

## *Nickel Market Dynamics and the Security of the Battery Supply Chain*

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**Abstract:** This memo provides an overview of nickel demand and the current nickel supply chain, focusing on recent market developments. It reviews relevant chemical processing routes, techno-economic considerations, and key geographies. The US battery industry risks losing competitiveness due to the growing concentration of the nickel supply chain in Indonesia and China. The memo identifies policies and strategies that can help reduce nickel supply chain risks to ensure an effective energy transition.

## 1. Growth in nickel demand is reshaping supply chains

Nickel demand has been growing rapidly due to its use in battery cathodes, with total nickel consumption increasing by 32% from 2019 to 2023<sup>1</sup>. Demand from the battery sector grew by over 200% in this same period, with the battery-sector's share of total demand growing from 5% to 15%<sup>2</sup>. While the majority of nickel consumption historically has been dominated by the stainless steel sector, the rapidly growing demand from the battery sector, with higher purity requirements, is re-shaping the nickel supply chain.

By 2050, more than half of the nickel produced may be used in battery applications. Table 1 displays projected nickel demand in three scenarios presented by the International Energy Agency (IEA). In the Net Zero Emissions Scenario, which represents clean energy deployment needed to meet climate goals that limit global warming to 1.5 degrees celsius, total nickel demand may double to 6702 kt per year by 2040 with a 10x growth in demand from EVs<sup>3</sup>. In this memo, we review how changes in demand are impacting the nickel supply chain. We will describe nickel processing pathways that currently meet battery demand requirements and highlight key risks to achieving the goals of sustainable nickel supply.

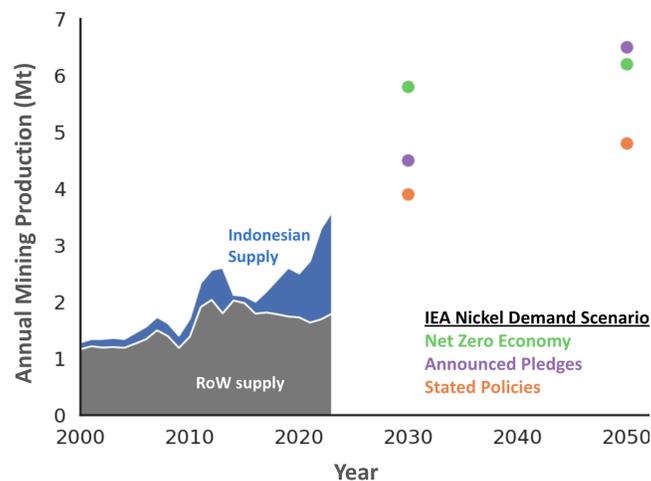


Figure 1: The shaded region represents annual nickel mining production from 2020-2023 in Indonesia (Blue) and Rest-of-World (Grey). In 2023, half of global nickel mining output came from Indonesia. The points represent nickel demand in 2030 and 2050 according to 3 scenarios defined by the International Energy Agency (IEA).

## 2. Pathways to producing nickel for batteries

Battery cathode active materials (CAMs) consume high purity chemicals as precursors, with nickel-containing chemistries requiring nickel sulfate. Nickel exists geologically as part of two ore types: laterites and sulfides. Historically, nickel sulfate was produced via the processing of two intermediates i) nicked matte or ii) refined nickel, both of which can be produced via **sulfide smelting (SS)**. Nickel matte is an intermediate with ~50% nickel that is primarily derived from the processing of sulfide ores. The nickel matte derived from sulfides can be further refined to 99.8% refined nickel briquettes or powders, which can be used for stainless steel applications or converted to nickel sulfate for batteries. However, many of the high-grade sulfide resources are already being extracted<sup>4</sup>, and there have been limited discoveries of new sulfide deposits (only 4 since 2013)<sup>5</sup>.

More recently, advances in processing have expanded the use of nickel laterite deposits to produce intermediates that can be converted to nickel sulfate. Most of this development has occurred in Indonesia. Smelters, typically rotatory kiln electric furnaces (RKEFs), convert nickel laterites to low-grade products such nickel pig-iron (NPI) or ferronickel (FeNi) which have historically been used in stainless steel production. Recent projects (the first was announced by Chinese-owned Tsingshan only in 2021) use a converter to process the NPI and FeNi further into a nickel matte, which can be processed into sulfate similar to the matte derived via sulfide smelting (**laterite smelting and sulfidation, LSS**). China's imports of matte have increased from just 10kt tons in 2020 to over 300kt in 2023, with 93% of the matte imported being produced in Indonesia<sup>6</sup>.

Nickel sulfate is now increasingly produced from mixed precipitates made by high pressure acid leaching (HPAL) of low grade laterite ores (**laterite leaching, LL**). Lower grade laterite ores are hydrometallurgically treated using high pressure acid leaching (HPAL) to produce mixed hydroxide/sulfide precipitates (MHP/MSP). MHP production exceeded 250kt in 2023, and is expected to grow by 28% in 2024<sup>7</sup>. The rate of MHP development in Indonesia has been astounding, with capacity expected to grow 4x between 2022 and 2027 and reach ~600kt<sup>8</sup>.

HPAL technology has existed for many years, with the oldest project (Moa Bay in Cuba) constructed in 1959 and still operating. However, very few HPAL projects have been constructed since then due to processing complexity and the high capital costs required. The most recent projects to open outside of Indonesia (Goro in New Caledonia in 2021, Ravensthorpe in Australia in 2015, Amabtovy in Madagascar in 2016, and Ramu in Papua New Guinea in 2017) involved long ramp-up durations and high capital costs exceeding \$100,000 per tonne of annual capacity<sup>9</sup>. The recent rise of HPAL in Indonesia is possible because recent projects have found ways to extract nickel with significantly lower capital costs of less than \$35,000 per tonne of annual nickel production capacity<sup>10</sup>. Much of the investment, and technical expertise, has been brought by Chinese producers to Indonesia who have derived learnings from previous projects. The recently opened HPAL project in Obi Islands (PT Halmahera Persada Lygend) took only 12 months to ramp up and uses a very similar flowsheet as the Ramu plant, which is owned by the same Chinese company. Companies have also been able to lower capital costs by leveraging existing infrastructure and setting up HPAL projects within Industrial Parks in Morowali and Weda Bay.

In 2019, a majority of nickel sulfate was produced via matte and mixed precipitate (MHP and mixed sulfide precipitate, MSP) intermediates, 20% was refined metal dissolution and 20% was from scrap<sup>11</sup>. In 2023, due to the growth in intermediate production and the higher cost of refined metal feedstocks, dissolution of class 1 nickel was limited<sup>12</sup>. In 2023, nickel sulfate production exceeded 500kt and surpassed demand. Feedstocks for nickel sulfate were dominated by nickel matte and mixed precipitates. Indonesia has the largest reserves of nickel in the world and have made it a national priority to develop a nickel supply chain. It is likely that much of the future growth in nickel sulfate production will be achieved via processing of Indonesian laterites into matte (LSS) or MHP (LL)

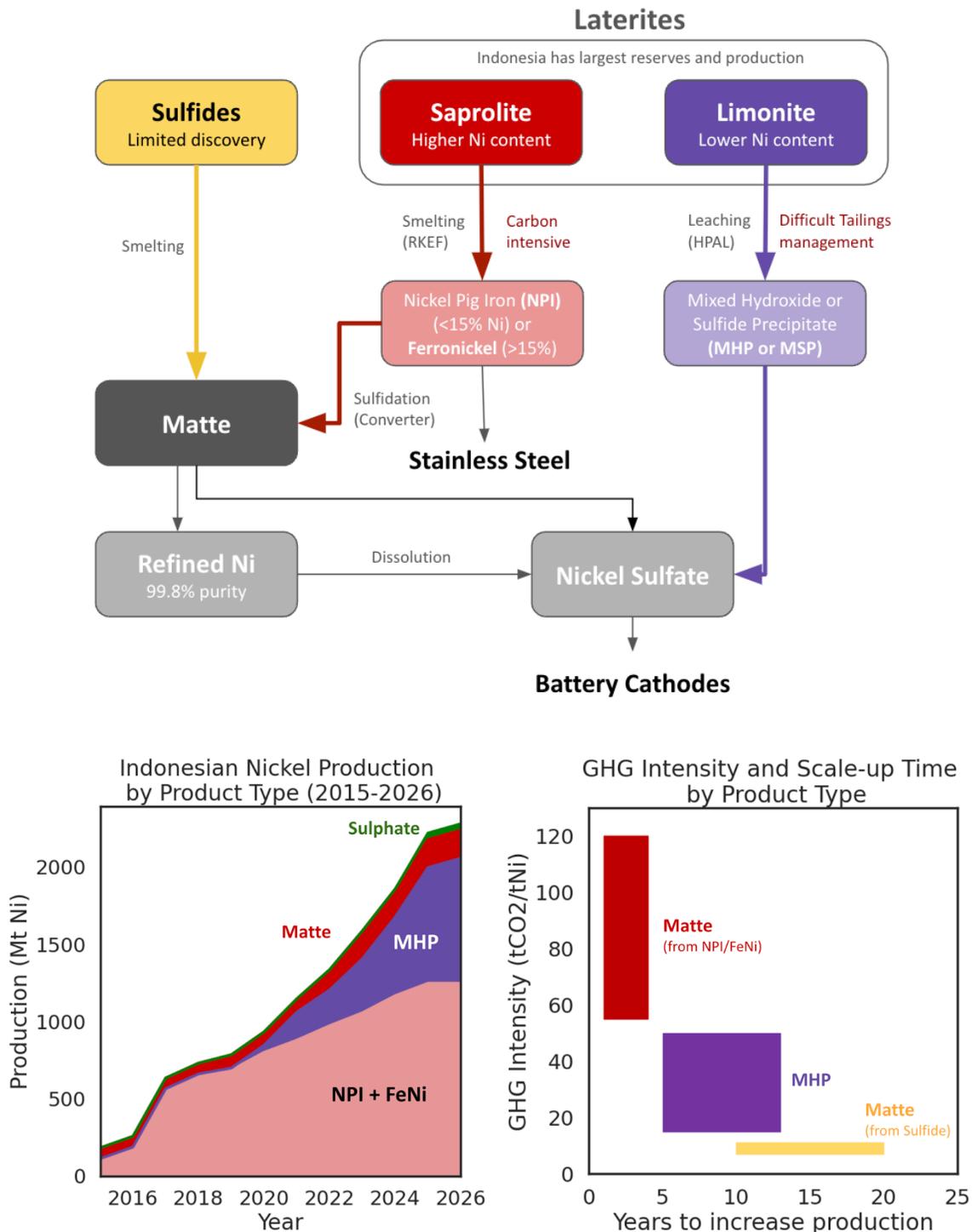


Figure 2: (Top) Overview of main routes to produce nickel sulfate. (Bottom-left) Annual capacity of nickel projects in Indonesia, broken down by product type, till 2026. Future projects are those that were under development in 2022. Data for operating and development-stage projects for nickel products in Indonesia compiled in 2022 by Heijlen and Dubayon (2024) by using company statements. Matte production can be increased in short timeframes by adding a converter to existing NPI smelters. MHP production corresponds to LL pathway, Matte corresponds to LSS pathway. NPI+FeNi is produced by laterite smelting (LS) but is not used to make battery-grade nickel sulfate. (Bottom-right) Comparison of GHG intensity and time to increase production for various processing pathways. Data from Young (2021)

### 3. Risks from the geographical concentration in nickel mining and processing

A large proportion of the nickel supply chain is concentrated in a handful of countries, which can lead to heightened risk of supply disruptions. Over 70% of nickel sulfate production takes place in China. Chinese companies have been able to rely on supply of intermediates from Indonesia to scale-up production of nickel sulfate, with 93% of the matte and 63% of the MHP imported by China in 2023 being produced in Indonesia<sup>6</sup>.

Based on projects under development, Indonesian battery-grade nickel capacity may double by 2027 from 2023 levels (Figure 2). Chinese firms play a central role in Indonesian nickel production and have heavily invested in Indonesian projects<sup>13</sup>. In 2023, 84% of the battery-grade nickel from Indonesia was produced by majority Chinese-owned companies<sup>14</sup>. Although this number is expected to reduce in the next 10 years due to investments by Western companies and Indonesia, market intelligence firms still expect over 50% of battery-grade nickel supply from Indonesia to be produced by majority Chinese owned companies.

By dominating nickel sulfate production as well as the processing of lateritic ores in Indonesia to intermediates, Chinese firms have a strong grasp over the nickel supply chain. Building a diversified supply chain outside of China will require building capacity across the supply chain- from mining and processing to sulfate production to CAM production and cell manufacturing. Increasing investment in nickel processing capacity by Western firms within Indonesia, as well as in other countries, could diversify the supply chain. Given the long timelines needed to open processing facilities, battery and cell manufacturing in the US will likely continue to rely on materials produced in China in the current decade. Other (sulfidic) sources have geopolitical challenges of their own. For example, the largest supplier of refined nickel from sulfides is Nornickel, a Russian company.

Proportion of Indonesian battery-grade projects with majority Chinese ownership	>80%
Proportion of global sulfate production that takes place in China	>70%
Proportion of global sulfate production using MHP and Matte intermediates	>70%
Proportion of global nickel production that occurs in Indonesia	>50%
Proportion of MHP imported by China that was produced in Indonesia	>60%
Proportion of Matte imported by China that was produced in Indonesia	>90%

*Table 1: Statistics highlighting the concentration of the nickel supply chain in China and Indonesia, and the extent of trade relationships between the two countries. All data from 2023*

#### 4. Environmental risks in the nickel production pathways

Each of the nickel production pathways described above come with significant environmental impacts, which we highlight in Table 2.

	<i>Laterite Smelting and Sulfidation (LSS)</i>	<i>Laterite Leaching (LL)</i>	<i>Sulfide Smelting (SS)</i>
<i>Carbon Intensity</i>			
<i>SOx emissions</i>			
<i>Waste disposal</i>			
<i>Land-use impacts</i>			

*Table 2: Comparative assessment of environmental impacts across the 3 pathways. Colours are used to qualitatively compare impact between pathways (red is greatest, green is lowest), and do not represent quantitative measures of absolute environmental impact. Most of the growth in supply is expected to come from the first two pathways (LSS and LL), due to resource availability and costs.*

In the LSS pathway, NPI is processed to matte by adding sulfur in a converter, but some of the sulfur is oxidised to SO<sub>2</sub> in the process. SO<sub>2</sub> emissions are significant as recent research shows that after factoring in SO<sub>2</sub> emissions externalities from nickel processing, an EV with nickel-based batteries may have a higher social cost over its lifetime compared to a combustion engine vehicle<sup>15</sup>. While data on SO<sub>2</sub> emissions from NPI-matte conversion is hard to come by, there is a risk of an increased footprint because the emissions control limits for SO<sub>2</sub> are higher in Indonesia than other countries. The 1-hr National Air Quality Standard in Indonesia for SO<sub>2</sub> is 900 µg/m<sup>3</sup><sup>16</sup>, compared to ~200 µg/m<sup>3</sup> in the USA<sup>17</sup>. China's 1-hr standards range from 150 µg/m<sup>3</sup> in residential areas to 700 µg/m<sup>3</sup> in industrial areas<sup>16</sup>. The 24-hr standard in Indonesia is 365 µg/m<sup>3</sup> which is much higher than the World Health Organization (WHO) guideline of 20 µg/m<sup>3</sup>. For comparison, India's 24-hr limit is 50 µg/m<sup>3</sup> while China's ranges from 50-250 µg/m<sup>3</sup>. Sulfide processing (SS) also produces significant SO<sub>2</sub> emissions (up to 4 tons of SO<sub>2</sub> per ton of Ni before controls), and Nor Nickel smelters in Russia are one of largest sources of sulfur dioxide emissions in the world<sup>18</sup> (efforts have been taken recently to reduce emissions). According to the GREET model, a life-cycle assessment tool, 1t of refined nickel production leads to roughly~1t of SO<sub>x</sub> emissions on average (GREET does not account for NPI-matte conversion due to data limitations)<sup>19</sup>

The LSS pathway, being a pyrometallurgical pathway that uses low-grade ores, is more energy-intensive than leaching processes. Since most of the furnaces are powered with coal on-site, and because coal is used as a reducing agent in the process, processing NPI to matte leads to carbon emissions of 70tCO<sub>2</sub>/tNi, which is significantly greater than HPAL (20tCO<sub>2</sub>/tNi) and sulfide smelting (10tCO<sub>2</sub>/tNi)<sup>20</sup>. Leaching processes produce direct emissions from neutralization of acid with limestone. While the LSS pathway is the most carbon intensive, it also requires the least time and capital investment to ramp-up production (Fig 2), since it existing NPI production capacity can be used with the addition of a converter. As a result, there is a risk that rapidly

increasing nickel demand will be supplied with nickel from this high-emissions pathway.

The key issue with HPAL is the large amount of waste generation, with an estimated 1.4-1.6 tonnes of fine-particle waste generated for every tonne of nickel produced. Many projects originally proposed deep sea tailings placement (DSTP) for the waste, similar to Ramu in Papua New Guinea, but the Indonesian government has not issued any permits for DSTP due to the potential implications on marine ecosystems. In environments like Indonesia, tailings disposal poses significant challenges due to the island's limited space for large dams, dense vegetation, high rainfall, and seismic activity. Dry stacking is a commonly proposed method for managing HPAL tailings. Several companies, including Vale SA and Lygend Resources & Technology Co. Ltd., plan to use dry stacking for their HPAL projects in Indonesia. Dry stacking involves filtering and drying tailings until they can be compacted and stored in a stable, dry state. In some cases, tailings are used to backfill old open pits. However, dry stacking is challenging and expensive in rainy areas, where waste can contaminate groundwater and nearby<sup>21</sup>. Meanwhile, conventional tailings dams with insufficient hard rock support carry a risk of collapse.

Regardless of processing pathways, mining projects clear large swathes of land and displace local communities. The growth in nickel mining will lead to significant increase in land-use in high bio-diversity regions, with research showing that emissions from land-use change could increase 6x by 2050 in a 1.5 degree C scenario<sup>22</sup>. A recent study showed that land footprint of laterite mining in Indonesia is particularly high and corresponds to ~40m<sup>2</sup>/tNi<sup>23</sup>. If all Indonesian projects in development open, the land area occupied by nickel mining industry in Indonesia would grow from 360 km<sup>2</sup> in 2020 to 800 km<sup>2</sup> by 2026.

Apart from the impact on biodiversity and carbon emissions, land-use changes can significantly hurt local communities. A recent report by Climate Rights International interviewed 45 people near Indonesia Weda Bay Industrial Park<sup>24</sup> (which is expected to produce over 500kt of nickel matte and MHP by 2030). The interviewees described serious threats to their land rights via land grabbing, as well as infringements on their right to clean water access.

## 5. Market risks for nickel supply

The rapid growth in nickel supply from Indonesia has driven down nickel prices from a high of \$48,000/t in March 2022 to \$16,000/t in March 2024<sup>25</sup>. Because of decreasing margins, many nickel projects outside of Indonesia such as BHP, IGO and First Quantum projects in Western Australia, have begun to curtail production and shut-down mines. Indonesia plans to keep ramping-up supply despite lower margins, hoping to keep prices low and maintain the demand for nickel which underpins their strategy of building a downstream battery value chain. Indonesia's deputy coordinating minister for mining stated "In the short term, you enjoy a very good profitability with higher prices. But if this level is maintained, you sacrifice long-term demand. And for a country like us, where we care about our downstream programme, that is really important."<sup>26</sup>. He went on to state that he expected long-term prices to be around \$18,000/t.

Nickel market dynamics are exacerbating both geographical concentration risks and Environmental and Social Governance (ESG) risks. Low margins threaten to reduce mining production and delay the opening of projects in other countries, further increasing supply chain concentration towards Indonesia. The challenge from a sustainability perspective is that the projects currently being developed typically have large environmental

impact in terms of emissions or waste management. This raises the question of whether the social and environmental costs of nickel processing are appropriately internalized in these costs. Lower profit margins also means less capital is available for innovation in alternative nickel production pathways. Building capacity for cleaner energy sources, better waste management, and SO<sub>x</sub> controls all require capital investment which might be unviable if margins remain low. For example NPI-to-matte converters can cost \$30m in CAPEX without SO<sub>2</sub> capture but \$100m with SO<sub>2</sub> capture<sup>27</sup>.

## 6. Strategies to build a secure and sustainable nickel supply chain

Given the multiple interacting risk factors in the nickel supply chain, we need coordination between policymakers, consumers (demand), and producers (supply) to ensure that nickel supply is developed sustainably.

Demand-side signals can significantly impact production decisions and motivate suppliers to adopt cleaner practices. For example, the demand for “green aluminum” by companies such as Apple, Audi and BMW is leading to a push by aluminum smelters in China to receive green certification<sup>28</sup>. With increased supply chain transparency and clear demand-side preferences for sustainable nickel, nickel producers will be motivated to transform production processes to be cleaner. To realize this transformation, the demand-side preference for “green nickel” will have to transform into a clear financial incentive for suppliers who reduce negative impacts, either through price premiums, offtake agreements, or co-investment by automakers.

Input from experts and local communities is needed on how to best define standards for what constitutes “green” or “sustainable nickel”. Once standards are defined, auditing and compliance is needed to differentiate between supply sources based on environmental performance. Policymakers can support standard-setting, reporting and compliance. Previous reporting regulations have helped modifying materials consumption and production. For example, Baik et al. found evidence that Section 1502 of the Dodd-Frank Act, which required companies to disclose if their products contained conflict minerals (i.e. tin, tantalum, tungsten or gold from the DRC or neighbouring countries), increased responsible sourcing and the demand for products made in certified smelters<sup>29</sup>.

Creating demand for “green nickel” and building certification can create a market for sustainable nickel and incentivise cleaner production in the long-run. Until then, suppliers will have to weather the economic risks posed by low nickel prices. Industrial policymakers will need to find mechanisms to support to nickel suppliers across a broad range of responsible suppliers. To tackle ESG risks, policymakers should help drive research and development into technologies that can lower the impact of nickel production, with a focus on scaling up promising technologies.

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