Institute.

Figure 11 shows the breakdown of first-use nickel and the end-use nickel. The following sections provide more detailed information on nickel uses and applications, and current Brazilian demand.

## 5.1 Nickel Uses and Applications

Nickel is mainly used to produce various stainless and alloy steels that are later used in building and construction materials, tubes, machinery and metal goods, transportation, electronics, engineering, and consumer and other products. Stainless steel is the biggest user of primary and scrap nickel, while batteries are another main user. *Annex 3 provides more information on nickel demand*.

[21] Norilsk Nickel Nov 2021.

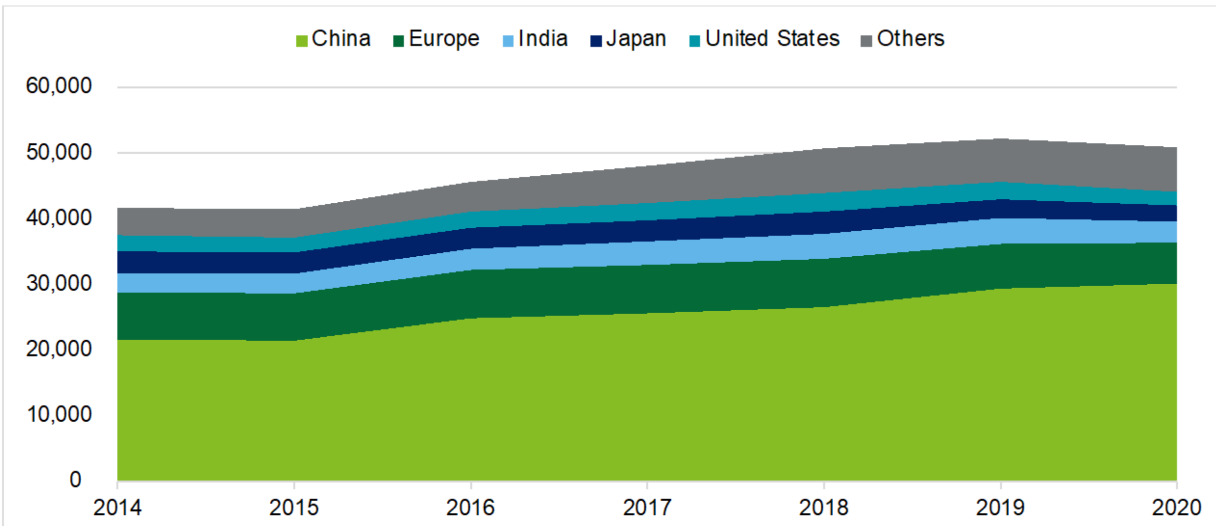
[22] Nickel Institute.

[23] Wood Mackenzie (June 2021).

### 5.1.1 Stainless Steel

In 2020, stainless steel consumption totaled 50.9 Mt. The stainless steel industry is the largest consumer of nickel and has been the main driver of the rise in primary nickel demand, which has grown by an average compound annual growth rate (CAGR) of 6 percent over the past decade. Nickel is used as an alloying element; in the most common types of stainless steel, nickel comprises 8 to 11 percent of the content. In 2020, the stainless steel industry consumed 1.7 Mt of primary nickel and a further 910 kt of nickel in scrap.[24]

**Figure 12: Global Stainless Steel Production 2014-2020 (kt)**



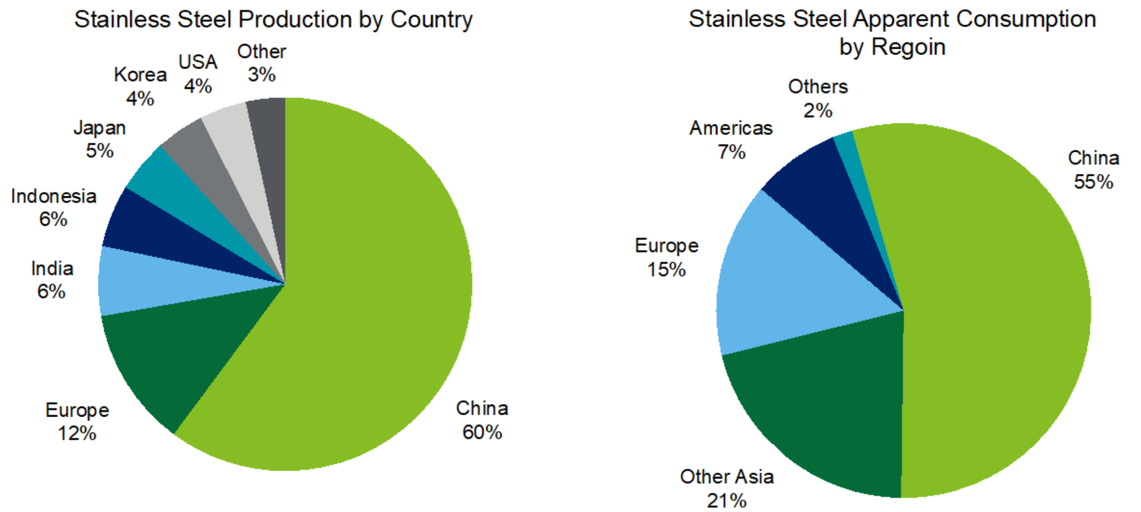

Source: International Stainless Steel Forum (ISSF).

China is the main primary nickel producing (and consuming) country, representing approximately 55 percent of global consumption in 2020, mostly for stainless steel used in the construction, transportation, and manufacturing sectors. Other significant producers of stainless steel include European countries (the largest being Finland, Sweden, Belgium, and Italy), as well as India, Japan, and the United States. Brazil, Russia, South Africa, South Korea, and Indonesia also produce stainless steel but to a smaller degree. Figure 12 shows global stainless-steel production by country over time, while Figure 13 shows global production and consumption by country in 2020.

Nearly all types of nickel feedstock are used in stainless steel production (except for several specific products, like nickel powder and compounds). Since the quality of nickel barely affects the quality of conventional stainless steel grades, the manufacturers select the cheapest nickel feedstock, turning to high-grade nickel as their last resort. This explains why the share of Class I nickel has been declining in the structure of nickel units consumed in stainless steel production in recent years.

[24] Macquarie 2021

**Figure 13: Global Stainless Steel Production and Consumption 2020**




Source: Macquarie, ISSF.

### 5.1.2 Nickel Alloys

Nickel will alloy readily with many other metals, including chromium, iron, molybdenum, and copper. This process allows results in a wide variety of alloys that demonstrate outstanding resistance to corrosion and high-temperature scaling, exceptional high-temperature strength, and other unique properties, such as shape memory and low coefficient of expansion.

### 5.1.3 Nickel Electroplating

Electroplating or surface treatment involves applying a thin layer of metal or metal alloy to items. The purpose is to change the technical or physical properties of the surface of the items that are plated—such as their electrical conductivity—or to improve their durability, appearance, and performance of these properties. Electroplating also provides excellent adhesion properties for subsequent coating layers, which is why nickel is often used as an 'undercoat' for other coatings, such as chromium.

### 5.1.4 Base Metal Alloys

The main engineering grades of copper-nickel alloys were developed for naval condenser and seawater pipework applications. Recognition of their unique combination of high levels of resistance to corrosion, good thermal conductivity, and low macro-organism attachment in marine environments led to applications in offshore oil and gas, shipbuilding, desalination, and power generation. Commercially, the 10 and 30 percent nickel (described as 90-10 and 70-30) alloys are the most commonly used.

### 5.1.5 Batteries

Nickel has long been widely used in batteries, most commonly in nickel cadmium (NiCd) and nickel metal hydride (NiMH) rechargeable batteries that were developed in the 1980s. In the mid-1990s, the first lithium-ion batteries were developed, many of which contain formulations of nickel-cobalt-manganese (NCM). The major advantage of using nickel in batteries is that it helps deliver higher energy density and greater storage capacity.

With the development of EVs, lithium-ion battery cathodes have increasingly shifted towards NCM formulations. NCM cell formulations started off with equal proportions of the three metals (NCM111); however, because of concerns about the cobalt supply chain and the desire to increase the energy density (for improved mileage per charge), battery manufacturers have moved towards higher nickel and lower cobalt formulations. NCM523, NCM622, and NCM811 are currently the three most common formulations of NCM batteries. NCM811 is currently the highest-growth ternary cell chemistry and is expected to dominate market share going forward. The other important type of nickel cathode battery is nickel-cobalt-aluminum (NCA), which has a significant demand.

An upcoming Report on the outlook for demand growth in EVs and lithium-ion batteries, which includes a discussion of battery technologies, will provide additional information on these topics as they relate to all the critical minerals selected for this analysis.

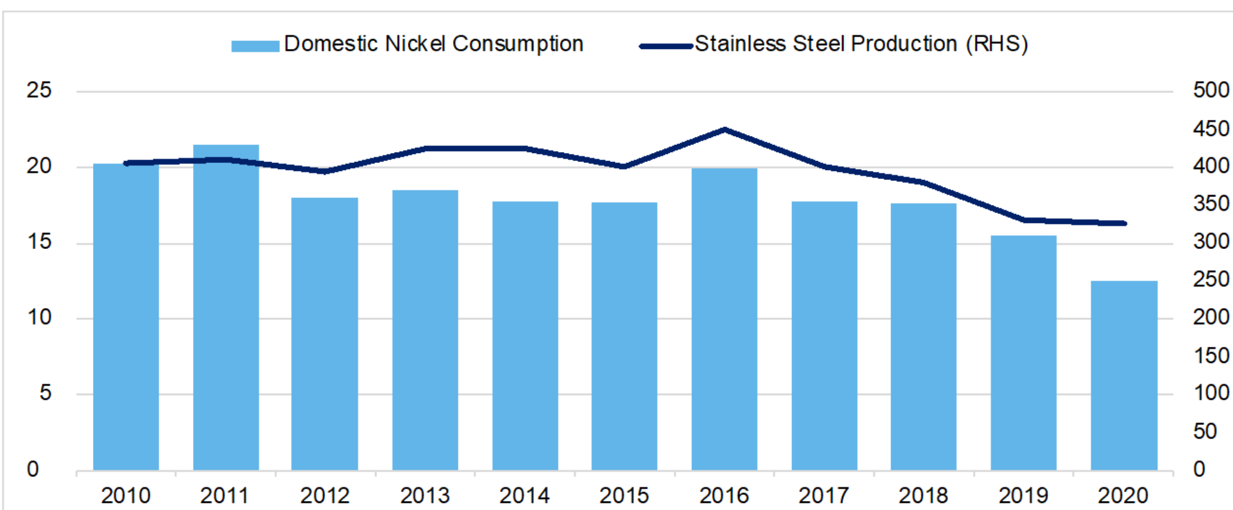
#### 5.1.6 Nickel Compounds

Nickel compounds, which are derived from nickel metal, are used in industries such as surface finishing, automotive, aerospace, electronics, glass, and ceramics. The compounds consist of nickel plus at least one other element, chemically bonded together. Nickel compounds are usually supplied in granule, powder, or liquid form.

### 5.2 Brazilian Consumption and Exports of Nickel

Brazil has three stainless steel producing companies using nickel: Aperam, Villares Metals, and Gerdau. They produced almost 330 kt of stainless steel in 2020, which corresponded to an estimated 13 kt of nickel consumption, including some tonnage used in non-stainless sectors. Figure 14 shows the annual stainless-steel production and nickel consumption in Brazil from 2010 to 2020. Nickel-containing stainless steel scrap usage to produce stainless steel is estimated to be in the range of 30 to 35 percent in Brazil for most years.

**Figure 14: Stainless Steel Production and Nickel Consumption in Brazil 2010-2020 (kt)**




Source: INSG, ISSF.

Most of the ferronickel nickel produced in Brazil is exported. Exports from Brazil commenced in 2011 at 20 kt of ferronickel and have steadily increased to 211 kt in 2020. Export destinations of Brazilian ferronickel are diverse, and include Belgium, the United States, and South Korea, but the main destination is China with a 45 percent share in 2020.[25]

[25] INSG Insight No.35.

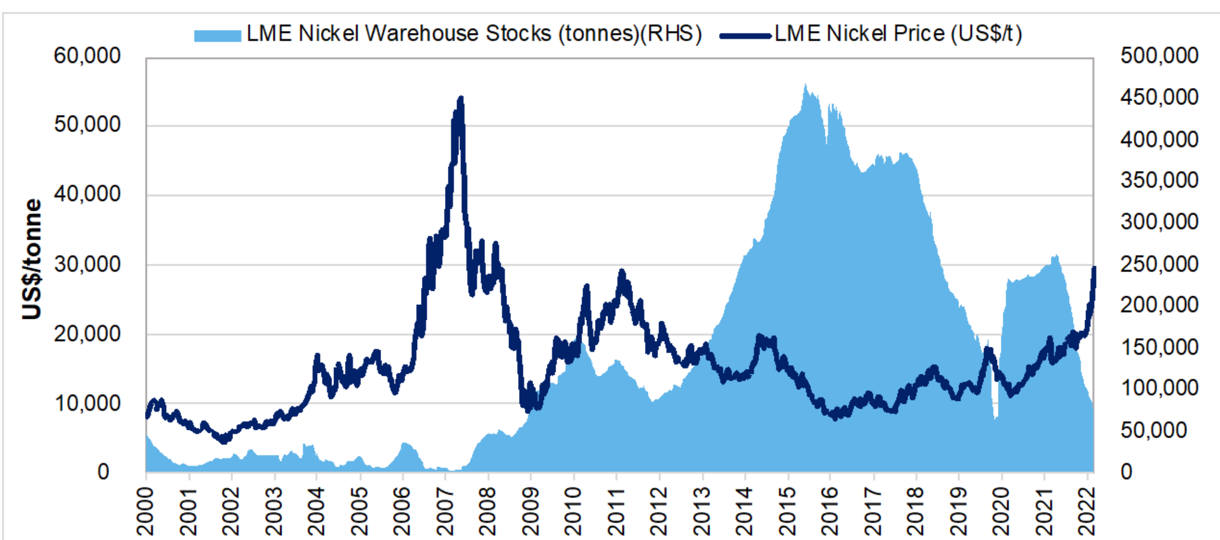
## 6. NICKEL TRADE AND PRICES

Nickel ores and concentrates, intermediates, and refined products are traded globally in different product specifications and qualities. Ores and concentrates are the most important trade product by quantity, while nickel metal is the most important product by value. Nickel metal is an exchange traded commodity and can be traded in futures and options contracts. Producers, semi-fabricators, consumers, recyclers, and merchants can use nickel futures contracts to hedge nickel price risks. Major exchanges include the LME and the Shanghai Futures Exchange (SHFE), which launched its nickel contract in 2015. LME nickel contracts include a relatively low share of physical nickel that is traded; however, global physical nickel transactions are usually based on LME nickel prices. The contract prices are quoted in US dollars per tonne but can also be settled or cleared in Japanese Yen, UK Sterling, and the Euro.

Nickel stocks are stored in warehouses around the world, including in LME-approved and non-approved warehouses. Nickel stocks in LME-approved warehouses are relatively transparent, while nickel stocks at non-approved warehouses can be hidden or difficult to interpret. LME warehouses are chosen worldwide based on their proximity to sources of demand rather than supply, ensuring that the buyer has immediate access to metals purchased on the LME. However, China does not allow warehouses in its territory to become LME-registered, and metal for Chinese delivery is typically shipped from Singapore or South Korea.

Figure 15 shows the LME nickel price since 2000 and LME warehouse stock levels over that period. Stock levels of commodities, including nickel, can be an important factor in price determination. Relatively low warehouse stocks can signal lack of supply or extra demand for nickel and drive up nickel prices, while high warehouse stocks can signal abundant supply or low demand for nickel and drive down prices. Nickel warehouse stocks in regions that historically consume high levels of nickel matter more in supply and demand terms than stocks in regions that consume low levels of nickel, and thus have higher impact on nickel pricing.

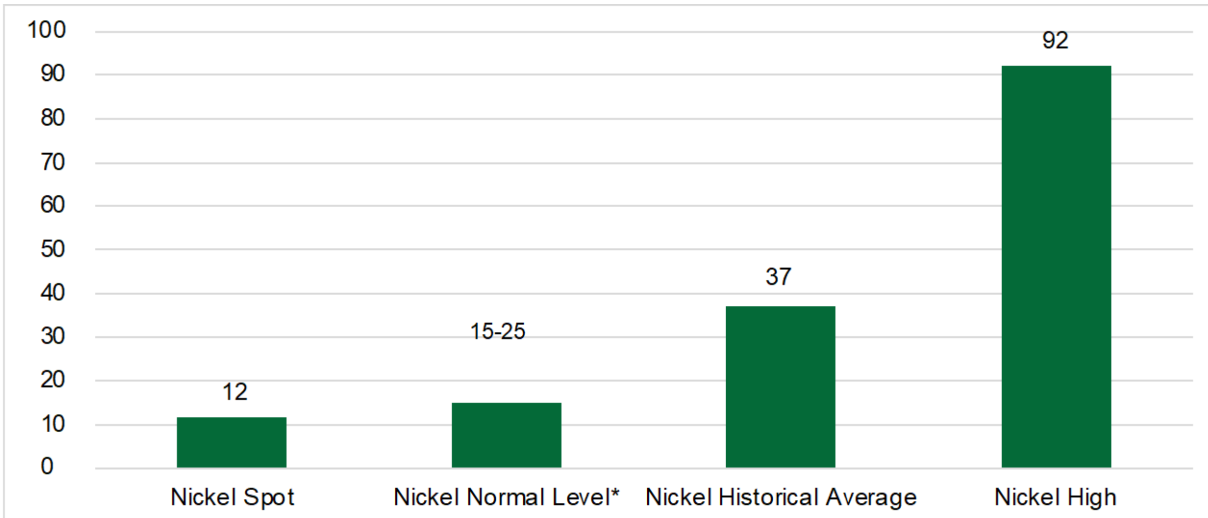
**Figure 15: LME Nickel Price and Warehouse Stocks**




Source: LME.

Figure 16 shows a range of values based on 'days of consumption' of nickel stocks that are used as a benchmark and highlights the current low level of exchange-traded warehouse stocks globally.

**Figure 16: Nickel Exchange Inventories (Days of Consumption)**




Source: Norilsk Nickel. * According to Norilsk customers and market participants as at Oct. 2021.

The price of nickel has shown considerable volatility. Figure 15 shows how the price escalated dramatically through 2006 and reached an historical peak of $52,179/t in May 2007. This was caused by supply problems (strikes at Sudbury, a major nickel mine operation in Canada, and delays to new mines), strong demand for stainless steel from China, and low inventories. Nickel prices then declined almost as sharply, as buyers withdrew from the market and operators resolved supply issues. Prices continued to fall, hitting a low of $9,678/t in December 2008. Nickel prices recovered and continued to move up and reach another (albeit lower) peak in February 2011, with an average price of $28,247/t. Nickel prices then moved into a long-term price decline until February 2016 when the metal traded at around $8,300/t. There has been a gradual recovery in prices since 2016.

In 2021, the nickel market moved into a deficit. A series of supply issues with new Indonesian NPI capacity, together with exceptionally robust demand recovery from the stainless steel and battery sectors, and massive restocking throughout the value chain triggered by the logistical constraints post COVID-19, have resulted in strong prices, with nickel moving to price levels not seen since 2011, as shown in Figure 15. Strong demand from stainless steel and batteries was slightly offset by lower activity in the alloys sector, which is mainly driven by the aerospace industry. Demand in the aerospace industry has been weak due to recent global travel restrictions. Overall, the estimated value of the commodity market based on average 2021 prices is $50 billion (compared with $144 billion for copper)[26].

---

[26] Deloitte

Norilsk Nickel notes that there has been a significant drawdown of the exchange inventories in the past 12 months. Most of this inventory is believed to have gone into China for use in the battery sector, given strong EV sales and the shortage of intermediates for nickel sulfate production. In addition, the LME nickel price spiked to over $100,000/t following Russia's invasion of Ukraine in March 2022. Short position covering and margin calls resulted in a halt in trading on metal exchanges. The price remains elevated, but is gradually declining.

The market focuses primarily on the LME nickel price, but increasingly the price of other nickel products is becoming important. In particular, this includes the price of nickel sulphate and NPI. The spot market for nickel sulfate is currently immature. A substantial proportion of nickel sulfate production is sold on a long-term contract basis to battery makers, which are usually negotiated annually, while buyers are similarly incentivized to lock in battery raw materials supply to protect the supply chain to the end-user market. Typically, the LME cash price for nickel is a component in contract pricing. An increase in supply and demand of nickel sulfate and the number of market participants in the supply chain will likely encourage more spot activity in the long term.

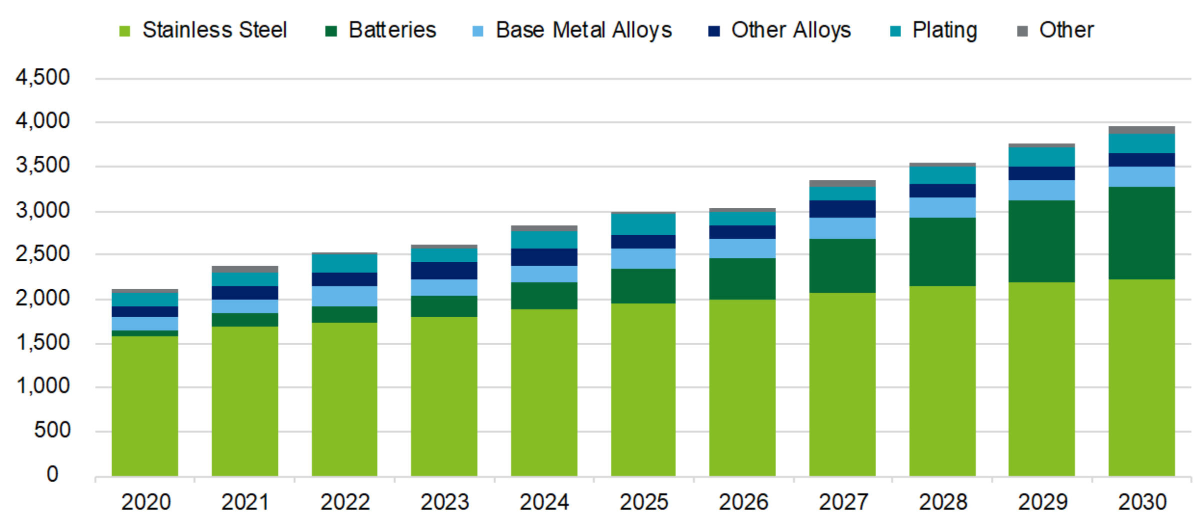
The bifurcation of the nickel value chain has also been driving price differentials among different nickel products: fast-growing NPI capacity, mainly from Indonesia, has pushed Class II nickel into oversupply and dampened its price. Meanwhile, Class I nickel required for nickel sulphate is traded at a premium when compared to both NPI and refined nickel due to a shortage. This premium will ultimately dictate the amount of Class II nickel converted to nickel matte and ultimately nickel sulfate.

# 7. OUTLOOK FOR NICKEL DEMAND

A wide range of forecasts exist in the market for total nickel demand in 2030. Demand for nickel is forecasted to increase to approximately 4.0 Mt according to Roskill, and 4.5 Mt according to Macquarie. These numbers are based off slightly different starting demand numbers for 2020, but both represent a CAGR of 6.5 percent out to 2030.

Over the next decade, nickel demand will be strongly driven by nickel use in battery markets; however, the stainless steel market is expected to remain an important demand driver and the largest overall sector. Figure 17 shows that the battery sector is expected to become a more important part in the overall demand for nickel, with Roskill forecasting demand for batteries to increase from 7 percent of nickel demand in 2020 to 26 percent in 2030. This demand growth is based on Roskill's forecast of EV, portable electronics, niche transport applications, and energy storage systems (ESS) sales.

**Figure 17: Forecast Primary Nickel Demand 2020-2030 (kt)**




Source: Roskill 2020.

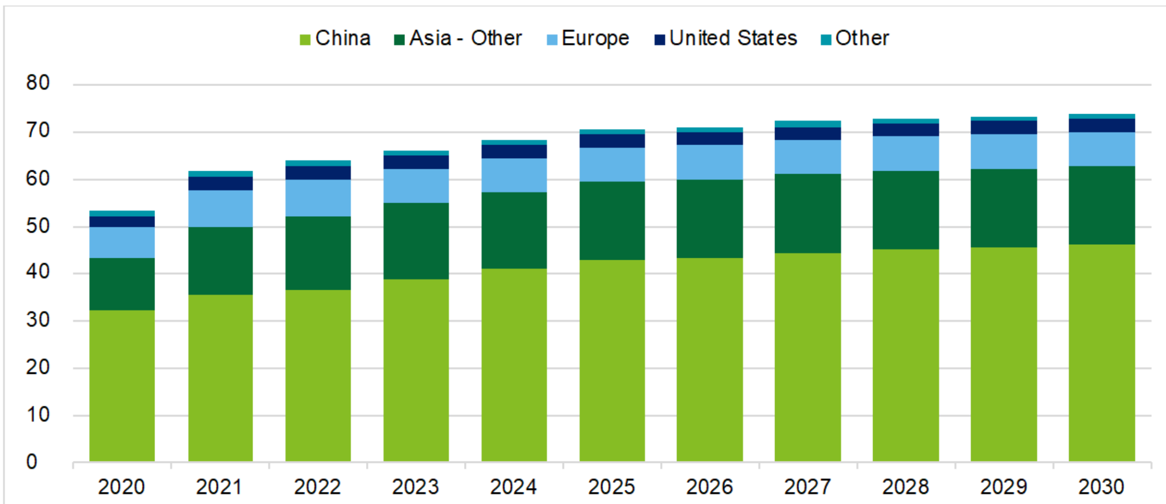
The sections the follow provide more information on projected demand growth for stainless steel, batteries, and other uses to 2030.

## 7.1 Nickel Demand Growth for Stainless Steel

As mentioned previously, stainless steel demand is expected to remain the largest demand segment for nickel out to 2030 and beyond, despite the strong growth in nickel demand for batteries. However, Roskill expects stainless steel's share of demand to fall from 69 percent in 2020 to 57 percent in 2030 as the importance of nickel for batteries increases. Chinese demand for construction, transportation, and manufacturing are expected to remain key drivers of stainless steel demand going forward.

Demand for stainless steel increased by 14 percent in 2021 to approximately 58 Mt from 50.9 Mt in 2020. This is significantly higher than the CAGR of 5.1 percent experienced from 1980 to 2020. From 2020 to 2030, demand growth forecasts by consultants range from 3 to 4 percent per annum. For example, Wood Mackenzie forecasts global stainless steel growth to be 3.8 percent annually from 2021 to 2025, eventually slowing to 1.2 percent annually from 2025 to 2030. This results in a CAGR of 3.4 percent from 2020 to 2030, as shown in Figure 18. Additionally, Outokumpu (the largest stainless steel producer in Europe and the second largest in the Americas, which is based in Finland) forecasts a 3.6 percent CAGR for stainless steel from 2019 to 2025.

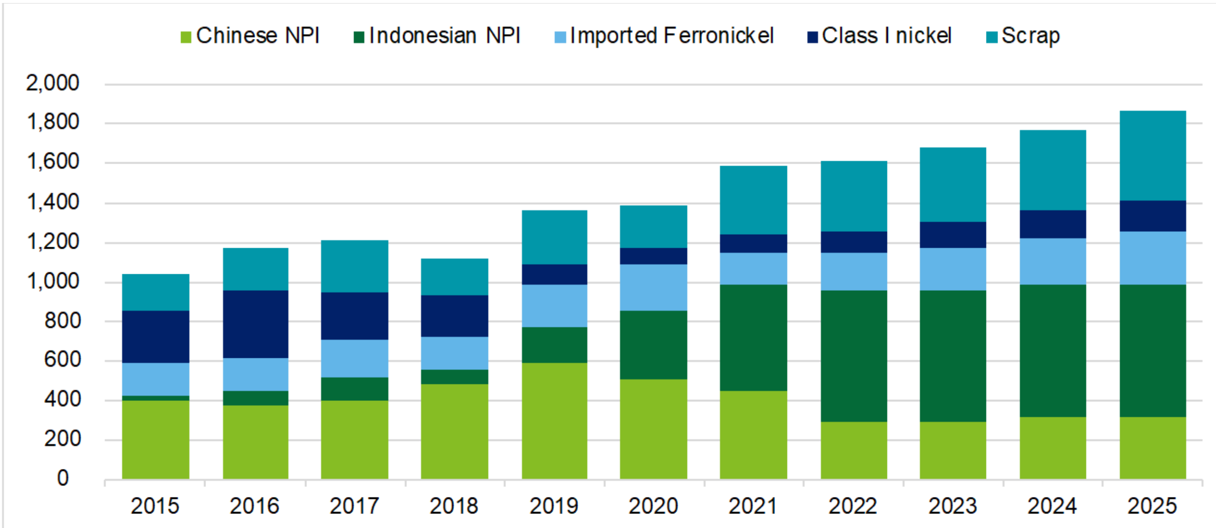
**Figure 18: Stainless Steel Production 2020-2030 (Mt Stainless Steel)**




Source: Wood Mackenzie, Nov 2021.

Figure 19 shows the type of nickel used by Chinese stainless-steel producers forecasted out to 2025. The data highlights a decrease in Chinese NPI production and a growth in Indonesian NPI as new Indonesian NPI capacity comes on stream. This is the result of the Indonesian government stopping exports of nickel laterite ore in 2017 and the development of the country's own nickel laterite processing industry. Class I nickel supplies approximately 20 to 25 percent of nickel used in stainless steel, due to technical requirements for higher-grade stainless steels.

**Figure 19: Chinese Stainless Steel Production Forecast by Nickel Type 2020-2025 (kt nickel)**




Source: Wood Mackenzie, Nov 2021.

## 7.2 Nickel Demand for Batteries

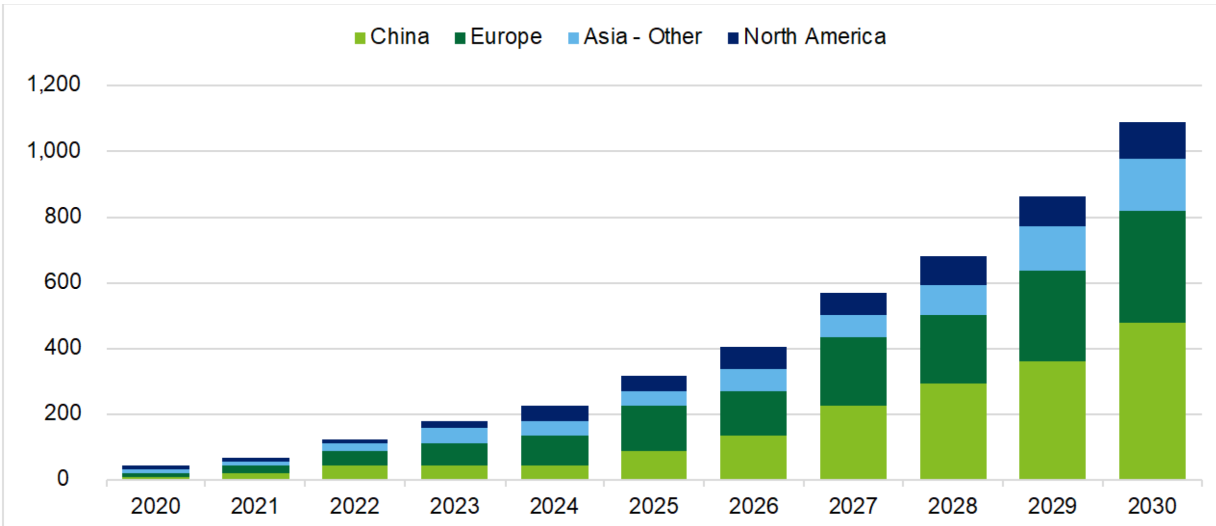
In 2020, nickel demand for batteries was approximately 170 kt[27] to 211 kt[28], or 7 to 9 percent of total nickel demand, depending on the data source. Positive forecasts for battery manufacturing and EV sales are expected to flow through to higher nickel consumption going forward. In terms of the switch to renewable energy and the adoption of EVs, the exact timing and magnitude of increases are difficult to predict, in part because global end-use demand drivers will be partly dependent on government policy and subsidies. Nevertheless, the demand for high-performance automotive batteries with high energy densities (NCM811 and NCA) is expected to grow given the focus on miles travelled per charge. BMI forecasts that China will remain the largest producer of battery cathode material over the next decade. NCM811 and NCA batteries are expected to make up slightly less than 40 percent of China's planned cathode capacity. NCM622 will comprise an additional 18 percent of this planned capacity, which overall will mean a higher nickel content in the batteries.

This demand growth for batteries is expected to result in over 1.1 Mt of nickel demand by 2030. Consultants have forecasted CAGRs ranging from 16 to 20 percent. Figure 20 shows the growth in nickel battery consumption by region as forecasted by Roskill. As mentioned previously, an upcoming report will provide more information on the outlook for demand growth in EVs and lithium-ion batteries.

[27] Nickel Institute.

[28] Norilsk Nickel.

**Figure 20: Nickel Consumed in EV batteries 2020-2030 (kt nickel)**




Source: Roskill 2020

Japan, South Korea, the United States, and Europe are planning cathode capacity additions which will be, for the most part, NCM811 or NCA. Overall, however, Chinese capacity growth plans currently overshadow plans to build cathode capacity outside of China.

BMI believes that additional cathode projects will likely emerge in the EU and the United States, and Western original equipment manufacturers (OEMs) are advocating to bring elements of the EV supply chain closer to their domestic operational hubs. This reduces working capital requirements and mitigates reliance on Chinese-based supply. As a result, nickel consumption in the EU and United States would increase at the expense of consumption in China and other Asian markets.

## 7.3 Nickel Demand for Other Uses

Nickel consumption in other industries (alloys, special steels, electroplating, etc.) has decreased from 34 percent of demand in 2010 to 19 percent in 2020.[29] Although these percentages are negatively impacted by the strong growth in stainless steel, consumption in these sectors as a whole has declined over this period. Consumption of alloys has halved, electroplating has remained broadly flat, and special steels have increased modestly.[30] Forecasts for these sectors show only modest growth out to 2030, and Deloitte has assumed an overall growth of 1 to 2 percent annually out to 2030.

[29] The share in nickel consumption is decreased by 15 percent (from 24 percent to 19 percent), mainly due to the growth in batteries.

[30] Based on data from Norilsk Nickel.

## 7.4 Overall Demand Forecasts for 2030

Table 7 shows the range of growth forecasts for the three areas of consumption, stainless steel, batteries, and other uses, based on the assumptions used by consultants. From these, Deloitte has calculated a low and high potential outcome for consumption in 2030. Macquarie has also taken this approach to look at the changes in each area over this period and the Macquarie numbers are also included in the table as another benchmark.

**Table 7: Nickel Consumption Outlook to 2030 (kt nickel)**

| Area of nickel consumption | 2020 demand reported* | Growth per annum | 2030 additional demand low | 2030 additional demand high | Macquarie Additional demand† |
|---|---|---|---|---|---|
| Stainless steel | 1,779 | 3-4% | 612 | 854 | 767 |
| Batteries | 211 | 16-20% | 720 | 1,095 | 1,024 |
| Other uses | 451 | 1-2% | 47 | 99 | 299 |
| Change 2020 to 2030 | | | 1,379 | 2,048 | 2,090 |
| **Total** | **2,441** | | **3,820** | **4,489** | **4,497** |

Source: Deloitte. *Norilsk Nickel. † Macquarie assume nickel consumption of 2,407 kt in 2020.

These assumptions result in an overall CAGR for nickel of 4.6 to 6.3 percent from 2020 to 2030 and indicate that the market requires an additional 1.4 to 2.0 Mt of nickel production out to 2030 from the base of 2020. Consumption in batteries requires the largest growth. BHP [ASX: BHP] reported in August 2021 that over 2020 to 2030, overall nickel demand will grow at 5 percent CAGR.[31]

[31] Eddy Haegel, BHP, Diggers and Dealers Conference 2021

# 8. OUTLOOK FOR NICKEL SUPPLY

Primary nickel production is required to grow by around 4.5 to 6.0 percent annually from 2.4 Mt in 2020, to supply the forecasted consumption of 3.8 to 4.5 Mt nickel by 2030. This would require an increase of 1.4 to 2 Mt of nickel per annum by 2030. Supply in 2021 increased by approximately 7 percent to 2.7 Mt nickel. This section examines potential locations to source this required supply over the next decade.

## 8.1 Expansion of Existing Producers

Over the next few years, some production expansion is expected from some existing major nickel producers, although no significant developments have been announced. In total, Deloitte estimates that these incremental expansions could add 120 kt/y of nickel production by 2030 (excluding Indonesian smelters, which are included separately in the new smelter data). These main developments are discussed below.

**Norilsk Nickel** laid out its strategic ambitions for its assets at its Capital Markets Day in November 2021. These ambitions included reaching a target of 260 to 280 kt/y of nickel from its Russian assets, compared with 233 kt produced in 2020. This includes the South Cluster project (major projects within Norilsk) that is currently being commissioned (but is excluded from the list of individual mines in Annex 4 as it is a brownfield expansion, and included here under existing producer expansions).

**Glencore** has a production target of 135 kt/y of nickel by 2024 (compared with 110 kt in 2020), which it plans to produce by focusing on delivering higher levels of sustainable production. **BHP** is considering a major expansion of its processing plant at the Mt Keith mine in Western Australia. Deloitte estimates that this could add about 20 kt/y of nickel production.

**Anglo American** anticipates that improvements at the Barro Alto and Codemin operations could lift production to 50 kt/y from 43.5 kt in 2020. Meanwhile, **Vale** is focused on delivering stability in its nickel division. The company is developing replacement capacity at its Voisey's Bay and North Atlantic operations, while planning to add production of 12 to 15 kt/y through the addition of a second furnace at the Onça Puma operations in Brazil. **PT Vale Indonesia** is planning two new smelter projects and **Eramet** is also expanding its business in Indonesia (these expansions are included separately in the new smelter data). **Sherritt** plans to roll out a nickel expansion strategy in 2022.

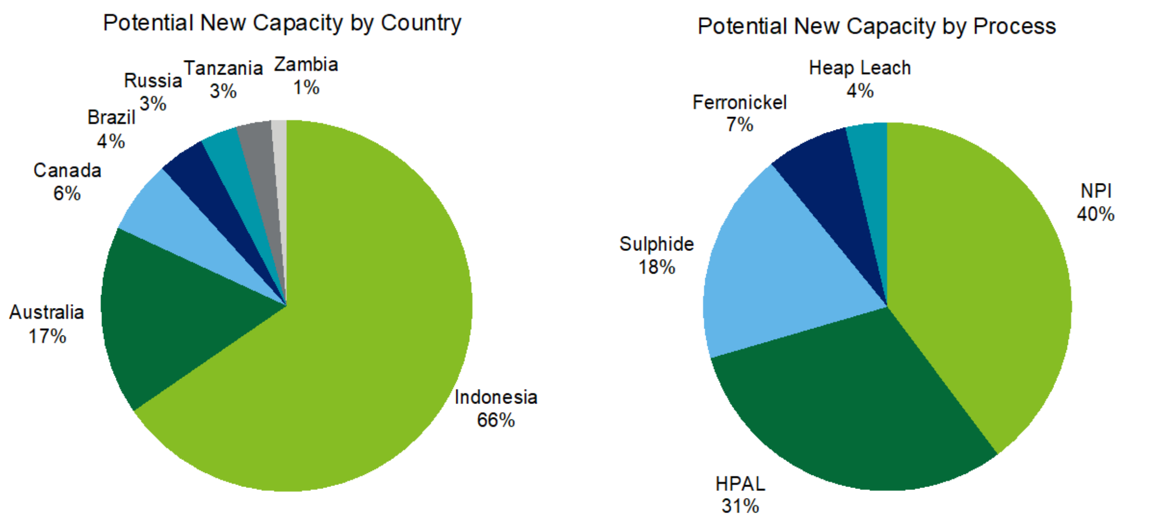
**Tsingshan Group** provides no outlook, although it continues to invest in new smelter capacity in Indonesia. This growth is captured through the individual projects discussed later (see Section 9.2).

## 8.2 New Nickel Mine Supply

Deloitte has assembled a database of nickel projects that could come onstream by 2030. Deloitte collected the data directly from company reports, technical papers, and news sources. The data for sulfide projects is reasonably transparent and based on new mines under construction, projects close to a final investment decision (FID), at feasibility stage, or at advanced pre-feasibility stage. However, the data for laterite deposits is somewhat opaque, especially in Indonesia where most of the focus is centered on smelters and smelter capacity. While these are assumed to be backed by laterite mine resources, the details are usually unspecified and some likely include DSO from the region. For that reason, the database excludes a number of DSO nickel mine projects identified to avoid double counting. Figure 21 shows the aggregated data analyzed by country and processing method.

Most of the growth in nickel production over the next decade will come from Indonesia, which will utilize its vast nickel laterite resource base. Indonesia has new ferronickel, NPI, and HPAL smelter capacity at the commissioning stage, under construction, and at feasibility stage. The ferronickel and NPI product will be fed principally to the stainless steel industry, although it will include some NPI nickel matte production that could be converted to nickel sulphate.

**Figure 21: Potential New Nickel Supply 2020-2030**




Source: Deloitte.

The HPAL capacity will produce MHP that will be further processed in Indonesia or shipped elsewhere in Asia to mainly produce nickel sulphate for the battery industry. New nickel supply from sulfide deposits is expected to be more limited due to a lack of discoveries of large deposits and limited investment in the development of available projects as a result of the relatively high CAPEX required.

### 8.2.1 Sulfide Nickel Projects

Table 14 in *Annex 4* shows the list of 15 new potential nickel sulfide mines that could come on stream by 2030. One is currently being commissioned, two are under construction, two are at late-stage development awaiting an FID, eight are at feasibility stage, and two are at pre-feasibility stage. This is not an exhaustive list and there is no guarantee that all projects will reach production. However, the projects appear to have a reasonable probability of achieving start-up. These projects have the potential to add 346.3 kt/y of nickel production capacity by 2030.

Most new sulfide deposits that have been brought on stream in recent years have been necessary merely to replace the depletion of existing nickel sulfide mines. Deloitte has also identified a further 78.5 kt/y of sulfide capacity depletion (mine closures) out to 2030.[32]

[32] The net increase in sulfide nickel projects is 267.8 kt (346.3 kt/y – 78.5 kt/y = 267.8 kt/y) as noted in Table 8

### 8.2.2 Indonesian Laterite Projects

Table 15 in *Annex 4* shows the list of 29 new potential nickel smelter projects in Indonesia. Deloitte has carefully compiled the list but it may not be exhaustive. Projects in the list are often referred to by more than one name—sometimes the project name, sometimes the name of the operating company, and sometimes the name of one or more of joint venture companies, or even the ultimate group holding company. These smelter projects include eight HPAL operations, 17 NPI plants, and four ferronickel operations. Of the 17 NPI plants, two are expansion projects, three are currently being commissioned, seven are under construction, and five are at feasibility stage.

Deloitte calculates that these projects have 1.31 Mt/y of potential nickel capacity that could come on stream by 2030. Norilsk Nickel at its Capital Markets Day in November 2021 discussed Indonesia as a wall of nickel supply and the 'Elephant in the Room' with the potential for additional supply of over 1.5 Mt/y of nickel by 2030.

### 8.2.3 Other Laterite Projects

Table 16 in Annex 4 shows the list of 13 new potential nickel laterite projects outside of Indonesia. These include HPAL, ferronickel, and heap leach projects principally in Australia and Brazil. One is a redevelopment project, three are at late-stage development awaiting an FID, five are at the feasibility stage, and four are at pre-feasibility stage. Of these, eight are HPAL projects, one is a ferronickel project, and four are heap or tank leach projects. This is not an exhaustive list and some projects may not reach production. Nevertheless, the projects appear to have a reasonable probability of achieving start-up. Deloitte calculates that these have the potential for 330.3 kt/y of nickel capacity that could come onstream by 2030.

### 8.2.4 Summary of New Supply Potential

Table 8 summarizes the potential new capacity that could come on stream by 2030 identified by Deloitte. Deloitte calculates that these projects could add just over 2 Mt/y of nickel capacity by 2030. Historically, HPAL projects have rarely consistently achieved nameplate capacity and ramp-up times are often protracted. Equally, new smelter projects in Indonesia not yet announced, or some advanced exploration projects not yet disclosed (held privately or within large mining companies), could come on stream within the current timeframe.

**Table 8: Potential New Nickel Capacity Growth 2020-2030**

| New Mine/Smelter | Potential Capacity Increase Ni kt/y |
|---|---|
| Existing Producers' Expansions* | 120.0 |
| Sulfide | 346.3 |
| Indonesian HPAL | 407.3 |
| Indonesian NPI | 802.5 |
| Indonesian Ferronickel | 109.6 |
| Rest of World HPAL | 226.3 |
| Rest of World Ferronickel | 14.5 |
| Heap Leach | 76.5 |
| Mine closures | -78.5 |
| **Total** | **2,024.5** |

Source: S&P Global Intelligence, Company data, Deloitte. *Excludes projects in Indonesia included under other headings.

## 8.3 Nickel Projects in Brazil

Based on available data, Deloitte has identified three nickel exploration projects at a relatively advanced stage in Brazil: Araguaia, Piauí, and Jaguar, and four projects at pre-feasibility stage. Table 9 shows these exploration projects and resources.

**Table 9: Brazilian Nickel Exploration Projects**

| Project | State | Development Stage | Owner | Type of Deposit | Ni Mt | Grade % Ni |
|---|---|---|---|---|---|---|
| Araguaia | Pará | Late-Stage | Horizonte Minerals | Laterite | 2.571 | 1.25 |
| Piauí | Piauí | Late-Stage | Brazilian Nickel | Laterite | 0.723 | 1.00 |
| Jaguar | Pará | Feasibility | Centaurus Metals | Sulfide | 0.731 | 0.91 |
| Itapitanga | Pará | Pre-feasibility | Centaurus Metals | Laterite | 0 | 0 |
| Vermelho | Pará | Pre-feasibility | Horizonte Minerals | Laterite | 1.555 | 1.05 |
| Jacaré | Pará | Pre-feasibility | Anglo American | Laterite | 3.913 | 1.28 |
| Morro Sem Bone | MG | Pre-feasibility | Anglo American | | | |

Source: S&P Global Intelligence.

### 8.3.1 Advanced Stage Projects

**Horizonte Minerals** [AIM: HZM] is developing the Araguaia ferronickel project located south of the Carajás Mining District in the Pará State in north Brazil. The area has well-developed infrastructure, including roads, rail, and hydroelectric power as a result of the sustained mining activity in Carajás. A feasibility study completed in August 2019 envisages an open-pit nickel laterite mining operation with a 28-year mine life that delivers ore from several pits to a central RKEF metallurgical processing facility. After an initial ramp-up period, the plant will reach full capacity to produce 52 kt/y of ferronickel, containing 14.5 kt/y of nickel. The ferronickel product will be transported by road to the port of Vila do Conde for sale to overseas customers. Included within the study is the option for future construction of a second process line which would double Araguaia's production capacity to 29 kt/y nickel.

**Brazilian Nickel** operates the Piauí nickel-cobalt project in the Piauí State. The project will use simple heap-leach technology to treat laterite ores and produce nickel and cobalt products suited for the battery market. The company operated a demonstration plant in 2016 and 2017 and has an ongoing BFS for the full-scale commercial operation which is envisaged to produce an average of 25 kt/y of contained nickel. **TechMet** funded the first commercial phase of project development and signed an agreement to jointly develop nickel laterite opportunities globally.

The Jaguar project, operated by **Centaurus Metals** [ASX: CTM], is also located in the Carajás Mining District and was acquired from Vale in April 2020. The Jaguar project includes multiple nickel-sulfide deposits and exploration targets. Centaurus completed an initial scoping study in March 2021 based on conventional mining and processing to produce nickel concentrate and completed another study in May 2021 that contemplated processing the nickel concentrate using a hydrometallurgical process (POx) to produce battery-grade nickel sulphate. Based on a 2.7 Mt/y nickel sulfate plant, the company anticipates the production of 20 kt/y of recovered nickel in sulphate and 9.6 kt/y of MSP over an initial 13-year mine life.

### 8.3.2 Earlier Stage Exploration Projects

The Vermelho nickel-cobalt laterite project owned by **Horizonte Minerals** lies in the Carajás Mining District as well. The project has a mine life of 38 years, and the pre-feasibility study released in October 2019 proposes an HPAL operation producing 24 kt/y nickel and 1.2 kt/y cobalt for the battery market. Horizonte acquired the project from Vale in 2017. A feasibility study, along with permitting, is advancing. As is the case with the Araguaia ferronickel project, Horizonte plans to transport the nickel and cobalt-sulfate products to the port of Vila do Conde for sale to overseas customers.

**Anglo American** reports that it has two promising exploration projects in Brazil—Jacaré and Morro Sem Bone. The Jacaré project is a high-grade, large-tonnage nickel-cobalt deposit. Anglo reports that Phase 1 of the project could deliver 35 kt/y of nickel, with Phase 2 potentially delivering a further 50 kt/y with cobalt byproducts. The Morro Sem Bone project located in Pará State could deliver 30 kt/y of nickel. The company has not given recent updates on these projects.

The Itapitanga nickel-cobalt project is another earlier stage project. It is owned by **Centaurus Metals** and been available for disposal since mid-2021, following a failed joint venture with Simulus Group and Centaurus' focus on the Jaguar project.

# 9. MARKET BALANCE AND PRICE OUTLOOK

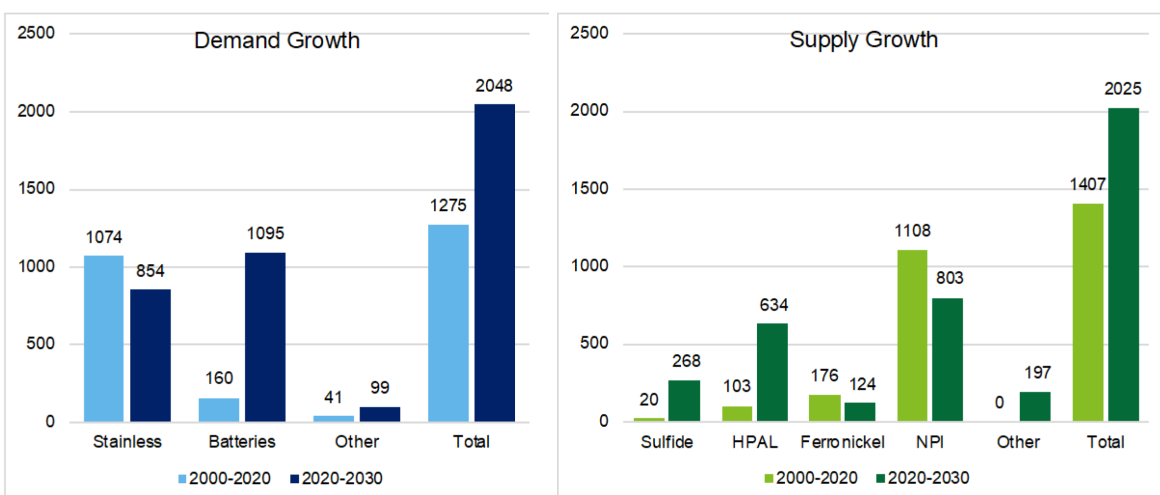
This section analyzes the possible market balance for nickel given the supply and demand forecasts discussed in the two previous sections. It also gives the current consensus price forecast for nickel.

## 9.1 Nickel Market Balance

Deloitte analysis shows strong nickel demand—with an expected increase from 2.4 Mt/y in 2020 to 3.8 to 4.5 Mt/y by 2030—will be driven by its use in lithium-ion batteries for EVs. At the same time, it appears that sufficient new capacity could increase supply to approximately 4.5 Mt/y by 2030. The increase will primarily come from Indonesian NPI and HPAL projects processing large resources of local laterite ores. This suggests the potential for a relatively balanced market over the period from a primary nickel perspective. Consultant projections vary slightly—Roskill expects the nickel market to be broadly balanced out to 2028 before starting to move into deficit. Norilsk Nickel suggests that the current consensus is that the nickel market will swing to over 100 kt/y surplus in 2023 onwards with deficits appearing closer to 2030.

Figure 22 shows the demand growth (based on the high-end estimates) broken down by the main sectors and supply growth broken down by the main sources of nickel output. The figure compares the data for 2020 to 2030 to the growth in the previous decade.

**Figure 22: The Balance Between Demand Growth and Supply Growth (kt)**




Source: Deloitte. NB the demand data represents the high growth scenario.

The nickel market was expected to be in surplus in 2021, but a series of production problems, exceptionally robust demand recovery, and massive restocking throughout the value chain triggered by logistical constraints, dramatically tightened the nickel market to move it into deficit that year.[33]

[33] Norilsk Nickel Nov 2021 report.

The overall market balance forecast is based on nickel production as a single multi-purpose product, which it is not. Typically, nickel market participants have been very focused on the supply and demand fundamentals of a two-tier nickel market: Class I and Class II nickel. Simplistically, Class I is used for alloys and battery markets and Class II is used for stainless steel. The industry assumed that Class II nickel was not a viable source of battery chemicals owing to the presumed high cost of refining Class II nickel to a form suitable for the lithium-ion battery market.

The market outlook was for Class II to move into oversupply as large new nickel laterite projects were developed in Indonesia, while Class I would be in supply shortage due to the strong demand from the battery industry. This changed in March 2021 after a Chinese company announced plans to begin producing nickel matte from NPI.

## 9.2 The Tsingshan Effect

In March 2021, Tsingshan, one of China's largest nickel and stainless steel producers, announced that it had signed contracts to supply 100 kt/y of nickel matte derived from NPI to Chinese battery raw material makers. The news resulted in a sharp fall in nickel prices, with LME nickel prices dropping from $18,600/t to $15,900/t, following the announcement. Investors and consumers reacted with concern as it was unclear whether this development amounted to a significant supply disruptor to the nickel market, and new material source of nickel to support the rapidly increasing EV battery market. The LME price has since recovered those losses, largely on continued strong market demand and reduced available supply.

The Tsingshan plan is to convert NPI, produced via the conventional RKEF process, into a nickel matte that can be further refined into nickel battery chemicals. The process to covert NPI to nickel matte involves adding elemental sulfur to NPI in a converter where it is blown with air to oxidize and separate iron and produce a high-grade nickel matte. The nickel matte can then be further refined in a similar way to a mixed nickel-cobalt sulfide precipitate to produce Class I nickel or battery-grade chemicals.

Tsingshan's plan to provide the lithium-ion battery supply chain with nickel matte sourced from NPI is essentially allowing the conversion of Class II nickel to Class I nickel. Tsingshan will be able to take advantage of swings in demand and pricing of Class I nickel versus Class II nickel, but it will require significant CAPEX and the additional processing will add to the cost of production. While Tsingshan's actual production cost premium has not been disclosed, presumably it is such that it will continue to provide an acceptable margin. The incremental cost to produce matte instead of NPI is estimated at below $1,000 per tonne of nickel, and the cost to convert matte to nickel sulfate is an estimated $2,000 per tonne of nickel.[34]

Production of Class I nickel or battery-grade nickel via nickel matte also results in a lower nickel yield due to process losses. However, it also adds value from the recovery of cobalt, which would have no value as Class II nickel. While the cobalt content in laterite ores typically processed via RKEF is low, it does provide the potential for additional byproduct credits to the producer.

Conversion of NPI to nickel matte now creates an opportunity for NPI producers to diversify the end market of their production and take advantage of potential premiums in Class I nickel. In April 2021, Chinese battery materials manufacturer CNGR announced that it would partner with Singapore-based Rigqueza International to establish a joint venture plant in Sulawesi, Indonesia, to produce nickel matte. In May 2021, Nickel Mines also announced plans to convert two of the company's RKEF lines in Indonesia to be able to produce low-grade nickel matte for potential conversion to battery-grade nickel.

---

[34] Ron Schonewille, Metallurgy Manager, Glencore Nickel.

NPI to matte is likely to become the high-cost route to produce nickel sulfate, but it has the potential to be part of the answer to the overall nickel supply problem. Other steps are being taken to increase the supply of nickel sulfate for the battery market. BHP has upgraded its nickel refinery at Kwinana, Western Australia, and commissioned a nickel-sulphate crystallizing plant, which processes nickel powder from its matte-leaching process to produce 100 kt/y nickel sulphate (22.3 kt/y nickel). This is effectively a divergence of Class I nickel from one form to another.

There is also likely to be a continued reduction in the amount of Class I nickel flowing into the stainless steel sector. However, Class I nickel will not be completely substituted from the stainless sector due to the minimum technical requirements and resilient demand in Europe and US, where the use of stainless scrap and low-carbon Class I nickel is prioritized.

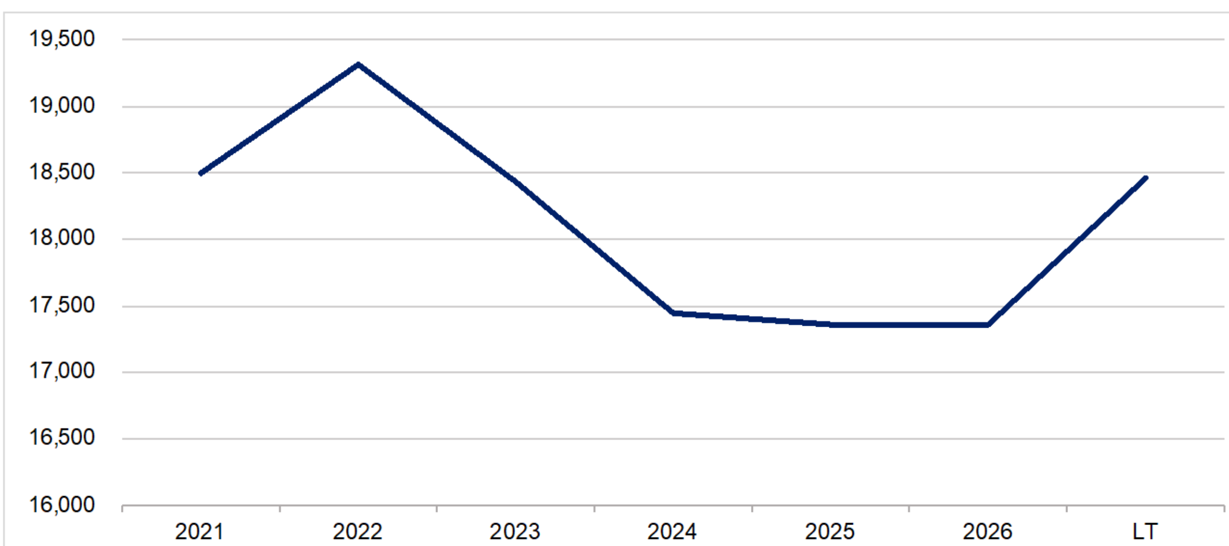
### 9.2.1 NPI To Nickel Matte Technologies Are Not New

The NPI-to-matte conversion process is a mature technology with no changes from conventional processing, as it is based on an existing process. The Tsingshan process is based on one previously practiced by Eramet's Société Le Nickel in New Caledonia to produce a nickel matte from ferronickel for its Le Havre Refinery. Eramet ceased nickel matte production at this facility in 2016 due, in part, to the high conversion cost.

## 9.3 Pricing

Figure 23 shows the consensus nickel price forecasts as of January 2022. While prices are partly a function of supply and demand and inventory levels, costs are also important. Nickel prices are being impacted by the rising cost of energy, as producing nickel is energy intensive. Higher sulfur costs are also adding to cost pressures.

**Figure 23: Consensus Price Forecast for Nickel ($/t)**




Source: Consensus Economics.

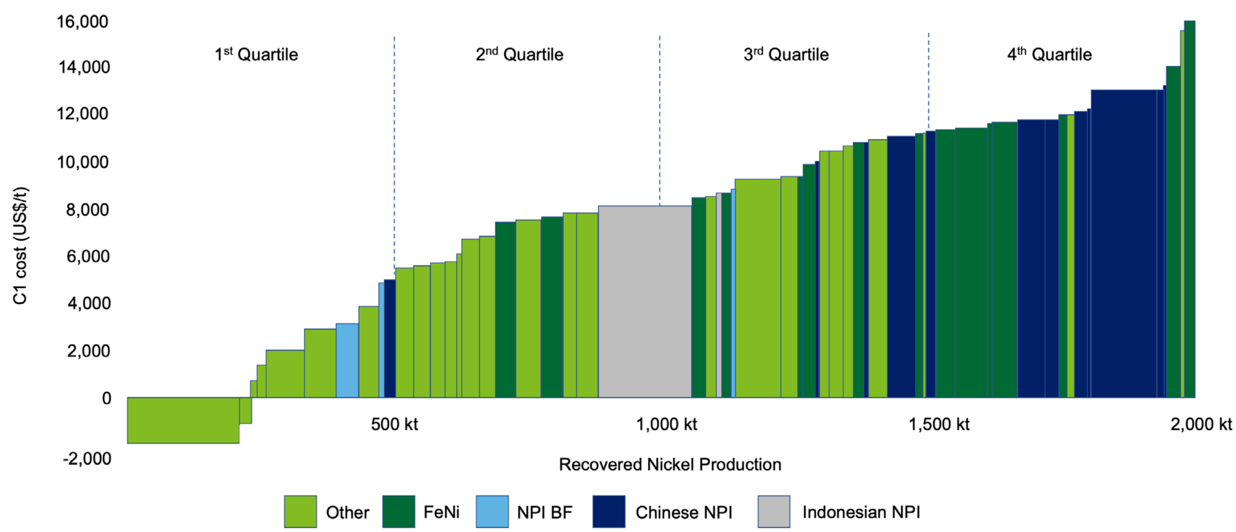
# 10. ECONOMIC COMPETITIVENESS

This section looks at existing mine operating costs and the economic parameters of projects that have yet to come on stream. Companies, investors, finance providers, and governments may find it useful to examine the existing mine and project data to benchmark potential nickel projects.

## 10.1 Comparison of Current Nickel Mining Operations

Figure 24 gives the general industry cash cost curve for nickel production. It shows the relatively high cost of producing ferronickel and Chinese NPI and how the new Indonesian NPI sits around the 50th percentile of costs. Some production has a negative cash cost due to the presence of byproduct credits.

**Figure 24: Nickel C1 Cash Cost Curve US$/t**




Source: Deloitte, Nickel Mines.

Figure 25 and Table 10 highlight the position of three Brazilian nickel mines on the global total cash cost curve, sourced from S&P Global Intelligence. S&P's mine economics data covers 49.2 percent of 2021 global recovered nickel production. Codemin sits at the bottom end of the cost curve, and Barro Alto and Santa Rita sit in the middle of the second cost quartile.

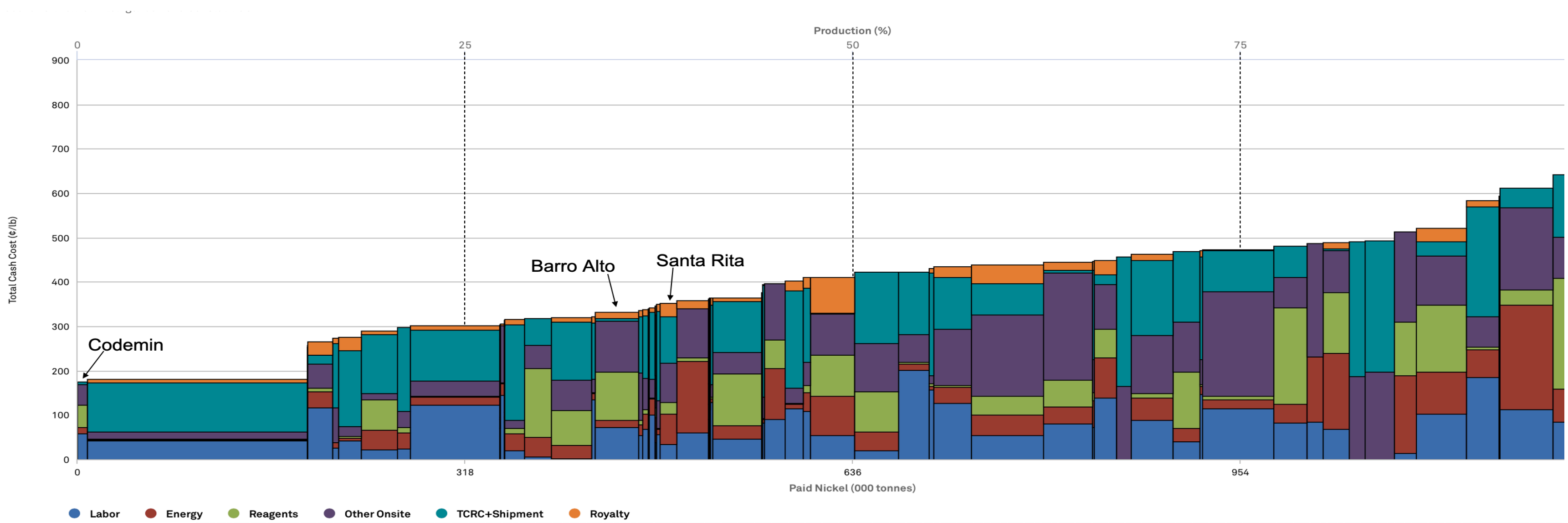
**Table 10: Brazilian Nickel Mine Total Cash Costs ($/t)**

| Mine | Labor | Energy | Reagents | Other | TCRC & Shipping | Royalty | Total |
|---|---|---|---|---|---|---|---|
| Codemin | 57.65 | 14.54 | 50.30 | 46.24 | 5.96 | - | 174.70 |
| Barro Alto | 72.22 | 16.59 | 109.00 | 114.95 | 6.28 | 12.60 | 331.60 |
| Santa Rita | 33.46 | 68.26 | 27.70 | 87.76 | 105.60 | 29.30 | 352.10 |
| | | | | | | | |
| **Industry** | **87.18** | **45.62** | **36.68** | **84.33** | **138.26** | **13.62** | **405.68** |

Source: S&P Global Intelligence.

Labor cost can be an important competitive advantage for Brazil and energy costs are particularly beneficial for Codemin and Barro Alto. The cost structures also partly reflect the type of orebody and recovery process. Santa Rita is a sulfide operation and just produces a concentrate, so it has low reagent costs and high Treatment Charges and Refining Charges[35].

**Figure 25: Nickel Production Ranked on Total Cash Cost ($/t)**



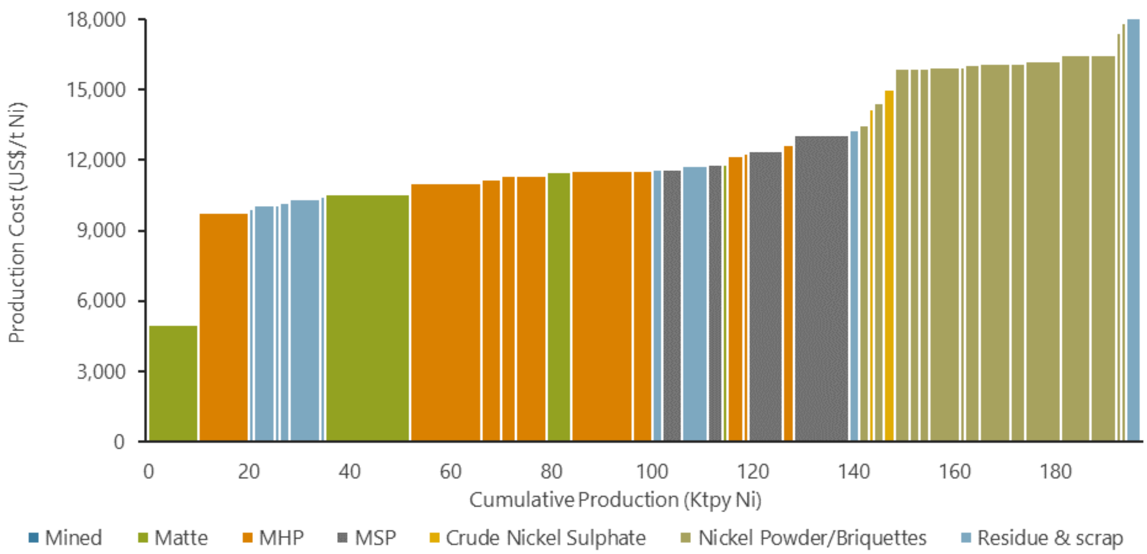

Source: S&P Global Intelligence.

These cost curves compare the cost of effectively producing finished nickel; however, there are many different nickel products and intermediaries produced and process routes used, making comparison more difficult. For example, nickel sulphate production costs are mostly sensitive to the type, and subsequent cost, of the feedstock used. Class I nickel metal is a significantly higher cost feedstock than that of intermediates such as MHP, as users of Class I metal are predominantly non-integrated producers of nickel sulphate. Mine-to-refinery integration can significantly lower feedstock costs. However, the effectiveness of such is a function of the mine assets' operational economics.

[35] Treatment Charge (TC) and Refining Charge (RC) are commonly used in the terms of purchase for nickel concentrate for refining.

Figure 26 shows the cost curve for nickel sulphate by feedstock type. This excludes the recently proposed route from NPI, as cost details are not yet available.

**Figure 26: Cost Curve for Nickel Sulphate by Feedstock Type ($/t contained nickel)**



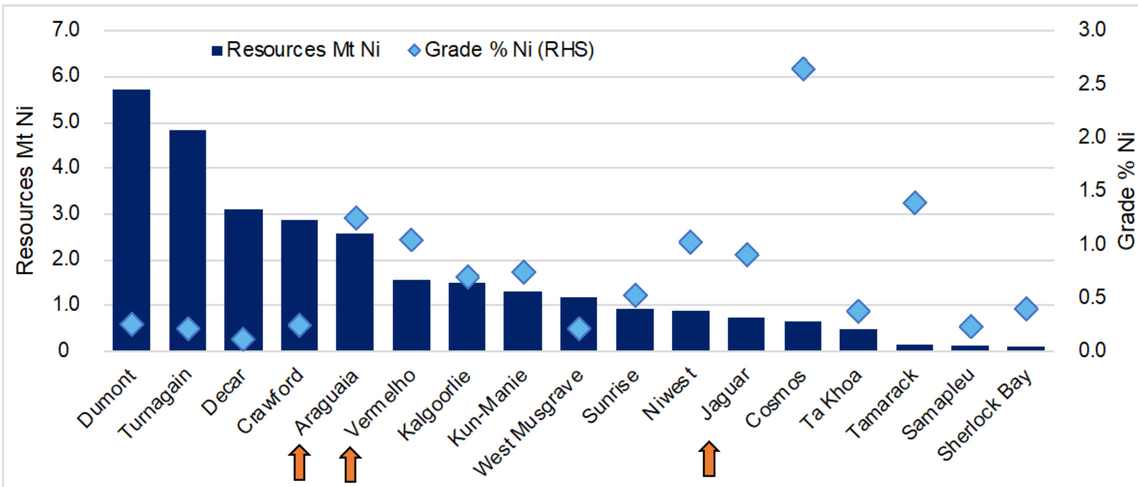

Source: Roskill 2020.

## 10.2 Comparison of Project Feasibility Studies

Deloitte has evaluated data from 17 companies that have produced recent feasibility, pre-feasibility, and scoping study reports for the market (which are typically done as part of the process of developing projects). Twelve of these projects are sulfide and five are laterite projects. These represent just one portion of the nickel market, because most new production is coming from Indonesian NPI and HPAL projects for which feasibility data is unavailable because Chinese companies are principally developing these projects. However, within the 17 projects there are two relatively advanced exploration projects in Brazil—Jaguar, Araguaia, and one pre-feasibility stage project, Vermelho. This allows an element of benchmarking for these three projects against global competitors. Data is not available for Piauí and Moro Sem Bone.

Figure 27 shows the resource and grade of these 17 projects, with the three Brazilian projects highlighted. Araguaia and Vermelho have a mid-sized resource, while Jaguar has a smaller resource. However, all three having a grade above 1 percent nickel. The weighted average grade of the 17 projects was just 0.29 percent nickel, due to the large low-grade sulfide projects in the group.

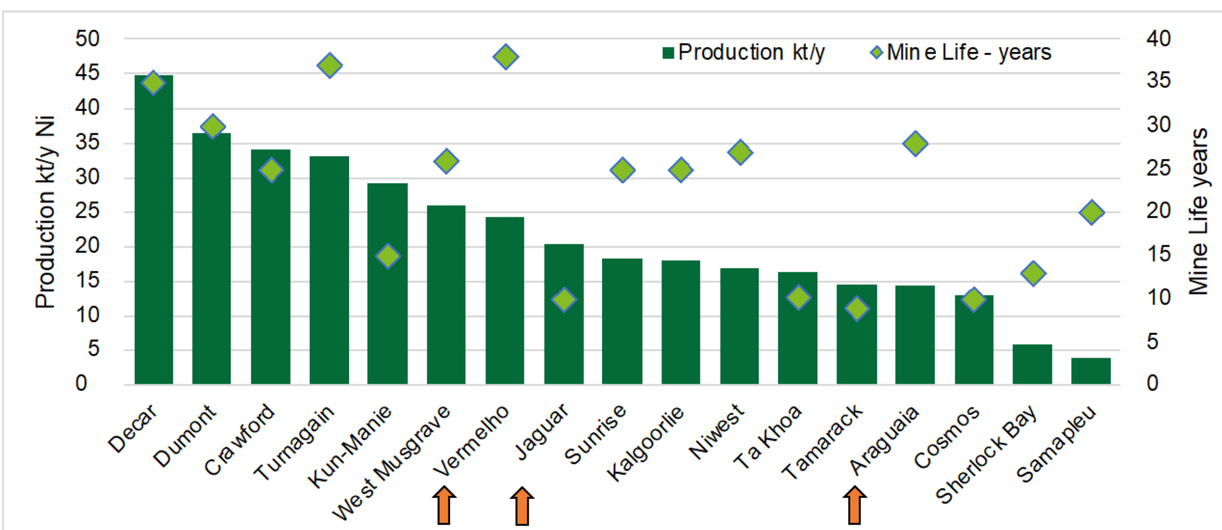
**Figure 27: Nickel Projects: Resources (Mt) and grade (% Ni)**




Source: Company data, Deloitte.

Figure 28 shows the projects ranked by the planned production capacity and the life-of-mine in years. It indicates that both Vermelho and Jaguar are mid-sized projects, while Araguaia is at the smaller end; however, both Vermelho and Araguaui are relatively long-life operations.

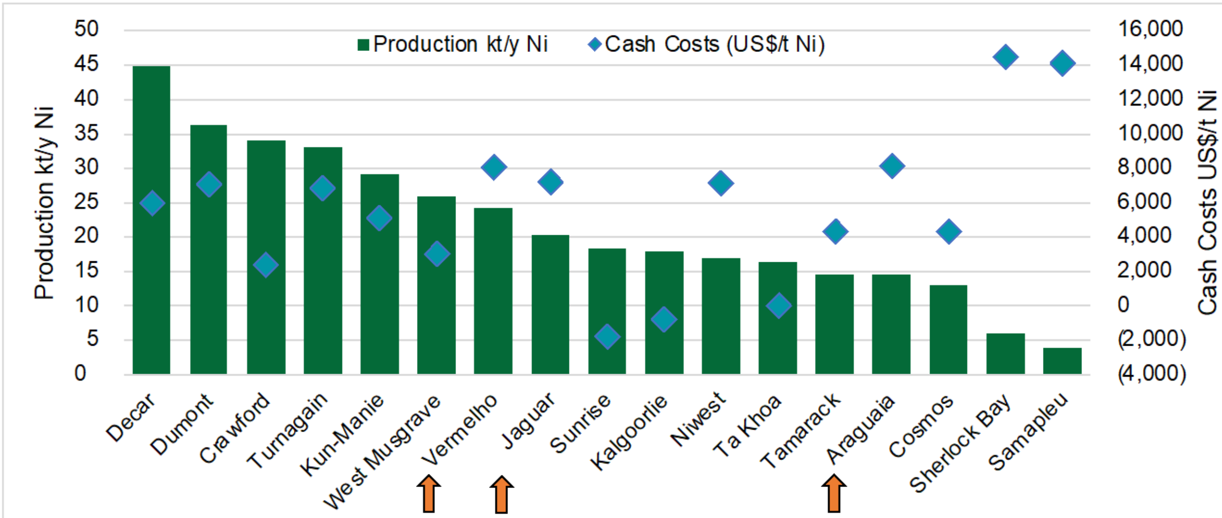
**Figure 28: Nickel Projects: Production Capacity (t/y) and Mine Life (years)**




Source: Company data, Deloitte.

Figure 29 shows the projects ranked by production capacity as well as the projected operating costs. Compared to all projects, Brazilian projects are all relatively high cash cost operations. The average weighted cost of operation of the group (including byproduct credits) was $5,290/t nickel.

**Figure 29: Nickel Projects: Production Capacity (t/y) and Operating Costs ($/t)**

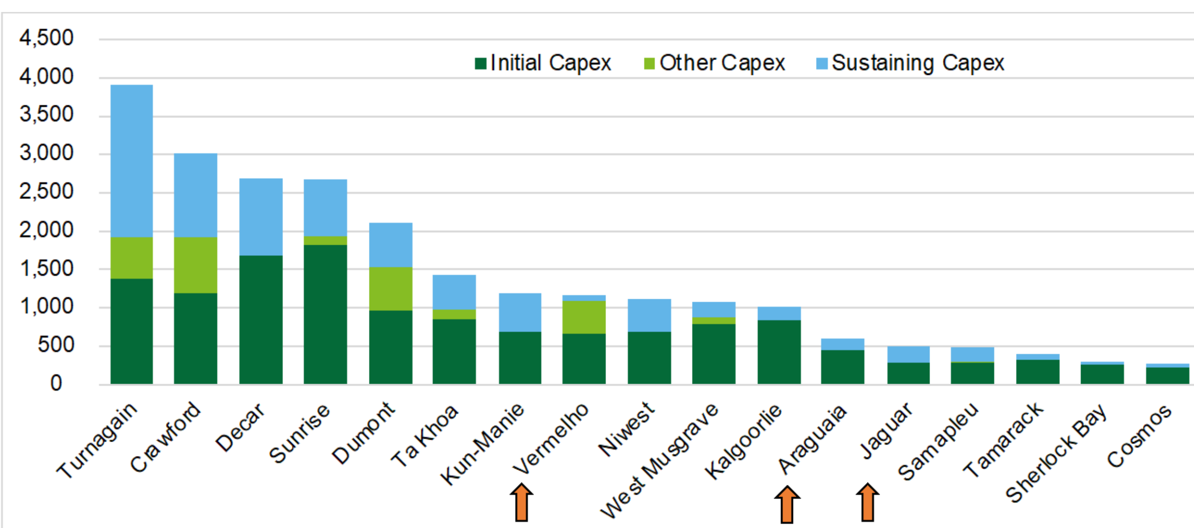



Source: Company data, Deloitte.

Another important factor in the economics of a mining project is the CAPEX required to establish and operate the mine. This includes the initial CAPEX, other CAPEX for later expansions, and sustaining CAPEX (usually for the replacement of plant and machinery).

Figure 30 show the CAPEX of each of the nickel projects. Companies usually focus on the initial CAPEX, but it is important to look at the CAPEX over the life of the mine (LOM) for project comparison. The project CAPEX can often vary due to the orebody location, depth, orientation, ore type, recovery methods, and the amount of labor and energy consumed in the process. This then has an important bearing on the economics of the project. The three Brazilian projects have relatively low CAPEX requirements.

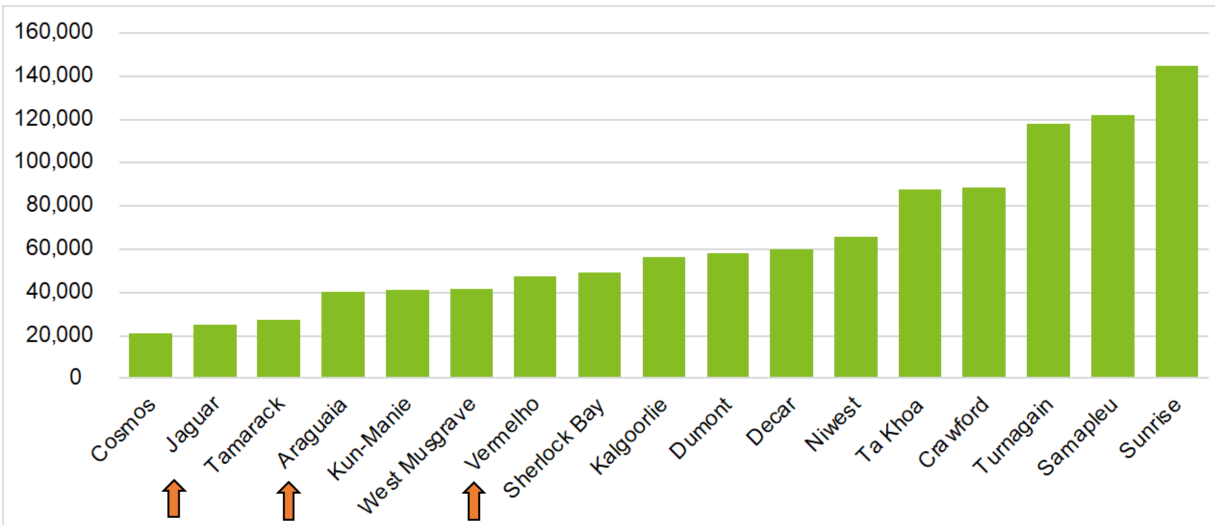
**Figure 30: Nickel Projects: LOM Capital Expenditure**




Source: Company data, Deloitte.

Capital intensity is often used to compare projects and their quality. Figure 31 shows the capital intensity of the projects based on average annual nickel production over the whole life of the project. The three Brazilian projects have relatively low capital intensity. The weighted average for the group is $64,434/t nickel.

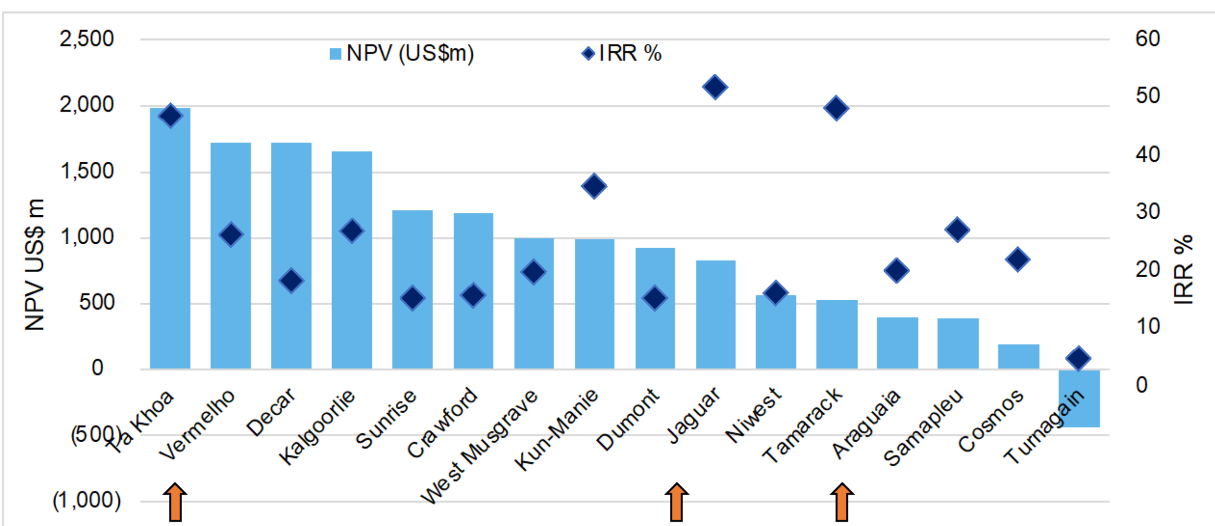
**Figure 31: Nickel Projects: Capital Intensity – Total Capex per Tonne Annual Production Ni (US$/t)**




Source: Company data, Deloitte.

The ultimate measure of economic viability is the NPV and the IRR. Figure 32 shows both the NPV and IRR, which are not totally comparable because of varying assumptions used. Post-tax values are shown. The average input price was $17,705/t nickel. The median IRR of this group was 21 percent (the average is distorted by a few high values), which suggests generally good, although not fantastic returns. The returns of the three Brazilian projects are higher than average, with particularly strong returns for Jaguar and Araguaia.

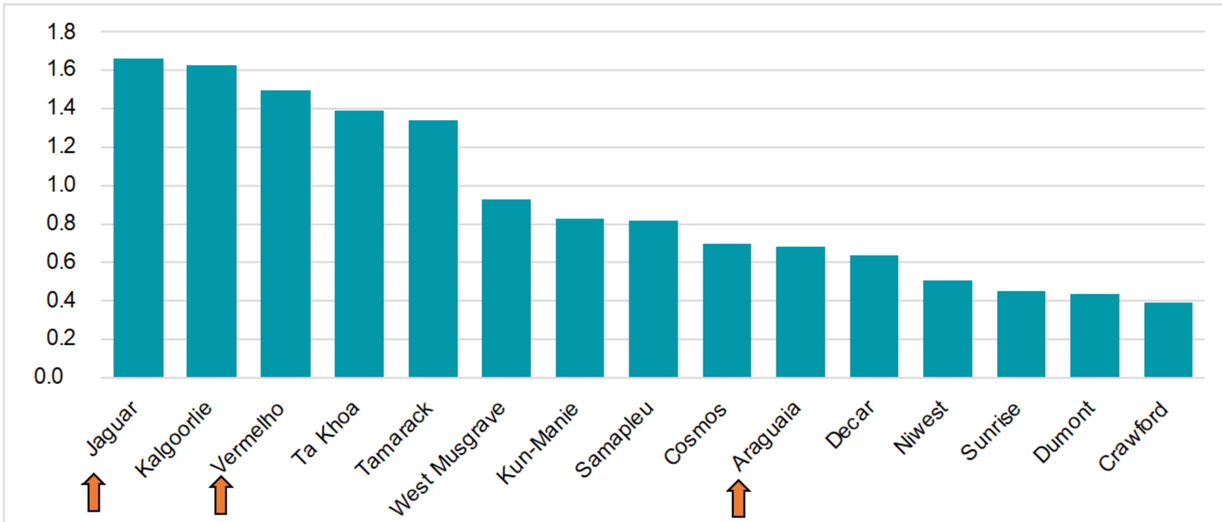
**Figure 32: Nickel Projects: NPV versus IRR**




Source: Company data, Deloitte.

Figure 33 shows that the Jaguar and Vermelho also have a relatively favorable capital efficiency (NPV/CAPEX).

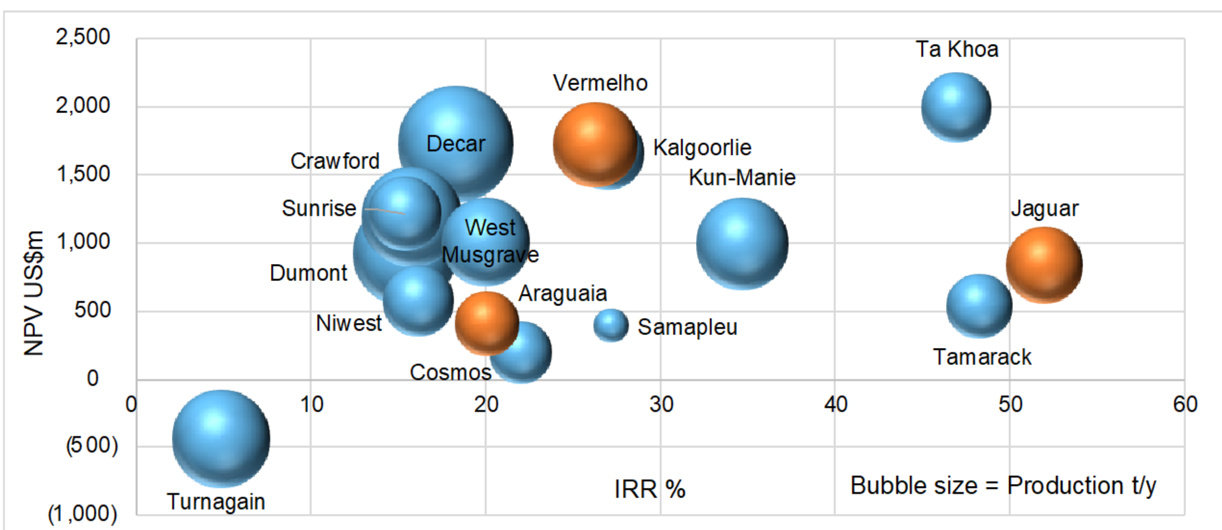
**Figure 33: Nickel Projects: Capital Efficiency (NPV/CAPEX)**




Source: Company data, Deloitte.

Figure 34 shows the NPV and IRR data in a bubble chart where there the bubble size represents planned annual output. Some of the projects that have relatively low returns, combined with low capital efficiency, such as Crawford, Dumont, Sunrise, NiWest, and Decar, may find financing more difficult.

**Figure 34: Nickel Projects: Nickel Projects NPV versus IRR**




Source: Company data, Deloitte.

In conclusion, of the three late stage/feasibility stage projects, Vermelho and Jaguar are mid-size projects and Araguaia is a smaller development. However, both Vermelho and Araguaia are scheduled to be relatively long-life operations. The three Brazilian projects have higher-than-average financial returns of between 20 and 52 percent, versus 21 percent IRR of the group of 17 projects. Jaguar and Araguaia have particularly strong returns of 52 percent and 26 percent, respectively. Jaguar and Vermelho also have relatively favorable capital efficiency ratios (NPV/ CAPEX) of 1.7 and 1.5, in comparison to 0.9 for the group of 17 projects as a whole.

# 11. CONCLUSIONS AND KEY RECOMMENDATIONS

This section provides a summary of the overall market analysis for nickel, outlines some of the challenges surrounding the forecasts, and explains how these issues could impact the outlook for nickel supply and demand. This section also examines potential threats and opportunities in the market. It summarizes key recommendations for the nickel industry in Brazil to help the government in its long-term strategic planning and future policy action for nickel development and commercialization.

## 11.1 Nickel Market Capacity

Deloitte analysis shows that there is potential for a relatively balanced market from 2020 to 2030 from a primary nickel perspective. However, there are some risks to the supply forecasts because not all the projects are guaranteed to come on stream. The new nickel sulfide projects hold risks in terms of potential long lead times and financing availability (given the relatively unexciting forecast returns). HPAL projects have also had a poor track record in terms of achieving targeted production levels and ramp-ups in production have been slow, while NPI projects currently hold significant ESG risks. These risks are focused on waste material handling and energy currently supplied from coal sources.

There are also risks on the demand side. In terms of the EV adoption, the exact timing and magnitude of increases are difficult to predict. Additionally, the end-use demand drivers in the world remain partly dependent on government policy and subsidies. Nevertheless, the demand for high-performance automotive batteries with high-energy densities is expected to grow strongly out to 2030, although the exact mix of the different types of battery chemistry is still uncertain. While high-nickel chemistry batteries (LCM) are forecast to be dominant, other lithium-ion batteries that do not contain nickel, such as lithium-iron-phosphate (LFP), could capture a larger share of the market than currently expected and would be a negative for nickel demand.

China and Indonesia are also likely to remain the key influences on nickel pricing through their pivotal position in NPI, stainless steel, and battery chemicals.

## 11.2 Nickel Market Structure

This overall market balance is based on nickel being produced as a homogenous multi-purpose product; however, the market is currently divided into Class I and Class II nickel. Class II nickel was not considered a viable source of nickel for batteries, owing to the presumed high cost of refining Class II nickel to Class I nickel. However, Tsingshan has announced plans to convert NPI into a nickel matte that can be subsequently refined into Class I nickel for battery grade chemicals. Conversion of NPI to nickel matte creates an opportunity for NPI producers to diversify their production and take advantage of potential premiums in Class I nickel. Most importantly, this conversion provides a route for the excess of Class II nickel production to satisfy the demand requirements of Class I nickel.

Although the economics are not totally clear and the capacity conversions to nickel matte are not yet sufficient to close the supply gap between Class I and Class II nickel, this conversion offers a route for that gap to be closed by 2030 and for the different classes of nickel to achieve balance. More NPI nickel capacity needs to be converted to matte, but there is also potential to help the markets balance through a reduction in the amount of Class I nickel that flows to stainless steel. In addition, stainless steel scrap use in China will increase and may help to fill the supply pipeline for stainless steel if the switch from NPI to matte in Indonesia accelerates.

## 11.3 The Russian War with Ukraine

The Deloitte team drafted this Report following the Russian invasion of Ukraine. Russia is a major producer of nickel, accounting for 9 percent of global production in 2021, and although sanctions to this market have not yet been raised, they could result in major supply disruptions to the global supply. The invasion has also created uncertainty about whether automakers will accept nickel from Norilsk Nickel, which has a deal to supply metal for EVs to German cathode-maker BASF.

The LME nickel price briefly spiked to over $100,000/t due to short position covering and margin calls, and resulted in a halt in trading on metal exchanges. The price remains elevated, but is gradually re-adjusting. This type of volatility in commodity prices can cause problems for producers or consumers. It could encourage buyers to take a more conservative, risk-averse approach, which means a preference towards longer-term contracts with less spot trade. Some primary nickel consumers may also seriously consider vertical integration into supply chains once the uncertainty subsides, while governments may move to increase regulation to manage volatility. Also, high nickel prices may increase the push of lithium-ion battery manufacturers towards alternative chemistries such as LFP, which contains no nickel.

## 11.4 Brazilian Nickel Opportunities

Brazil has significant nickel reserves and resources and is a top 10 global nickel producer. It has a nickel industry that includes five mining operations, as well as three nickel exploration projects at feasibility/late-stage (Araguaia, Piauí, and Jaguar) and four other projects at the pre-feasibility stage. Mining takes place from both sulfide and laterite projects and the operations produce both class I and Class II nickel. Three of the five mining operations operate in the lower half of the cost curve (information is not available for the other two).

The three advanced stage projects comprise two laterite projects and a sulfide project. The sulfide project is planning to process the ore through to battery-grade nickel sulfate while the laterite projects are for ferronickel and a heap leach operation to produce nickel hydroxide.

Brazil consumes around 13 kt/y (17 percent) of its nickel production in domestic stainless steel, but the remainder of it is exported, with China importing 45 percent of exports. If Brazil decides to develop downstream battery facilities, it is likely that battery grade nickel would be available, or could potentially be produced, by Brazil's nickel industry. Piauí and Jaguar, Brazil's late-stage nickel development projects are both planning to produce Class I nickel, with domestic conversion facilities for battery-grade nickel sulphate. Proactive marketing by the Government of Brazil, with existing global lithium-ion battery companies about investment and construction of battery Gigafactories in Brazil, may help to increase the consumption of domestic nickel production.

## 11.5 Key Recommendations

The nickel market will likely remain balanced through 2030, with the possibility of a slight deficit in 2029 and 2030, excluding any impacts created by the Russian invasion of Ukraine. This offers opportunities for continued supply growth to mines and projects, including those operating and planned in Brazil. The Government of Brazil should continue to further develop its resources to meet global demand and encourage investment in the longer term by:

- **Streamlining access to, and circulation of, up-to-date domestic nickel resource data to domestic and international exploration companies to encourage exploitation and to promote nickel development in Brazil.** This may require gathering and distributing more extensive information for those regions considered to have significant nickel potential, including Goiás, Pará, Bahia, and Minas Gerais. Legacy CPRM geological data, reports, and studies should be broadly published online and in multiple languages. Brazil should also actively 'market' these documents to expand their circulation, use, and impact.

- **Providing nickel producers with access to Brazil's low-cost and low-emissions hydroelectric power.** In 2020, 66 percent of Brazil's electricity generation came from hydropower. Access to low-cost and low-emissions hydroelectricity in Brazil gives nickel producers a competitive advantage in their operating costs and carbon footprint. The nickel market is increasingly focused on the carbon footprint of nickel producers, feeding into the lithium-ion battery market, particularly given the high carbon footprint of Indonesian nickel producers. Figure 8 shows a global comparison of nickel production carbon footprints based on tonnes of $CO_2$ per tonne of nickel production, with Brazil having a low to medium carbon footprint, and Indonesia showing the highest carbon footprint. Addressing ESG challenges related to mining, smelting, refining, and tailings management in nickel production is becoming increasingly important to OEMs. Tesla has reportedly signed contracts with Vale in Canada, BHP in Australia, and Talon Metals in the United States for the supply of low-carbon footprint nickel. It is critical for nickel producers in Brazil to demonstrate to OEMs that these challenges are being addressed successfully throughout the value chain.
- **Ensuring Brazilian nickel projects achieve timely production by 2030 to capture potential higher returns of the forecast tight market.** Deloitte anticipates that three of the late-stage development projects (Araguaia, Piauí, and Jaguar) could come into production by 2030. If this is the case, these projects will likely benefit from the forecast tight nickel markets and the likely higher prices anticipated by the end of 2030. To ensure that these four projects come into production by 2030, the Government of Brazil should encourage these companies to apply for assistance under the Policy for Supporting the Environmental Licensing of Investment Projects for the Production of Strategic Minerals (Decree No. 10,657 of March 24, 2021)[36]. For example, the Government of Brazil recently selected three mining projects to receive accelerated environmental licensing support. Jaguar, was one of projects selected by the government.[37]
- **Developing downstream processing facilities to capture more of the nickel value chain domestically.** A portion of Brazil's nickel production could be refocused from direct exports towards the downstream development of domestic cathode-manufacturing and lithium-ion battery production. Proactive marketing by the Government of Brazil with existing global lithium-ion battery companies about investment and construction of battery Gigafactories in the country, may help to increase the consumption of domestic nickel production. The 'Colossus Cluster Minas Gerais', which aims to build a 35 GWh battery Gigafactory, an initiative between the Minas Gerais Investment and Trade Promotion Agency and US-based Bravo Motor Company, is the first such project under way.

---

[36] The Pro-Strategic Minerals Policy has been qualified under the Investment Partnerships Program (PPI), which is a government entity dedicated to expanding and accelerating the implementation of projects with the participation of the private sector in Brazil. Accordingly, if it meets specific criteria, the company that has a project of a mineral deemed strategic, may request that their project be qualified as a PPI project.

[37] The projects, all in northern Pará state, are considered by the Government of Brazil as strategic for the expansion of aluminum, nickel, and copper production. The selected projects include: Novas Minas, owned by Mineração Rio do Norte (aluminum), Centauros Níquel's Jaguar (nickel), and Pantera of Avanco Resources Mineração (copper).

# ANNEX 1 – NICKEL ORES AND RESOURCES

Nickel was first identified and isolated as an element by the Swedish chemist, Axel Cronstedt, in 1751. Mine production of nickel began in Norway in 1848, followed by New Caledonia in 1875 and Canada in 1886. During this period in the 19th century, nickel came to prominence in plating and in alloys with copper and zinc.

Economic concentrations of nickel-bearing minerals occur as sulfides and in laterites. Pentlandite ($Fe_5Ni_4S_8$) is the main nickel sulfide mineral in economic deposits where it occurs with pyrrohotite, chalcopyrite, and pyrite in mafic and ultramafic (iron- and magnesium-rich) igneous rocks. Garnierite ($Ni_2Mg_4Si_4O_{10}(OH)_8$) and nickeliferous limonite [(Fe,Ni)O(OH)] are the main nickel-bearing minerals in laterites. Nickel can occur in different minerals in the same ore, although in some cases they are not all economic to recover and so are rejected to tails, lowering the overall recovery to the concentrate.

## Nickel Sulfide Deposits

Sulfide deposits are generally formed by fractional crystallization[38] within magma chambers or ancient lava flows. Sulfide ore grades range from 0.15 to around 8.0 percent nickel, although most are in the range of 0.2 to 2.0 percent. Most nickel sulfide deposits have been overprinted by significant post-ore deformation and alteration which can result in the upgrading of disseminated ores.

Australia, Canada, and Russia contain major resources of nickel sulfide deposits. In some deposits the nickel is associated with concentrations of platinum-group elements, copper, and cobalt such as at Norilsk in Russia, and increase the value of the nickel ore deposits.

Nickel sulfide orebodies are closely associated with magmatic conduit zones, either volcanic or intrusive, and the identification of such zones is a focus for exploration. In general, the largest and most dynamic conduit zones are most prospective. Nickel sulfide deposits are usually classified based on their sulfide content and on the fractionation state (MgO content) of their parental magma.

On the basis of their principal metal production, magmatic sulfide deposits in mafic rocks can be divided into two major types: those that are sulfide-rich, typically with 10 to 90 percent sulfide minerals, and have economic value primarily because of their nickel and copper contents; and those that are sulfide-poor, typically with 0.5 to 5 percent sulfide minerals, and are exploited principally for platinum group metals.

### Nickel Sulfide Ultramafic Deposits

In recent years, attention has turned to ultramafic deposits following the decline in new discoveries of traditional sulfide deposits. Ultramafic deposits are low grade sulfide deposits but tend to be very large. The scale is important and treatment plants are up to three times the size of traditional nickel sulfide operations. A recent example is the Yakabindie project in Australia which started production in 2020. Other development projects include Honeymoon Well in Australia, Crawford, Dumont, Turnagain, Nickel Shaw, Baptiste, and Pipe in Canada, and Ronnbacken in Sweden.

---

[38] Fractional crystallization is the precipitation and segregation of minerals from magmas.

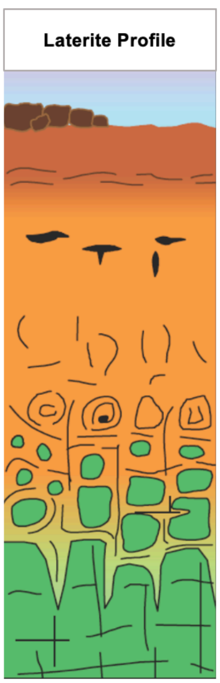
Nickel ultramafic deposits can contain different recoverable minerals in addition to pentlandite such as heazlewoodite (NiS) and awaruite (NiFe), and magnesium silicate minerals can cause very thick slurry which makes flotation difficult. Key to the assessment and development of these projects is the nickel recovery that can be achieved.

## Nickel Laterite Deposits

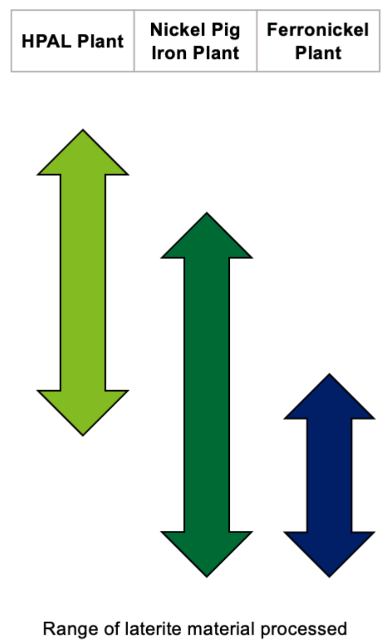
Laterite orebodies are widespread, and the industry is characterized by the similarity of orebodies around the world. Typical nickel laterite ore deposits are very large tonnage, low-grade deposits located close to the surface. Nickel-bearing laterite ores are formed by tropical and sub-tropical weathering of ultramafic rocks and typically have grades of 0.8 to 3.0 percent nickel. Mineralization is generally hosted in two horizons, limonites and saprolites, with the difference being the degree of weathering which results in magnesia and silica levels being much lower and iron levels being much higher in limonites. The key factor in all laterite deposits are the proportions of iron, magnesium, and silica, as they largely determine the optimal processing route.

The majority of nickel laterite deposits are confined to the equatorial belt, dominated by Indonesia, the Philippines, Cuba, and New Caledonia. Laterite resources outside this belt (Australia, Brazil, and Madagascar) are generally much older in geological terms.

**Figure 35: Schematic of Nickel Laterite and Processing Methods**




| Laterite Zone | Nickel | Cobalt | Iron | MgO |
|---|---|---|---|---|
| Iron cap | | | | |
| Red Limonite | <0.8% | <0.1% | >50% | <0.5% |
| Yellow Limonite | 0.8 – 1.5% | 0.1 – 0.2% | 40 - 50% | 0.5 – 5.0% |
| Transition Zone | 1.5 – 4.0% | 0.02 – 0.1% | 25 – 40% | 5 – 15% |
| Saprolite | 1.8 – 3.0% | 0.02 – 0.1% | 10 - 25% | 15 – 35% |
| Bedrock | 0.3% | 0.01% | 5.0% | 35 – 45% |




Source: Deloitte.

## Deep-Sea Manganese Nodules

Manganese nodules contain large amounts of metals and are present over many thousands of square kilometers of the ocean floor. They contain primarily manganese, but also nickel, cobalt, and copper, which makes them economically promising. Although many countries and companies are already intensively investigating their distribution, the mining of these nodules faces technical challenges and environmental issues. There is currently no commercial mining of these nodules.

Occurrences of economic interest are concentrated particularly in the Pacific and Indian Oceans, in the wide deep-sea basins at depths of 200 to 5,000 meters. The individual nodules, about the size of a potato, lie loosely on the sea floor but can sometimes be covered by a thin sediment layer. Theoretically they can be harvested relatively easily from the sea floor.

Manganese nodules occur in many marine regions. They are found in significant abundances in four regions of the ocean:

- Clarion-Clipperton Zone (CCZ) - The CCZ is located in the Pacific, extending from the west coast of Mexico to Hawaii and covers an area of around 9 million square kilometers. It is the largest and most dense area of nodule mineralization;
- Peru Basin - The Peru Basin lies about 3000 kilometers off the Peruvian coast. It is about half as large as the Clarion-Clipperton Zone;
- Penrhyn Basin – The basin is located very near the Cook Islands, a few thousand kilometers east of Australia. It has an area of around 750,000 square kilometers; and
- Indian Ocean – An area comparable to that of the Penrhyn Basin has been located in the central Indian Ocean.

The CCZ is the most intensively explored area and has high grades and continuity. The nodules are precipitated on the ocean floor at the seawater interface and grow slowly from metals precipitated from the seawater. Following extensive surveys and sampling, the International Seabed Authority[39] has estimated an inferred resource of 30 billion tonnes of nodules containing 70 Mt of cobalt, 40 Mt of nickel and 340 Mt of copper. Although the conditions for the formation of manganese nodules are the same in all four of the major regions, their metal contents vary from place to place.

The international Law of the Sea precisely regulates who can mine manganese nodules in the future. If the resources are located within the Exclusive Economic Zone (EEZ) of a country, the so-called 200 nautical mile zone, this country has the sole right to mine them or to award mining licenses to foreign companies. This is the case, for example, in a part of the Penrhyn Basin near the Cook Islands. The CCZ, the Peru Basin, and the Indian Ocean area, however, all lie far outside the Exclusive Economic Zones. Here, mining is centrally regulated by an agency of the United Nations, the International Seabed Authority (ISA). In particular, the ISA ensures that the benefits from future activities related to marine mining are shared equitably.

The potential of these resources is too large to ignore and in March 2022, The Metals Company (TMC), announced that its subsidiary NORI had signed a non-binding term sheet with its strategic partner and shareholder Allseas, to develop and operate a commercial nodule collection system from the CCZ seafloor. The system has a targeted production capacity of 1.3 Mt/y of wet nodules and expected production readiness by Q4 2024.

[39] https://www.isa.org.jm

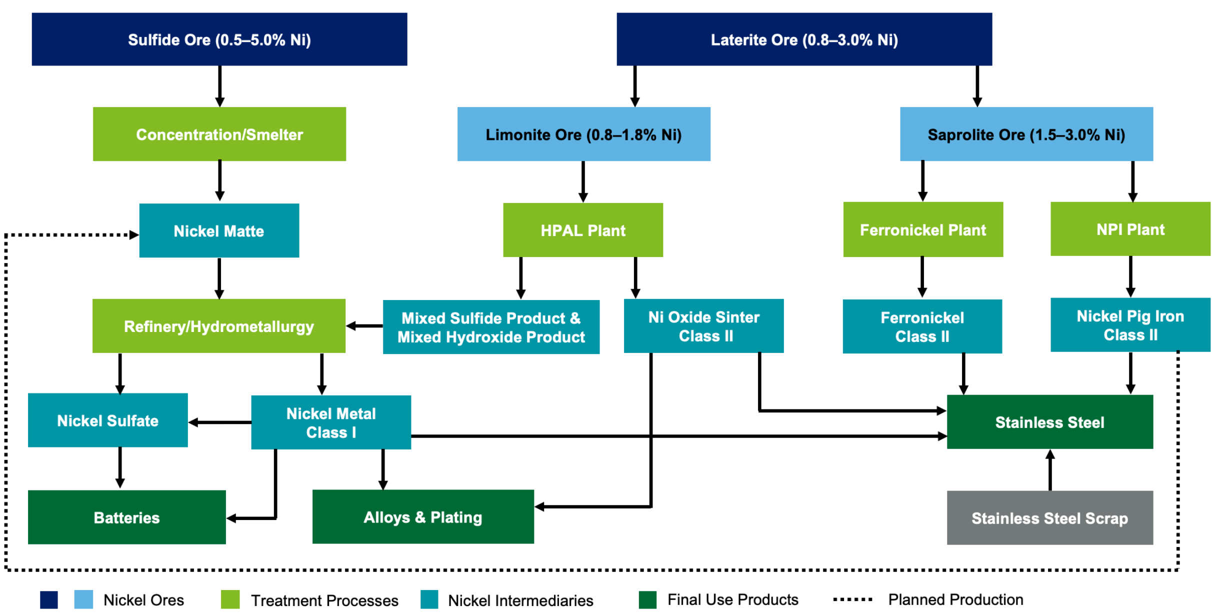
# ANNEX 2 – MINING AND PROCESSING OF NICKEL ORES

This Annex covers in more detail the different types of mining and processing methods for different nickel ores.

## Mineral Extraction and Processing of Nickel

The processing of nickel is varied and complex and to understand the dynamics of the nickel market it is essential to understand the different types of nickel ores, processing routes, nickel end products, and nickel end markets. Figure 36 gives a simplified view of the processing routes and products.

**Figure 36: Simplified Flow Sheet for Nickel Mining & Processing**




Source: Deloitte

### Nickel Sulfide Mining and Ore Processing

In general, production of nickel from sulfide ores involves either open cut or underground mining, followed by concentration through the process of flotation. Sulfide ores are firstly crushed and ground in order to liberate nickel minerals and then concentrated by selective flotation, sometimes in conjunction with magnetic separators. A nickel concentrate (containing 6 to 20 percent nickel) is then produced. The enriched concentrate also contains iron sulfide, which can act as a fuel in the smelting process and reduce the energy consumption. Flash smelting and pool smelting are the main smelting processes of nickel sulfide concentrates and produce a nickel matte[40] (75 percent nickel) intermediary product. The nickel matte is then refined to produce pure metal or processed to chemical nickel sulphate (see more on nickel refining below).

[40] A crude mixture of molten sulfides formed as an intermediate product of the smelting of sulfide ores of metals.

It is common for mines, smelters, and refineries to be located in different locations, depending on local geographic factors, although they are usually designed to treat specific intermediate feeds. There are a limited number of sulfide smelters due to the limited nickel concentrate availability. Consequently, nickel concentrate and matte do not have a broad commodity type market as found in the copper industry. The processing of sulfide ores in this manner is known as pyrometallurgy[41], with copper either an important byproduct or co-product (depending on ore grades).

**Table 11: Typical Processing Factors for Sulfides and Laterites**

| Factor | Sulphide Processing | Laterite Processing |
|---|---|---|
| Primary Mineral | Pentlandite | Garnierite |
| Pre-concentration | 5–10 times | Minimal |
| Associated Pay Metals | Cu, Co, Au, Ag, PGMs | Co |
| Major Impurities | Iron, Sulfur, Gangue | Iron, Gangue |
| Processing Options | Electric Furnace Smelting<br>Flash Furnace Smelting | Rotary Kiln<br>Electric Furnace Smelting |
| Smelting Temperature | 1,300°C | 1,600°C |
| Energy Source | Concentrate, Electricity | Fossil Fuel, Electricity |
| Primary Energy Consumption | 500-2,500 kWh per tonne Ni | 20,000 kWh per tonne Ni |
| Concentration Factor | 4x | 10-20x |
| Nickel/Cobalt Recovery | 96-98% / 50-75% | 92% / NA |
| Sulphur Capture | 90% | NA |
| Primary Product | Nickel Matte (78% Ni) | Ferronickel (20-40% Ni) |
| Atmospheric Emission | Sulphur Dioxide | Carbon Dioxide |
| Final Product Post Refining | High Purity Nickel (>99.8%) | Fed to Stainless Steel Mills |

Source: Glencore Nickel

## Nickel Laterite Mining and Ore Processing

Lateritic nickel deposits are generally mined from open pits by strip mining, due to the shallow depth of most deposits and their clay-type nature. The overburden is removed and generally deposited in the pit created from earlier mining. Mining is generally low cost as little, or no drilling and blasting is required. Problems can occur with high moisture content (typically 25 to 30 percent) which can cause ores to behave more like a slurry with handling and sediment control can be challenging to prevent impact on surrounding streams and rivers.

There are three principal processing methods for the treatment of laterite nickel ores:

- HPAL;
- Ferronickel production; and

[41] The use of high temperatures to extract and purify metals.

- NPI production.

The processing method selected depends partly on which part of the laterite profile is to be mined, and the type of nickel product that is to be produced, depending on which end market it is destined (see Figure 36). Generally, the energy consumption for laterite production is significantly higher than that for sulfide smelting. Depending on the processing configuration, a sulfide process will consume 500 to 2,500 kWh per tonne of nickel while a laterite RKEF process will consume approximately 20,000 kWh per tonne nickel.

**High Pressure Acid Leaching (HPAL)**

HPAL plants typically treat low-grade limonite ores, usually with a head-grade of greater than 1.0 percent nickel. Historically, the Caron process was used but this process is no longer viewed as economic. The core process of all HPAL plants is generally the same, and is a hydrometallurgical process[42], while the back end of plants may vary depending on what products are recovered.

Limonite slurry is fed into an autoclave with sulphuric acid at an average temperature of 255°C and pressure of 4,500 kPa (45 bar, 653 psi) and nickel and cobalt are leached (selectively dissolved). The autoclaves are titanium lined to make them acid resistant. Sulfuric acid consumes the magnesium and aluminium, forming solid products, and sulfuric acid is a major operating cost. The high magnesium content of saprolite ores is the reason why they are not treated by HPAL. Laterite ores with a magnesium grade above 5.0 percent are generally not treated. Nickel and cobalt in the form of oxides dissolve and remain in the aqueous phase as sulfates.

Depending on the backend of the processing, a combination of MSP, MHP, nickel oxide, and nickel carbonate can be produced. The MSP and the MHP are sent to a refinery to produce pure metal or produce chemical nickel sulphate. MSP tends to have a higher-grade nickel content (56 to 58 percent) than MHP (33 to 40 percent), however the capital cost of producing MSP is higher than MHP but the operating costs are lower.

The refining of MSP and MHP takes place through the processing route of leaching and hydrogen reduction to produce refined metal. Nickel and cobalt briquettes and coarse powders are produced, and ammonium sulphate is a common byproduct used as a fertilizer. HPAL plants are currently in operation in Australia, Philippines, New Caledonia, Papua New Guinea, Cuba, and Turkey.

**Table 12: Existing HPAL Plants**

| Operation | Start-end | Production Ni kt/y | Production Co kt/y | HPAL Capacity Mt/y | Number of Autoclaves | Ni % grade |
|---|---|---|---|---|---|---|
| Moa | 1959 | 37 | 3.7 | 3.4 | 4 | 1.30 |
| Murrin | 1999 | 45 | 3.0 | 4.0 | 4 | 1.24 |
| Cawse | 1998-08 | 9 | 2.0 | 0.5 | 1 | 1.69 |
| Bulong | 1999-03 | 10 | 0.9 | 0.6 | 1 | 1.70 |
| Coral Bay | 2005 | 24 | 1.9 | 2.4 | 2 | 1.26 |
| Ravensthorpe | 2007-17 | 36 | 1.3 | 2.0 | 2 | 1.65 |

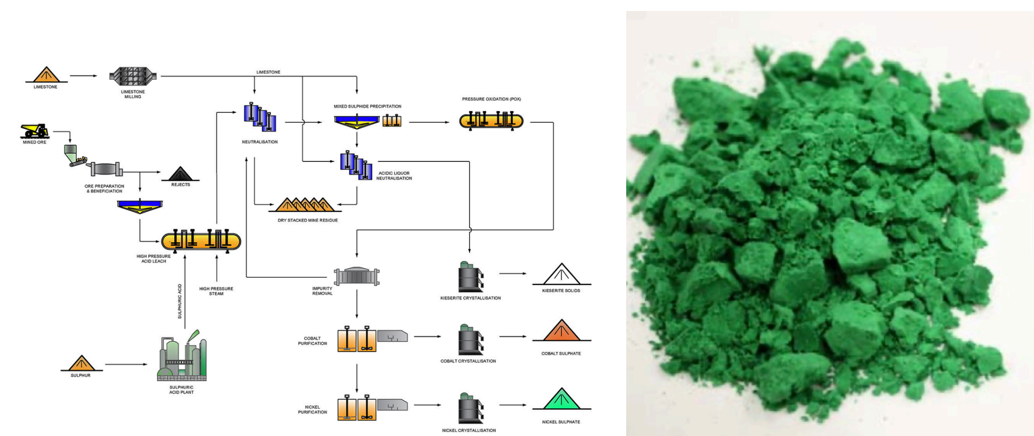
[42] Hydrometallurgy involves the use of aqueous solutions for the recovery of metals.

| Operation | Start-end | Production Ni kt/y | Production Co kt/y | HPAL Capacity Mt/y | Number of Autoclaves | Ni % grade |
|---|---|---|---|---|---|---|
| Goro | 2010 | 60 | 4.5 | 4.0 | 3 | 1.50 |
| Ambatovy | 2012 | 60 | 5.6 | 6.1 | 5 | 1.13 |
| Ramu | 2012 | 33 | 3.3 | 3.4 | 3 | 1.15 |
| Toganito | 2013 | 36 | 2.6 | 3.4 | 2 | 1.25 |
| Gordes | 2014 | 10 | 0.8 | 1.4 | 1 | N/A |
| | | | | | | |
| **Total** | **420** | **794** | **1,099** | **679** | | |

Source: Company data.

One advantage of HPAL over a ferronickel or NPI plant is that cobalt can be recovered and can be an important byproduct in the economics.

**Figure 37: HPAL Process Flowsheet and MHP**



Source: Horizonte Minerals, CESL Ltd.

### Ferronickel Production

The majority of ferronickel processing takes place in smelters which treat higher grade saprolite ores. The ferronickel is then used in stainless steel. Though cost competitive, recoveries of cobalt are generally low, and this process is not suitable for most limonite ores. Ferronickel smelters require nickel grades of typically over 1.8 percent, with initial grades of greater than 2 percent required for up to five years to enable capital payback. They also require an iron to nickel ratio of 12, a nickel to cobalt ratio of greater than 30 and a silicon oxide to manganese oxide ratio of 1.9.

The production of ferronickel from lateritic ores follows a pyrometallurgical route. Almost all current ferronickel production is now based on the RKEF process. After crushing and screening, the ore passes through a rotary kiln for drying and one for calcining (thermal decomposition) before being fed to the electric furnace and smelted at a temperature of around 1,600°C. This produces a ferronickel alloy and a slag with carbon monoxide gas. The main disadvantage with the RKEF process is its high energy consumption.

The slag produced in the smelter represents about 80 to 90 percent of the mass of the feedstock material. As a result, a vast quantity of slag is generated in ferronickel production, which is a significant concern for ferronickel plants worldwide. The ferronickel can undergo further refining for the removal of impurities. Ferronickel usually contains 15 to 40 percent nickel.

**Figure 38: Ferronickel Process Flowsheet and Product**


Source: Vale.

### Nickel Pig Iron Production

Global NPI production has grown from 50 kt in 2008 to 1,300 kt in 2021 and was 47 percent of the nickel market.[43] NPI is essentially ferronickel but with a lower nickel content and higher iron content. NPI typically contains less than 15 percent nickel. NPI production uses the same equipment and metallurgical process as convention RKEF, but usually smaller and the plant is not custom designed for the ore. However, in general an NPI plant requires a higher-grade laterite ore than an RKEF plant.

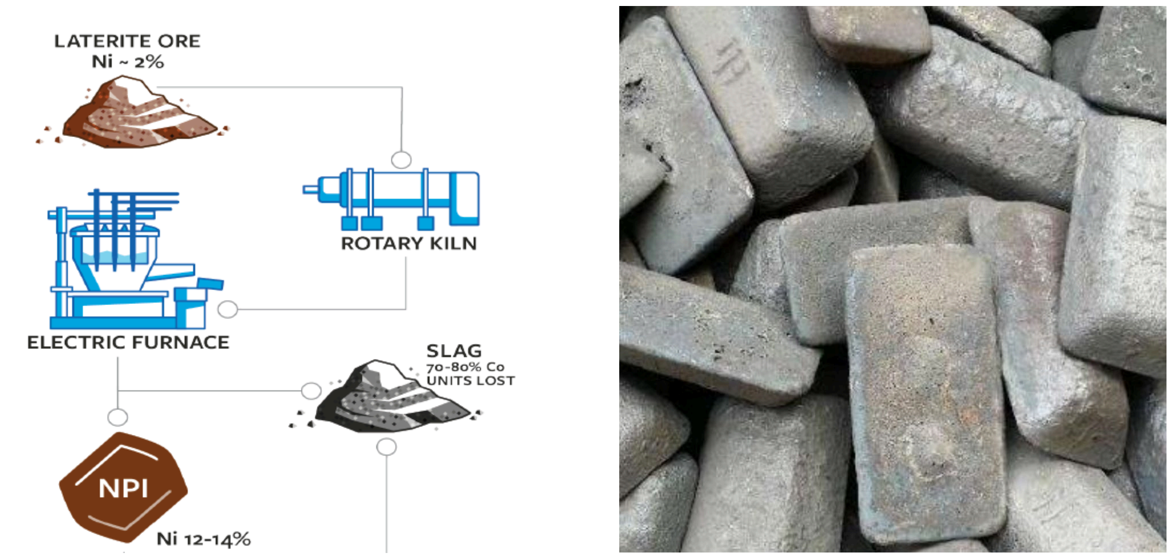
For NPI smelters, the ore must meet fixed requirements in terms of their nickel grade, iron to nickel, nickel to cobalt, and silicon oxide to manganese oxide ratios. These are typically an iron to nickel ratio of 12, a nickel to cobalt ratio of 40 and a silicon oxide to manganese oxide ratio of 1.9. If these criteria are met, then good recovery and good product grade can be obtained. These ratios can be extended but then the recovery and the product grade are much lower at similar operating costs.

The main advantage of the smelting process is that it can process limonite and saprolite ores and an NPI plant is proven technology that can be constructed, brought on-line, and capacity ramped up in a relatively short period of time. The current generation of NPI plants achieve comparable energy efficiencies, nickel recoveries, and environmental standards as conventional RKEF processing.

[43] Ron Schonewille, Metallurgy Manager, Glencore Nickel.

NPI is created by mixing saprolite ores with coking coal and a mixture of fluxes in a rotary kiln followed by processing in an electric arc or blast furnace. This process renders the unwanted impurities into slag and allows the molten mixture to be cast into molds, forming NPI. The smelting process, however, requires a large amount of energy to operate, and doesn't separate out cobalt in the process. NPI also generates significant amounts of slag. More than 95 percent of the charge material to furnaces report to the slag phase, which is regarded as waste.

**Figure 39: Nickel Pig Iron Flowsheet and Product**




Source: Sherritt

To convert NPI to matte, sulfur is added to the rotary kiln, yielding matte instead of ferronickel. The nickel matte is then upgraded in standard converting furnaces and the product is refined to produce electrolytic nickel and nickel sulphate.

**Heap Leaching**

Heap leaching is a well-established process used for the treatment of copper and gold and is now used in varying degrees for nickel laterites. The heap leach process has the potential to be the lowest capital cost and most environmentally friendly of the processes to recover nickel from laterite ores. However, while there have been a number of pilot projects, there have been only a few fully commercial operations. This is because the heap leaching of nickel oxides is not always straightforward and can be resistant to leaching. Heap leaching nickel oxides produces a low (less than 50 percent) recovery and can result in high acid consumption due to the iron content, and the fine clay morphology of the material means that acid penetration can be low.

The heap leaching of nickel laterites is under investigation with several pilot projects underway but is not yet commercialized. Brazilian Nickel is planning to use heap leaching at the Piauí project in Brazil. The company has successfully completed large scale demonstration of the heap leaching, purification and recovery of nickel and cobalt from the Piauí ore. Three commercial height heaps have been operated, with target nickel extractions of greater than 80 percent achieved with low consumption of acid. The downstream impurity removal precipitation circuit was continuously operated for nine months. Nickel and cobalt hydroxide products were produced exported and sold.

Brazilian Nickel has begun the final phase of a BFS on the project. Current internal company estimates indicate that the project is expected to have CAPEX requirement of $465 million for 25 kt/t of contained nickel and 900 t/y of contained cobalt, with production targeted for the end of 2024. Operating costs after refining charges and cobalt credits are expected to be less than $6,173/t of nickel.

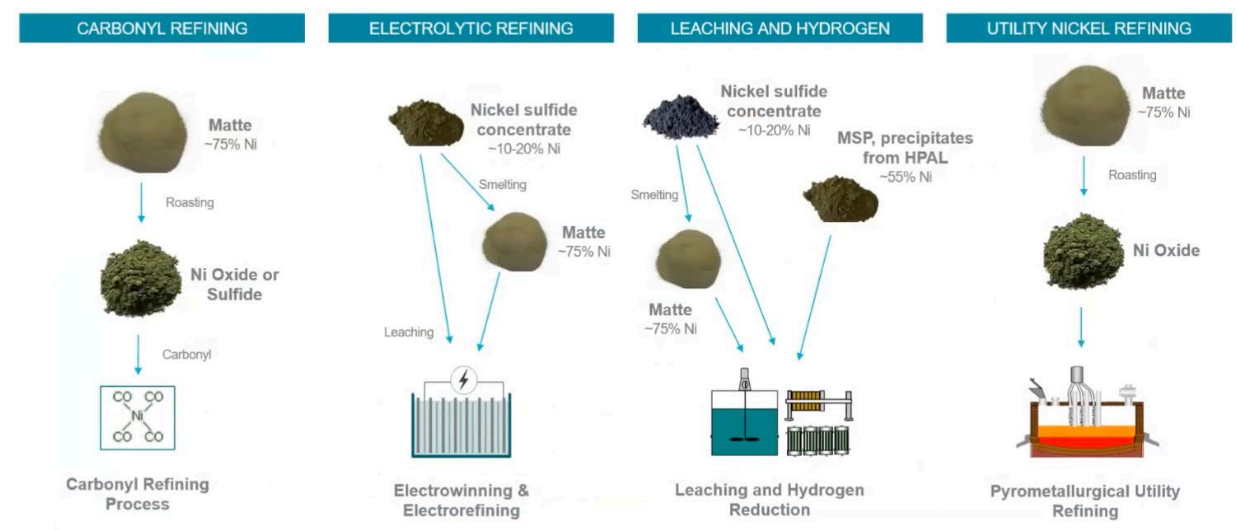
## Refining of Nickel Intermediaries

Various processes are used to refine nickel matte and nickel sulfide intermediaries to final products, usually nickel metal or nickel sulphate. These tend to be more complicated than for other metals and tailored to specific ores. Large orebodies often have their own refinery and selling nickel concentrate on the open market is usually not straightforward.

### From Nickel Matte to Refined Metal

The refining of nickel intermediaries to nickel metal is more technically complex than other metals. Figure 40 shows the four main processes currently used.

**Figure 40: Four Main Nickel Refining Methods**




Source: Vale.

The refining of the nickel matte is either a pyrometallurgical or a hydrometallurgical route. The hydrometallurgical route usually comprises an ammonia leach process and sometimes a chlorine or acid leach process. The nickel metal is then recovered through electrowinning. The pyrometallurgical route involves the heating of the matte and the reaction of oxygen with iron and sulfur.

### From Intermediaries to Nickel Sulfate

Nickel sulfate is a product of primary nickel refineries but is also produced by dissolving pure nickel metal in sulfuric acid. There will be a much higher requirement for nickel sulfate to satisfy global demand for batteries and global production has expanded considerably in recent years, largely due to capacity expansions in China, Japan, and Taiwan.

Nickel sulphate can be produced in one of three ways:

- Crystallized from process solutions in refineries producing metal.
- Dissolving intermediaries (matte, MHP, MSP) followed by removing impurities and crystallization.
- Dissolving nickel metal (powders, briquettes) followed by removing impurities and crystallization.

Nickel sulphate is approximately 22 to 24 percent nickel by weight.

# ANNEX 3 – NICKEL USES

This Annex provides greater detail on the different uses for nickel. Stainless steel currently dominates the demand for nickel, accounting for approximately 70 percent of consumption. Lithium-ion battery demand currently accounts for approximately 7 percent of demand but is the fastest growing sector for nickel consumption.

## Stainless Steel

In addition to their inherent corrosion resistance, nickel-containing stainless steels are easy to form and weld; they remain ductile at very low temperatures and yet can be used for high-temperature applications. In addition, unlike conventional steel and non-nickel-containing stainless steel, they are non-magnetic. This means they can be made into an exceptionally wide range of products, spanning applications in the chemical industry, the health sector, and domestic uses. In fact, nickel is so important that nickel-containing grades make up 75 percent of stainless steel production.

There are four types of stainless steel:

- Austenitic – These contain a significant amount of chromium and sufficient nickel or manganese to give the steels good formability and ductility and makes them non-magnetic;
- Ferritic – These contain no nickel but show better corrosion resistance and are magnetic;
- Austenitic-Ferritic – These are an equal mixture of austenitic and ferritic steels and are both strong and ductile and mostly used in the process industry and in seawater applications; and
- Martensitic – These are like ferritic grades but have a high carbon content and subjected to specific heat treatments making them very hard and strong. These are used for turbine blades, and cutlery.

The most common type of stainless steel is the austenitic stainless steel which features Type 304, which has 8 percent nickel, and Type 316, which has 11 percent nickel. This range is known for its high resistance to corrosion because of its high chromium content combined with nickel.

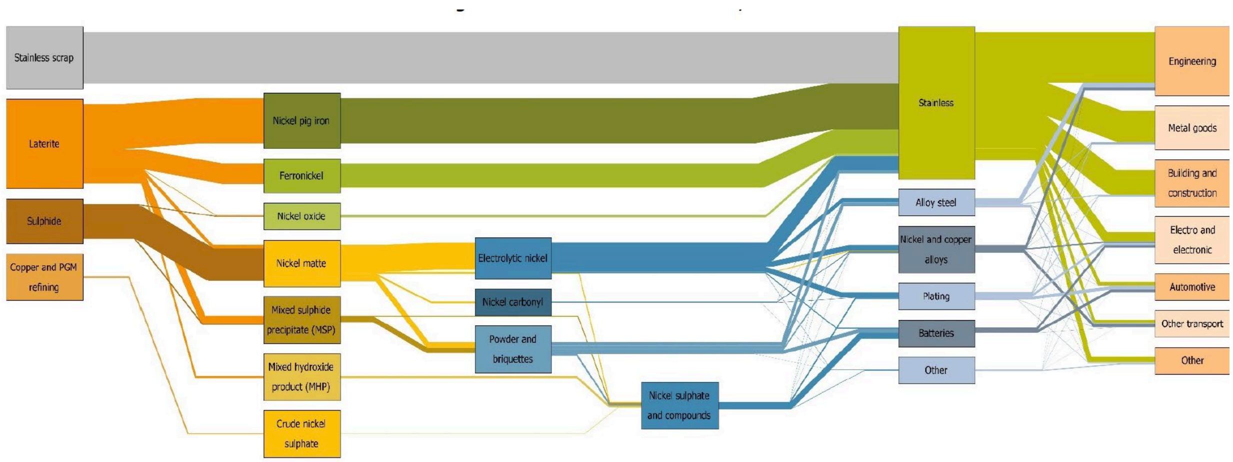
Stainless steel frequently offers the most practical, lowest-risk material choice, meaning it can be found in a wide range of applications:

- Food contact materials and the health sector, because of their ease of cleaning and disinfection, making it easy to maintain hygiene;
- Industry, for process plant, oil and gas, power generation, pollution control, chemical, and pharmaceutical production;
- Transport, in cars, trains, aerospace, and shipping;
- Architecture, for cladding, street furniture, structural applications, and reinforcement in concrete; and
- Water, in wastewater treatment, water distribution, plumbing, and desalination.

Ferritic stainless steel is the second most popular but contains no nickel. It includes grade 430 stainless steels. While this range doesn't match the corrosion resistance of austenitic steels, it is a cost effective alternative and is often used in the catering industry.

The 200-series of low-nickel, austenitic grades was developed during the 1950s, when nickel was scarce. It contains reduced chrome and extra-low nickel content but in many aspects are inferior to other stainless steels in terms of corrosion resistance, formability, and weldability.

**Figure 41: Nickel Market Flowchart**




Source: Roskill 2019

## Nickel Alloys

Nickel will alloy readily with many other metals, including chromium, iron, molybdenum, and copper. This allows for a wide variety of alloys that demonstrate outstanding resistance to corrosion and high-temperature scaling, exceptional high-temperature strength, and other unique properties, such as shape memory and low coefficient of expansion.

High-temperature and nickel super alloys provide superior corrosion, heat resistance, and strength for applications in extreme and critical circumstances as required in industries such as petrochemicals, aerospace, military, power, and energy.

## Base Metal Alloys

The main engineering grades of copper-nickel alloys were developed for naval condenser and seawater pipework applications. Recognition of their unique combination of high levels of resistance to corrosion, good thermal conductivity, and low macro-organism attachment in marine environments led to applications in offshore oil and gas, shipbuilding, desalination, and power generation.

Commercially, the 10 and 30 percent nickel (described as 90-10 and 70-30) alloys are the most commonly used. They have small but important addition of iron and manganese to optimize their corrosion resistance. These very ductile alloys can only be strengthened by cold work, the 70-30 alloy being the stronger of the two and capable of handling higher flow rates. Good thermal conductivity is also beneficial for heat exchangers and condensers, particularly in the 10 percent alloy. These alloys are readily fabricated and welded and can also be successfully welded to steel. Other wrought alloys include a 2 percent manganese and 2 percent iron grade, (66-30-2-2), only available as tubing, which can be used at higher flow velocities and in the presence of abrasive particles.

As with other nickel-containing alloys, 90-10 and 70-30 copper-nickel alloys rely on a protective surface film to maintain their corrosion resistance. However, they differ because the protective films result from a reaction with the seawater itself, rather than the oxide film formed in air, and are a complex and layered mixture of oxides, chlorides, and hydroxychlorides. These protective surfaces initially form rapidly but will continue to develop over time, providing low corrosion rates.

### Nickel Electroplating

Electroplating or surface treatment involves applying a thin layer of metal or metal alloy. The purpose is to change the technical or physical properties of the surface of the items being plated - such as their electrical conductivity - or to improve their durability, appearance, and performance. It also provides excellent adhesion properties for subsequent coating layers, which is why nickel is often used as an 'undercoat' for other coatings, such as chromium.

The technology of nickel electroplating has been extensively developed, particularly during the last 50 years making it possible to efficiently produce a broad range of industrial coatings for both decorative and functional applications. Electroplated nickel is commercially important, with upwards of 150 kt being deposited globally each year. This widespread use reflects nickel's beneficial properties and versatility as a coating material. A particular feature of electroplating is that, by modifying the composition of the electrolyte and the operating conditions, the properties and appearance of the nickel can be customized to specific needs. In many important applications, the nickel coating serves the dual purpose of providing a bright, attractive finish as well as imparting improved corrosion resistance or other functional properties.

### Batteries

Nickel has long been widely used in batteries, most commonly in nickel cadmium (NiCd) and nickel metal hydride (NiMH) rechargeable batteries which were developed in the 1980s. In the mid-1990s, the first lithium-ion batteries were developed, many of which contain formulations of NCM. The major advantage of using nickel in batteries is that it helps deliver higher energy density and greater storage capacity.

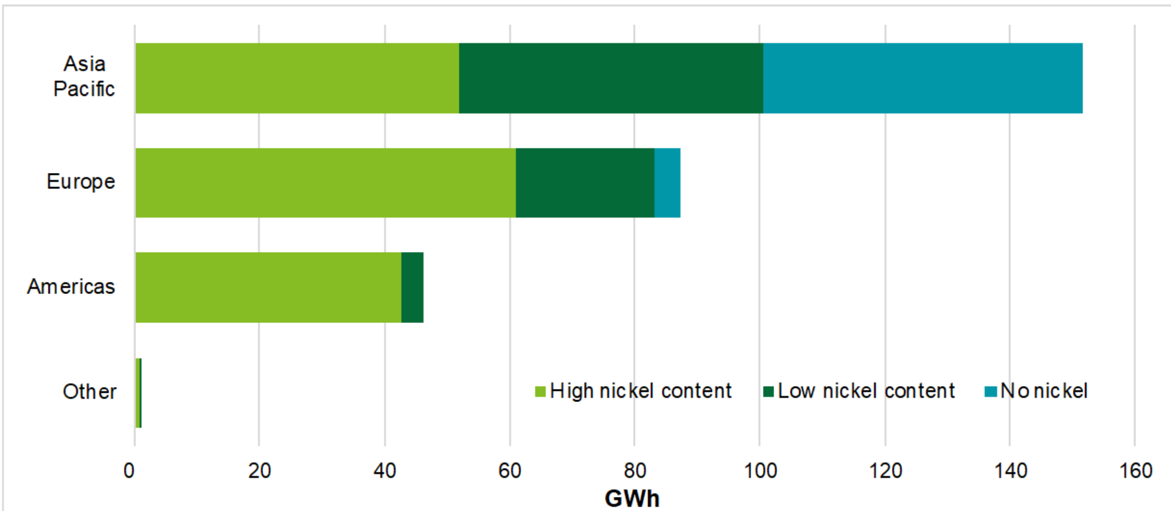
As a result, with the development of EVs, lithium-ion battery cathodes have increasingly shifted more towards NCM formulations. NCM cell formulations started off with equal proportions of the three metals (NCM111) but because of concerns regarding the cobalt supply chain and to increase the energy density (for improved mileage per charge), battery manufacturers have moved towards higher nickel and lower cobalt formulations. NCM622 and NCM811 are currently the two most-common formulations of NCM batteries. NCM811 is currently the highest-growth ternary cell chemistry and is expected to dominate market share going forward. Table 13 shows the nickel content of the different types of lithium-ion batteries.

**Table 13: Metal Content of Different Battery Cathodes kg/kWh**

| Metal | NMC111 | NMC622 | NMC811 | NCA5 | LFP |
|---|---|---|---|---|---|
| Nickel | 0.333 | 0.525 | 0.653 | 0.725 | 0.000 |
| Cobalt | 0.333 | 0.176 | 0.082 | 0.065 | 0.000 |
| Lithium | 0.120 | 0.104 | 0.096 | 0.095 | 0.084 |
| Manganese | 0.312 | 0.164 | 0.076 | 0.000 | 0.000 |
| Aluminium | 0.000 | 0.000 | 0.000 | 0.011 | 0.000 |
| Iron | 0.000 | 0.000 | 0.000 | 0.000 | 0.674 |
| Phosphate | 0.000 | 0.000 | 0.000 | 0.000 | 0.374 |

Source: Fraunhofer ISI & Fraunhofer IZM 2021 for DERA 2021.

### Figure 42: GWh in EVs Deployed on Roads by Nickel Cell Chemistry 2021




Source: Adamas Intelligence

Figure 42 shows the breakdown of nickel cell chemistries of EVs deployed on the roads in 2021 by GWh by region. The total globally was 286 GWh, with Asia Pacific accounting for 53 percent, Europe 31 percent, and the Americas 16 percent.

### Figure 43: Main Uses of Nickel Compounds

| | | | Automotive | Aircraft | Electronics | Batteries | Plastics | Paints | Ceramics | Fuels |
|---|---|---|---|---|---|---|---|---|---|---|
| Nickel sulphate | $NiSO_4$ | Metal surface treatment, battery cathodes | ● | ● | ● | ● | ● | | | |
| Nickel chloride | $NiCl_2$ | Metal surface treatment, catalysts | ● | ● | ● | | | | | ● |
| Nickel sulphamate | $Ni(H_2NO_3S)_2$ | Metal surface treatment | ● | ● | ● | | | | | |
| Nickel oxide | NiO | Catalysts, pigments, frits, glass | | | | | | ● | ● | ● |
| Nickel hydroxycarbonate | $CH_2O_3Ni$ | Metal surface treatment, catalysts, pigments and frits | ● | ● | ● | | ● | ● | ● | |
| Nickel nitrate | $Ni(NO_3)_2$ | Metal surface treatment, catalysts, battery cathodes | ● | ● | ● | ● | | | | ● |
| Nickel diacetate | $Ni(OCOCH_3)_2$ | Metal surface treatment | ● | ● | ● | | | | | |
| Nickel hydroxide | $H_2NiO_2$ | Metal surface treatment, battery cathodes, pigments | ● | ● | ● | ● | ● | ● | ● | |
| Nickel sulphide | NiS | Catalysts | | | | | | | | ● |
| Nickel subsulphide | $Ni3S_2$ | Catalysts | | | | | | | | ● |

Source: Nickel Institute.

## Nickel Compounds

Nickel compounds which are derived from nickel metal, are used in industries including surface finishing, automotive, aerospace, electronics, glass, and ceramics. They consist of nickel plus at least one other element, chemically bonded together. Nickel compounds are usually supplied in granule, powder, or liquid form. Figure 43 shows the main uses of nickel compounds.

# ANNEX 4 – LIST OF NICKEL PROJECTS

**Table 14: Potential New Sulphide Projects 2020-2030**

| Project | Country | Status | Company | Capacity Increase kt/y |
|---|---|---|---|---|
| Honeymoon Well | Australia | Late-Stage Dev. | BHP Group | 40,000 |
| Kabanga | Tanzania | Feasibility | Kabanga Nickel | 40,000 |
| Crawford | Canada | Feasibility | Canada Nickel | 34,000 |
| Dumont | Canada | Feasibility | Waterton Global | 33,000 |
| Turnagain | Canada | Pre-feasibility | Giga Metals | 33,000 |
| West Musgrove | Australia | Pre-feasibility | Oz Minerals | 32,300 |
| Trident - Enterprise | Zambia | Commissioning | First Quantum | 28,000 |
| Kun-Manie | Russia | Feasibility | Amur Minerals | 27,000 |
| Jaguar | Brazil | Feasibility | Centaurus Metals | 20,000 |
| Victoria | Canada | Late-Stage Dev. | KGHM Int. | 17,000 |
| Eagle's Nest | Canada | Feasibility | Noront Resources | 15,500 |
| Cosmos | Australia | Construction | Western Areas | 13,000 |
| Sherlock Bay | Australia | Feasibility | Sabre Resources | 6,000 |
| Black Swan | Australia | Feasibility | Poseidon Nickel | 5,000 |
| North Kambalda | Australia | Construction | Mincor Resources | 2,500 |
| **Total** | | | | **386,300** |

Source: Deloitte.

**Table 15: Potential New Indonesian Smelter Capacity 2020-2030**

| Project | Status | Company | Capacity Increase kt/y | Process |
|---|---|---|---|---|
| Weda Bay | Construction | Huafei Nickel Cobalt | 120,000 | HPAL-MHP |
| Morowali-IP | Commissioning | Huayue Nickel Cobalt | 60,000 | HPAL-MHP |
| Morowali-IP | Construction | PT QMB New Energy | 50,000 | HPAL-MHP |
| Weda Bay | Feasibility | Eramet/BASF | 42,000 | HPAL-MHP |
| Pomalaa East | Feasibility | PT Halmahera Persada Lygend | 40,000 | HPAL-MSP |
| Obi Island 1 | Commissioning | PT Halmahera Persada Lygend | 37,260 | HPAL-MHP |
| Pomalaa | Feasibility | Sumitomo Metal/PT Vale Indon. | 30,000 | HPAL |
| Obi Island 2 | Construction | PT Halmahera Persada Lygend | 18,000 | HPAL-MHP |
| Gunbuster-Moro. | Commissioning | Jiansu Delong Nickel | 120,000 | NPI |
| Morowali-IP | Commissioning | Tsingshan Group | 100,000 | NPI Matte |

| Project | Status | Company | Capacity Increase kt/y | Process |
|---|---|---|---|---|
| Bahodopi-Moro. | Feasibility | PT Vale/Shandong Xinhai/Tiagang | 73,000 | NPI |
| Morowali | Construction | PT ZhongTsing NE/ Rigqueza | 60,000 | NPI Matte |
| | Feasibility | Shandong Xinhai/Silkroad Nickel | 46,000 | NPI |
| Weda Bay | Construction | PT Huake Nickel | 45,000 | NPI Matte |
| Bantaeng IP | Construction | PT Huadi Nickel | 43,000 | NPI |
| | Feasibility | Weiming Group | 40,000 | NPI Matte |
| Weda Bay | Feasibility | PT ChengMach Nickel | 40,000 | NPI Matte |
| Cilegon | Construction | PT Indoferro | 40,000 | NPI |
| Angel-W.Bay IP | Commissioning | Hengjara Nickel (Nickel Mines) | 36,000 | NPI |
| Oracle-Moro. | Construction | Hengjara Nickel (Nickel Mines) | 36,000 | NPI |
| Weda Bay | Construction | PT Youshan Nickel | 34,000 | NPI Matte |
| Morowali | Construction | Qingdao Zhongcheng | 29,000 | NPI |
| Mandiodo | Feasibility | PT Aneka Tambang | 24,000 | NPI |
| Hengjara-Moro. | Expansion | Hengjara Nickel (Nickel Mines) | 18,486 | NPI |
| Jakarta Selatan | Expansion | PT Gebe Nickel | 18,000 | NPI |
| Wolo-Kolaka | Construction | PT Ceria Nugraha Indotama | 55,600 | Ferronickel |
| Morowali | Commissioning | PT Wanxiang Nickel | 30,000 | Ferronickel |
| East Halmahera | Commissioning | PT Aneka Tambang | 12,500 | Ferronickel |
| Weda Bay | Expansion | Eramet/Tsingshan | 11,500 | Ferronickel |
| **Total** | | | **1,309,346** | |

Source: Deloitte.

**Table 16: Potential Other New Laterite Projects 2020-2030**

| Project | Country | Status | Company | Capacity Increase kt/y | Process |
|---|---|---|---|---|---|
| Gladstone | Australia | Feasibility | Gladstone Pacific | 63,000 | HPAL |
| Central Musgrave | Australia | Feasibility | NICO Resources | 40,000 | HPAL |
| Vermelho | Brazil | Prefeas/Scoping | Horizonte Minerals | 25,000 | HPAL-MSP |
| Mt Thirsty | Australia | Prefeas/Scoping | Conico/Greenstone | 24,800 | HPAL-MSP |
| Sunrise-Clean TeQ | Australia | Late-Stage Dev. | Sunrise Energy | 21,000 | HPAL |
| Kalgoorlie | Australia | Feasibility | Ardea Resources | 19,500 | HPAL |
| Ravensthorpe | Australia | Re-development | First Quantum/Posco | 17,000 | HPAL-MHP |
| Sconi | Australia | Late-stage Dev. | Australian Mines | 16,000 | HPAL-MHP |

| Project | Country | Status | Company | Capacity Increase kt/y | Process |
|---|---|---|---|---|---|
| Araguaia | Brazil | Late-Stage Dev. | Horizonte Minerals | 14,500 | Ferronickel |
| Piaui | Brazil | Feasibility | Brazilian Nickel | 25,000 | Heap leach |
| Dutwa | Tanzania | Feasibility | Blackdown Resources | 23,200 | Tank leach |
| Niwest | Australia | Prefeas/Scoping | GME Resources | 19,200 | Heap leach |
| Nico Young | Australia | Prefeas/Scoping | Jervois Mining | 9,100 | Heap leach |
| **Total** | | | | **317,300** | |

Source: Deloitte.

Deloitte Financial Advisory Services LLP
1919 N. Lynn Street
Arlington, VA 22209
Phone: +1 571 882 5000
Fax: +1 571 882 5100